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Relations between the bone density values from computerized tomography, and implant stability parameters: a clinical study of 230 regular platform implants

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Abstract

Aims: The objective of this study was to determine the relationship between bone density, insertion torque, and implant stability at implant placement.

Materials and Methods: One-hundred and eight patients were treated with 230 Brånemark System implants. A computerized tomography (CT) machine was used for pre-operative evaluation of the jaw bone for each patient. The maximum insertion torque values were recorded with the OsseoCare equipment. Implant stability measurements were performed with the Osstell machine for only 142 implants.

Results: The mean bone density and insertion torque values were 721 $\pm$ 254 Hounsfield unit (HU) and 39.1 $\pm$ 7 N cm for 230 implants, and the correlation was significant ($r = 0.664$, $p < 0.001$). The mean bone density, insertion torque, and resonance frequency analysis values were 751 $\pm$ 257 HU, 39.4 $\pm$ 7 Nc m, and 70.5 $\pm$ 7 implant stability quotient (ISQ), respectively, for 142 implants. Statistically significant correlations were found between bone density and insertion torque values ($p < 0.001$); bone density and ISQ values ($p < 0.001$); and insertion torque and ISQ values ($p < 0.001$).

Conclusion: The bone density values from pre-operative 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.

Key words: bone density; computerized tomography; CT; dental implants; Hounsfield unit; implant stability; insertion torque; resonance frequency analysis

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Dental implants have been a popular alternative in the oral rehabilitation after the introduction of osseointegration (Brånemark 1985). Numerous studies related to the dental implant treatment have indicated successful results (Wennström et al. 2005, Roos-Jansåker et al. 2006, Turkyilmaz 2006a, Weber et al. 2006). It has been suggested that the successful outcome of any implant procedure involves a series of patient-related and procedure-dependent parameters (Beer et al. 2003). The volume and quality of the bone are important factors determining the type of surgical procedure and the type of the implant, and they are related to the success of dental implant surgery (Ekfeldt et al. 2001).

Clinical studies have shown a higher survival rate for the dental implants in the mandible (Engfors et al. 2004, De Backer et al. 2006, Turkyilmaz 2006b). However, the dental literature has included studies with a lower survival rate of the implants placed in the maxilla (Jemt & Lekholm 1995, Kaptein et al. 1999). More failures for

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the immediately/early-loaded maxillary implants have also been reported (Grunder 2001). It has been considered that the discrepancy in the survival rates of the implants placed in maxilla and mandible arises from the bone conditions around the implants. It is evident that, when compared with the maxilla, the bone surrounding the implant has better volume and quality in the mandible (Norton & Gamble 2001).

Various classification methods were proposed for assessing the bone quality because the mechanical behaviour of the bone is a principal factor for osseointegration (Lekholm & Zarb 1985, Thruhlar et al. 1997, Misch 1999, Norton & Gamble 2001). There are also other methods that may provide valuable knowledge of the bone density but their benefit to both the clinician and the patient is limited because osteotomies have already been completed or implants have already been placed (Engquist et al. 1988, Friberg et al. 1995). To remove the above limitations, a method using computerized tomography (CT) scans for pre-operative quantitative assessment of dental implant patients that is more objective and reliable has been developed (Schwarz et al. 1987a, b).

Primary stability having a basic role in successful osseointegration (Friberg et al. 1991) is a function of local bone quality and quantity, the geometry of an implant, and the placement technique used. Non-invasive clinical test methods (i.e., insertion torque, the Periotest, vibration methods) and invasive research test methods (i.e., removal torque) are available for implant stability measurements (Meredith 1998). The insertion torque method, which records the torque during implant placement, provides valuable information about the local bone quality (Johansson & Strid 1994). Another quantitative method is the resonance frequency (RF) analysis technique where the implant stability is recorded using an Osstell machine and a transducer including piezoceramic elements (Meredith et al. 1997).

The dental literature has numerous studies on the usefulness of CT for assessing bone volume and morphology (Homolka et al. 2002, Fanuscu & Chang 2004, Hanazawa et al. 2004), and few clinical studies on the relationship between CT values and primary implant stability (Beer et al. 2003, Ikumi & Tsutsumi 2005). However, so far, there has only been one clinical study (Turkyilmaz et al. 2006) that has sought to determine the correlations between bone density, and insertion torque, and the dental implant stability values. This study aimed to examine the relationship between the local bone density derived from CT, the insertion torque values, and the primary stability values.

Materials and Methods

One-hundred and eight patients with 230 implant sites, who had undergone implant surgery in two clinics (one university clinic, one private clinic), were recruited for this study from 2000 to 2006. The patients were either fully or partially edentulous. Both panoramic radiograph and CT were utilized for the pre-operative radiological examination of the patients. The implants used in this study included 230 Brånemark TiUnite MK III implants (Nobel Biocare AB, Göteborg, Sweden) with diameters of 3.75 and 4 mm and lengths of 10, 11.5, 13, and 15 mm.

Pre-operative radiological evaluation

A spiral CT machine (Siemens AR-SP 40, Munich, Germany), which was calibrated daily according to the manufacturer's instructions, was used for the pre-operative evaluation of the jaw bone for each patient. CT scanning of the maxilla or mandible was performed after positioning either a previously fabricated surgical acrylic template including 1-mm-diameter indicator metal rods located in the centre of the missing teeth, or the existing removable complete dentures attached the same indicator rods under the following conditions: 130 kV, tube current 83 mA, slice thickness 1 mm, and slice intervals 1 mm. The proper implant for each previously designated implant area was selected using cross-sectional images. The rectangular area of each implant placed was plotted on the cross-sectional images with a tool incorporated into the CT equipment, and the mean bone density of the implant area with a surrounding 1 mm thickness was measured using a software that had already been incorporated into the CT machine (Turkyilmaz et al. 2006) (Fig. 1). The

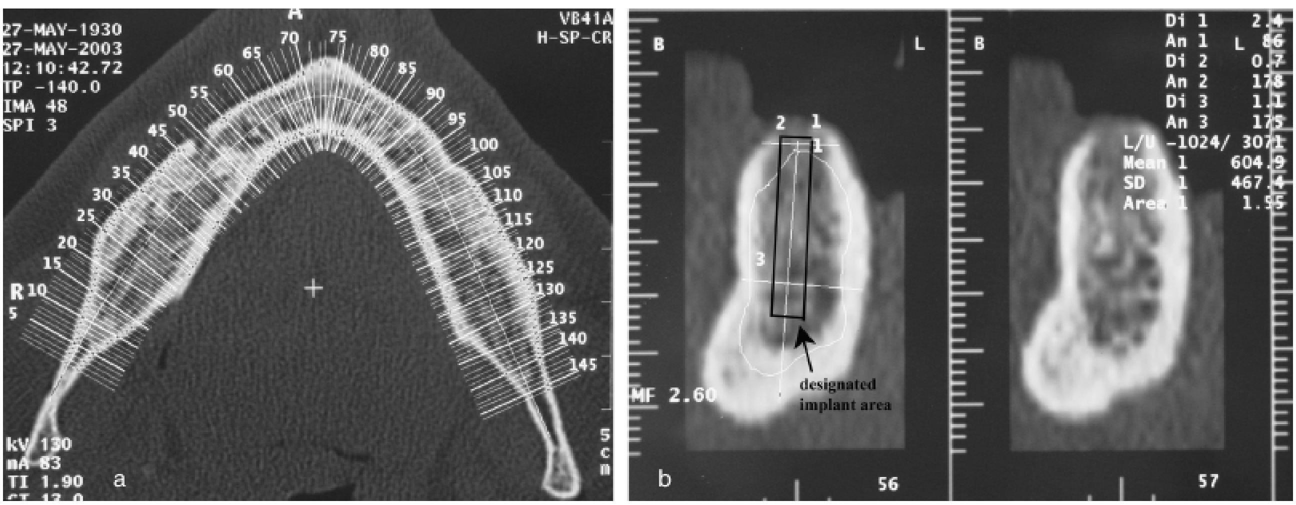

Fig. 1. Axial computerized tomography (CT) image (a) of a mandible and cross-sectional CT image (b) of the designated implant site evaluated in this study.

bone density measurements were recorded in Hounsfield units (HU).

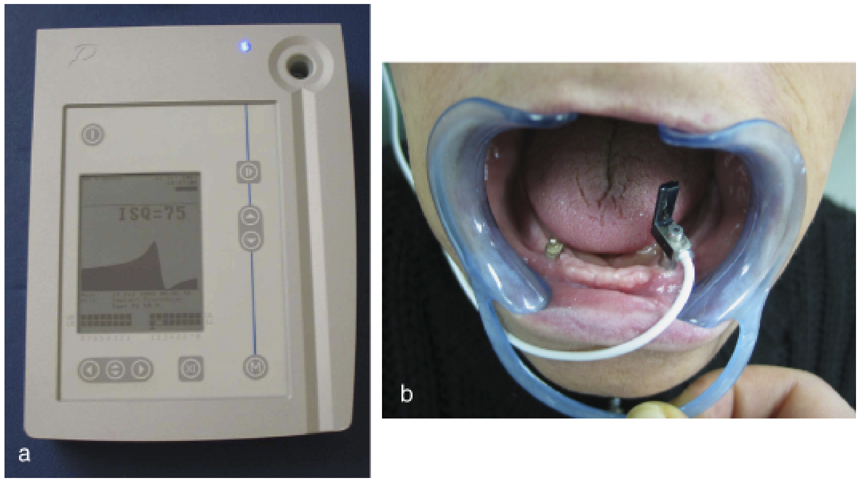

Fig. 2. Osstell machine (a) and clinically resonance frequency measurement (b) of an implant.

Surgical procedures

The implants were placed using either a single-stage or a two-stage surgical procedure. The surgical procedure included local anaesthesia, a crestal incision, and mucoperiosteal flap elevation, respectively. Spherical drills for marking the implant location, cylindric drills 2 mm wide, pilot drills 2–3 mm wide, cylindric drills 3 mm wide, and countersink drills were used for regular platform implants (Nobel Biocare AB).

Insertion torque measurements

The maximum insertion torque value of each implant, which was the latest value seen on the screen of the OsseoCare motor (Nobel Biocare AB), was recorded. Starting from 20 N cm, the insertion torque was increased in steps of 5 N cm, when the rotation stopped due to friction before the implant was fully inserted. The OsseoCare machine enables the perforation of bone, implant placement, and abutment connection, and also records the torque during the implant placement and the prosthetic procedures. It has three modes (high-velocity surgery, low-velocity surgery, and prosthetic), and it can only apply a limited amount of torque in order to avoid mechanical overload of the equipment or bone tissue.

Implant stability measurements

RF measurements for only 142 implants were performed using the Osstell machine immediately after the implant placement. An L-shaped transducer was screwed onto an implant (Fig. 2a and b). The transducer including two piezoceramic elements is vibrated by exciting one of the elements with a sine wave varying in frequency from 5 to 15 kHz with a peak amplitude of 1 . The second element measures the response of the beam, and the signal generated is amplified and compared with the original signal frequency by the Osstell machine. RF values are represented in a quantitative unit called implant stability quotient (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 low implant stability.

Statistical analysis

SPSS statistical software program (SPSS Inc., Chicago, IL, USA) was initially utilized for the comparative analysis of the data. The Shapiro–Wilk test was used to test the normality of distribution. Because the data were normally distributed, ANCOVA (the age and gender of the patients were taken as covariates) was performed for the comparison of bone density and insertion torque values according to the implant recipient regions. For multiple comparisons, Bonferroni's test was used. Pearson's test was used to determine any correlation between the bone density, and the insertion torque values (implant recipient regions; female–male; and older–younger) for 230 implants. However, for 142 implants, possible correlations between the bone density, insertion torque, and ISQ values according to the implant dimensions were tested with Spearman's test as the number implants in few subgroups were limited. p-values <0.05 were considered to be significant.

Results

One-hundred and eight patients (60 females, 48 males, mean age 52 ± 12) were included to this study. A total of 230 implant sites were provided from the 108 CT scans. There were 80 anterior mandibular sites, 50 posterior mandibular sites, 45 anterior maxillary sites, and 55 posterior maxillary sites. The bone density values varied from 271 to 1231 HU. The mean bone density value of all implant sites was 721 ± 254 HU while the average maximum insertion torque value for all implants was 39.1 ± 7 N cm, which indicated a statistically significant correlation ($p<0.001$, $r=0.664$). For all 230 implants, Table 1 includes the average HU and insertion torque values according to the regions, gender, and age.

The difference in the average bone density of the implant sites between the mandibles (828 ± 245 HU) and the maxillae (582 ± 192 HU) was statistically significant for all patients ($p<0.001$) (Table 1). Also, the average insertion torque value of the implants placed in the mandibles (40.5 ± 6 N cm) was higher than that in the maxillae (37.3 ± 8 N cm) ($p<0.05$). It was observed that the average bone density value of the implant sites in the anterior regions of jaws was higher than that in the posterior regions (anterior mandible–posterior mandible; anterior maxilla–posterior maxilla) ($p<0.001$) (Fig. 3). However, the difference in the average bone density of the implant sites was not statistically significant between the posterior mandible and the anterior maxilla ($p>0.05$). The average maximum insertion torque values indicated statistical significance between the anterior and posterior regions of the mandible ($p<0.001$), and between the anterior and posterior regions of the maxillae ($p<0.001$).

There was a statistically significant difference in the average bone density of the implant sites between females and males ($p<0.001$) (Fig. 4). Also,

Table 1. Correlations between average HU and maximum insertion torque values according to the groups

Groups	Number of implant sites	Number of patients	Average HU values (± SD)	Average maximum insertion torque values (± SD)	*r*-value	*p*-value
Anterior mandible	80	38	928 ± 220	42.1 ± 5	0.449	< 0.001
Posterior mandible	50	24	669 ± 194	38 ± 7	0.745	< 0.001
Anterior maxilla	45	20	732 ± 163	40.7 ± 6	0.606	< 0.001
Posterior maxilla	55	26	459 ± 108	34.5 ± 8	0.766	< 0.001
Female	113	60	634 ± 220	37.4 ± 8	0.582	< 0.001
Male	117	48	805 ± 258	40.7 ± 7	0.656	< 0.001
Older	147	56	755 ± 241	40.1 ± 7	0.628	< 0.001
Young	83	52	662 ± 268	37.4 ± 7	0.693	< 0.001

HU, Hounsfield unit.

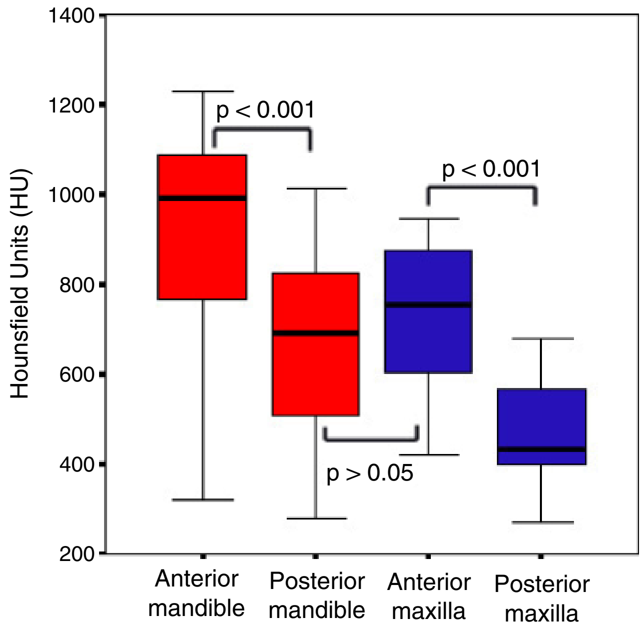

Fig. 3. Average bone densities according to the different regions within the mouth.

a statistically significant difference in the average maximum insertion torque values of the implants was found between females and males ($p < 0.001$). Higher average bone density ($p < 0.05$) and insertion torque values ($p < 0.05$) were observed in the older patients (mean age 59 ± 6, ranged from 51 to 76) than the younger patients (mean age 39 ± 8, ranged from 23 to 50).

The RF values were recorded for only 142 implants immediately after the placement. The average RF, bone density, and maximum insertion torque values for these implants were 70.5 ± 7 ISQ, 751 ± 257 HU, and 39.4 ± 7 N cm, respectively. Statistically significant correlations have been found between the RF values, and bone density ($r = 0.659$, $p < 0.001$) and insertion torque values ($r = 0.583$, $p < 0.001$). It was also observed that the correlation between bone density and insertion torque values was statistically significant ($r = 0.630$, $p < 0.001$). Table 2 included the RF, HU, insertion torque values, and corresponding correlations according to the implant dimensions.

Discussion

Although several classification systems were proposed for assessing bone quality and predicting the prognosis (Misch 1999, Trisi & Rao 1999), the most popular method for bone quality assessment was suggested by Lekholm & Zarb (1985). They classified bone density radiographically into four types. With respect to their classification, their method has recently been questioned due to poor objectivity and reproducibility. The use of CT, which is more objective and reliable, for the assessment of the bone density of the patients requiring implant therapy was introduced (Schwarz et al. 1987a), and this method has been in utilized several studies (Beer et al. 2003, Ikumi & Tsutsumi 2005).

It is difficult to make a direct comparison between the present study and previous studies because many previous studies on the bone density from CT included cadaver specimens (Shahlaie et al. 2003, Fanuscu & Chang 2004, Hanazawa et al. 2004, Aranyarachkul et al. 2005). Fanuscu & Chang (2004) reported that the bone density values ranged from 51 to 529 HU in the mandible, and from 186 to 389 HU in the maxilla for a 72-year-old male cadaver. Shahlaie et al. (2003) reported that the bone density values from nine human cadavers ranged from 18 to 1265 HU, with a mean of 457 HU.

In the present study, the recorded bone density values are higher than those in earlier studies (Norton & Gamble 2001, Shapurian et al. 2006). Norton and Gamble (2001) reported that the mean bone density from CT was 682 HU for 139 sites. They reported that the mean bone densities in the anterior mandible, the posterior mandible, the anterior maxilla, and the posterior maxilla were 970, 669, 696, and 417 HU, respectively. They also reported a strong correlation between the bone density and the regions within the mouth, which is in agreement with the present study. Shapurian et al. (2006) reported that the average bone density values in the anterior mandible, the anterior maxilla, and the posterior maxilla, the posterior mandible were 559, 517, 333, and 321 HU for 219 implant sites, which are lower than those in the present study. These discrepancies might result from the distribution of implant recipient sites because the relatively high number of implant recipient sites in the posterior mandible with the lowest bone density values dominated their results. When considering all implant sites, the mean bone density was 721 ± 254 HU in the present study, which is higher than those reported earlier (Norton & Gamble 2001, Shapurian et al. 2006). These differences are most likely to result from the variations in the age and the gender of the patients, and the distribution of implant recipient sites.

The older patients had a higher average bone density value at the implant sites than that in the younger patients, and this finding was obtained due to the relatively more number of mandibular anterior sites with a high bone density in the older patients. The patients in the older group also have significantly more bone resorption and thus more basal (corticalized) bone remaining resulted in higher bone density values. However, the difference in the mean bone density value between females (mean age 51 ± 13 years) and males (mean age 54 ± 9 years) has not been associated with the distribution of the interest sites or the age of the patients, which may be explained by the hormonal peculiarities in females and generally higher bone mass in males. Previous studies including the measurement of the bone mineral contents in the jaws and forearms have already indicated that, when compared with the males, lower bone mineral densities in females have been found throughout adult life with a significantly larger bone mineral content loss in elderly females (Von Wovern 2001, Von Wovern et al. 2001). However, Shapurian et al. (2006), reported that, although the average bone density value was higher in the males, the average bone density values in the females (400 HU) and males (429 HU) did not differ significantly. It has been considered that further studies including more number of patients are needed to better understand the relations between the age and gender of the patients and bone density values.

The insertion torque values of Brånemark System implants, and the correlations between insertion torque and bone density values have additionally been evaluated in the present study. Statistically significant correlations exists between the insertion torque and bone density values for regular platform implants.

High average insertion torque (39.3 ± 7 N cm) and RF values (70.5 ± 6 ISQ) were recorded for 142 implants. It was considered that these high values resulted from the higher quality of bone in the anterior mandible, the surgical technique with no pre-tapping, and the roughened-surface implants used, which corroborate earlier studies (Payne et al. 2003; Turkyilmaz 2006c).

Furthermore, a direct relationship between ISQ and insertion torque with the Brånemark System TiUnite MK III implants was found. This finding is partially in agreement with the earlier studies (Friberg et al. 1999, Da Cunha et al. 2004), although a direct comparison among the three studies was not possible, because they used different types of implant or different recipient

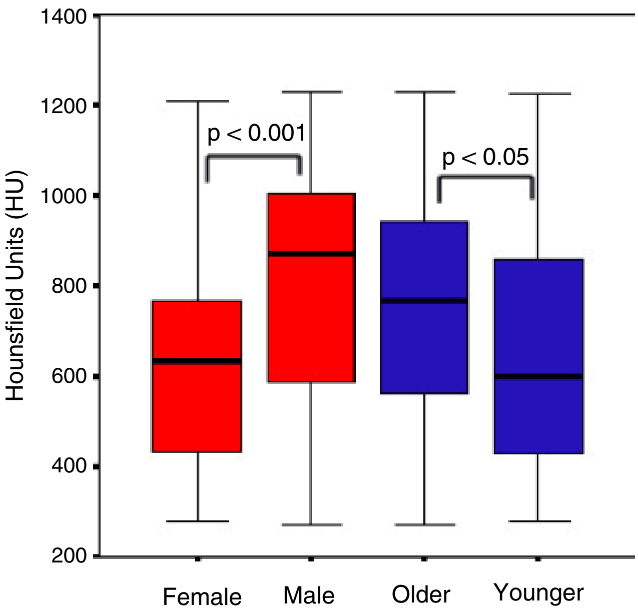

Fig. 4. Average bone densities according to the gender and age of the patients.

Table 2. For 142 implants, HU and maximum torque, and ISQ values, and corresponding correlations according to the implant dimensions

Dimensions of implants (mm)	Number of implants	HU (SD)	Maximum torque (SD)	ISQ (SD)	Correlations between HU and insertion torque		Correlations between HU and ISQ		Correlations between insertion torque and ISQ	
					r-value	*p*-value	*r*-value	*p*-value	*r*-value	*p*-value
3.75 × 15	78	854 ± 231	41.6 ± 6	73.2 ± 6	0.56	<0.001	0.34	<0.05	0.40	<0.001
3.75 × 13	22	855 ± 217	40.9 ± 6	71.7 ± 3	0.10	>0.05	0.67	<0.001	0.53	<0.05
3.75 × 11.5	9	472 ± 78	36.3 ± 7	64.8 ± 3	0.83	<0.05	0.91	<0.001	0.84	<0.05
3.75 × 10	11	490 ± 113	31 ± 7	65.4 ± 7	0.78	<0.05	0.79	<0.05	0.69	<0.05
4 × 11.5	10	647 ± 116	41.1 ± 6	69.4 ± 5	0.65	<0.05	0.84	<0.05	0.62	<0.05
4 × 10	12	429 ± 97	33.1 ± 7	60.5 ± 4	0.76	<0.05	0.74	<0.05	0.74	<0.05

4-mm-diamater implants were placed 3-mm-diameter implant sockets.
HU, Hounsfield unit; ISQ, implant stability quotient.

sites. Friberg et al. (1999) compared cutting torque and RF measurements of TiUnite MK II implants placed in the maxilla. A significant correlation between placement torque and RF was observed only in the crestal third of the implants. However, they reported no overall correlation between cutting torque and ISQ. Da Cunha et al. (2004) placed 12 standard Brånemark System implants and 12 TiUnite MK III Brånemark System implants in the maxilla. Significant linear correlations were found between the placement torques for the apical, middle, and crestal third for TiUnite implants. The linear correlations between the placement torques for the same variables were not significant for the standard implants. This difference might be considered an indication that the two types of implants showed different ISQ and placement torques. They also reported no overall correlation between insertion torque and RF values. However, the strong correlation between the insertion torque values and RF values in the present study concurred with the previous report including 60 Brånemark System TiUnite MK III implants placed in the anterior mandible (Turkyilmaz 2006c).

In the present study, the average insertion torque values of both female and male and younger and older patients differed significantly. Higher insertion torque values were recorded for men and older patients. This may be explained by the different bone qualities at implant sites. It appears that the age and gender of the patients have an influence on the insertion torque values, which is consistent with an earlier study (Turkyilmaz et al. 2006).

In the present study, strong correlations (bone density–insertion torque, bone density–RF, and insertion torque–RF) were found at implant placement, which confirmed those in the previous study by our group (Turkyilmaz et al. 2006). Our previous study, which includes 158 implant sites from 85 patients, showed strong correlations among the parameters mentioned.

Under the guidelines of this study, the bone density measurements using preoperative CT may provide quantitative determination of bone quality, and significant correlations between bone density and implant stability parameters may help clinicians to predict primary stability before implant insertion, which is associated with implant survival rates.

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Clinical Relevance

Scientific rationale for the study: The use of CT scans for pre-operative quantitative assessment in dental implant patients that is more objective and reliable has recently increased.

Principal findings: Significant correlations were observed between the recorded bone density, insertion torque, and implant stability values at implant placement, which means that primary implant stability can be predicted using CT scans.

Practical implications: A pre-operative CT examination may be a helpful technique for the clinicians to determine bone quality, and may help them to obtain a higher implant stability that is related to better implant survival rates.