Sensitivity of Resonance Frequency Analysis for Detecting Early Implant Failure: A Case-Control Study

Alberto Monje, DDS[1]/Inmaculada Ortega-Oller, DDS[2]/Pablo Galindo-Moreno DDS, PhD[2]/ Andrés Catena, PhD[3]/Florencio Monje MD, PhD[4]/Francisco O´Valle MD, PhD[5]/ Fernando Suarez, DDS[1]/Hom-Lay Wang, DDS, MS, PhD[1]

Purpose: *The aim of this study was to test the sensitivity of the resonance frequency analysis for detecting early implant failure.* **Materials and Methods:** *In all, 3,786 implants placed from June 2007 to January 2013 were retrospectively evaluated. A total of 20 implants (in 20 patients) placed in pristine bone were found to have failed before loading. The implant stability quotient (ISQ) values were extracted from these 20 implants at baseline (immediate) and 4 months after placement (delayed). Simple linear regression, logistic regression, and two-way contingency tables were used to test for the relationships between ISQ values and early implant failure.* **Results:** *Immediate ISQ values were significantly related to failure (odds ratio [OR] = 4.27). Furthermore, the results of the second regression showed a significant relationship between ISQ at delayed measurement and implant failure (OR = 9.20). For immediate ISQ, it seems that the 73.7% correct classifications were obtained at the cost of an incorrect classification of 55% of the implant failures. However, for the delayed ISQ, 86.2% correct classifications were obtained at the cost of considering* **[Au: "assuming"?]** *that all implants will survive.* **Conclusion:** *The present study showed that ISQ values are not reliable in predicting early implant failure. In addition, the real cutoff ISQ value to differentiate between success and early implant failure remains to be determined.* Int J Oral Maxillofac Implants 2014;29:xxx–xxx

Key words: *early failure, implant failure, implant stability, ISQ, primary stability, resonance frequency analysis*

Primary or mechanical implant stability plays an important role in implant osseointegration[1] as well as long-term implant survival. Implant stability is determined by the availability of bone and its quality for anchoring dental implants. Both have been shown to be the key factors for ensuring implant success.[2] Hence, a quantitative measurement of bone quality is essential prior to implant restoration to determine whether implants can be loaded. When implants have achieved both primary mechanical and secondary biologic stability, they seldom fail unless it is caused by peri-implant disease[3] or occlusal overloading.[4] On the other hand, early implant failure is defined as implant failure that occurs before loading, and it most likely can be attributed to poor bone quality, impaired healing, or lack of initial primary stability.[5]

Many techniques and tools have been proposed to assess initial implant osseointegration.[6] However, most of them are no longer available due to their invasiveness and inaccuracy.[6] More recently, resonance frequency analysis (RFA) was developed, using implant stability quotient (ISQ) as a quantitative unit to assess implant stability.[7] The reading of RFA reflects on the combination of the three main factors: *(1)* stiffness of the implant fixture and its interface with the surrounding tissues, *(2)* design of the transducer, and *(3)* total effective length below the bone level.[8] The ISQ reading ranges from 0 to 100, with a higher number indicating higher stability. It has been considered a reliable tool to quantify implant stability (both mechanical and biologic) and can be used to determine implant prognosis.[9] It has been suggested that integrated implants have an ISQ ranging from 57 to 82 after 1 year of loading[10] and that a value of less than 50 might indicate implant failure.[11,12] Nevertheless, there is no definitive threshold

[1]Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, Michigan, USA.
[2]Oral Surgery and Implant Dentistry Department, School of Dentistry, University of Granada, Granada, Spain.
[3]Department of Experimental Psychology, School of Psychology, University of Granada, Granada, Spain.
[4]Center of Implantology, Oral and Maxillofacial Surgery (CICOM), Badajoz, Spain.
[5]Department of Pathology. School of Medicine & IBIMER. University of Granada, Granada, Spain.

Correspondence to: Alberto Monje, Calle Juan Miró s/n, local 16-17, 06010 Badajoz, Spain. Fax: +34-924-260-773. Email: amonjec@umich.edu

value to differentiate a stable and functional implant from a failing or failed implant. This is because most of the published papers only focus on showing the effectiveness of RFA in predicting implant stability.[13,14]

It has been suggested that ISQ value at time of implant placement records primary or mechanical stability and is determined mostly by the availability of bone surrounding the implant as well as the drilling protocol.[15] However, over time the ISQ value reflects the healing process of the bone, ie, so-called secondary or biologic stability.[16] In addition, implant macro- and microdesign have both been shown to have an impact on ISQ value.[14,17] For example, a 0.5-mm increase in implant width provides 10% to 15% more implant surface, suggesting greater bone-to-implant interface and a higher degree of osseointegration.[18] However, some have reported that neither implant diameter[19–22] nor implant macrodesign[20] influence ISQ values. Therefore, it is difficult to come to a firm conclusion and an ISQ value or range that can be used to differentiate between implant success and failure.

Recently, Al-Nawas et al[23] in an animal study suggested that implant sensitivity and specificity was 83% and 61%, respectively, for implants under load with an ISQ value of 65.5 at implant placement. In this study, no statistically significant difference in primary stability between successful and failed implants was found. As reported above, RFA might predict long-term implant stability, but it is unreliable to predict implant failure. Hence, the question arises: should we keep trusting in ISQ as a tool for quantitative measurement in determining when is the best time to load implants?

Therefore, the purpose of the present study was to retrospectively assess the sensitivity of RFA for detecting early implant failure (ie, before functional loading).

MATERIALS AND METHODS

An total of 3,786 implants placed between June 2007 and January 2013 were retrospectively evaluated in order to extract information regarding failed implants and the reasons for their failures.

Inclusion Criteria

All patients had to meet the following inclusion criteria: age between 18 and 85 years, no systemic diseases or conditions known to alter bone metabolism, good bone quality, and adequate ridge width and height to ensure good implant primary stability. All the implants included were lost before loading. Patients who received socket preservation or soft tissue **[Au: "soft tissue" correct? Original said "soft".]** or bone grafts at the time of implant surgery or previously were excluded from the study. Implants that failed after loading were not included.

Implant Placement

Each patient was required to take 500 mg amoxicillin, or 300 mg clindamycin if allergic to amoxicillin, 1 hour prior to surgery. All procedures were performed under local anesthesia or under local anesthesia and intravenous sedation. Implants were inserted according to the manufacturer´s protocol with flap access. All implants were placed with 35 to 40 Ncm final insertion torque. Primary closure of flaps without tension was achieved. All patients received postoperative instructions and were given antibiotics and analgesic drugs. The sutures were removed after 7 to 10 days.

Resonance Frequency Analysis

An RFA device (Ostel Mentor, Integration Diagnostics) was used following the manufacturer's recommendations for the measurement of primary implant stability. Briefly, a designated metal rod (Smartpeg, Integration Diagnostics) was screwed into the implant screw vent. Then, a probe was placed close to the rod at the midfacial side and the buccal side of the implant. The ISQ was generated and recorded for both sides. The two measurements were averaged to represent the primary stability of each implant.

Statistical Analysis

After descriptive analysis, the Pearson linear correlation coefficient was used to test the ISQ reliability. Simple linear regression, logistic regression, and two-way contingency tables were used to test for the relationships between ISQ scores and implant failure. Nonparametric receiver operating characteristic (ROC) analysis was used to determining the optimum cutoff values for implant failure classification. A group of successful/stable implants (56) from patients with similar clinical features were randomly selected to compare with the failed implants (20). The number of successful/stable implants of the control group was based on a random selection out of the 3,766 successful/stable implants. The analysis was repeated with the 56 control implants in order to verify the findings. SPSS (v. 17.0, IBM) was used for all statistical analysis. A significance level of a = .05 was established for all hypothesis testing.

RESULTS

Of 3,786 dental implants, 20 implants placed in 20 patients (0.52%), with a mean age of 52.3 ± 16 years old, failed before implant loading (Table 1). ISQ was measured at implant placement before placing the cover screw (immediate) and in some cases at 4 months (delayed) when the healing abutment was placed. All 20 implants were retrieved after ISQ measurement and before functional loading due to clear clinical mobility.

Table 1 Characteristics and Mean ISQ Values of Implants with Early Failure Included in the Study

Sex	Age (y)	Implant position	Implant manufacturer	Length (mm)	Width (mm)	Initial ISQ value (immediate)	4-month ISQ value (delayed)	Failure (mo)
F	52	AMX	NB	15	4	55	—	4
F	45	PMX	MG	13	4.25	77	76	5
M	68	PMD	MG	10	4.25	72	—	4
M	43	AMX	MG	15	4	68	—	3
F	39	PMX	NB	13	4	59	—	4
F	44	PMX	MG	8	4.25	66	65	5
M	53	AMX	NB	13	4	75	77	5
M	49	PMX	NB	10	5	82	69	5
F	64	PMX	MG	11.5	4	68	74	5
F	56	AMX	NB	8.5	4	54	58	5
F	51	AMX	NB	10	4	64	60	5
F	48	PMX	MG	10	4	74	—	4
F	67	PMX	NB	9	5	66	—	4
M	36	PMX	NB	15	4	70	70	5
F	57	PMX	MG	11.5	4	70	—	4
F	38	PMX	NB	13	4	58	64	5
M	55	PMX	MG	8	4.25	77	—	3
M	61	PMD	NB	8	4.25	77	—	4
F	68	AMX	NB	13	3.3	67	—	3
F	49	AMX	NB	10	4	60	—	4

F = female; M = male; PMX = posterior maxilla; PMD = posterior mandible; AMX = anterior maxilla; MG = MozoGrau; NB = Nobel Biocare; — = [Au: Please explain what — signifies: unavailable? not applicable?].

Implant Location, Manufacturer, Length, and Width and Patient Sex

Forward linear regression including implant length, width, location, manufacturer, and immediate ISQ as well as patient sex as predictors and month of failure as the dependent, showed no significant association, with no variables entering in the prediction equation. Additionally, forward linear regression including implant length, width, location, and manufacturer and patient sex as predictors and immediate ISQ as the dependent indicated that sex is significantly associated with immediate ISQ values (b = 9.967, t_{18} = 3.336, P = .004), but all the remaining predictors were unable to enter in the linear equation. Averages showed that men's immediate ISQ was greater (74.42, standard deviation [SD] = 4.79) than that of women (64.46, SD = 7.03).

ISQ Values

The Pearson linear correlation coefficient indicated that the test-retest reliability of ISQ was rather small, although significant (r = 0.509, P < .001).

ISQ Values Unable to Predict Implant Failure

Simple linear regression indicated that ISQ immediate scores were unable to account for the observed variability in failure time (in months) ($F_{1,18}$ = 0.049, P > .82, adjusted R^2 = –0.053).

ISQ Values Unable to Discriminate Implant Failure

The authors used several indexes to estimate the ability of the ISQ to discriminate whether an implant will fail or not within the 5-month observation period. First, a 2 ´ 2 repeated measures analysis of variance in which the between-group factor was implant failure and the repeated factor was the ISQ measures (immediate and delayed) yielded main effects of failure ($F_{1,3}$ =11.478, P = .001, R^2 = 0.154), but neither the repeated factor nor its interaction with failure was significant (both $F_{1,63}$ < 1, P > .444). This and the regression result speak about the possibility of considering ISQ an unreliable predictor of implant failure. The immediate ISQ averages were 68.22 and 75.41, respectively, for failure and survival implants, and 68.11 and 77.10 for failure and

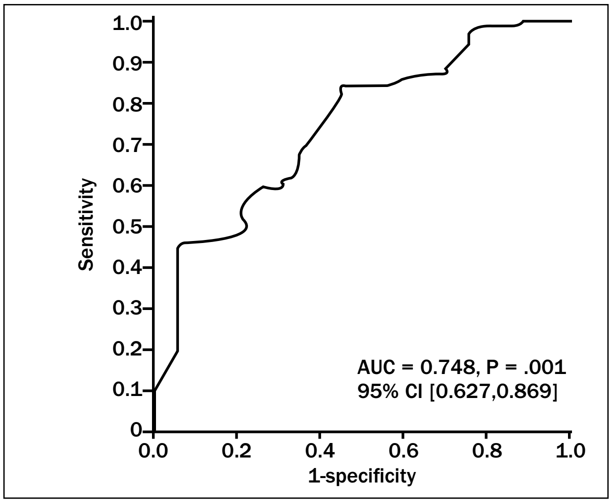

Fig 1 Nonparametric ROC analysis for immediate ISQ. AUC = area under the curve; CI = confidence interval.

survival at the second measurement time (delayed). Hence, the ISQ scores are larger for implant survival than for failure.

Secondly, the authors tried to ascertain if there is a single cutoff ISQ value that allows precise classification of the failure status of the implants. Nonparametric ROC analysis (Fig 1) indicated that the best ISQ score cutoff would be 68 for the immediate and 70.50 for the delayed measurement. Subsequently, the authors defined two new variables to mark whether the ISQ score were equal or greater than the cut-points (hereafter, immediate or delayed ISQ). Logistic regression was used to test the ability of each binary variable to predict the implant failure. Immediate ISQ was significantly related to failure (B = 1.452, Wald F_1 = 6.307, *P* = .012, OR = 4.273). This seems to show that the probability of failure when the ISQ score is below the cutpoint is considerably larger than when it is equal to or higher than this cutoff value. However, as indicated by the classification table, it seems that the 73.7% correct classifications were obtained at the cost of incorrect classification of 55% of failures. The results of the second logistic regression supported this assumption. Nonetheless, a significant correlation was identified between delayed ISQ and early implant failure (B = 2.219, Wald F_1 = 7.921, *P* = .005, OR = 9.20); however, the 86.2% correct classifications were obtained at the cost of considering [Au: "assuming"?] that all implants will survive.

If implants failure were then categorized simply by the cutoff value, total correct classifications would be: for immediate ISQ, 76.33%, at the cost of classifying 45% of failed implants as surviving and 16.07% of surviving implants as failures; and for delayed ISQ, 63.07%, at the cost of incorrectly classifying 33.33% of failed implants as surviving and 32.14% of surviving implants as failed.

Finally, if the cutoff value was modified in order to obtain the maximum number of correct classifications for failed implants, the false positive rate was so high as to diminish the true clinical relevance. For example, fixing the immediate ISQ value at 82 increases correct classification of failures to 95%, but also raises the false positive rate to 80.36% (Table 2).

DISCUSSION

It is important to know that the implant mechanical stability is mediated by macroretentions and influenced primarily by the drilling protocol as well as the implant insertion torque.[23,24] Biologic stability, which largely relies upon implant primary stability, determines the long-term implant success. Micromovement that occurs during implant healing might disturb the normal healing process and cause implant failure.[25]

RFA is a tool developed to determine the implant stability, using quantitative ISQ values, at different time points of implant therapy. However, data from the present study suggested that ISQ values might not be reliable in predicting early implant failure. This is in agreement with many previous publications that also suggested that RFA has a low specificity in predicting early implant failure.[2,6,12,23,26,27] Although ISQ lacks sensitivity, specificity, and accuracy to determine implant stability,[28] it might be a useful tool in determining when is the proper time to load the healed implants and to determine the amount of osseointegration.

Factors that may influence the ISQ value include implant micro- and macrodesign features; however, data from the literature are conflicting. One recent publication[29] showed that the wider the implant is, the greater the bone-to-implant contact and the higher the ISQ value.[17] Other studies have demonstrated that neither implant diameter[19–21] nor implant macrodesign[20,30] could affect ISQ values. Hence, due to the disparity among studies and many factors that might affect ISQ value, to recommend detecting ISQ value at the time of implant placement is not warranted.

Results from the present study also indicated that it is almost impossible to identify a cutoff ISQ value that could be used clinically to differentiate between success and early implant failure. Since the introduction of RFA, many studies have tried to establish a reliable cutoff value to determine whether the treatment is predictive. Interestingly, most of the studies reporting implant stability have shown a lower ISQ value for

Table 2 Nonparametric ROC Coordinates for Each of the Two Measurement Times*

Immediate ISQ			Delayed ISQ		
Cutoff	Sensitivity	1 – Specificity	Cutoff	Sensitivity	1 – Specificity
53.0	1.000	1.000	57.0	1.000	1.000
54.5	1.000	.950	59.0	1.000	.889
56.5	1.000	.900	60.5	1.000	.778
58.5	.982	.850	62.0	.982	.778
59.5	.982	.800	63.5	.964	.778
61.5	.964	.750	64.5	.946	.667
63.5	.946	.750	65.5	.946	.556
64.5	.893	.700	66.5	.911	.556
65.5	.875	.700	67.5	.893	.556
66.5	.857	.600	68.5	.875	.556
67.5	.839	.550	69.5	.839	.444
68.5	.839	.450	70.5	.821	.333
69.5	.821	.450	72.0	.768	.333
70.5	.679	.350	73.5	.714	.333
71.5	.643	.350	74.5	.679	.222
72.5	.607	.300	75.5	.589	.222
73.5	.589	.300	76.5	.571	.111
74.5	.589	.250	77.5	.536	.000
75.5	.536	.200	78.5	.482	.000
76.5	.482	.200	79.5	.464	.000
77.5	.446	.050	80.5	.268	.000
78.5	.429	.050	81.5	.250	.000
79.5	.375	.050	83.0	.196	.000
80.5	.232	.050	84.5	.143	.000
81.5	.196	.050	86.0	.089	.000
82.5	.125	.000	88.0	.054	.000
84.0	.107	.000	89.5	.036	.000
86.5	.054	.000	91.0	.000	.000
90.0	.036	.000			
93.0	.018	.000			
95.0	.000	.000			

*The shaded row contains the categorization thresholds.

failed implants.[31] Fischer et al[32] reported that failing implants had a decrease in the ISQ value right before the implants failed. It is also important to note that the authors showed that when ISQ value is below 44, a 100% chance of implant failure could be predicted. However, Nedir et al[12] did not find the presence of any single peak value to predict implant failure. Additionally, they questioned the value of ISQ since they believe ISQ might not be a reliable tool in identifying stable implants since the probability of the ISQ to detect implant mobility (ISQ < 47) was extremely low. Similar observation was also reported by Huwiler et al,[33] who suggested that a decline in the ISQ value for failing implants was not outside the range of all implants analyzed. Glauser et al[34] showed that failed implants had an ISQ around 52 at 1 month after placement. Interestingly, they showed a mean ISQ of 68 for the successful implants, which coincides with the current study's mean ISQ value found in the failed implants. Results obtained from the present study showed that there was no dramatic decline in ISQ values for failing implants before they failed.

Certainly, ISQ values at baseline were significantly related to failure (OR = 4.27). Therefore, the probability of failure when ISQ score is below 68.22 is considerably greater than when it is equal or higher than this cutoff point. Furthermore, the results of the second regression analysis showed a significant relationship between ISQ at delayed measurement and implant failure (OR = 9.20). However, for immediate ISQ it seems that the 73.7% correct classifications were obtained at the cost of incorrect classification of 55% of the failures, and for the delayed ISQ the 86.2% correct classifications were obtained at the cost of considering **[Au: "assuming"?]** that all implants will survive. Moreover, the present study showed the absence of differences between the two ISQ measures, and the fact that the measures were separated in time by about 4 months is in full agreement with the regression result, which shows that similar ISQ can be obtained even when failure is impending. This suggests that ISQ value might not be sensitive enough to detect implant osseointegration. Thus, from the current findings and others,[12,33] it can be stated that the RFA device might mislead the clinician when assessing implant stability to predict implant failure.

CONCLUSION

Within the limitations of the present study, it may be concluded that ISQ values are not reliable in predicting early implant failure. In addition, the real cutoff ISQ value to differentiate between success and early implant failure remains to be determined.

ACKNOWLEDGMENTS

The authors thank the Foundation for the Study of Implantology and Oral and Maxillofacial Surgery (FEDICOM), Badajoz, Spain, for financial support. This study was partially supported by the Junta de Andalucía Funding Program for research groups in Spain (Projects #CTS-138 and #CTS-583). The authors do not have any financial interests, either directly or indirectly, in the products listed in the study.

REFERENCES

1. Misch CE, Hoar J, Beck G, Hazen R, Misch CM. A bone quality-based implant system: A preliminary report of stage I & stage II. Implant Dent 1998;7:35–42.
2. Molly L. Bone density and primary stability in implant therapy. Clin Oral Implants Res 2006;17(Suppl 2):124–135.
3. Lindhe J, Meyle J. Peri-implant diseases: Consensus Report of the Sixth European Workshop on Periodontology. J Clin Periodontol 2008;35:282–285.
4. Isidor F. Loss of osseointegration caused by occlusal load of oral implants. A clinical and radiographic study in monkeys. Clin Oral Implants Res 1996;7:143–152.
5. Sakka S, Baroudi K, Nassani MZ. Factors associated with early and late failure of dental implants. J Investig Clin Dent 2012;3:258–261.
6. Huang HM, Lee SY, Yeh CY, Lin CT. Resonance frequency assessment of dental implant stability with various bone qualities: A numerical approach. Clin Oral Implants Res 2002;13:65–74.
7. Meredith N, Alleyne D, Cawley P. Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. Clin Oral Implants Res 1996;7:261–267.
8. Chan HL, El-Kholy K, Fu JH, Galindo-Moreno P, Wang HL. Implant primary stability determined by resonance frequency analysis in surgically created defects: A pilot cadaver study. Implant Dent 2010;19:509–519.
9. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont 1998;11:491–501.
10. Balleri P, Cozzolino A, Ghelli L, Momicchioli G, Varriale A. Stability measurements of osseointegrated implants using Osstell in partially edentulous jaws after 1 year of loading: A pilot study. Clin Implant Dent Relat Res 2002;4:128–132.
11. Atsumi M, Park SH, Wang HL. Methods used to assess implant stability: Current status. Int J Oral Maxillofac Implants 2007;22:743–754.
12. Nedir R, Bischof M, Szmukler-Moncler S, Bernard JP, Samson J. Predicting osseointegration by means of implant primary stability. Clin Oral Implants Res 2004;15:520–528.
13. Herrero-Climent M, Albertini M, Rios-Santos JV, Lazaro-Calvo P, Fernandez-Palacin A, Bullon P. Resonance frequency analysis-reliability in third generation instruments: Osstell mentor(R). Med Oral Patol Oral Cir Bucal 2012;17:e801–e806.
14. Ostman PO, Hellman M, Sennerby L. Direct implant loading in the edentulous maxilla using a bone density-adapted surgical protocol and primary implant stability criteria for inclusion. Clin Implant Dent Relat Res 2005;7(Suppl 1):S60–S69.
15. Blanco J, Alvarez E, Munoz F, Linares A, Cantalapiedra A. Influence on early osseointegration of dental implants installed with two different drilling protocols: A histomorphometric study in rabbit. Clin Oral Implants Res 2011;22:92–99.
16. Gapski R, Wang HL, Mascarenhas P, Lang NP. Critical review of immediate implant loading. Clin Oral Implants Res 2003;14:515–527.
17. Polizzi G, Rangert B, Lekholm U, Gualini F, Lindstrom H. Branemark System Wide Platform implants for single molar replacement: Clinical evaluation of prospective and retrospective materials. Clin Implant Dent Relat Res 2000;2:61–69.
18. Capek L, Simunek A, Slezak R, Dzan L. Influence of the orientation of the Osstell transducer during measurement of dental implant stability using resonance frequency analysis: A numerical approach. Med Eng Phys 2009;31:764–769.
19. Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP, Samson J. Implant stability measurement of delayed and immediately loaded implants during healing. Clin Oral Implants Res 2004;15:529–539.
20. Han J, Lulic M, Lang NP. Factors influencing resonance frequency analysis assessed by Osstell mentor during implant tissue integration: II. Implant surface modifications and implant diameter. Clin Oral Implants Res 2010;21:605–611.
21. Monje A, Monje F, Suarez F, et al. Comparison of implant primary stability between maxillary edentulous ridges receiving intramembranous origin block grafts. Med Oral Patol Oral Cir Bucal 2013;18:e449–e454.
22. Pommer B, Hof M, Fadler A, Gahleitner A, Watzek G, Watzak G. Primary implant stability in the atrophic sinus floor of human cadaver maxillae: Impact of residual ridge height, bone density, and implant diameter. Clin Oral Implants Res 2014;25:e109–e113.
23. Al-Nawas B, Wagner W, Grotz KA. Insertion torque and resonance frequency analysis of dental implant systems in an animal model with loaded implants. Int J Oral Maxillofac Implants 2006;21:726–732.
24. Cehreli MC, Karasoy D, Akca K, Eckert SE. Meta-analysis of methods used to assess implant stability. Int J Oral Maxillofac Implants 2009;24:1015–1032.
25. Brunski JB. Biomechanics of oral implants: future research directions. J Dent Educ 1988;52:775–787.

26. Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP, Samson J. Implant stability measurement of delayed and immediately loaded implants during healing. Clin Oral Implants Res 2004;15:529–539.
27. Rodrigo D, Aracil L, Martin C, Sanz M. Diagnosis of implant stability and its impact on implant survival: A prospective case series study. Clin Oral Implants Res 2010;21:255–261.
28. Atieh MA, Alsabeeha NH, Payne AG. Can resonance frequency analysis predict failure risk of immediately loaded implants? Int J Prosthodont 2012;25:326–339.
29. Guler AU, Sumer M, Duran I, Sandikci EO, Telcioglu NT. Resonance frequency analysis of 208 Straumann dental implants during the healing period. J Oral Implantol 2013;39:161–167.
30. Valderrama P, Oates TW, Jones AA, Simpson J, Schoolfield JD, Cochran DL. Evaluation of two different resonance frequency devices to detect implant stability: A clinical trial. J Periodontol 2007;78:262–272.
31. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: Biological and biomechanical aspects and clinical implications. Periodontol 2000 2008;47:51–66.
32. Fischer K, Backstrom M, Sennerby L. Immediate and early loading of oxidized tapered implants in the partially edentulous maxilla: A 1-year prospective clinical, radiographic, and resonance frequency analysis study. Clin Implant Dent Relat Res 2009;11:69–80.
33. Huwiler MA, Pjetursson BE, Bosshardt DD, Salvi GE, Lang NP. Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation. Clin Oral Implants Res 2007;18:275–280.
34. Glauser R, Sennerby L, Meredith N, et al. Resonance frequency analysis of implants subjected to immediate or early functional occlusal loading. Successful vs. failing implants. Clin Oral Implants Res 2004;15:428–434.