Early Detection of Alterations in the Resonance Frequency Assessment of Oral Implant Stability on Various Bone Types: A Clinical Study

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This study was undertaken to evaluate the relation between bone quality and alterations of implant stability quotient values measured during the initial phase of healing. Nineteen patients treated with 106 implants were included in the current study. The mean bone density of the implant recipient area was measured using Simplant 11 software incorporated in the computerized tomography (CT) machine. Mean bone density measurements were recorded in Hounsfield units. The implant recipient sites were subdivided into 5 groups according to bone quality. The numbers of the structures on the recipient site belonging to D1 and D5 types showed no statistical significance and were excluded. Standard 2-stage surgical technique was utilized to prepare the surgical sites. The implant stability quotient (ISQ) value at implant placement was recorded and did not influence the treatment procedure. The ISQ was measured by an Osstell instrument. The ISQ was further registered on the 21st and 60th days. SPSS statistical software was used for the statistical analysis. In comparison with the time of insertion, the mean values of the ISQ were decreasing for the first 21 days. However, on subsequent days, the ISQ values of all bone types have increased and on the 60th day reached the values recorded at the time of insertion. Analysis of the relation between changes in stability and bone type does not reveal statistical significance. With knowledge of the current clinical study, it can be concluded that bone quality in the recipient bone site does not effect changes in implant stability at the early stages of the osseointegration process.

Key Words: bone quality, computerized tomography, implant stability, resonance frequency analysis, Simplant

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Introduction

Oral implants have been used widely to restore missing teeth and have become increasingly important in oral rehabilitation over the past 2 decades. Several clinical reports on the success rate of dental implants mentioned that the volume and quality of the bone are determinant factors in postoperative outcomes.[1] The classification of bone quality is based on the amount of cortical bone and the density of trabecular bone.[2] It has been suggested that oral implants placed into soft bone are more prone to failure.[3]

Implant stability can be defined as the absence of clinical mobility. Implant stability is the implant's initial mechanical subjection after placement and is mainly determined by initial bone implant contact.[4] Implant stability has been identified to be the most important and useful predictor of implant anchorage,[5] especially when immediate loading has been planned and considered to be one of the most important indications for the osseointegration process.[2,6]

The volume and quality of bone play a fundamental role in the success of dental implant surgery.[7] The best method for evaluating bone density is histomorphometric analysis of a bone sample obtained from the recipient site. However, this approach is not applicable to routine clinical practice. In 1985, Lekholm and Zarb developed a method to assess bone quality and introduced a scale of 1–4, based on radiographic assessment and on the sensation of resistance experienced by the surgeon when preparing the implant site.[8] Their classification has recently been questioned because of poor objectivity and reproducibility.[9] Subsequently, Johansson and Strid[10] described a technique that measured cutting resistance during implant placement as a function of the electrical current drawn by the handpiece. However, Friberg et al explored the relationship between cutting resistance and bone quality.[11] All of these methods may provide helpful information about bone density, but they offer poor information and are considered to be only retrospective to patient assessment.[12]

Other methods of assessing bone quality have included histomorphometry of bone biopsies,[13] densitometry,[14] digital image analysis of radiographs,[15] and ultrasound.[16] Most of these techniques provide a reliable quantitative measure of bone density but are impractical for the practicing implant surgeon.

The literature includes studies performed to compare the diagnostic information gathered by computerized tomography (CT) and by orthopantomography for presurgical implant dentistry assessment to establish a basis for weighing potential diagnostic and therapeutic benefits of each imaging technology in implant dentistry.[17] CT scans, which are more objective and reliable, may offer the best radiographic method for morphologic and qualitative analyses of residual bone, and this imaging technique has been used in several studies.[18–20] In 1987, Schwartz et al[21,22] introduced the concept of using CT scans for preoperative assessment of dental implant candidates.

In particular, the introduction of interactive software specifically designed for assessment of implant surgery has been hailed as a significant contribution to the diagnostic armamentarium. Simplant software (Columbia Scientific, Inc, Columbia, Md) has been presented in the literature[23] and can be used to map the bone around an interactively placed implant or within a defined area of the jaw, and have the computer provide the density in Hounsfield units (HU) with both mean and standard deviation values.

The Hounsfield units determined by the software programs in CT machines ranges from −1000 (air) to 3000 (enamel). The density of structures within the image is absolute and quantitative and can be used to differentiate tissues in the region (ie, muscle, 35–70 HU; fibrous tissue, 60–90 HU; cartilage, 80–130 HU; bone 150–1800 HU) and to characterize bone quality (D1 bone, >1250 HU; D2 bone, 850–1250 HU; D3 bone, 350–850 HU; D4 bone, 150–350 HU; D5 bone, <150 HU).[24] CT enables the evaluation of proposed implant sites and provides diagnostic information that other imaging methods cannot provide.[25]

In the past, several methods have been proposed to measure implant stability. Johansson and Albrektsson proposed a removal torque analysis, in which they assess stability by measuring the peak torque necessary to shear the interface between the implant surface and surrounding bone.[26] The technique could be carried out easily, but it is thought to be destructive. Kaneko used impulse tests to assess implant stability.[27] Pull and push through tests,[28] X-ray examinations,[5] and histomorphometric observations[29] also have been proposed. In recent years, Periotest (Siemens AG GmBh, Berlin, Germany), an electronic device, has been used to measure stability. This device measures the damping capacity of an implant that has been tapped and deflected by the instrument's hitting pistil. The technique does not damage the implant-tissue interface; however, it has been suggested that Periotest is sensitive to angle, height on the abutment, and distance that the handpiece is held from the implant.[30] Recently, Meredith[5] developed an easy, noninvasive, reproducible method known as resonance frequency analysis (RFA). With this method, implant stability can be measured immediately after implant placement and during the osseointegration process, either by determining the resonance frequency of the implant-bone complex stiffness or by reading an implant stability quotient (ISQ) derived from the resonance frequency given by the Osstell equipment (Integration Diagnostics AB, Gothenburg, Sweden). The measurement is carried out to each model of implant to obtain an ISQ value whose range oscillates between 1 and 100. The RFA method with the Osstell equipment has been claimed to be useful for monitoring implant stability at any time during the healing phase.[5] The RFA technique has proved sensitive in monitoring changes in implant stability.[31,32] However, according to Bischof,[33] the method does not provide a measure of implant osseointegration.

Several studies in the literature have investigated resonance frequency assessment of dental implant stability with various bone qualities. Implants stability was seen to decrease within the first 2 weeks.[34] Buser et al[35] measured increasing removal torques for SLA implants after 4, 8, and 12 weeks. However, the effects of different bone types on the response of the implants to resonance frequency assessment at different times remain uncertain. The aim of this study was to evaluate the relation between bone quality and alterations in ISQ values measured just after insertion on the 21st and 60th days.

Materials and Methods

Patients

The study group consisted of 106 implants, placed in 19 patients. The mean age of patients (11 females, 8 males) was 41 ± 4 years. All patients were treated in Gülhane Military Medical Academy, Department of Oral and Maxillofacial Surgery clinic, from April 2008 to July 2009. Patients enrolled in the study met the following inclusion criteria: (1) absence of uncontrolled medical conditions such as diabetes, and (2) availability for follow-up visits. Exclusion criteria were (1) uncontrolled diabetes or systemic disease, (2) radiation to head and neck, and (3) need to bone graft for the implant recipient site due to inadequate bone

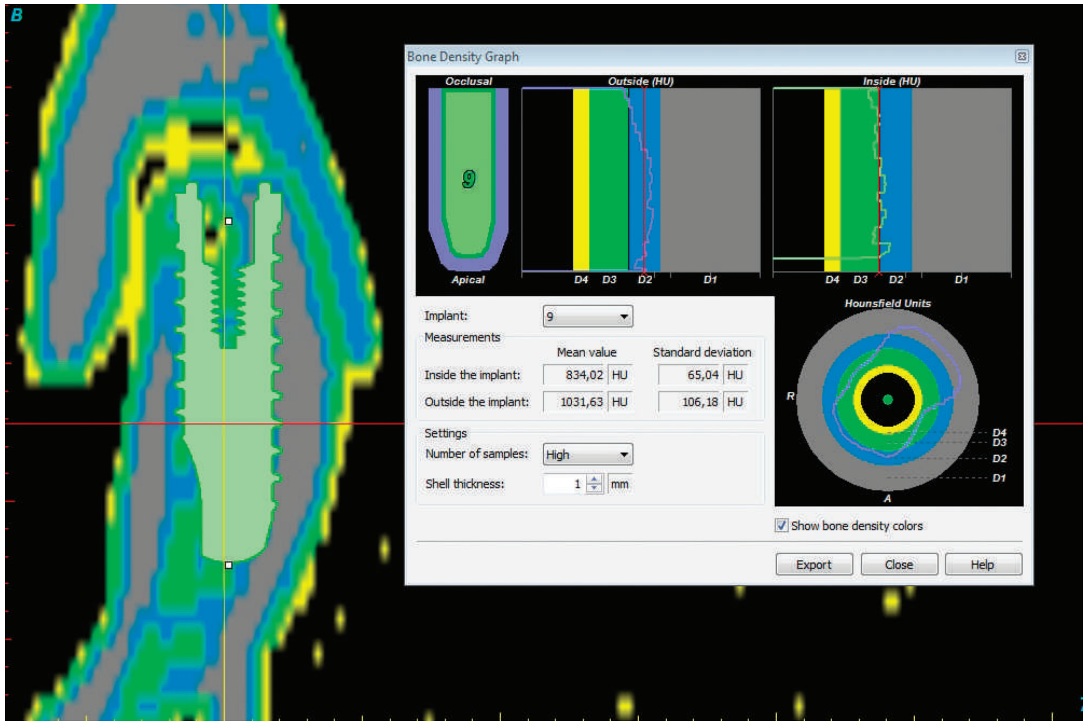

FIGURE 1. The suitable implant for each previously designated implant recipient site was selected by using cross-sectional images. The mean bone density of the implant recipient area was measured using Simplant incorporated in the computerized tomography machine. Mean bone density measurements were recorded in Hounsfield units.

volume for regular platform implants. The presurgical evaluation consisted of clinical and radiographic examinations, including CT scans. All patients were thoroughly informed about the procedure and signed a written consent. Also, local ethic approval was obtained for the main study.

Computerized tomography scans

To assess the bone density of implant recipient sites, a spiral CT machine (Siemens Somatom AR-SP 40, Erlanger, Germany) was utilized. Cross-sectional, coronal, and axial images for each maxilla/mandible were obtained. The suitable implant for each previously designated implant recipient site was selected by using the cross-sectional images. The mean bone density of the implant recipient area was measured using Simplant software, version 11 (Materialise Dental, Leuven, Belgium), incorporated in the CT machine. Mean bone density measurements were recorded in Hounsfield units (Figure 1). Implant recipient sites were subdivided into 5 groups according to bone quality. The numbers of the structures on the recipient site belonging to D1 and D5 types showed no statistical significance and were excluded. The bone structures considered as being between D2 and D3 were included in the subgroup of D2.

Surgical procedure

Standard 2-stage surgical technique was utilized to prepare the surgical sites. Full-thickness mucoperiosteal flaps were raised while patients were under local anesthesia. Swiss Precision Implant (SPI) system implants (Thommen Medical AG, Waldenburg, Switzerland) were placed under sterile saline irrigation. The frequencies of the implant diameters are shown in Table 1.

All drilling and implant insertion procedures were carried out with the same motor (Ti-Max NL 400, NSK Nakanishi, Kanuma,

Table 1		
Frequencies of implant diameters		
Diameter, mm	Frequency	Percent
3.5	24	22.6
4	17	16
4.5	38	35.8
5	27	25.5
Total	106	

Table 2		
Frequencies of bone types at implant insertion sites		
Bone Type	Frequency	Percent
D2	21	19.8
D3	56	52.8
D4	29	27.4
Total	106	

Japan) with placement torque of 50 Ncm, when the rotation stopped because of friction before the implant was fully inserted.

RFA procedure

An implant stability quotient (ISQ) value based on the resonance frequency was calculated for each measurement. The ISQ is presented as a value from 1 (lowest stability) to 100 (highest stability) and represents a standardized unit. The ISQ value at implant placement was recorded and did not influence the treatment procedure. The ISQ was measured by an Osstell instrument with a commercially available transducer (type L_4F_5) adapted to the SPI implants. The transducer was maintained perpendicular to the implant, as recommended by the manufacturer. The ISQ was further registered on the 21st and 60th days.

Statistical analysis

SPSS statistical software (SPSS Inc, Chicago, Ill) was used for all statistical analyses. The distribution of the data was nonparametric, and this was determined by 2-way Kruskal-Wallis analysis of variance (ANOVA) testing done to verify possible differences between groups in terms of bone density, time of assessment, and resonance frequency values. $P < .05$ was considered statistically significant.

Results

A total of 106 dental implants were included in the current study. With consideration of the type of bone at the placement site, the D2 group consisted of 21, the D3 group 56, and the D4 group 29 recipient sites, which are shown in Table 2.

Mean RFA values of the 3 groups were 73.66 ± 6.30 ISQ at the time of implant placement, 72.28 ± 6.31 ISQ on the 21st day after implant insertion, and 74.55 ± 6.11 ISQ on the 60th day after implant insertion. Values are shown in Table 3.

Table 4 shows alterations in stability reflecting bone type at insertion and at the 21st and 60th days. In the D2 group, the mean value of the ISQ at the time of insertion was 80.10. However, the mean value of the ISQ for the D2 group was measured at 78.76 on the 21st day and 80.02 on the 60th day after insertion. In the D3 group, the mean value of the ISQ at the time of insertion was 73.69. On the 21st day, the mean value of the ISQ for the D2 group decreased to 72.46, and it recently increased to 74.88 on the 60th day after insertion. In the D4 group, the mean values of the ISQ at insertion and at the 21st and 60th days were 68.95, 67.24, and 69.97.

When analyzed according to the time of insertion, the mean values of the ISQ were decreasing for the first 21 days. However, on

Table 3		
Mean RFA values of the 3 groups on the 1st, 21st, and 60th days*		
Time of Measurement	Mean ISQ Value	Standard Deviation
0 day (insertion)	73.66	6.3
21st day	72.28	6.31
60th day	74.55	6.11

*RFA indicates resonance frequency analysis; ISQ, implant stability quotient.

Table 4

Alterations in ISQ values considering bone type on insertion, 21st, and 60th days*

Bone Type	Time of Insertion			21st Day			60th Day		
	N	ISQ	SD	N	ISQ	SD	N	ISQ	SD
D2	21	80.1	3.53	21	78.76	3.38	21	80.02	5.15
D3	56	73.69	5.87	56	72.46	5.68	56	74.88	5.43
D4	29	68.95	4.28	29	67.24	4.45	29	69.97	4.29

*N indicates number of the recipient bone site; ISQ, implant stability quotient; SD, standard deviation.

subsequent days, the ISQ values have increased and on the 60th day reached values at the time of insertion. Especially in the D3 and D4 groups, on the 60th postoperative day, ISQ values were moving higher than values at the time of implant placement.

Alterations in mean ISQ values according to bone type at the 21st and 60th days are shown in Figure 2. To detect the relation between bone type and changes in implant stability, a 2-way ANOVA test was used. Analysis of the relation between changes in stability and bone type does not reveal statistical significance ($F_{(4-206)} = 1.789$; $P > .1$).

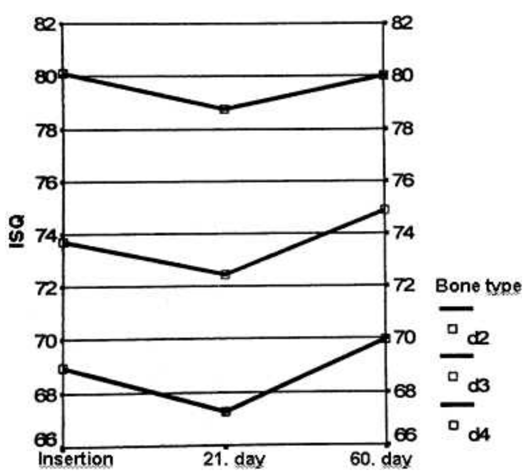

Figure 2. In comparison with the time of insertion, mean ISQ values were decreasing for the first 21 days. However, on subsequent days, the ISQ values have increased and reached the values at the time of insertion on the 60th day. Especially in the D3 and D4 groups, on the 60th postoperative day, ISQ values tended to be higher than values at the time of implant placement.

Discussion

Achieving and maintaining implant stability are essential for successful clinical outcomes with dental implants.[36] The stability of the implant depends on factors such as contact between implant surfaces, placement technique, and surrounding bone quality. Differences in diameter between the final drill and the implant can result in increasing stress forces on the surrounding bone and can jeopardize the initial stability of the implant. Additionally, the profound structure of the chamfer is more prone to restraint and to high ISQ values.[37] The implicit assumption is that implants undergoing stability are supposed to increase their stability over time, or at least maintain it.[5] A review of the literature shows that failure to establish osseointegration occurs during the first 3 to 6 months of loading.[38–40] When stability is maintained afterward, implants should be considered as osseointegrated.[41]

Implant healing time can be probably adjusted according to bone density and available bone volume. In a clinical study, Jaffin and Berman[42] stated that implant insertion in soft-bone structures has a higher failure rate. Ivanoff[43] recommended extending the healing time in soft-bone situations. Additionally, the mechanical properties of bone are determined by the composition of the bone at the placement site and may increase during healing because soft trabecular bone tends to undergo a transformation to dense cortical bone at the vicinity of the implant surface.[44] The implant surface and the design of the implant may influence the strength of the implant; however, in the current study; identical implants were placed in various bone sites using identical surgical techniques.

Assessment of stability at the time of insertion may be done to determine the prognosis or to decide whether early or even immediate loading can be performed.[45] In the literature, ISQ measurements obtained during the early phases of the healing period revealed greater implant stability in the high crestal cortical bone, and a significant correlation between bone quality and ISQ values; these findings are in accordance with findings of the current study.[46,47]

During the first weeks of healing, bone modeling and remodeling take place around the implant surface. This phase with the formation of lamellar bone from woven bone may cause a decrease in primary bone contact.[4] Data on higher implant survival with dense bone types also support results of previous studies. Bischof et al stated that implant stability varied according to jaw and bone type; the mean ISQ remained stable during the first 4–6 weeks and then increased noticeably, but did not reveal any decrease in implant stability in the delayed loaded or initially loaded group.[33] The finding that the bone-implant interface transitions through an adaptive phase of lowered stability and back to a more stable configuration over a 60-day period is consistent with previous studies.[48]

In the current study, we computed the resonance frequencies of implants using various bone types classified in 5 different groups, similar to the classification used by Lekholm and Zarb[8] (Figure 2). Our results show that the implant installed in D2-type bone has the highest resonance frequency.

According to Balshi et al,[48] because of the amount of cortical and trabecular bone, type 1 bone had the highest primary stability but showed the greatest decrease in mean ISQ in the first 30 days. Bone types 2 and 3 showed more consistent return of primary stability, and bone types 1 and 4 did not. Therefore, investigators suggested that bone types 2 and 3 would be advocated for an immediate loading protocol, because of their combined innate stability and regenerative capabilities. However, a correlation between bone type and changes in implant stability could not be confirmed. In the current study, investigators noted that a decrease in stability from the time of implant insertion to the 21st day post-surgery was followed by an increase in stability approaching the original stability level. This is supported by several other studies,[33] but the decrease in ISQ values was less reflective of results reported in the literature.

On the basis of this result, immediate loading protocols can be used for soft-bone implantation, but a 60-day healing period is needed after implant insertion. Nedir et al[34] suggested that for implants with high ISQ values, reduced implant stability during the first 12 weeks of healing is considered a common event that should not require alterations to routine follow-up.

Conclusion

The resonance frequency of a dental implant with similar design and surface would be associated only with its boundary conditions, such as surrounding bone quality and tissue response at the recipient site. In this regard, in the present study, the only variable of significance observed to affect the implant stability measurement seems to be the type of bone at the recipient site. It has been advocated that in dense bone, no or only a short healing period may be needed, although prolonged healing may be desirable with softer bone densities. However, given the findings of the current clinical study, it can be concluded that bone quality in the recipient bone site does not effect changes in implant stability at the early stages of the osseointegration process.

Abbreviations

CT: computerized tomography

HU: Hounsfield units

ISQ: implant stability quotient

RFA: resonance frequency analysis

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