Determination of Bone Quality of 372 Implant Recipient Sites Using Hounsfield Unit from Computerized Tomography: A Clinical Study

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ABSTRACT

Background: The type and architecture of bone are very important factors in the successful implant treatment, and it is manifested that higher implant failure is more likely in the poorer quality of bone. Conventional bone classifications have recently been questioned because they are subjective and retrospective.

Purpose: This clinical study aimed to determine the variations of the bone density in dental implant recipient sites using computerized tomography (CT).

Materials and Methods: The study group comprised of randomly selected 140 patients with 372 implant sites. Recipient sites for implant placement were determined based on CT data using implant planning StentCad software (Media Lab Software, La Spezia, Italy). The mean bone density values in Hounsfield unit (HU) of the simulated implant areas were recorded using the StentCad software.

Results: The HU values ranged from 68 to 1,603 HU. It was found that mean bone density values were 927 ± 237, 721 ± 291, 708 ± 277, and 505 ± 274 HU in the anterior mandible, posterior mandible, anterior maxilla, and posterior maxilla, respectively.

Conclusion: Preoperative CT examination may be a useful method for determining the bone density of recipient areas before implant placement, and this valuable information about bone quality helps clinicians to make better treatment planning regarding the implant positions.

KEY WORDS: bone density, computerized tomography, CT, Hounsfield value, implant, surgical stent

Dental implants have become a popular alternative in oral rehabilitation in the past two decades, and numerous studies regarding dental implant therapy have showed successful outcomes.[1–4] When compared to the maxilla, clinical reports have indicated a higher survival rate for dental implants in the mandible, particularly in the anterior region of the mandible, which has been associated with better volume and density of the bone.[5] Clinical studies have also showed that the highest failure rate has been faced in the maxillary posterior region, which has been associated with poorer volume and/or density of bone.[6,7]

Fastidious examination of the bone including actual bone dimensions and bone quality helps the clinicians to make a decision regarding patient selection, the implant/surface type, and the surgical technique. Because mechanical properties of the bone are an important factor for osseointegration, several classification systems and procedures were proposed to determine the bone quality and predicting prognosis.[8–10] The most popular conventional bone quality classifications

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with four different types were proposed by Lekholm and Zarb[8] and Misch.[9] The former classification was based on the amount of cortical versus cancellous bone, while the latter one included the tactile sensation perceived by the dental practitioners during drilling. Other studies have included a variety of methods for assessing the bone density, but these have required evaluation either at the time of osteotomy preparation or subsequent to implant placement.[11,12] Although these methods may provide valuable information about the bone density, it is retrospective to patient assessment, and its value to both clinician and patient is questioned as osteotomies have already been performed or implants have already been placed. To remove these concerns, the use of computerized tomography (CT) scans for preoperative, objective, and quantitative assessment of the implant recipient sites of patients who need dental implant treatment has been introduced.[13,14]

It has been considered that primary implant stability is an important factor in successful osseointegration.[15] Primary stability is a function of local bone quality and quantity, the geometry of an implant (ie, length, diameter, and type), and the placement technique used (relation between drill size and implant size, whether a pre-tapped or self-tapped implant is used). Implant stability can be measured by noninvasive clinical test methods (ie, tapping, insertion torque, the periotest, vibration methods). One of these quantitative methods is the insertion torque described by Johansson and Strid.[16] This method records the torque required to place the implant and provides valuable information about the local bone quality. The periotest method based principally on transient excitation has commonly been used for determining implant stability. However, the sensitivity of periotest values was seriously questioned because of its narrow range of scale of the instrument.[17] The latest method, resonance frequency analysis (RFA), utilizes insertion of an electronic transducer onto the implant head or prosthetic abutment, and passing a low-voltage current through the transducer. Resistance to vibration of the transducer to the surrounding bone is registered in a small computer device. Measurements are recorded as implant stability quotient (ISQ) values. This noninvasive technique seems to provide relatively more sensitive information in comparison with the periotest values, which makes it more popular in monitoring implants nowadays.[3] Friberg and colleagues[18] compared cutting torque and resonance frequency measurements of TiUnite Mk II implants placed in the maxilla. A significant relationship was observed, only in crestal third of the implants, between placement torque and resonance frequency at implant placement. However, their final results showed no overall correlation between cutting torque and ISQ. Another earlier clinical study by Turkyilmaz and colleagues[19] evaluated correlations between bone density, insertion torque, and resonance frequency 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 Hounsfield unit (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.

Although few cadaver studies[20,21] and clinical studies[20–24] regarding the assessment of bone volume and morphology have been available, no clinical study including this number of actual implant recipient sites is currently available in the dental literature. The aim of the present study was to evaluate the bone density in stimulated implant sites recorded by CT.

MATERIALS AND METHODS

For this study that was approved by the Ethical Board of Ankara University, Ankara, Turkey, a total of 140 patients with 372 implant sites were randomly selected from a pool of patients treated with implants from 1999 to 2006. Four clinics (two university and two private clinics) provided the CT images. Existing edentulous spans were allocated into four groups: anterior mandible, posterior mandible, anterior maxilla, and posterior maxilla. One hundred and forty-one implants were used to support single-tooth crowns in 56 patients, 108 implants were used to support the overdentures in 44 patients, and 123 implants were used to support the fixed partial/full dentures in 40 patients.

Preoperative CT Examination

A spiral model CT machine (Siemens AR-SP 40, Munich, Germany) was utilized for the preoperative evaluation of the jawbones for each patient. The CT machine has been calibrated daily according to the manufacturer's instructions. The scanning conditions were: tube voltage 130 kV, tube current 83 mA, slice thickness 1 mm, slice intervals 1 mm, pixel size 512/512,

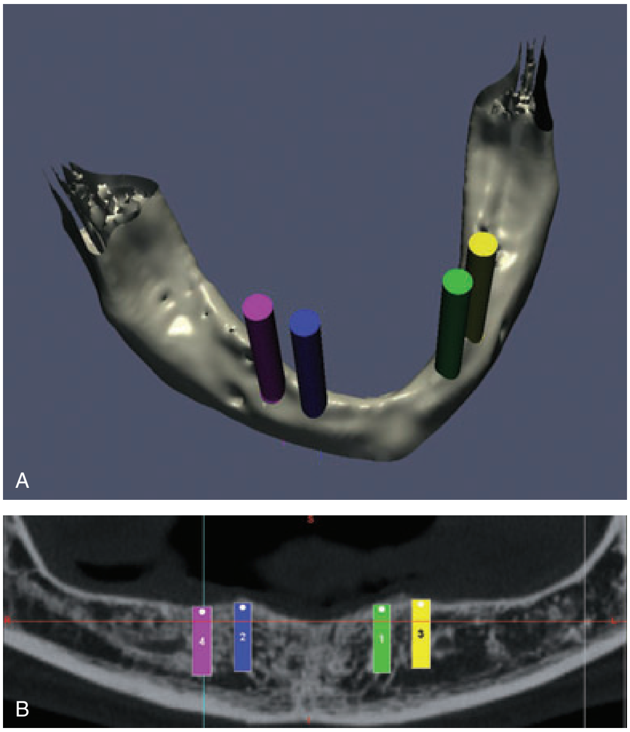

Figure 1 Implant placement simulation was performed using the StentCad software on CT images. Optimum implant recipient sites (A) and implant sizes (B) were determined presurgically.

sec/rotation 0.5. Cross-sectional, coronal, and axial images for the mandible or maxilla have been obtained with the CT machine. The proper implant recipient sites have been selected by the sagittal CT images using the following two methods:

1. Previously fabricated surgical acrylic templates including 1-mm-diameter indicator metal rods located in the center of the missing teeth, or the existing removable complete dentures attached to the same indicator rods were placed in the patients prior to CT scan. The rectangular area of each implant placed was plotted on the sagittal images with a tool included to the CT machine,[19] and the mean bone density of each implant area including 1 mm surrounding bone was measured using a software which has already been included in the CT machine.
2. The locations and directions considered to be optimum for each implant on CT images were determined and tested using implant placement simulation by means of the three-dimensional StentCad software (Media Lab Software, La Spezia, Italy) (Figure 1). The mean bone density of each implant area has been measured using the StentCad software on cross-sectional CT images (Figure 2). This StentCad software also allowed us to prepare CT-guided surgical templates (Figure 3), and the implants were placed according to the previously prepared CT-guided surgical templates (Figure 4). The mean bone density value of each implant recipient site was recorded in HU. Three different observers performed the bone density measurements independently.

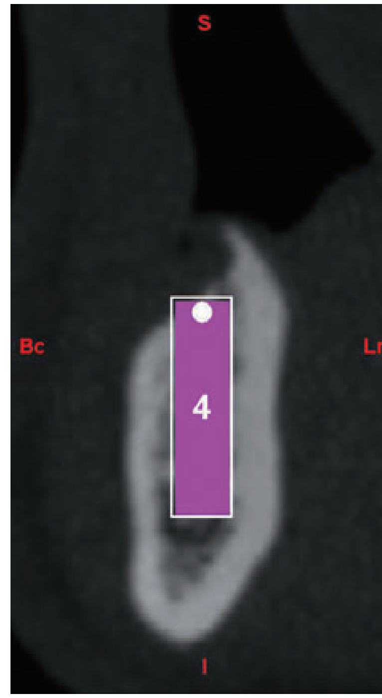

Figure 2 Cross-sectional computerized tomography image of the simulated implant site for the bone density measurement.

Initial statistical analysis was performed using SPSS version 11.0 statistical software (SPSS, Inc., Chicago, IL,

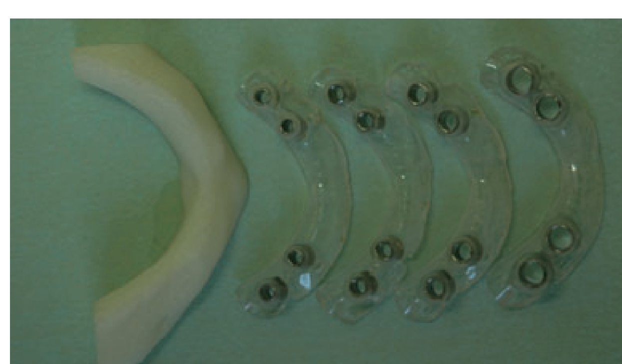

Figure 3 The computerized tomography-guided surgical templates with different drill sizes for implant placement.

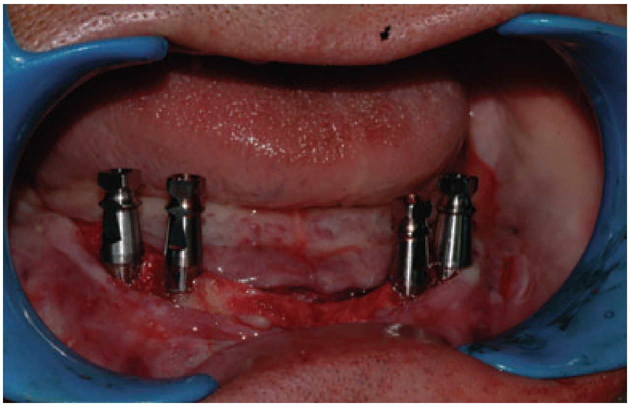

Figure 4 Intraoral view immediately after implant placement using the computerized tomography-guided surgical templates.

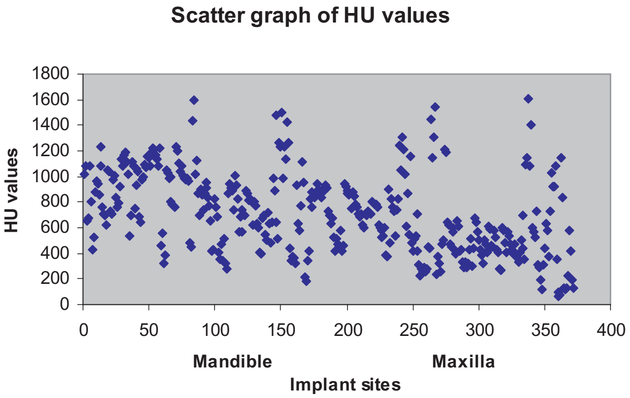

Figure 5 The distribution of Hounsfield unit (HU) values for all 372 implant sites.

USA). Mann–Whitney test was used to determine the differences in the bone density values (HU) between mandible and maxilla, women and men, older and younger patients, as well as among four quadrants of mouth. A value of $p < .05$ was considered significant.

RESULTS

One hundred and forty patients with 372 implant recipient sites (71 women, 69 men; mean age 51 ± 11) were used for this study. There were 92 anterior mandibular sites, 81 posterior mandibular sites, 102 anterior maxillary sites, and 97 posterior maxillary sites. It has been observed that the bone density in all patients ranged from 68 to 1, 603 HU with a mean value of 713 ± 310 HU (Figure 5).

The statistically significant difference ($p < .001$) in the mean bone density of the implant recipient sites has certainly been established between the mandibles (831 ± 282 HU) and the maxillae (609 ± 293 HU).

When compared to the posterior implant recipient sites for each jaw, higher mean bone density values have been found in the corresponding anterior implant recipient sites ($p < .001$) (Table 1). A significant difference in the mean bone density of the implant recipient sites was found between the anterior mandible and the posterior maxilla ($p < .001$), but no significant difference in the mean bone density of the implant recipient sites was found between the posterior mandible and the anterior maxilla ($p > .05$).

The mean bone density values of the implant recipient sites in the younger (age between 22 and 50, with a mean of 41 ± 7) and older (age between 51 and 76, with a mean of 58 ± 6) patients differed significantly ($p < .05$). Also, similarly, the mean bone density values of the implant sites in the women and men differed significantly ($p < .05$) (Table 2).

DISCUSSION

The use of dental implants has recently been increased because many studies have included good and predictable results.[1–4] It was considered that traditional panaromic radiographs were sufficient to evaluate the anatomic regions in the past years. However, those radiographs have some disadvantages as two-dimensional view, magnification, and no quantitative information about bone density. Therefore, the researchers have currently focused to understand the bone accurately using CT images,[25,26] because it is well known that the precise and quantitative evaluation of the dimension and density of bone provides valuable information to the clinician with the treatment planning of implant therapy. In addition, the clinicians have now a possibility to assess the bone quality at the implant recipient sites by means of the

TABLE 1 The Bone Density Values (Hounsfield Unit) in the Four Quadrants of the Mouth

Quadrant	Number of Implant Sites	Mean Bone Density Values (±SD)	*p* Values
Anterior mandible	92	927 ± 237	<.001
Posterior mandible	81	721 ± 291	
Anterior maxilla	102	708 ± 222	<.001
Posterior maxilla	97	505 ± 274	

No significant difference between posterior mandible and anterior maxilla ($p > .05$).

TABLE 2 The Bone Density Values (Hounsfield Unit) According to Gender and Age

	Number of Implant Sites	Mean Bone Density Values (±SD)	*p* Values
Gender			
Female	168	663 ± 295	<.05
Male	204	753 ± 313	
Age			
Older	215	745 ± 309	<.05
Younger	157	668 ± 303	

relatively new software programs associated with the CT machine. CT is an established method for the measurement of bone density and provides quantitative data of trabecular and cortical bone.[27] It provides both precise three-dimensional anatomic localizations and direct density measurements given in HU. The units are based on density values for air (–1,000 HU) and pure water (0 HU), and cortical bone may range from +1,000 to +1,600 HU values.[22,28]

Detailed information about bone density will help the surgeon identify optimum implant sites, thereby improving the success rate of the procedures. Several methods have been suggested to enhance the primary implant stability.[29–32] First is to place the implant into a smaller diameter hole than is usual, which is preferred by some surgeons in regions of poor bone quality. Compressive forces related to the quality of the bone and the mismatch between the hole and the implant diameter are set up along the implant/tissue interface, which enhances the implant stability. Another method to enhance primary stability in poor bone quality is to place a tapered implant into a standard parallel-sided socket, which induces controlled compressive forces in the cortical bone layer as the implant is inserted; these forces would increase the primary stability of the implant. Also, extended healing periods are used to provide required implant stability in the poor bone.

The clinical study by Norton and Gamble[22] comprised 32 CT scans and a total of 139 implant sites, which were 25 anterior mandible sites, 45 posterior mandible sites, 42 anterior maxillary sites, and 27 posterior maxillary sites. The mean bone density values ranged from 77 to 1,421 HU with a mean of 682 HU for all 139 sites. They observed 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. Another earlier clinical study by our group included 85 patients with 158 implant sites, and the bone density values ranged from 278 to 1,227 HU, with a mean of 751 HU.[19] Shapurian and colleagues[24] reported that their bone density values ranged from –240 to 1,159 HU, and the bone density values were 559, 517, 333, and 312 HU in the anterior mandible, anterior maxilla, posterior maxilla, and posterior mandible, respectively. The diversities are likely to come from the distribution of the sites considered and the patient-related factors (ie, age, gender).

In this study, the mean bone density value of the implant recipient sites in younger patients was lower than that in older patients. It has been considered that this difference resulted from the distribution of the interest areas. Seventy-one mandibular anterior interest areas with better bone quality in older patients were assessed, while 21 mandibular anterior interest areas with poorer bone quality in younger patients were evaluated. However, the difference in the mean bone density value between women (mean age 51 ± 12 years) and men (mean age 52 ± 10 years) was not associated with the distribution of the interest sites, which may be explained with the hormonal differences in women and generally higher bone mass in men. Earlier studies with the measurement of the bone mineral contents in the jaws and forearms by Von Wovern and colleagues[33,34] have already showed that, when compared to the men, lower bone mineral densities in women have been observed throughout adult life with a significantly larger bone mineral content loss in elderly women. Also, the difference in bone density values between women and men found in the present study confirms the previous report, including the bone density values of 656 and 861 HU in women and men, respectively, by Turkyilmaz and colleagues.[19] However, Shapurian and colleagues[24] reported no significant difference between women and men because the corresponding values were 400 and 429 HU, which are not in agreement with the present study.

Under the guidelines of this study, the results suggest that CT is a useful tool to evaluate the bone density of implant recipient sites before implant placement, and the quantitative and objective information obtained from CT may alter the dental practitioners to modify the treatment plan, particularly in the soft bone where implant failure is more common.

REFERENCES

1. Turkyilmaz I, Sennerby L, Tumer C, Yenigul M, Avci M. Stability and marginal bone level measurements of unsplinted implants used for mandibular overdentures. A one-year randomized prospective clinical study comparing early and conventional loading protocols. Clin Oral Implants Res 2006; 17:501–505.
2. Maló P, Nobre MA, Rangert B. Short implants placed one-stage in maxillae and mandibles: a retrospective clinical study with 1 to 9 years of follow-up. Clin Implant Dent Relat Res 2007; 9:15–21.
3. Ostman PO, Hellman M, Sennerby L. Direct implant loading in the edentulous maxilla using a bone density-adapted surgical protocol and primary implant stability criteria for inclusion. Clin Implant Dent Relat Res 2005; 7:60–69.
4. Turkyilmaz I, Tözüm TF, Tumer C, Ozbek EN. A 2-year clinical report of patients treated with two loading protocols for mandibular overdentures: early versus conventional loading. J Periodontol 2006; 33:1998–2004.
5. Maló P, Rangert B, Nobre M. "All-on-Four" immediate-function concept with Brånemark System® implants for completely edentulous mandibles: a retrospective clinical study. Clin Implant Dent Relat Res 2003; 5:2–9.
6. Jemt T, Lekholm U. Implant treatment in edentulous maxilla: a five-year follow-up report on patients with different degrees of jaw resorption. Int J Oral Maxillofac Implants 1995; 10:303–311.
7. Kaptein MCA, De Lange GL, Blijdorp PA. Peri-implant tissue health in reconstructed atrophic maxillae – report of 88 patients and 470 implants. J Oral Rehabil 1999; 26:464–474.
8. Lekholm U, Zarb GA. Patient selection and preparation. In: Branemark PI, Zarb GA, Albrektsson T, eds. Tissue integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:199–209.
9. Misch CE. Density of bone: effect on surgical approach, and healing. In: Misch CE, ed. Contemporary implant dentistry. St. Louis, MO: Mosby, 1999:371–384.
10. Trisi P, Rao W. Bone classification clinical–histomorphometric comparison. Clin Oral Implants Res 1999; 10:1–7.
11. Engquist B, Bergendal T, Kallis T, Linden U. A retrospective multicenter evaluation of ossointegrated implant supporting overdentures. Int J Oral Maxillofac Implants 1988; 3:129–134.
12. Friberg B, Sennerby L, Roos J, Johansson P, Strid CG, Lekholm U. Evaluation of bone density using cutting resistance measurements and microradiography: an in vitro study in pig ribs. Clin Oral Implants Res 1995; 6:164–171.
13. Schwarz MS, Rothman SLG, Rhodes ML, Chafetz N. Computed tomography: part I. Preoperative assessment of the mandible for endosseous implant surgery. Int J Oral Maxillofac Implants 1987; 2:137–141.
14. Schwarz MS, Rothman SLG, Rhodes ML, Chafetz N. Computed tomography: part II. Preoperative assessment of the maxilla for endosseous implant surgery. Int J Oral Maxillofac Implants 1987; 2:143–148.
15. Friberg B, Jemt T, Lekholm U. Early failures in 4641 consecutively placed Branemark dental implants: a study from stage I surgery to the connection of completed prostheses. Int J Oral Maxillofac Implants 1991; 6:142–146.
16. Johansson P, Strid KG. Assessment of bone quality from placement resistance during implant surgery. Int J Oral Maxillofac Implants 1994; 9:279–288.
17. Lachmann S, Laval JY, Jager B, et al. Resonance frequency analysis and damping capacity assessment. Part 2: peri-implant bone loss follow-up. An in vitro study with the periotest and Osstell instruments. Clin Oral Implants Res 2006; 17:80–84.
18. Friberg B, Sennerby L, Meredith N, Lekholm U. A comparison between cutting torque and resonance frequency measurements of maxillary implants. A 20-month clinical study. Int J Oral Maxillofac Surg 1999; 28:297–303.
19. Turkyilmaz I, Tözüm TF, Tumer C, Ozbek EN. Assessment of correlation between computerized tomography values of the bone, and maximum torque and resonance frequency values at dental implant placement. J Oral Rehabil 2006; 33:881–888.
20. Fanuscu MI, Chang TL. Three-dimensional morphometric analysis of human cadaver bone: microstructural data from maxilla and mandible. Clin Oral Implants Res 2004; 15:213–218.
21. Hanazawa T, Sano T, Seki K, Okano T. Radiologic measurements of the mandible: a comparison between CT-reformatted and conventional tomographic images. Clin Oral Implants Res 2004; 15:226–232.
22. Norton RM, Gamble C. Bone classification: an objective scale of bone density using the computerized tomography scan. Clin Oral Implants Res 2001; 12:79–84.
23. Ikumi N, Tsutsumi S. Assessment of correlation between computerized tomography values of the bone and cutting torque values at implant placement: a clinical study. Int J Oral Maxillofac Implants 2005; 20:253–260.
24. Shapurian T, Damoulis PD, Reiser GM, Griffin TJ, Rand WM. Quantitative evaluation of bone density using the Hounsfield index. Int J Oral Maxillofac Implants 2006; 21:290–297.
25. Wyatt CC, Pharoah MJ. Imaging techiques and image interpretation for dental implant treatment. Int J Prosthodont 1998; 11:442–452.
26. Lundgren S, Anderson S, Gualini F, Sennerby L. Bone reformation with sinus membrane elevation: a new surgical technique for maxillary sinus floor augmentation. Clin Implant Dent Relat Res 2004; 6:165–173.

27. Cann CE. Quantitative CT for determination of bone mineral density: a review. Radiology 1988; 166:509–522.
28. Lindh C, Nilsson M, Klinge B, Petersson A. Quantitative computed tomography of trabecular bone in the mandible. Dentomaxillofac Radiol 1996; 25:146–150.
29. Martinez H, Davarpanah M, Missika P, Celletti R, Lazzara R. Optimal implant stabilization in low density bone. Clin Oral Implants Res 2001; 12:423–432.
30. O'Sullivan D, Sennerby L, Meredith N. Influence of implant taper on the primary and secondary stability of osseointegrated titanium implants. Clin Oral Implants Res 2004; 15:474–480.
31. Khang W, Feldman S, Hawley CE, Gunsolley J. A multicenter study comparing dual acid-etched and machined-surfaced implants in various bone qualities. J Periodontol 2001; 72:1384–1390.
32. O'Sullivan D, Sennerby L, Jagger D, Meredith N. A comparison of two methods of enhancing implant primary stability. Clin Implant Dent Relat Res 2004; 6:48–57.
33. Von Wovern N. General and oral aspects of osteoporosis: a review. Clin Oral Invest 2001; 5:71–82.
34. Von Wovern N, Westergaard J, Kollerup G. Bone mineral content and bone metabolism in young adults with severe periodontitis. J Clin Periodontol 2001; 28:583–588.