Stability Measurements of 1-Stage Implants in the Edentulous Mandible by Means of Resonance Frequency Analysis

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Objective: *Resonance frequency analysis (RFA) is a method of measuring implant stability. However, little is known about RFA of implants with long loading periods. The objective of the present study was to determine standard implant stability quotients (ISQs) for clinical successfully osseointegrated 1-stage implants in the edentulous mandible.* ***Materials and Methods:*** *Stability measurements by means of RFA were performed in regularly followed patients who had received 1- stage implants for overdenture support. The time interval between implant placement and measurement ranged from 1 year up to 10 years. The short-term group comprised patients who were followed up to 5 years, while the long-term group included patients with an observation time of > 5 years up to 10 years. For further comparison RFA measurements were performed in a matching group with unloaded implants at the end of the surgical procedure. For statistical analysis various parameters that might influence the ISQs of loaded implants were included, and a mixed-effects model applied (regression analysis,* $P < .0125$*).* ***Results:*** *Ninety-four patients were available with a total of 205 loaded implants, and 16 patients with 36 implants immediately after the surgical procedure. The mean ISQ of all measured implants was 64.5 ± 7.9 (range, 58 to 72). Statistical analysis did not reveal significant differences in the mean ISQ related to the observation time. The parameters with overall statistical significance were the diameter of the implants and changes in the attachment level. In the short-term group, the gender and the clinically measured attachment level had a significant effect. Implant diameter had a significant effect in the long-term group.* ***Conclusions:*** *A mean ISQ of 64.5 ± 7.9 was found to be representative for stable asymptomatic interforaminal implants measured by the RFA instrument at any given time point. No significant differences in ISQ values were found between implants with different postsurgical time intervals. Implant diameter appears to influence the ISQ of interforaminal implants.* (Case Series) Int J Oral Maxillofac Implants 2008;23:353–358

Key words: *implant stability, mandible, 1-stage implants, resonance frequency analysis*

Currently a variety of techniques are in use for the clinical evaluation of implant stability and osseointegration. Percussion of the implant with a metal stick handle (the "tapping" test) is the simplest noninvasive test method. It is easily and quickly performed and allows the detection of mobile implants and fibrous encapsulation. But this technique is not sensitive enough to discriminate between different degrees of implant stability.[1] Simple radiographs may reveal marginal bone resorption, but they are not sensitive enough to determine and predict clinical implant instability.[2] Comparison of repeated radiographs enables the investigator to detect marginal bone resorption, particularly with standardized radiographs. However, these procedures are time consuming, and computer-assisted analysis may be necessary for accurate measurements. For anatomical reasons it is not always possible to take standardized radiographs. Crestal bone resorption does not necessarily decrease clinical implant stability unless crestal bone loss is significantly advanced.

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Noninvasive techniques that may be used for quantitative assessment of implant stability include the Periotest[3,4] and resonance frequency analysis (RFA).[1] Both methods are based on dynamic measurements using a controlled force to detect lateral movement of an implant in its surrounding bone. The Periotest method appears less reliable than RFA because the device depends on free-hand manipulation. In contrast, RFA is a more sophisticated method.[4–6] A simple RFA measuring instrument is now commercially available from Osstell (Osstell, Integration Diagnostics, Sävedalen, Sweden). The measuring device is mounted with a screw directly onto the implant, which enables accurate measurements, particularly for repeated testing. 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.[7] For different implant brands and types the corresponding transducer has to be used. If a 2-stage implant is measured, the RFA measuring device is mounted at the height of the bone level to the implant, while in a 1-stage implant, the instrument is positioned up to 3 mm above the bone level.[8,9] This influences the implant stability quotients (ISQs) of different implant systems and explains why they cannot directly be compared. So far ISQs have mostly been used to determine primary mechanical stability after placement and to get information about the remodeling process at the end of the healing period. Since osseointegration is a dynamic process and continuous remodeling of the bone takes place after loading of the implants, it is of interest to determine standard values for clinically stable implants with varying observation periods.

Mandibular interforaminal implants have been widely used in elderly edentulous patients with good survival rates.[9–11] A dense bone structure is often found in the interforaminal region, which enhances primary implant stability and is expressed in low Periotest values.[12] In the maxilla, implant stability is often compromised by predominantly trabecular bone and a loose bone structure. Studies have reported on lower implant survival rates in this region.[13–15] For example, a multicenter study with 2,359 nonsubmerged Straumann implants found better success rates for mandibular implants (95%) compared to maxillary implants (87%).[16] In general, this difference in survival rates between implants in the edentulous mandible and maxilla appears to be independent of the implant system.

The objective of the present study was to measure ISQ by means of the RFA method for clinically asymptomatic and stable 1-stage implants in the interforaminal region with different loading periods.

MATERIALS AND METHODS

Patients and Implants

Volunteer patients who had received 2 (or in a few cases, 3) interforaminal implants and overdenture treatment at the Department of Prosthodontics, University of Bern, Switzerland, participated in this study. All patients were edentulous with complete dentures in the maxilla and implant-supported overdentures in the mandible. Their implants (Straumann Dental Implant System; Straumann, Basel, Switzerland) had been placed with a nonsubmerged, single-stage technique according to a standard surgical procedure.[17] During the implant healing time any loading by a provisional prosthesis was avoided. After the healing time bar-supported overdentures were fabricated. When the treatment was completed all patients were scheduled to follow a regular maintenance program with at least 1 visit per year (2 visits per year in most cases).

For RFA measurements, the patients were selected during an 8-month period in 2005 from the pool of implant patients who followed regularly the maintenance care program. Only patients with asymptomatic and stable implants throughout the observation period were included in the study. Clinical parameters to determine this were absence of bleeding on probing, absence of deep probing depths (≥ 5 mm), no signs of peri-implant infection, or suppuration, and measurements of clinical attachment loss related to the implant shoulder. This information was obtained from the patients' medical records. Patients were assessed by personal interview and medical history review; all were in good general health. Exclusion criteria for the present study were irradiation of the oral cavity, serious systemic diseases, immunocompromised status, current steroid treatment, current chemotherapy, and leukocytic systemic diseases. Patients who had well-controlled diabetes mellitus and 3 patients who were diagnosed as osteoporotic by osteodensitometry were included as well. Only a few patients were light smokers. In the context of the present study, the RFA measurements were carried out during the patients' recall visits.

Additionally, a matching group of patients were selected for comparative measurements of unloaded implants. They were undergoing the surgical procedure of implant placement during the period of data collection for the present study.

Radiographs and Clinical Attachment Level

Prior to the surgical intervention, panoramic radiographs were obtained for all patients to assist treatment planning. This allowed for assessment of the bone quantity to select the proper implant length and bone quality according to the criteria of Lekholm

and Zarb.[18] After the surgical procedure, panoramic radiographs were obtained when the bar was placed and 1, 3, 5, and 10 years after loading. When possible, standardized radiographs were obtained; however, because of anatomic conditions, it was not possible to obtain standardized radiographs in most cases. Thus, accurate radiographic measurements of minimal crestal bone loss were not performed. However, during the follow-up visits the clinical attachment level was regularly measured related to the implant shoulder with a periodontal probe and the attachment loss was calculated. In absence of deep probing depths an increase of attachment loss means recession of the peri-implant tissues. Changes of the attachment level were calculated.

Resonance Frequency Analysis

All implants were measured at the patients' recall visits. The connecting implant bar was removed prior to RFA. The ISQs were recorded and analyzed by personal computer (MS Excel 9.0, Microsoft Corporation, Redmond, WA). Fig 1 shows the RFA technique with the Osstell device.

Statistical Analysis

Descriptive statistics were used for patient groups and implant size. Mean ISQs were calculated for the 3 subgroups and compared with the Mann-Whitney test.

Statistical analyses of all loaded implants were performed with a mixed-effects model using S-Plus 6.0 Professional for Windows. Based on this statistical model, the influence of the following variables was tested as a fixed effect: loading time, gender, implant diameter, and attachment level. Because the observations were not independent, a Bonferroni correction was applied. $P < .0125$ was considered statistically significant.

RESULTS

A total of 204 loaded implants were available for measurements in 94 patients (63 women, 31 men) with a mean age of 68.8 ±10 years. No patient was younger than 52 years. Fifty-two patients had a follow-up period of 1 to 5 years (short-term group, with 116 implants), and 42 patients had a follow-up period of 6 to 10 years (long-term group, with 88 implants). Sixteen patients were measured immediately after surgery (nonloaded group, with 36 implants).

The implant length of all 240 implants ranged from 6 to 12 mm. All implants were either 3.3 or 4.1 mm in diameter. The predominant implant length was 12 mm (71.5%), while the most commonly used diameter was 4.1 mm (77.5%). Table 1 gives an overview on implant length and diameter.

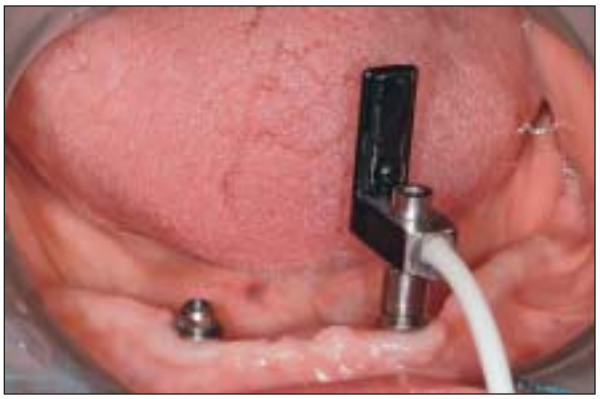

Fig 1 RFA measuring device mounted on an octa-abutment after removal of the connecting bar.

The mean ISQ of all measured implants was 64.5 ± .9 ISQ (range, 58 to 72). Table 2 shows the mean ISQs for each subgroup: nonloaded, loaded ≤ 5 years, and loaded > 5 to 10 years. No significant differences were found between the subgroups.

The statistical analysis of all loaded implants by means of the mixed-effects model is shown in Table 3. An overall statistically significant effect was observed for the variables peri-implant attachment loss and implant diameter. Some differences were found if the mixed model was applied separately to the short-term and long-term groups. While the attachment level and gender had significant effects in the short-term group, only the diameter had a significant effect in the long-term group.

Two implants in one patient exhibited low values, below the gross average of all measurements. There were no clinical signs of instability, such as attachment loss, deep probing depths or peri-implant infection, nor was the patient aware of any pain or discomfort. They were further analyzed with radiographs and clinical testing in order to detect disintegration.

DISCUSSION

The present study was conducted to evaluate the RFA measuring instrument in clinical use and to learn more about "normal" values for stable healthy implants. The goal of RFA is not to detect mobility but the degree of stability, which is not measurable with conventional clinical parameters. A selective single measurement of an implant at a given time point, as performed in the present study, does not allow the assessment of current implant status or prediction of future performance. So far, ISQs for healthy stable implants have not been measured over differ-

Table 1 Distribution of Implants: Length and Diameter

Length	Diameter 3.3 mm	Diameter 4.1 mm	Total
6 or 8 mm	–	13	13
10 mm	18	37	55
12 mm	46	126	172
Total	64	176	240

Table 2 Mean ISQ

Group	Mean	SD	*P*
Unloaded	62.3	6	
≤ 5 years	65.1	6	NS
> 5 years	63.8	5	

Table 3 Mixed-Effects Model: Regression Analysis

Dependent variable	*P*	≤ 5 years	> 5 years
Gender	NS	< .005	NS
Loading time	NS	NS	NS
Implant length	NS	NS	NS
Implant diameter	< .001	.019	< .007
Attachment loss	< .001	< .002	.025

ent time periods and thus are not known. To detect changes in stability of individual implants, repeated measurements over a long time period should be performed. Such results are rarely reported,[19] and mean RFA from implants with different loaded time periods are known for the early healing phase up to 1 year of loading.[20,21] ISQ measurements of long-term loaded implants are not easily obtainable since removal of superstructures is complicated, not indicated, or not possible due to cementation. While recent studies have reported mostly on a small number of implants and on measurements that were performed in both maxilla and mandible or in both edentulous and partially edentulous patients,[20] the present study deals exclusively with interforaminal implants in elderly edentulous patients. Since more than 1 implant was measured in each patient, this could have an impact on the validity of the presented results. However, the measurements revealed a very low difference, if any, between the measurements of both implants in a single patient. Thus, an average ISQ of about 64 is considered representative and can be determined as standard for stable interforaminal Straumann implants at various loading times. This is confirmed by the regression analysis, which indicated that the loading time was not a significant effect. This is in contrast to results obtained for the maxilla, where loaded implants exhibited higher values than those measured postsurgically in a previous study by the same authors.[22] For these maxillary implants ISQs were lower by an average of 10. When the unloaded implants of the mandible and maxilla were compared separately, the difference increased by an average of 15. Furthermore, ISQs for these maxillary implants were significantly lower for female patients. Thus it seems that the RFA method exhibits some sensitivity, probably more sensitivity with a less dense bone structure.

The comparative data analysis of both studies also reveals that implants with a diameter of 3.3 mm and a length of 10 mm were placed in the maxilla more often (up to 50%). This difference to the present study is ascribed to less favorable bone quantity in the maxilla. A recent study on Straumann implants identified lower values for maxillary implants as well.[23] Another study reported that during the early healing phase a slight increase of ISQ in the mandible and maxilla was observed; however, this increase was only statistically significant for the maxilla.[24]

Although a range of 58 to 72 was found, the majority of the measured values were between 60 and 66. Altogether, a larger range of ISQ values was found in the maxilla, with a mean of 52 and a range of 40 to 68 as compared to the interforaminal region, which again can be ascribed to different bone structure and quality.[21,25,26]

It is also of interest that gender was not an overall significant effect, except in the short-term group, in the present investigation, while in the maxillary study lower values were observed significantly more often for women. Osteoporotic bone appears to develop more often in elderly women than in men, and one may conclude that due to its specific trabecular structure, signs of osteoporosis are more often present in the maxilla than in the mandible. This may explain the difference in mean ISQ between the edentulous maxilla and mandible of elderly patients in general and as well as gender-related differences. Nevertheless, in a 15-year follow-up study, sex could not be identified as a risk factor.[27]

One study aimed at establishing standard ISQs for clinically successful Brånemark system implants (Nobel Biocare, Göteborg, Sweden).[20] The mean ISQ of 24 mandibular implants 1 year after loading was about 73, while in the present study a mean value of 64 was calculated. When comparing different implant systems, differences in ISQ values should not be mis-

interpreted as differences in stability or degree of osseointegration. Brånemark system implants are placed on the level of the crestal bone, while Straumann implants have a 3-mm supracrestal shoulder. If with the RFA method the supracrestal height is important, this would explain why infra-bony implant length did not have a significant effect. Otherwise, the implant diameter was identified as a significant effect in the mixed model, in contrast to the maxillary study.[22] In some studies the use of larger implants has been suggested to obtain better implant stability.[28] Particularly in dense and cortical bone, as opposed to a loose trabecular bone structure, a tight bone-implant contact zone and the stiffness of the bone itself are parameters that could influence the ISQ. Thus, the amount of the implant surface in contact with the bone may play a role. One study on RFA measurements with Straumann implants with diameters of 4.1 mm and 4.8 mm did not exhibit differences in ISQ.[24] However, the number of 4.8-mm implants was small, and implants of 3.3-mm diameter had not been used. Data do not exist that compared all 3 diameters of Straumann implants. One study suggests that the survival rate is equally favorable for 3.3-mm implants as compared to standard-diameter implants.[29] Altogether the interpretation of ISQs regarding implant diameters remains controversial.

Clinically measured AL, which is clinically diagnosed as recession of the peri-implant tissues, may reflect the loss of crestal bone. This was not directly investigated in the present study but would explain the statistically significant effect of the variable AL, particularly related to the short-term subgroup. Peri-implant tissues may be more stable around implants in patients with a longer observation time.

Single RFA measurements do not have a predictive value. If more investigations are performed and more information is gathered, standard ISQs might be determined for stable implants of different types. These values could be considered reference values for single measurements at various time points.

CONCLUSIONS

The present study found a mean value of 64.5 ± 7.9 ISQ, which can be considered representative for stable asymptomatic interforaminal Straumann implants at any given time point. No statistically significant difference in ISQ values was found between unloaded and loaded interforaminal implants, and the loading time was not a significant parameter. The diameter had a significant influence, with lower ISQ values for implants with a diameter of 3.3 mm.

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