Stability Measurements of 1-Stage Implants in the Maxilla by Means of Resonance Frequency Analysis: A Pilot Study

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Purpose: *The objective of the present study was to determine standard Implant Stability Quotient (ISQ) values for apparently successfully osseointegrated 1-stage implants in the maxilla.* ***Materials and Methods:*** *To measure implant stability, resonance frequency analysis (RFA) was performed in 35 patients (18 women, 17 men) with a total of 120 maxillary ITI implants. Based on the time interval between implant placement and measurements, the ISQ values of anterior and posterior implants were divided into subgroups: unloaded (n = 41), loaded ≤ 12 months (n = 31), and loaded > 1 year (n = 48). Statistical analysis was performed using a mixed-effects model with the variables lading, implant location, and gender as fixed effects.* ***Results:*** *The mean ISQ of all measured implants was 52.5 ± 7.9 (range 40 to 68). Statistical analysis showed no significant differences in ISQ values between the 3 tested time intervals: unloaded (48.8 ± 3.6), loaded ≤ 12 months (54.1 ± 7.0), and loaded > 1 year (53.1 ± 9.5). Neither for the location in the jaw nor for bone quality (assessed using radiographs) could a significant difference be found. Gender was the only parameter which was found to be significant (P < .003); on average, men showed higher implant stability than women (56.3 ± 6.6 versus 48.7 ± 7.4).* ***Discussion:*** *Standard values for osseointegrated maxillary ITI implants exhibited an individual range. Single RFA measurements of an implant do not allow assessment of its current status or prediction of its performance. Repeated measurements over a longer time period would be necessary.* ***Conclusions:*** *No significant differences in ISQ values were found between implants with regard to loading period or location in the jaw. Postmenopausal women exhibited significantly lower ISQ values compared to men of the same age group.* Int J Oral Maxillofac Implants 2005;20:747–752

Key words: *implant stability, maxilla, resonance frequency analysis*

Currently a variety of techniques for the clinical evaluation of implant stability and osseointegration are in use. The "tapping" test (percussion of the implant with a mirror handle) is the simplest noninvasive test method. Though easily and quickly performed, this technique is not sensitive enough to discriminate between different degrees of implant stability.[1] It only allows the detection of mobile or poorly osseointegrated implants. Radiographs, in spite of their relatively good diagnostic accuracy in detecting bone level changes, are not sensitive enough to predict clinical implant instability with any certainty.[2]

Noninvasive techniques for quantitative assessment of implant stability include the Periotest[3–5] (Siemens, Bensheim, Germany) and resonance frequency analysis (RFA),[1] both of which are vibration tests in which a controlled force is used to detect lateral movement of an implant in bone. A group of investigators, after conducting a study of 2,623 implants, concluded that the Periotest method provides reproducible assessment of stability and that changes in measurement may be helpful in evaluating improvement or degradation of the implant-bone complex.[3] After a comparison of Periotest values (PTVs) and RFA methods, it was concluded that several factors of the Periotest technique limit the application of the instrument as a diagnostic aid for measuring implant stability.[4,6] RFA, however, is a sophisticated method, and a simple measuring

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Table 1 Implant Lengths and Diameters

Diameter (mm)	Length (mm)			
	8	10	12	14
3.3	5	18	22	4
4.1	5	29	30	1
4.8	4	2	—	—

instrument (Osstell; Integration Diagnostics, Sävedalen, Sweden) utilizing RFA is now commercially available. Forces are generated by means of the piezo effect, and the subsequent response oscillation is amplified, analyzed,[8] and finally displayed graphically as well as numerically in a unit called implant stability quotient (ISQ). This value is dependent mainly on stiffness of the implant in the surrounding tissue and on the implant height above the crestal bone level.[9] A transducer that corresponds to the implant type must be used. Calibration of the instruments refers to the implant's "normal" height above bone level; there is no compensation for crestal bone loss. The results of most studies conducted prior to 2003 were presented in hertz and are therefore not comparable to more recent articles, in which results have been presented in ISQ values. One study evaluated the Brånemark System (Nobel Biocare, Göteborg, Sweden) 1 year after loading[10] and tried to determine standard ISQ values. It is not clear whether ISQ values for Straumann implants (Institut Straumann, Waldenburg, Switzerland) and Brånemark System implants are directly comparable.

Maxillary implant stability is of special interest, since survival rates of these implants appear to be less favorable, particularly in the edentulous maxilla.[11] Implant placement in the posterior maxilla is often complicated by bone that is predominantly trabecular and loose in structure. Numerous studies have reported lower implant survival rates in this region.[12–17] For example, 1 multicenter study with 2,359 nonsubmerged Straumann implants found better success rates for mandibular implants when compared to maxillary implants (95% versus 87%).[18] Altogether, the higher failure rate of maxillary implants seems to be independent of the implant system used.

The objective of the present study was to measure ISQ values by means of the RFA method for clinically asymptomatic and stable Straumann implants in the maxilla. Since little information is available on ISQ values of 1-stage implants, the aim was to determine standard values for 120 implants. The influence of several variables on ISQ values was evaluated. These included loading (loaded versus nonloaded), location (anterior versus posterior), and gender.

MATERIALS AND METHODS

Patients

Thirty-five patients who had received 1 or more maxillary Straumann implants at the Department of Prosthodontics, University of Bern, Switzerland, participated in this study. They were selected at random from the pool of patients who either *(1)* had followed the maintenance care program after completion of implant-prosthodontic treatment in the maxilla or *(2)* had just undergone the surgical procedure and were in the healing phase. Patients with symptomatic implants or implants that showed clinical signs of instability were excluded. The group consisted of 18 women and 17 men with a mean age of 62 years at the time of ISQ measurement. The average age of the men was 61.2 years (range, 46 to 81 years); the average age of the women was 62.1 years (range, 43 to 77 years). The patients' health was assessed by personal interview and by review of the patients' medical history; all participants were in good general health. Patients with well-controlled systemic diseases (2 with diabetes mellitus and 4 female patients with osteoporosis, 2 of which were confirmed by osteodensitometry) were included in the study. Exclusion criteria were irradiation of the maxilla, serious systemic diseases, and immunocompromise, including current steroid treatment, current chemotherapy, and leukocytic systemic diseases. Eight patients claimed to be light smokers, and 2 patients with bruxing habits were identified.

Implants

A total of 120 solid-screw Straumann implants had been placed in these patients in the Department of Prosthodontics during a time period of 6 years. All implants were placed either by 1 clinician or under his supervision. Nonsubmerged single-stage implants were placed using the standard surgical procedure.[19] A provisional prosthesis was carefully adapted during the healing period without any connection to the implants to aviod load transfer to the implants. A minimum of 3 months was allowed before loading implants with a definitive prosthesis; the actual length was mostly dependent on individual treatment plans and time schedules. After completion of the treatment, all patients were required to follow a regular maintenance program.

The implant lengths used ranged from 8 to 14 mm; implants with diameters of 3.3, 4.1, and 4.8 mm were used (Table 1). Ninety-six of the 120 implants had a sand-blasted, large-grit, acid-etched (SLA) surface, and 24 had titanium plasma-sprayed (TPS) surfaces. The predominant implant lengths were 10 and 12 mm (84%), while the most commonly used diame-

Table 2 No. of Tested Implants Per Patient

No. of tested implants	Men	Women
1	2	1
2	3	2
3	1	3
4	11	10
5	1	0
6	0	1
Mean	3.33	3.53

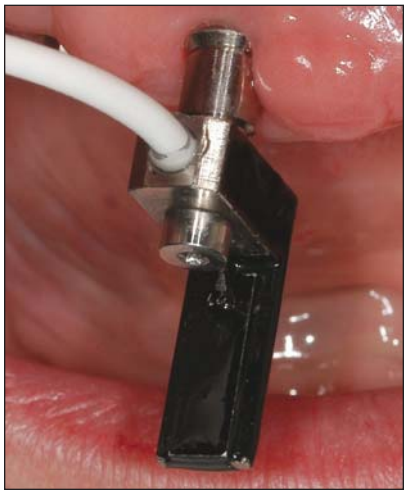

Fig 1 *(Right)* Intraoral view of RFA measuring device (Osstell) mounted to a Straumann implant with the octa-abutment in situ.

ter was 4.1 mm (54%). Sixty implants (50%) were placed in female patients; 60 (50%) were placed in male patients. Slightly less than half (47%) of all implants were located in the posterior maxilla; 53% were in the anterior maxilla. Approximately 66% of the implants had been loaded with a definitive prosthesis before measurement. Table 2 gives an overview of the number of implants per patient.

Radiographs

Prior to the surgical intervention, panoramic radiographs were obtained for all patients to assist treatment planning. This allowed for assessment of the bone quality according to the criteria by Lekholm and Zarb.[20] After the surgical procedure, either single periapical radiographs or panoramic radiographs were obtained, depending on the total number of implants that had been placed per patient. Several patients had received 4 to 6 implants distributed over the entire arch to support overdentures or fixed prostheses. At the time of measurement, the radiographs were obtained again. The amount of peri-implant bone resorption was measured mesially and distally to the implant using a slide caliper and magnifying glasses (3.2× telescopic dental magnifying glasses; Sandy Grendel, Aarburg, Switzerland). All radiographs were analyzed and measured twice by the same examiner. If the difference in crestal bone level did not exceed 0.2 mm, the value of the second measurement was taken. In the case of major differences, the radiographs were analyzed again, and then a final decision was made regarding whether to use the first or second value.

RFA

Implant stability was measured in triplicate for each patient using the RFA technique with the Osstell device (Fig 1). Forty-one implants had not yet been loaded with prostheses. Unloaded implants were directly connected with the standard and wide neck transducer (type F4). In the case of loaded implants, the screw-retained suprastructures were removed and the transducer (type A11) was screwed onto the octa-abutment. The values, given as ISQs, were recorded and analyzed Microsoft Excel (version 9.0; Microsoft, Redmond, WA).

Time between implant placement and RFA measurement varied. Measurements were performed either during the healing period or anywhere from several months to 6 years postloading. Thus, the ISQ values were placed in 1 of 3 groups: not loaded (n = 41), loaded for ≤ 12 months (n = 31), and loaded for > 12 months (n = 48). The measurements were also analyzed in relation to the anterior or posterior location and in relation to gender.

Statistics

Descriptive statistics were used for implant size and distribution, and mean ISQ values and standard deviations were calculated for various subgroups. Statistical analyses were performed with a mixed-effects model using S-Plus 6.0 Professional for Windows (Insightful, Seattle, WA). Based on this statistical model, the influence of loading, implant location, and gender were tested. These variables were included as fixed effects. Because the observations were not independent, corrections according to Bonferroni were applied. Thus, a P value < .0125 was considered to be statistically significant.

RESULTS

Resorption of the crestal bone (≥ 1 mm) was detected in 23 patients, 35.8% of all implants (48 sites), all after loading. Crestal bone loss ranged from 1 to 5 mm, with an average of 1.8 ± 1.1 mm. The

Table 3 Mean ISQ Values by Subgroup

	ISQ value
Implant	
Diameter	
3.3 mm	49.8 ± 7.1
4.1 mm	54.9 ± 7.8
4.8 mm	48.8 ± 5.9
Length	
8 mm	54.1 ± 7.0
10 mm	53.2 ± 7.4
12 mm	52.0 ± 6.9
14 mm	46.7 ± 9.8
Bone quality	
2	52.7 ± 7.0
3	52.6 ± 8.1
4	51.1 ± 7.8
Location	
Anterior	53.1 ± 8.2
Posterior	51.8 ± 7.7
Loading	
Not loaded	48.8 ± 3.6
≤ 12 mo	54.1 ± 7.0
> 12 mo	53.1 ± 9.5
Gender	
Male	56.3 ± 6.6
Female	48.7 ± 7.4

Table 4 Mixed Effects Model (Correction Bonferroni)

	Effect	SE	*P*
Model	56.5	2.08	< .0001
Unloaded	−2.87	2.56	.271
Loaded	1.55	2.38	.521
Location	−0.94	1.11	.396
Gender	−7.07	1.76	.0003

mean value computed for all implants was 0.7 ± 1.1 mm.

Evaluation of the radiographs showed that 53% of the implants were placed in type 3 bone, 35% were placed in type 2 bone, and 12% were placed in type 4 bone. Type 1 bone was not found. The mean ISQ of all measured implants was 52.5 ± 7.9 (range, 40 to 68). Table 3 shows the mean ISQ values by subgroup. No tendencies were observed in regard to bone quality. Standard-diameter implants exhibited slightly higher ISQ values compared to reduced or wide-diameter implants, and slightly lower ISQ values were found for unloaded implants as opposed to those that had been loaded and for posterior implants as compared to anterior implants. The highest values were observed in anterior implants loaded for no more than 12 months (58.3 ± 2.1), while the lowest were found in nonloaded posterior implants (42.3 ± 2.0).

Table 4 shows the statistical analysis by means of the mixed-effects model. This statistical analysis showed no significant differences in ISQ. Gender was the only fixed-effect variable for which a highly significant difference was found ($P < .003$).

DISCUSSION

There is still little information available about the significance of RFA measurements. While recent studies reported mostly on a small number of implants and on measurements that were performed in both maxilla and mandible or in edentulous and partially edentulous patients, the present study exclusively deals with 120 maxillary implants in edentulous patients. However, with this number of implants and patients, only a limited number of variables were incorporated in the mixed model, and intraindividual patient effects were not fully integrated.

The average bone density of the maxilla is less than half of that of the mandible, with the posterior maxilla showing the lowest bone mineral density of all jaw regions.[21] In addition, jawbone quantity is more often compromised in maxillary than in mandibular sites.[22] This may explain why implants in the maxilla appear to be significantly less stable when measured by the RFA method.

The mean ISQ of 52.5 ± 7.9 should not be considered to be representative for osseointegrated implants in general because it comprises data from both implants in the very early healing phase and implants that were loaded for more than 1 year. Despite the fact that 6 weeks after surgery, ITI implants with an SLA surface are generally stable enough for loading[23,24] if bone quality is normal, it was assumed that a time span of at least 3 months would be necessary to obtain the desired stability for implants placed in the maxilla. Thus ISQ values of implants that have been in place for at least 3 months can be regarded as normal, standard values for osseointegrated ITI implants in the edentulous maxilla. Posterior implants exhibited slightly lower ISQ values. One study on immediate loading[25] found that the majority of failed implants were located in the posterior maxilla; all exhibited below-normal ISQ values. Since these were not ITI implants, comparisons with the present data cannot be made reliably.

A single ISQ measurement of an implant at a given time point does not allow full assessment of its current status and prediction of its future performance. It is possible to obtain an ISQ value within the standard range for an implant in the process of losing stability. However, repeated measurements of an implant over a longer time period may provide a

basis on which to judge its performance. Although tendencies were observed in the present study, the statistical analysis revealed no significant effect with regard to period of time loaded. This can be ascribed to individual variability and the limited number of implants that could be included in the present study.

In comparison with the Brånemark System (Nobel Biocare), for example, ITI implants seem to show lower ISQ values on average. One study aimed at establishing standard ISQ values for clinically successful Brånemark System implants.[10] Forty-five implants, of which 21 were located in the maxilla, were measured after 1 year of loading. The mean ISQ value was 64.7 ± 4.8. For the best matching subgroup in the present study, implants loaded for > 1 year, a mean ISQ values of 53.1 ± 9.5, about 10 lower, was found. Another team of researchers[27] measured 61 maxillary Brånemark implants after placement and at the time of definitive prosthesis connection, which was 4 months postplacement on average. The mean ISQ values were 60.1 ± 3.6 and 62.8 ± 1.6, respectively, compared to the matching period of unloaded implants (48.8 ± 4.6) in the present study. Again the difference was about 10 ISQ values.

When comparing different implant systems, it must be kept in mind that differences in ISO values should not be misinterpreted as differences in stability or degree of osseointegration. Several factors influence RFA: *(1)* the stiffness of the implant-bone interface, *(2)* the stiffness of the bone itself, and *(3)* the stiffness of the implant components.[8] The rigidity of implant components is a function of their geometry (including implant diameter), material composition, and the tightness with which the individual components are joined together. Furthermore, there is a strong correlation between supracrestal implant height and RFA.[28] Brånemark System implants are placed on the level of the crestal bone, while ITI implants have a 3-mm supracrestal shoulder. If values of ITI implants are corrected for this height of the implant shoulder, about 9 ISQ values could be added to the present measurements, resulting in similar ISQ values to those reported for Brånemark System implants.

Data concerning ISQ values for maxillary ITI implants are very limited. A recently published study[29] measured 21 SLA implants in the molar and premolar regions of the maxilla and mandible during the early healing phase. Because the authors were mainly interested in changes of stiffness over time, no differentiation between mandibular and maxillary implants was made. A graphic illustration in this study showed mean ISQ values at different time points up to 10 weeks after placement. The mean value for maxillary implants in the early healing phase was around 55 ISQ, which is higher than the mean ISQ of the nonloaded group in the present study.

The significant differences between male and female subjects in regard to ISQ values must be assessed in consideration of the patients' advanced age. All women with the exception of 1 were climacteric or postmenopausal. As aging proceeds with a general decrease in bone density, this effect of bone change is much more pronounced in menopausal and postmenopausal women. Therefore the findings of the present study might not be transferable to women in general. Nevertheless, the finding of lower implant stability in women seems to have not an effect on the failure rate. In a 15-year follow-up study, sex could not be identified as a risk factor.[30] Women exhibited lower values, which might be interpreted as indicative of their having lower bone quality according to the Lekholm and Zarb classification system. When implants were grouped by bone quality, the mean ISQs for bone qualities 2, 3, and 4 were nearly identical. This observation might be an indicator that the simple radiographic interpretation of bone quality is not of high validity and reliability.

CONCLUSIONS

- Within the limitations of the present study, the clinical observations show some tendencies and statistical significance for ISQ values measured in the edentulous maxilla.
- The present study, using RFA, found that osseointegrated loaded maxillary ITI implants had a mean ISQ value of approximately 54.
- Loaded implants exhibited slightly higher mean ISQ values compared to unloaded implants.
- Postmenopausal women exhibited significantly lower ISQ values for maxillary implants compared to male patients of the same age.

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