Resonance Frequency Analysis of 208 Straumann Dental Implants During the Healing Period

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The most important prerequisite for the success of an osseointegrated dental implant is achievement and maintenance of implant stability. The aim of the study was to measure the 208 Straumann dental implant stability quotient (ISQ) values during the osseointegration period and determine the factors that affect implant stability. A total of 164 of the implants inserted were standard surface, and 44 of them were SLActive surface. To determine implant stability as ISQ values, measurements were performed at the stage of implant placement and healing periods by the Osstell mentor. The ISQ value ranges showed a significant increase during the healing period. Except for the initial measurement, the posterior maxilla had the lowest ISQ values, and there was no significant difference among anterior mandible, posterior mandible, and anterior maxilla ($P < .05$). Implant length did not have a significant influence on ISQ value ($P > .05$). The second measurement was significantly higher in men compared with women ($P < .05$). The second measurement was significantly higher than the others at 4.8 mm, and for the final measurement, there were no significant differences between 4.8 and 4.1 mm, which were higher than 3.3 mm ($P < .05$). When comparing sandblasted, large-grit, acid-etched (SLA) and SLActive surface implants, there were no significant differences for insertion measurements, but for second measurements, SLActive was significantly higher ($P = 0$), and for the final measurement, there was no significant difference. It appears that repeated ISQ measurements of a specific implant have some diagnostic benefit, and the factors that affect implant stability during the healing period are presented.

Key Words: implant stability, ISQ value, resonance frequency analysis, Strauman dental implant

INTRODUCTION

Osseointegration has been used to define a direct structural and functional connection between ordered living bone and the surface of a load-carrying implant.[1]

The stability of a dental implant can be defined as the absence of clinical mobility, and this is also the suggested definition of osseointegration. The most important prerequisite for success of ossointegrated dental implants is achievement and maintenance of implant stability.[2] Primary stability is a merely a mechanical phenomenon depending on local bone quality and quantity, surgical preparation technique, and implant design[3,4] and one of the most important factors in the osseointegration process.

Initial stabilization is not the same as osseointegration; it must carry the implant during the critical time of the early stages in the development of osseointegration, during which the implant is at risk.[5] The clinical measurement of implant stability and osseointegration is important to be able to assess success in implant dentistry. It is now

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possible to measure implant stability at any time during the course of implant treatment and loading.[6]

There are some traditional methods, including histological and histomorphometric observations, removal torque analysis,[7] percussion tests, pull- and push-through tests,[8] and Periotest,[9] to evaluate the initial bone quality and degree of osseointegration.

In 1996, Meredith et al[6] developed a noninvasive and nondestructive method to evaluate the condition of the implant-tissue interface; it was called resonance frequency analysis (RFA). The use of RFA provides the possibility to clinically measure implant stability and osseointegration. In 1997, Meredith et al[10] used RFA to study bone formation at the implant-tissue interface in the rabbit tibia during healing, and resonance frequency measurements can be related to the stiffness of an implant in the surrounding tissues and also the level of the surrounding bone. The measurement is carried out with a machine connected through a specific transducer to each model of implant, obtaining a numerical value known as the implant stability quotient (ISQ), whose range oscillates between 1 and 100.[11]

The primary implant stability at placement is a mechanical phenomenon related to the quality and quantity of bone at the recipient site, the type and design of implant used, and the surgical technique employed. The secondary implant stability is the increase in stability attributable to bone formation and remodeling at the implant-tissue interface and in the surrounding bone.[12]

The aim of this prospective clinical study was to evaluate the influence of parameters such as jaw region, implant diameter, implant length, and implant surface property on ISQ values of Straumann dental implants during the osseointegration period. The research hypothesis was that ISQ values of Straumann dental implants are affected by jaw region, implant diameter, implant length, and implant surface property.

Materials and Methods

Ethical approval for this study was obtained from Ethics Committee of Ondokuz Mayıs University. A total of 208 Straumann solid screw implants (Straumann AG, Basel, Switzerland) were placed in a total of 59 patients in the Ondokuz Mayıs University Faculty of Dentistry Department of Oral and Maxillofacial Surgery from March 2007 to March 2010 according to the manufacturer's protocol.

Delay-loaded dental implants were used, and nonsmoker patients requiring implant therapy without bone augmentation were included in the study. Assessment of suitability (the morphology and the skeletal relationships) was based on a clinical examination and bone height, width, and quality; internal anatomy of bone; jaw boundaries; and pathology detection evaluated by presurgical ortopantomograms and dental computerized tomograms. The study included the implants placed in mature bone. A total of 164 of the implants inserted were sandblasted, large-grit, acid-etched (SLA) surface, and 44 of them were SLActive surface.

Straumann SLA

The SLA surface is produced by a large-grit sandblasting process with corundum particles that leads to a macro-roughness on the titanium surface. This is followed by a strong acid-etching bath with a mixture of HCl/H_2SO_4 at elevated temperature for several minutes.

Straumann SLActive

A new chemically modified titanium surface, SLActive (Straumann AG), has been developed using the well-documented topography of the SLA (Straumann AG) surface. Chemical modification of the surface is characterized by a hydroxylated/hydrated TiO_2 film and is carried out under N_2 conditions, maintained by storage in isotonic saline.[13,14]

All operations were done under local anesthesia by the same oral surgeon in the same operating room and under similar conditions. Analgesia was achieved by regional or infiltration anesthesia according to the jaw region with articaine containing 1:100 000 epinephrine (Ultracaine DS, Aventis, Istanbul, Turkey). A full-thickness incision was made to prepare the flaps. Implants were inserted according to the manufacturer's protocol. The flaps were closed using 3-0 silk sutures. All patients received postoperative instructions (soft warm diet for the first 24 hours, normal oral hygiene from the day after surgery, mouthwash with 0.2% chlorhexidine twice daily). Patients were given antibiotics (amoxicillin, 2 mg per day for 5 days) and analgesic drugs (flurbiprofen, 200 mg per day for 3 days). The sutures were removed after 7 days.

Table 1

Measurement periods*

Implant Surface	Inserted Area	n	ISQ Values Measurement Time		
			Initial	Second	Third
SLA surface	Anterior maxilla	27	+	4th week	12th week
	Posterior maxilla	63	+	4th week	12th week
	Anterior mandible	35	+	4th week	8th week
	Posterior mandible	39	+	4th week	8th week
SLActive surface	Anterior maxilla	7	+	4th week	8th week
	Posterior maxilla	16	+	4th week	8th week
	Anterior mandible	8	+	4th week	—
	Posterior mandible	13	+	4th week	—

*SLA indicates sandblasted, large-grit, acid-etched; ISQ, implant stability quotient.

To determine implant stability as ISQ values, RFAs were used, and the measurements were performed by the help of an Osstell mentor (Integration Diagnostic AB, Goteborg, Sweden) with the Smart peg abutment (Integration Diagnostic AB). The initial and second measurements were performed for all types of implants, and third measurements were performed before the prosthetic phase, except for SLActive surface implants localized in the mandibular anterior and posterior regions. Measurement periods according to the implant insertion regions and implant surface types are listed in Table 1.

According to the manufacturer's recommendations, two ISQ values were obtained for each implant at both times. Measurements were taken twice in each direction: in the buccolingual direction from the buccal side and in the mesiodistal direction from the masial side. For statistical analysis, the mean values of scores were calculated and the implants were divided into four groups according to their localization in the upper and lower jaw. To evaluate the influence of implant length, implant diameter, initial ISQ value, and healing period on implant stability, one-way and two-way analyses of variance (ANOVAs) and independent-samples *t* tests were computed at a level of significance of $\alpha = .05$.

Results

Descriptive statistics

A total of 208 implants were inserted, and all the implants included in the study osseointegrated successfully and could be restored.

The number of implants inserted in men was 116 (55.2%), whereas the number was 92 (44.2%) in women. The mean age of the patients was 53.39 (range, 16–81) years. The implants were distributed according to regions as 79 (38.0%) in the maxillary posterior area, 52 (25.0%) in the mandibular posterior area, 43 (20.7%) in the mandibular anterior area, and 34 (16.3%) in the maxillary anterior area. The lengths of the implants ranged from 8 to 14 mm, and the diameters ranged from 3.3 to 4.8 mm.

A total of 164 (78.8%) of the implants were SLA surface implants, whereas 44 (21.2%) of them were SLActive surface. The largest number of SLA surface implants (n = 63) and SLActive surface implants (n = 16) were placed in the maxillary posterior region.

The ISQ values in different areas ranged from 41 to 82 at implant insertion and 44 to 78 in the second measurement, whereas there were 50 to 85 in the third measurement. Mean ISQ values of

Table 2

Mean and standard deviation (SD) of ISQ values for implants in different diameters*

Measurement	Diameter, mm	n	Mean	SD
Initial measurement	3.3	72	62.7778	6.95098
	4.1	108	65.0741	8.18901
	4.8	28	65.5357	8.70709
	Total	208	64.3413	7.90241
Second measurement	3.3	72	60.8056	6.75870
	4.1	108	63.5278	7.54731
	4.8	28	64.6786	8.03259
	Total	208	62.7404	7.46068
Third measurement	3.3	70	67.7429	6.30777
	4.1	91	71.1978	5.57020
	4.8	26	72.1154	6.49509
	Total	187	70.0321	6.21990

*ISQ indicates implant stability quotient.

TABLE 3

Mean and standard deviation (SD) of ISQ values for implants in different lengths*

Measurement	Length, mm	n	Mean	SD
Initial measurement	8	5	67.4000	4.21900
	10	61	63.3770	7.64671
	12	134	65.0149	7.65023
	14	8	58.5000	12.68295
	Total	208	64.3413	7.90241
Second measurement	8	5	66.6000	5.85662
	10	61	62.7869	7.98982
	12	134	62.8507	7.00001
	14	8	58.1250	10.62931
	Total	208	62.7404	7.46068
Third measurement	8	5	72.8000	2.68328
	10	51	70.2157	5.79418
	12	125	69.7040	6.49196
	14	6	73.0000	5.58570
	Total	187	70.0321	6.21990

*ISQ indicates implant stability quotient.

groups according to implant diameter, length, and regions are listed in Tables 2, 3, and 4, respectively. The highest mean ISQ at insertion was recorded in the posterior mandible (66.30), whereas the lowest mean ISQ value was recorded (62.65) in the posterior maxilla. In the second measurement, the largest mean ISQ value was also found in the posterior mandible (65.38), and the lowest mean ISQ was again in the posterior maxilla (60.89). In the third measurement, the largest mean ISQ was found in the posterior mandible (72.33), and the lowest mean ISQ was in the posterior maxilla (68.57) as mentioned above.

TABLE 5

Two-way analysis of variance for region and measurement time

Variable (source)	*df*	Sum of Squares	Mean Squares	*F*	*P*
Region	3	1636.035	545.345	10.759	.000*
Measurement time	2	5360.353	2680.177	52.875	.000*
Interaction	6	41.165	6.861	0.135	.992
Error	591	29 957.072	50.689		

*Significant difference at $P < .05$.

Factors and ISQ

According to one-way ANOVA results for all regions, implant length did not had a significant influence on ISQ value ($P > .05$), but there were significant differences for implant diameters in the second ($P = .018$) and third measurements ($P = .001$). According to Tukey HSD results, the implant diameter did not affect the stability at insertion, for the second measurement of 4.8 mm was significantly higher than the others, and for the final measurement there was no significant difference between 4.8 and 4.1 mm, which demonstrated higher values than 3.3 ($P < .05$). Gender influenced ISQ values significantly only for the second measurement, for which men had significantly higher values ($P = .028$). When comparing SLA and SLActive surface implants, there

TABLE 4

Mean and standard deviation (SD) of ISQ values for implants inserted in different regions*

Measurement	Region	n	Mean	SD
Initial measurement	Posterior maxilla	79	62.6456	7.69455
	Posterior mandible	52	66.3077	7.40836
	Anterior maxilla	34	63.7941	7.55898
	Anterior mandible	43	65.5116	8.62823
	Total	208	64.3413	7.90241
Second measurement	Posterior maxilla	79	60.8861	7.25009
	Posterior mandible	52	65.3846	7.15419
	Anterior maxilla	34	62.1471	6.46732
	Anterior mandible	43	63.4186	8.11299
	Total	208	62.7404	7.46068
Third measurement	Posterior maxilla	79	68.5696	5.86315
	Posterior mandible	39	72.3333	5.72314
	Anterior maxilla	34	68.9706	6.40779
	Anterior mandible	35	71.8000	6.39761
	Total	187	70.0321	6.21990

*ISQ indicates implant stability quotient.

were no significant differences for insertion measurements, but SLActive was significantly higher ($P = .001$) for the second measurement, and for the final measurement, there was no significant difference ($P > .05$).

According to the two-way ANOVA results, although interaction between regions and measurement times was not statistically significant ($P > .05$), the regions and measurement times were statistically significant ($P < .0001$; Table 5). For all regions, there was no statistically significant difference between the initial and second measurement. Third measurements demonstrated the highest ISQ values ($P < .05$). When comparing different regions, there was no statistically significant difference between anterior maxilla and posterior maxilla ($P = .697$), and these groups demonstrated the lowest ISQ values ($P < .05$). There was no statistically significant difference between anterior mandible and anterior maxilla ($P = .239$), and these groups demonstrated average ISQ values. There was no statistically significant difference between anterior mandible and posterior mandible ($P = .631$), and these groups demonstrated the highest ISQ values ($P < .05$).

Discussion

The present study showed that implant stability can be affected a number of factors.

As implant failures are often related to biomechanical factors, an assessment of implant stability may significantly lower the risk of failure. Studies have shown that high RFA values are indicative of a successful implant treatment with a small risk for future failure. Conversely, low or decreasing RFA values point to an increased risk for implant complications, although the exact RFA threshold values have yet to be identified.[15]

Both Meredith et al[12] and Sennerby and Meredith[15] concluded that resonance frequency was a highly effective qualitative method and proposed its use to assess implant stability. In 2002, Huang et al[16] reached similar conclusions after evaluating implant behavior in different types of bone.

The mechanism behind the fall of ISQ during the first month in the present study is probably related to changes in the bone-implant interface as well as the properties of the surrounding bone. In parallel to this, the healing response to implant surgery itself may result in a decreased stiffness as a result of bone resorption, since extensive remodeling occurs in the cortical bone as a healing reaction to surgical wounding. In 1999, Friberg at al[17] evaluated 75 one-stage implants in the edentulous mandible by means of repeated RFA measurements. They stated that resonance frequency values slightly decreased for most of the implants during the study period independent of design and that the implants were as stable at the time of placement as when measured at 3–4 months postsurgery (when the prostheses were attached). Also, in the present study, second measurements demonstrated the lowest ISQ values among the measurement periods. In addition to these findings, Han et al[18] stated that implants showed a slight decrease after installation, with the lowest ISQ values being reached at 3 weeks. The ISQ values were restored 8 weeks postsurgically. The initial decrease in the ISQ values within the first 3–4 weeks is in agreement with the results of other studies.[19,20] Similarly, in the present study, an initial decrease in ISQ values was observed, but third measurements showed a significant increase. Rasmusson et al[21] inserted implants in the rabbit tibia with or without the use of bone grafts. They found a statistically significant increase in implant stability during the study period of 24 weeks, as assessed by RFA.

Bischof et al[22] found an average ISQ value of 60.3 following surgery, Boronat-López et al[11] found 62.1, and in the present study, an average value of ISQ following surgery was 64.57.

Boronat-López et al[23] evaluated the RFA of dental implant stability in 24 patients (12 women, 12 men) with a total 64 Defcon implants. In their study, RFA was used for direct measurement of implant stability on the day of implant placement and consecutively once a week for 8 weeks and at week 10. The lowest mean stability measurement was at 4 weeks (60.9), which is in agreement with the present study.

Brochu et al[24] stated that there was a significant relationship between sex and Ostell values. Authors found a higher stability quotient in females. In contrast with this finding, in Zix et al,[25] men showed higher implant stability than women. Ostman et al[26] pointed out that differences between RFA values with respect to sex were not clinically significant and that there were no differences in the failure rates between men and women. According to the present study's results, gender influenced ISQ

values significantly only for the second measurement, and men had significantly higher values.

Considering these results of the ongoing process of healing between men and women, it is true to say that there will be a difference in terms of stability. In the other words, at the end of the healing period, the clinician should not accept sex as a criterion.

As a result of this study, the use of implants may not be required longer than necessary. Considering the length of the implant, there is no significant effect on the value of stability. It may not be correct to say that longer implants bring a high clinical success. In parallel with this, Balleri et al[27] investigated the stability of 45 implants using Ostell. They found no correlation between implant length and stability; related findings are reported by Bischof et al,[28] who also stated that implant length had no influence on primary implant stability. On the contrary, Ostman et al[26] claim that this parameter could influence ISQ at placement. According to the results of the present study, there was no correlation between implant length and ISQ values. Thus, it can be expressed that it is not always necessary to use longer implants.

Bischof et al[22] stated that the implant position, implant length, and implant diameter did not affect primary stability. To the contrary, results of the investigations by Ostmann et al[26] suggest that factors related to bone density and implant diameter/length may affect the level of primary implant stability. Han et al[18] found that implant diameter was not revealed by RFA. In the present study, the implant diameter did not affect the stability at insertion, but along with the healing period, 4.8-mm implants had higher ISQ values than 3.3-mm implants.

Han et al[18] monitored the development of the stability of Straumann implants during the early phases of healing by RFA and to determine the influence of implant surface modification and diameter. A total of twenty-five 10-mm-length implants including SLA RN, SLA WN, and SLActive RN were placed. They pointed out that implant surface modifications (SLActive) were not revealed by RFA. In the present study, for only second measurements, SLActive demonstrated higher ISQ values than SLA surface, but for the initial and third measurements, there was no significant difference between the two surfaces. Correspondingly, the SLActive surface could be more suitable for early loading. But 3 months later, considering stability, there was no statistically significant difference between the two surfaces.

With the findings of this study, it can be said that implant stability is subsequently poorer in the posterior area, and this might explain the lower success rates reported in the posterior maxilla when compared with the other region. Ersanli et al[29] pointed out that implant stability was higher on the mandible compared with the maxilla for each implant system studied. Balleri et al[27] found that mandibular implants were significantly more stable than were maxillary implants, and there was no significant difference between implants placed in posterior and anterior sites. For Bischof et al,[22] the ISQ was higher in the mandible than in the maxilla during the healing period. In the present study, after surgery there was no difference for ISQ values between the regions. In the second and third measurements, however, the highest ISQ value was observed in the posterior mandible, and no difference was seen among the posterior mandible, anterior maxilla, and anterior mandible. The lowest ISQ value was in the posterior maxilla for both second and third measurements. The reason for this may be low bone density, which causes decreased implant stability. The clinician should consider this situation at the stage of prosthetic treatment.

Atsumi et al[30] concluded that although the theory behind RFA is sound, the technology cannot provide a critical value that can determine the success, failure, or long-term prognosis of an implant; therefore, bone quality classification and insertion torque should be considered as parameters. There are some limitations of the study. There were a limited number of SLActive surface implants compared with the SLA surface implants. When considering different manufacturers, implants have various surface geometries that can affect the stability. It appears that only repeated ISQ measurements of a specific implant have some diagnostic benefit, although the parameters influencing the absolute values still remain unclear.

Conclusion

The stability quotient can be affected by a number of factors. Except for implant length, other factors

including implant diameter, measurement period, gender, different jaw regions, and surface properties of implants should be considered by the clinician before implant therapy.

Abbreviations

ISQ: implant stability quotient
RFA: resonance frequency analysis
SLA: sandblasted, large-grit, acid-etched

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