

# Evaluation of Two Different Resonance Frequency Devices to Detect Implant Stability: A Clinical Trial

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**Background:** Resonance frequency analysis (RFA) provides a non-invasive assessment of implant stability. The established RFA device uses electronic technology, whereas a recently developed device uses magnetic technology. The goal of this clinical trial was to evaluate the ability of the magnetic RFA device to detect changes in stability during early healing following implant placement and to determine whether the implant stability quotient (ISQ) values obtained correlated with those made with the electronic device.

**Methods:** RFA assessments were performed using electronic- and magnetic-based devices on 34 non-submerged titanium dental implants in 17 patients. Each patient received two implants in the posterior maxilla or mandible. Implant stability was measured at placement and weekly until week 6, when implants received provisional crowns, and at 12 weeks, when definitive crowns were cemented. During each visit, measurements were taken three times and averaged to obtain a single representative ISQ for each device.

**Results:** At placement, the mean ISQ obtained with the electronic device was 61.9 (95% confidence interval [CI], 59.4 to 64.3); it increased to 63.2 (95% CI, 61.2 to 65.2) at 12 weeks. With the magnetic device, the mean ISQs were 70.6 (95% CI, 68.4 to 72.8) and 75.9 (95% CI, 74.2 to 77.7), respectively. Both devices indicated a pattern of decreased mean stability from 1 to 3 weeks post-placement, small fluctuations in mean ISQ from 3 to 6 weeks, and significantly increased mean stability from 6 to 12 weeks. For the complete set of implant measures across all weeks, the paired electronic and magnetic ISQ values correlated significantly ( $r = 0.52$ ;  $P < 0.001$ ).

**Conclusions:** This study demonstrates that changes in implant stability measured with the newer magnetic device correlate well with those found with the electronic device. Both devices confirmed the initial decreases in implant stability that occur following placement and identified an increase in stability during the first 6 weeks of functional loading. *J Periodontol* 2007;78:262-272.

## KEY WORDS

Bone; clinical trial; dental implants; healing; implant stability; resonance.

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The establishment and maintenance of osseointegration, as defined by Brånemark et al.<sup>1</sup> in 1985 as “a direct structural and functional connection between ordered, living bone and a surface of a load-bearing implant,” are requirements for long-term implant success. Advances in implant design continue to affect the integration process. It was demonstrated that bone–implant contact may be enhanced by physical modifications, such as roughened titanium surfaces,<sup>2-7</sup> and chemical modifications.<sup>7,8</sup> However, assessment of the benefit of these surface modifications has been dependent upon invasive techniques, such as histology and torque removal. These approaches have obvious limitations in clinical settings, necessitating the development of non-invasive approaches.

Resonance frequency analysis (RFA) has been established as a non-invasive and non-destructive quantitative measurement of implant integration by assessing changes in implant stability over time.<sup>9</sup> RFA measurements have documented healing changes along the implant–bone interface by measuring the increase/decrease in stiffness of the implant in the surrounding tissues.<sup>10-14</sup> RFA also has been used to determine whether implants are sufficiently stable to receive the final restoration<sup>15</sup> or to be loaded<sup>12</sup> and to identify “at-risk” implants.<sup>16-18</sup>

Two commercially available RFA devices have been developed to detect implant stability. The original (electronic) method uses a direct connection (wire) between the transducer and the resonance frequency analyzer. The second methodology uses magnetic frequencies between the transducer (magnetic peg) and the resonance frequency analyzer. In the electronic device, the transducer is an L-shaped cantilever beam, which connects to the implant via a screw attachment. A piezoelectric crystal on the vertical portion of the L-shaped beam is used to stimulate the implant/transducer complex; a second piezoelectric crystal on the opposite side of the beam is used as the receiving element to detect the response of the beam. The results are expressed as an implant stability quotient (ISQ), which represents a standardized unit of stability.<sup>9,12,13</sup> The new magnetic RFA device has a transducer, a metallic rod with a magnet on top, which is screwed onto an implant or an abutment. The magnet is excited by a magnetic pulse from a wireless probe. The pulse duration is about 1 millisecond. After excitation, the peg vibrates freely, and the magnet induces an electric voltage in the probe coil. That voltage is the measurement signal sampled by the resonance frequency analyzer.

It is unknown if the RFA measurements made by the electronic device and the magnetic device are similar, nor is it known if they can detect similar

changes in an implant stability pattern. Therefore, the purpose of this prospective human clinical trial was to determine whether both devices were able to detect the changes in stability that occur during early healing of dental implants and to evaluate the correlation in stability findings between the two techniques.

## MATERIALS AND METHODS

### *Participants*

Seventeen patients (14 females and three males) with a mean age of 52 years (range, 29 to 74 years) presenting with missing posterior teeth in the mandible or the maxilla were enrolled in this study. Subjects were recruited from the patient population of the Dental Clinic of the University of Texas Health Science Center at San Antonio (UTHSCSA) that had been referred to the Department of Periodontics after initial screening for tooth replacement. The protocol of the randomized clinical trial was approved by the Institutional Review Board of UTHSCSA, and informed consent was obtained. Patients were enrolled in the study from November 2004 to March 2005 and met the following inclusion criterion: the tooth at the implant site must have been extracted or lost  $\geq 4$  months prior to the date of implantation. Both implants were placed in the same jaw, but could be placed on opposite sides. Primary implant stability, determined clinically, had to be obtained to include the implant in the study. Exclusion criteria included conditions requiring chronic routine prophylactic use of antibiotics (e.g., history of rheumatic heart disease, bacterial endocarditis, cardiac valvular anomalies, or prosthetic joint replacements); medical conditions requiring prolonged use of steroids; history of leukocyte dysfunction and deficiencies, bleeding disorders, neoplastic disease requiring the use of radiation or chemotherapy, renal failure, or uncontrolled endocrine disorders; metabolic bone disorders; physical handicaps that would interfere with the ability to perform adequate oral hygiene; smoking  $> 10$  cigarettes per day; and implant sites requiring an augmentation procedure.

### *Surgical and Prosthetic Procedures*

All patients had a medical and dental history taken, including photographs, periapical radiographs, and a panorex. Each patient received two implants in the posterior maxilla or the posterior mandible: one sandblasted, acid-etched surfaced implant<sup>§</sup> and one chemically modified, sandblasted, acid-etched surfaced implant.<sup>||</sup> All were cylindrical screw-type implants with a diameter of 4.1 mm. Thirty-four implants were placed using standard one-stage surgical techniques, 30 (88.24%) in the mandible and four (11.76%) in the maxilla, consistent with the manufacturer's

§ SLA Surface, Straumann, Straumann AG, Basel, Switzerland.

|| SLActive Surface, Straumann, Straumann AG.

recommendations. Implant sites were recorded according to tooth position. Surface selection for implant placement site was designated according to a computer-generated randomization list, performed by an independent statistician. Implants were 8 or 10 mm in length, and both implants in each patient were identical in length. The distance between implant shoulder and bone was measured along the mesial and distal aspects of each implant using a UNC periodontal probe. The resonance frequency measurements were performed using the electronic device first, followed by the magnetic device. Postoperatively, patients were medicated with oral amoxicillin, 500 mg, three times per day for 5 days. If the patient was allergic to penicillin, clindamycin was substituted. Mild analgesics were prescribed and used as necessary. Sutures were removed after 1 week. The implants were restored and loaded with individual temporary prostheses at 6 weeks and with definitive prostheses at 12 weeks.

### Implant Assessment

Clinical examination of the implants was performed at all follow-up visits, at provisional crown placement, and at definitive crown placement. The success criteria proposed by Buser et al.<sup>19</sup> were followed: absence of persistent or irreversible signs, such as pain, foreign body sensation, and/or dysesthesia; absence of peri-implant infection with suppuration; absence of mobility when tested with instrument pressure; and no evidence of continuous periapical radiolucency.

### Implant Stability Measurement

Two different resonance frequency analyzers were used to determine the ISQ at implant placement and at 1, 2, 3, 4, 5, 6, and 12 weeks. Measurements were taken first using the original (electronic) resonance frequency analyzer<sup>¶</sup> (Fig. 1). The cover screw was removed, and a transducer (type L4 F5) for the electronic device was attached in a buccal-lingual direction, perpendicular to the bone, by screw attachment to the top of the implant using a metallic hex screwdriver. The measurement was taken, and the ISQ value was recorded. To improve precision and assess repeatability, two additional ISQ values were obtained, with the transducer loosened and retightened each time; a single representative implant stability value was computed by averaging the three ISQ values. The same transducer was used for the same patient at all time points. Only those measurements that exhibited graphs with a distinct resonance peak were included and analyzed. To obtain the measurements with the magnetic transducer,<sup>#</sup> a magnetic peg<sup>\*\*</sup> (type 4) was inserted using a plastic screwdriver. The plastic probe of the wireless device was placed in the proximity of the transducer without contacting the peg, until the machine registered the ISQ



**Figure 1.**  
Original transducer attached to one implant at surgery for implant placement.



**Figure 2.**  
Magnetic transducer attached to one implant with probe in close proximity taking the resonance frequency measurement.

value (Fig. 2). As with the electronic device, a set of three measurements was taken to determine repeatability and averaged to obtain a more precise stability value. The probe was oriented in the same direction for the three magnetic measurements, which were obtained after screwing and unscrewing the magnetic peg three times. The cover screws were replaced at completion of the visit. At 12 weeks, the temporary crowns were removed to obtain the ISQ values prior to insertion of permanent restoration. If clinical lateral or rotational mobility was detected or the patient presented discomfort or pain during the process, the measurements were not taken until the following visit. If the discomfort occurred when using the original device, the measurement was not taken with the magnetic device.

### Data Analysis

The primary hypotheses tested assessed the association between the implant stability values for the electronic and magnetic resonance frequency analyzers

¶ Osstell, Integration Diagnostics AB, Gothenburg, Sweden.

# Osstell *mentor*, Integration Diagnostics AB.

\*\* Smartpeg, Integration Diagnostics AB.

and the ability of each device to detect changes in mean stability across the first 12 weeks of healing after implant placement. These analyses used the single representative (average of triplicate ISQs) stability value measured for each device. For each visit and device, box plots were used to identify any extreme outliers. Given the sample size, extreme outliers can exert undue influence on sample means and variances, so these were excluded from the analysis. Pearson correlation coefficients describing the association between electronic and magnetic ISQ values were obtained for the entire data set and for each week separately, and Student *t* tests were performed to check if the correlation was significantly greater than zero. When considering the stability readings for a specific week, the sample size of 34 implants was sufficient to detect a clinically significant Pearson correlation coefficient (*r*) between electronic- and magnetic-derived ISQs (versus *r* = 0) by the Student *t* test at the 0.05 level with power of 87%. This correlation should be at least *r* = 0.5 to be clinically significant.

A series of mixed-model analyses of variance (ANOVA) were performed for stability data from the electronic and magnetic devices separately. The primary one-factor ANOVAs assessed whether mean stability, as measured with either device, changed across time, controlling for any between-implant variance. Post hoc Dunnett tests compared mean stability at 12 weeks versus each of the previous early healing times if the F-test indicated a significant time effect. To evaluate the association between the two RFA devices further, a two-factor mixed-model ANOVA was performed to determine whether differences between electronic and magnetic ISQ means changed across time.

To ensure that initial implant stability did not influence the results, the implants were classified as having lower or higher initial stability if the single representative stability value, as measured by the electronic device, was less than or greater than the reference value of 60 ISQs. This initial stability classification factor and other possible confounding factors, such as implant location (maxilla versus mandible), bone type, ridge shape and width, distances from implant shoulder to bone crest, and implant length, as well as the implant surface (sandblasted/acid etched only versus chemically modified and sandblasted/acid etched), also were analyzed; however, because of the sample size, each factor was included in a separate two-factor ANOVA in combination with the time effect. If the F-test of the interaction term for a two-factor ANOVA was significant, comparisons for the secondary factor were performed using unadjusted Student *t* tests for each week separately. The F-test for the main effect for the secondary term also was reported.

Another hypothesis test was performed to determine whether stability measurement repeatability was consistent for the electronic and magnetic devices. The range (maximum difference) of the triplicate values for each implant at each visit, for which data were available for both devices, was compared for electronic and magnetic data using the Wilcoxon matched-pairs signed-rank test. Further testing, using mixed-model ANOVAs, was performed to determine whether the distribution of range values for a device changed across weeks. For all statistical tests, *P* < 0.05 was considered significant. Statistical analyses were performed using a statistical software package.<sup>††</sup>

## RESULTS

The placement characteristics and lengths of implants are described in Table 1. Thirty-four implants were placed; all were classified as successful through the 12 weeks of the study.

The flow diagram of patients and implants is represented in Figure 3. A total of 777 measurements (259 triplicate sets) was taken with the original electronic resonance frequency analyzer, and 711 measurements (237 triplicate sets) were taken with the newer magnetic analyzer. Stability measures were obtained for all implants using both devices. Among the total of eight visits and 34 implants, RFA was performed using both devices 86.7% of the time. Box plots of the stability values identified five extreme outliers for the magnetic device measures: two at placement and one each at weeks 1, 2, and 4. No extreme outliers were detected for the electronic stability measures. After the exclusion of extreme outliers, complete data for both devices were available for 84.9% of the 272 implant examinations.

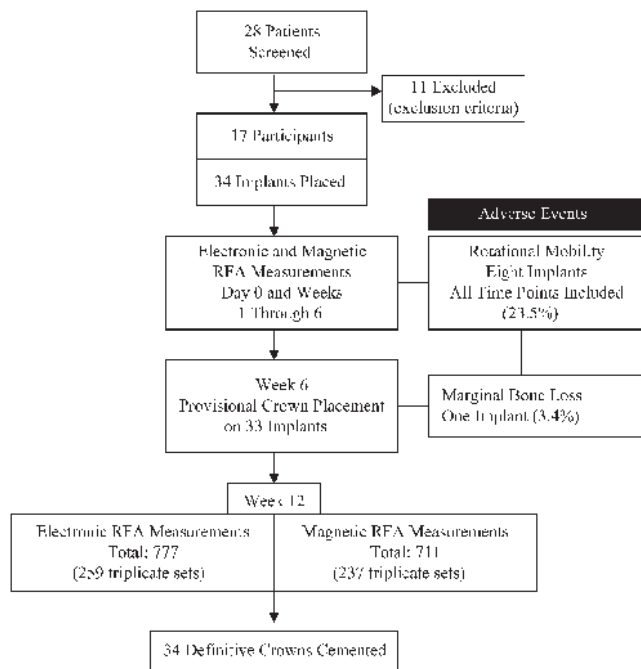
The adverse events are summarized in Figure 3. Eight of the 34 implants rotated during RFA measurement at different time points. The resonance frequency of these implants decreased (6.11 mean electronic ISQs and 11 mean magnetic ISQs); however, within 2 or 3 weeks all of them showed increasing ISQ values, and there was no evidence of peri-implant radiolucency at abutment connection. One implant presented marginal bone loss at 6 weeks. The magnetic ISQ values decreased for this implant; thus, it was not loaded at 6 weeks. The provisional crown placement was delayed until the radiographic appearance of this implant could be evaluated at 12 weeks.

The mean ISQ values obtained at each time point are presented in Table 2. The magnetic ISQ means were eight to 12 ISQs higher than the electronic ISQ means across weeks. At implant placement, mean

†† SPSS, SPSS, Chicago, IL.

**Table 1.**  
**Information About Implants Placed**

Jaw Implanted		Implant Position		Bone Type				Implant Length (mm)	
Maxilla	Mandible	Premolar Region	Molar Region	1	2	3	4	8	10
4 (11.8%)	30 (88.2%)	14 (41.2%)	20 (58.8%)	2 (5.9%)	11 (32.4%)	18 (52.9%)	3 (8.8%)	16 (47.06%)	18 (52.94%)



**Figure 3.**  
Flow diagram of patients and implants placed.

stability was 61.9 (95% confidence interval [CI], 59.4 to 64.3) ISQs for the electronic device and 70.6 (95% CI, 68.4 to 72.8) ISQs for the magnetic device; the 12-week means were 63.2 (95% CI, 61.2 to 65.2) and 75.9 (95% CI, 74.2 to 77.7) ISQs, respectively. For the one-factor mixed-model ANOVAs, significant mean stability differences across time were observed for the electronic device data ( $F = 5.66$ ;  $P < 0.001$ ) and the magnetic device data ( $F = 7.92$ ;  $P < 0.001$ ). Post hoc Dunnett tests for the electronic device data indicated that mean stability was significantly greater at 12 weeks compared to 2, 3, 4, 5, and 6 weeks ( $P < 0.010$ ), whereas for the magnetic device data, 12-week mean stability was significantly greater than for all other time points ( $P < 0.010$ ).

#### Changes in Stability During Early Healing

The overall patterns of change in mean stability during early healing are shown in Figure 4. The patterns for the two RFA devices were consistent; mean stability decreased for both by  $>1.5$  ISQs from 1 to 2 weeks

and increased for both by  $>1.5$  ISQs from 3 to 6 weeks. The increase in mean stability from 6 to 12 weeks (2.6 ISQs for electronic data and 5.6 ISQs for magnetic data) was the largest change for both between consecutive visits.

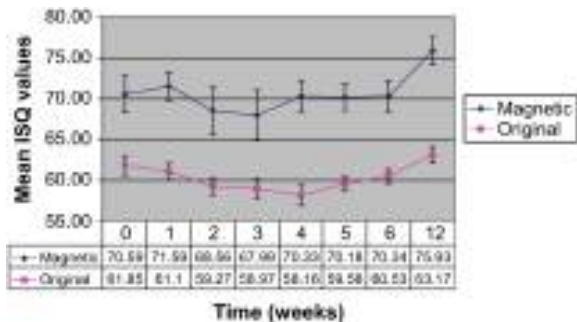
The analysis of possible confounders with two-factor mixed-model ANOVAs demonstrated that the main effect of jaw location was significant for electronic ( $F = 11.53$ ;  $P < 0.005$ ) and magnetic ( $F = 8.85$ ;  $P < 0.005$ ) ISQ values, indicating lower stability for maxillary implants relative to mandibular implants, regardless of healing time. For both RFA devices, mean stability at 2, 3, 4, and 6 weeks post-placement was  $>5$  ISQs lower in the maxilla compared to the mandible. The jaw location effect was detected even though only four implants were placed in the maxilla. Because the four maxillary implants had lower stability than the 30 mandibular implants and were represented uniformly in a confounder group, they were excluded to prevent biasing of the results. The analysis of the bone type in which the implants were placed, the shape of the maxillary or mandibular alveolar ridge (tapered, parallel, or undercut), the width of the ridge (4 to 7 mm versus 8 to 10 mm), and implant length (8 mm versus 10 mm) revealed no significant interactions. The distance between the shoulder of the implant and the mesial and distal marginal bone, measured with the magnetic device, was the only factor for which a significant interaction with time was observed ( $F = 2.67$ ;  $P < 0.020$ ). Implants with shorter distances had a mean ISQ at 12 weeks that was significantly greater than the mean ISQ at placement ( $P < 0.015$ ) and at all other weeks ( $P < 0.005$ ); implants with longer distances had a mean stability at 12 weeks that differed only with placement and at week 5 ( $P < 0.030$ ) and week 6 ( $P < 0.001$ ). No comparable effect was observed for the electronic device readings.

The effect of type of implant surface (chemically modified sandblasted, acid etched versus sandblasted, acid etched) did not have significant interaction with weeks post-placement for electronic ISQ values ( $F = 0.40$ ;  $P > 0.80$ ) or magnetic ISQ values ( $F = 0.39$ ;  $P > 0.90$ ), nor was the main effect of type of implant surface significant for electronic ( $F = 0.74$ ;  $P > 0.35$ ) or magnetic ( $F = 2.08$ ;  $P > 0.15$ ) ISQs.

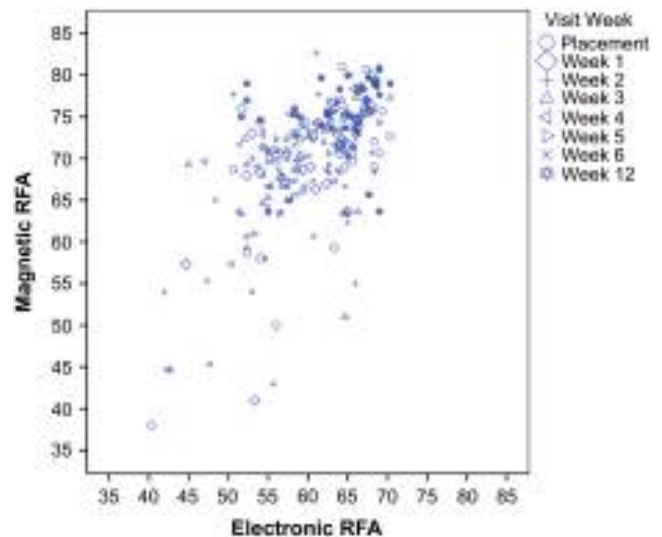
**Table 2.**

**ISQ Values and Mixed-Model ANOVA Results of Evaluation of Main Effect of Time Point on Resultant ISQ**

Visit	Magnetic Resonance Frequency Analyzer				Electronic Resonance Frequency Analyzer			
	Mean	SE	95% CI		Mean	SE	95% CI	
			Lower	Upper			Lower	Upper
Placement	70.59	1.09	68.35	72.82	61.85	1.20	59.43	64.28
Week 1	71.59	0.87	69.83	73.35	61.10	1.01	59.05	63.14
Week 2	68.56	1.43	65.67	71.46	59.27	1.06	57.12	61.42
Week 3	67.99	1.53	64.89	71.09	58.97	1.18	56.59	61.35
Week 4	70.33	0.94	68.42	72.23	58.16	1.24	55.64	60.67
Week 5	70.18	0.81	68.53	71.83	59.58	0.87	57.81	61.34
Week 6	70.34	0.95	68.41	72.27	60.53	0.85	58.82	62.23
Week 12	75.93	0.85	74.19	77.68	63.17	0.98	61.17	65.16
Main effect of week	F = 7.92; P <0.001 Week 12 > all others (P <0.010)				F = 5.66; P <0.001 Week 12 > weeks 2 through 6 (P <0.010)			



**Figure 4.** Mean ISQ values (SE and 95% CI) obtained with the original electronic resonance frequency analyzer and the newer magnetic resonance frequency analyzer at different time points.



**Figure 5.** Scatter plot of Pearson r correlation between electronic and magnetic RFA ISQ values.

When the analysis was restricted to the 30 mandibular implants, the mean ISQ for the chemically modified sandblasted, acid-etched surfaced implants was consistently higher across weeks compared to the mean ISQ for the sandblasted, acid-etched surfaced implants. Moreover, the main effect of implant surface was marginally significant for the electronic ISQ values ( $F = 3.31$ ;  $P = 0.072$ ); however, it was not significant for the magnetic RFA ( $F = 0.66$ ;  $P > 0.40$ ).

**RFA Device Correlation**

The electronic and magnetic RFA device correlation is shown in Figure 5. For the complete set of implant

measures across all weeks, the paired electronic and magnetic ISQ values were correlated significantly ( $r = 0.52$ ,  $P < 0.001$ ). Pearson correlation coefficients ranged from 0.43 to 0.69 during the first 5 weeks, all of which were significantly greater than zero ( $P < 0.020$ ). Pearson r decreased to 0.37 at 6 weeks, but remained significantly greater than zero ( $P < 0.045$ ).

No significant correlation was found when implants were evaluated at 12 weeks ( $r = 0.09$ ;  $P > 0.60$ ).

### Repeatability of Measurements

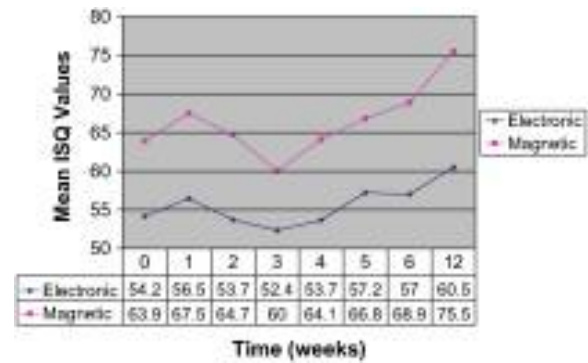
Repeatability was assessed by measuring the ISQ of each implant three times at each time point with the two RFA devices. The analysis of the three independent measurements (the transducers were loosened and retightened between each measurement) showed that the sets of three readings obtained with the magnetic RFA device had more variance than the sets of three readings obtained with the electronic RFA device. When pairing the sets of three RFA readings obtained with the magnetic and electronic devices for each implant and each time point, the range of the three readings obtained with the magnetic device was larger than the range of values of the electronic device 52.8% of the time. The electronic RFA device ranges were larger than those of the magnetic device 26.4% of the time. The two ranges were the same 20.8% of the time. These results were statistically significant using the Wilcoxon matched-pairs signed-rank test ( $Z = 5.25$ ;  $P < 0.001$ ).

One-factor mixed-model ANOVAs for the ranges of ISQ triplicate values indicated significant mean differences across weeks for the electronic device ( $F = 2.87$ ;  $P < 0.015$ ) and the magnetic device ( $F = 2.71$ ,  $P < 0.015$ ). In particular, for both devices, mean ranges at the time of placement were significantly greater than mean ranges at 4, 5, 6, and 12 weeks ( $P < 0.030$ ).

### Implant Stability According to Initial ISQ Value

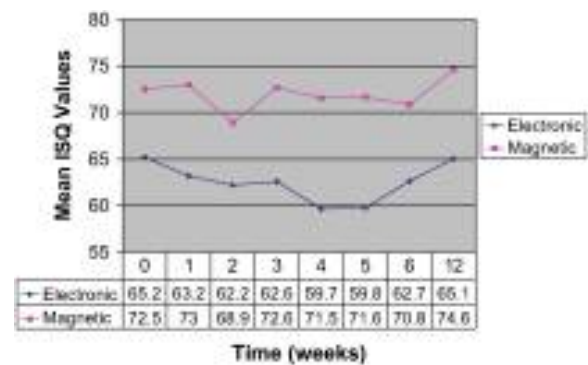
Based on the representative ISQ value for the electronic device obtained at the time of implant placement and the stability reference value of 60 ISQs, 12 implants were classified as having lower initial stability and 22 implants were classified as having higher initial stability. The trends of mean ISQ across weeks for these groups of implants are shown in Figures 6 and 7. The group of 12 implants with lower initial ISQ had an initial mean electronic ISQ value of 54.2 (range, 40.3 to 59.3), whereas the corresponding value measured in nine of these implants with the magnetic RFA device was 68.1 (range, 58.0 to 74.3). The group of 22 implants with higher initial ISQ had a mean electronic ISQ of 66.0 (range, 61.3 to 70.3), whereas the mean magnetic ISQ value measured in 17 of these implants was 72.8 (range, 59.3 to 81.0).

For the two-factor mixed-model ANOVAs, the interaction between initial stability level and weeks post-placement was significant for the electronic ISQ values ( $F = 5.37$ ;  $P < 0.001$ ) and the magnetic ISQ values ( $F = 2.66$ ;  $P < 0.020$ ). For both RFA devices, the group with lower initial stability had the lowest mean stability at week 3, followed by a sustained increase in mean stability. This tendency was main-



**Figure 6.**

Changes in stability of implants with initial ISQ values  $< 60$  measured with the electronic resonance frequency analyzer and ISQ values for the same implants with the magnetic resonance frequency analyzer.



**Figure 7.**

Changes in stability of implants with initial ISQ values  $> 60$  measured with the electronic resonance frequency analyzer and ISQ values for the same implants measured with the magnetic analyzer.

tained after loading until the end of follow-up. For the group of implants with higher initial stability, the fluctuations in mean stability from 2 to 6 weeks were  $< 2$  ISQs for both devices, indicating a more constant pattern of stability compared to the other group.

## DISCUSSION

Dental implants are a successful treatment modality for missing teeth; however, failures do occur.<sup>6,19-22</sup> These failures can occur early in the healing process after primary stability has been achieved at the time of implant placement, or after initial bone remodeling and new bone growth have taken place. The ability to detect implants that are failing or will fail, although small in number, is not possible at this time. There are several ways to evaluate the bone-implant interface. Invasive methods, like the amount of torque required to remove an implant, have been used in animal studies.<sup>23,24</sup> Clearly, this is a destructive method in which the application of shear stress at the implant interface

leads to failure; therefore, it is not applicable for clinical assessment.<sup>17,25</sup> Cutting torque measurement, a clinical method that uses cutting resistance measurements during threading of implants, has been used by several investigators to identify bone densities during implant placement.<sup>26-28</sup> Although this technique provides an assessment of bone quality at the time of placement, it does not allow for any direct measurement of the changes that occur to the supporting bone over time.

RFA is a non-invasive objective testing modality of implant stability. The original electronic RFA device is able to distinguish implants placed in different bone qualities, and it has been used to evaluate the prognosis of implants with different designs and surface characteristics.<sup>9,26,27,29-31</sup> Electronic RFA correlated with cutting insertion torque<sup>26-28</sup> and with bone-implant contact in histomorphometric studies in animals<sup>32</sup> and in human cadavers.<sup>28</sup> There is a newer, commercially available magnetic resonance frequency analyzer with a different mechanism of action about which no articles have been published. The present longitudinal prospective study was designed to determine whether both devices were able to detect changes in stability during early healing times and to determine whether there was a correlation between both resonance frequency analyzers.

Based on the 777 measurements taken with the original electronic resonance frequency analyzer and the 711 measurements taken with the newer magnetic device, both were able to detect the changes in stability of the two different implants studied and both RFA devices were correlated moderately at most time points ( $r = 0.52$ ;  $P < 0.001$ ). The absence of correlation at 12 weeks was primarily due to the fact that for 26 of the 34 implants, the magnetic device values ranged from 74.3 to 80.7 ISQs, which was considerably less than the 57.7 to 70.3 ISQ range for the electronic device.

For both devices, the analysis of the repeatability of the three separate RFA measurements obtained at each time point showed more ISQ variability at early healing times (0 to 3 weeks) than at 4 to 12 weeks. This may suggest that when the stability is low, during early healing times, it is more difficult for the devices to establish an exact value. Another possibility is that both devices are technique sensitive, and a learning curve of the operators is required. A further, and perhaps more likely, possibility is that the force needed to tighten the transducer (performed six times at each visit) to the implant at early healing times may displace the implant slightly; thus, the ISQ value changes with each of the three measurements. Additionally, the force required to connect both transducers seems to be different; this phenomenon may have resulted in the variability of ISQ values when repeated measurements were made.

An important finding is that the mean ISQ obtained with the magnetic device was eight to 12 ISQs higher than the ISQ obtained with the original device. Therefore, direct comparisons of the stability values (ISQ) between these two devices cannot be made. These discrepancies may be attributed to the built-in settings of the two resonance frequency analyzers or the fact that the transducer of the electronic device is screwed on top of the non-submerged implant (2.8 mm above the bone level in this study), whereas the peg of the magnetic device is screwed inside the implant.

The stability of the implants evaluated in this prospective study was affected by healing time, as has been shown in previous studies in humans<sup>11,16,17,30,31,33</sup> and animals.<sup>17,25,34</sup> In this study, both devices detected a slight decrease in stability between weeks 1 and 3, followed by an increase in ISQ values until week 12. In the subgroup analysis, with healing, implants with the lowest ISQ values were able to reach levels of stability consistent with the implants with the highest initial values. Conversely, implants with the highest initial ISQ values showed much less decrease in stability during the early healing period (first month following placement) compared to those with less initial stability. At the 3-month follow-up visit, most of the implants showed very similar stability values, irrespective of initial ISQ. It is expected that higher initial ISQ values are related to denser bone, which would take longer to remodel than less dense trabecular bone.<sup>35</sup> Implants with lower stability values suggest not just less dense bone but less bone contact; these implants likely would undergo a faster decrease in ISQ value because remodeling would occur over a higher proportion of bone contacting the implant.

Both devices were able to detect significantly lower ISQ values for implants placed in the posterior maxilla relative to those placed in the posterior mandible. Similar findings were reported by Bischof et al.<sup>30</sup> However, in the present study, no differences were detected between implants placed in different bone types. This may be explained by the fact that most of the implants were placed in bone type 2 or 3, and it is known that the ability of a clinician to detect differences in bone quality during drilling is subjective and very limited in bone type 2 and 3.<sup>36</sup>

The two RFA devices were not able to detect significant differences between the two types of implants used in this study. It is possible that no differences exist in stability between the two implants with different surfaces in the early phase of healing, the RFA measurements are not able to detect small differences, or not enough implants were evaluated. This study was not powered with the objective of comparing stability changes between these two surfaces, as was the 27-patient parent study on which this investigation was based.



The electronic and magnetic RFA did not detect differences between implants that were 8 and 10 mm in length, yielding similar ISQ values, as shown previously.<sup>16,26,30</sup> This finding indicates that implant stability can be achieved with short sandblasted, acid-etched surfaced implants or with chemically modified sandblasted, acid-etched surfaced implants placed in posterior regions. Another possible explanation is that once the bone–implant contact is established at the marginal level and the implant is stable, a 2-mm difference in length in the apical region, in areas typically composed of very cancellous bone, does not provide a significant improvement in the overall implant stability.

Previous *in vivo* studies<sup>9</sup> showed that the exposed implant height above the marginal bone and the amount and shape of the bone around the osseointegrated surface of the implant are factors influencing implant stability measurements.<sup>17</sup> In our study, the implant length above the bone at the implant site was determined using the distance between the shoulder of the implant and the mesial and distal marginal bone. However, this distance did not correlate with the implant stability measured with the electronic device. Conversely, the magnetic device was able to detect significantly higher stability at 12 weeks for implants with shorter distances. Moreover, we found that the shape and width of the alveolar ridge did not affect the ISQ value. Our findings are in accordance with previous studies.<sup>30</sup>

In this study, eight of 34 implants rotated slightly upon transducer or peg tightening during the follow-up visits. Most of these implants were in the group with the lowest initial ISQ values. Based on these observations, it may be that low initial ISQ values are related to implants that need a more extended healing period, and, therefore, may have greater susceptibility to implant failure with functional loading prior to complete healing. This may be consistent with what was reported by Friberg et al.,<sup>10</sup> who described that “the lowered RF value indicated failure several weeks before the bone loss was radiographically diagnosed.” Glauser et al.<sup>12</sup> agreed, concluding, “the RFA could identify failing implants before failure was clinically manifested.” These results are in contrast with the findings of other investigators who found RFA unable to identify mobile implants with accuracy.<sup>31</sup> However, mobility and rotation upon tightening may represent a very different biologic phenomenon compared to failure. In our study, all implants with rotational movement showed an initial decrease in the ISQ value followed by an increase in value measured with both devices. Similar findings were reported in studies in animals<sup>16</sup> and in humans by Meredith et al.<sup>17</sup> and Barewal et al.<sup>11</sup> However, the sample size and duration of this study are not sufficient to determine

whether the changes in ISQ measured by the original or magnetic RFA devices are associated with implant survival or failure. Moreover, the amount of rotational movement of implants in this study could be related to the weekly manipulations and multiple measurements taken with both devices during early healing. Only one implant presented with minimal marginal bone loss, but it resolved spontaneously. This implant was loaded and was functionally restored.

An interesting observation was that five of eight implants that exhibited rotational movement during cover screw removal or tightening had initial ISQs between 50 and 56, the lowest initial values obtained in this study. These data suggest that implants with an ISQ <56 may require longer healing periods prior to manipulation. Although this finding is based on a very small number of implants, it is in accordance with a previous publication.<sup>31</sup> Nevertheless, these implants showed an increase in stability and were loaded at 6 weeks, remaining stable until the definitive cementation of the final crowns. The demonstrated increase in stability could be related to the ability of the sandblasted, acid-etched surfaced implant and the chemically modified sandblasted, acid-etched surfaced implant used in this study to respond to this type of healing disturbance or to the biomechanical stimulation after the provisional restorations were cemented.

## CONCLUSIONS

The electronic resonance frequency analyzer and the newer magnetic resonance frequency analyzer seem to be capable of measuring similar changes in implant stability over time. This study indicates that although both devices can detect implant stability changes, the magnetic device resulted in consistently higher (approximately eight to 12) ISQ values when measuring the stability of non-submerged dental implants; therefore, measurements made with the two devices cannot be compared directly.

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