Changes in Stability After Healing of Immediately Loaded Dental Implants

Antonin Simunek, MD, PhD[1]/Jakub Strnad, Ing, PhD[2]/Dana Kopecka, MD, PhD[3]/Tomas Brazda, MD[3]/Shriharsha Pilathadka, BDS, PhD[3]/Ravi Chauhan[4]/Radovan Slezak, MD, PhD[1]/Lukas Capek, Ing, PhD[5]

Purpose: *To investigate the parameters that affect primary stability of dental implants, to determine how primary stability influences posthealing stability, and to ascertain the effect of primary stability and insertion parameters on marginal bone loss.* ***Materials and Methods:*** *A total of 940 immediately loaded implants were considered. Using resonance frequency analysis, primary stability (primary implant stability quotient [pISQ]) and stability after 4 months (tISQ) were recorded. When the differences between pISQ and tISQ exceeded 5 units, marginal bone loss was measured. The implants were placed into three groups based on their primary stability: high (pISQ > 72), moderate, and low (pISQ < 68). Changes in stability after 4 months of loading were evaluated. The relationships between pISQ, insertion parameters, ΔISQ (ie, tISQ − pISQ), and marginal bone loss were analyzed. The Student t test, one-way analysis of variance, and Spearman nonparametric correlation coefficient were employed for statistical evaluation.* ***Results:*** *Of the 940 implants, tISQ was recorded in 526 implants and marginal bone loss was measured in 76 implants. There was no statistical relationship between pISQ and insertion torque. Primary stability was influenced by implant diameter but not by implant length. There was a significant relationship between implant insertion torque and bone type. The low primary stability group showed a significant increase in stability during healing. However, high primary stability implants demonstrated a significant reduction in their stability. The linear regression analysis demonstrated that at a pISQ of 69.2, tISQ value would equal pISQ value. Correlations between marginal bone loss and final insertion torque and between marginal bone loss and ΔISQ values were observed.* ***Conclusions:*** *Stability of immediately loaded implants with high pISQ decreased significantly during the initial 4 months of healing. However, stability of implants with low primary stability increased significantly. ΔISQ and insertion torque showed correlation with marginal bone loss.* Int J Oral Maxillofac Implants 2010;25:1085–1092

Key words: *alkali treatment, dental implants, immediate loading, implant stability, insertion torque, resonance frequency analysis*

Dental implant stability is a measure of the anchorage quality of an implant in the alveolar bone and is considered to be the consequential parameter in implant dentistry. Implant stability has been confirmed to affect the process of osseointegration, the pattern of implant loading, and, finally, the success of an implant.[1] Stability of an implant can be classified into that measured immediately after implantation (ie, primary stability) and that seen posthealing (ie, secondary stability). Primary implant stability has been proven to be a mechanical phenomenon.[2] On the other hand, secondary stability occurs through a cascade of biologic events, such as bone regeneration and remodeling at the bone-implant interface.[2] It is influenced by many factors, including implant surface topography, bone quality, and patient behavior.[3] Earlier investigation showed that during the healing process, mechanical anchorage of the implant in the bone weakens; conversely, biologic stability of the implant increases.[4]

[1]Associate Professor, Department of Dentistry, Charles University in Prague, Faculty of Medicine in Hradec Kralove, Czech Republic.
[2]Engineer, Lasak Ltd, Prague, Czech Republic.
[3]Assistant Professor, Department of Dentistry, Faculty of Medicine at Hradec Kralove, Charles University in Prague, Czech Republic.
[4]Student, Faculty of Medicine at Hradec Kralove, Charles University in Prague, Czech Republic.
[5]Assistant Professor, Department of Mechanical Engineering, Technical University of Liberec, Czech Republic.

Correspondence to: Dr Antonin Simunek, Department of Dentistry, Teaching Hospital, 500 05 Hradec Kralove, Czech Republic. Fax: +420-495-832-024. Email: simunek@email.cz

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

Several methods have been proposed to determine implant stability in clinical practice. Among these, resonance frequency analysis (RFA) has been found to be the most accurate.[5] Meredith et al introduced RFA into implant dentistry in the 1990s. Since then, it has become a widely accepted and used technique.[6] The only commercially available device based on RFA is Osstell (Integration Diagnostics). It has lately been modified and upgraded in the Osstell Mentor device. The function of this instrument is to measure resonance frequency, which is automatically transformed into an implant stability quotient (ISQ) ranging from 0 to 100.[5]

The absolute RFA values are not completely dependent on the quality of osseointegration. There are three important factors that can directly influence RFA: the stiffness of the implant-bone interface, the stiffness of the bone itself, and the stiffness of the implant components.[6–8] Consequently, the clinically measurable characteristic of implant stability can be compared in the follow-up of each individual implant, but caution should be exerted in comparing these values among different implants, either in the same patient or interindividually.[9]

Previous longitudinal studies have indicated that implant stability changes during the process of osseointegration. Typically, implant stability is anticipated to decrease during the early weeks of healing; this is followed by an increase in stability.[5,7,10] This is related to the biologic reaction of the bone to surgical trauma. During the initial bone remodeling phase, bone and necrotic material are resorbed by osteoclastic activity, which is reflected by a reduction in the ISQ value. This process is followed by new bone apposition initiated by osteoblastic activity, ie, adaptive bone remodeling around the implant.[3,11] There is a lack of agreement among investigators regarding the exact timing of the greatest decrease in postinsertion stability of an implant; the recorded data range between the third and eighth weeks following implant placement.[3,4,12–16] Some studies did not observe any decline in stability during the healing phase.[17,18] The reason for these differences in results may have to do with variations in the designs of the implants employed, especially variations in surface properties.[8,19] Time dependence of implant stability without the initial decline was observed in association with fast increases in bone-implant contact, which is typical for fluoride-treated or alkali-treated (and thus potentially bioactive) surfaces.[18,20] An accelerated formation of bone-to-implant contact contributes to a faster increase in secondary stability. This biologic process eliminates the decrease in primary stability and ensures consistency of stability over time (without the drop during the healing period).[18] There is a limited amount of documentation about the relationship between primary and secondary stability. Sennerby and Meredith[8] confirmed that implants of many types would, over time, approach a similar level of secondary stability. He also denoted that consistent attainment of an ISQ value of 65 to 75 seems to correspond to Brånemark implants and an ISQ value of 55 to 65 was seen for Straumann implants.[8]

Hence, it was the intent of this retrospective clinical study to further elucidate some aspects related to the stability of immediately loaded implants under relatively uniform clinical conditions in the interforaminal region of the mandible. The objectives of the present study were *(1)* to investigate how primary stability influences posthealing stability, *(2)* to determine the parameters that can affect primary stability of dental implants, and *(3)* to ascertain the effect of primary stability and insertion parameters on marginal bone loss.

MATERIALS AND METHODS

Surgical Procedure and Measurement of Implant Stability

In this study, consecutively placed implants in the interforaminal region of the mandible, which were designed for the immediate loading concept "Teeth in 6 Hours," were considered. This concept is based on the insertion of five implants in the region between the first premolars, which are then immediately loaded by a provisional cantilevered prosthesis fabricated from an existing mandibular removable complete denture and attached to the abutments by means of titanium impression copings. All surgical procedures were performed between October 2004 and January 2008 at The Center for Dental Implantology, University Hospital, Hradec Kralove, Czech Republic. The local ethical committee officially approved the design of this study. All the patients were informed about the nature of the study, and their participation and written consent were obtained according to the Helsinki Declaration of 1994.

All included patients needed a fixed full-arch prosthesis supported by dental implants for their edentulous mandible. Patients were included based upon a current stable medical condition and the ability to withstand the stress of dental implant surgery. Patients with metabolic bone disease, unstable systemic conditions (eg, uncontrolled diabetes or untreated hypothyroidism), and smokers of more than five cigarettes a day were excluded. All surgical procedures were performed under local anesthesia in a sterile hospital setting. Amoxicillin clavulanate (1 g orally twice per day) was prescribed for 6 days; an initial dose (2 g) was administered 1 hour before surgery. All implants were inserted into healed extraction

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

sockets. After a mucoperiosteal flap was raised, both mental nerves were isolated and the alveolar crest was contoured as required. Then five self-drilling, screw-form implants with sandblasted, acid-treated, and alkali-treated surfaces (STI-BIO-C, Lasak) were inserted at regular intervals into the interforaminal region according to the manufacturer's protocol. The final insertion torque of the implants was measured using a torque wrench. The type of bone was classified using Lekholm and Zarb criteria on the basis of the subjective evaluation of the surgeon.[21]

Primary stability (pISQ) of each implant was measured using an Osstell device. Two experienced surgeons conducted measurements independently. The transducer was secured at the implant level perpendicular to the long axis of the alveolar bone. Measurements were repeated until the same value was measured twice in succession, and this value was recorded. Following this, the abutments were attached and the wound was sutured. Tiaprofenic acid (300 mg) was recommended three times a day for pain relief. An abutment-level impression was immediately made with additional silicone material (Aquasil Rigid and Aquasil Ultra LV, Dentsply Caulk) with a modified preformed plastic impression tray. A cantilevered fixed screw-retained provisional prosthesis was fabricated that extended to the second premolars. The prosthesis was delivered and fully functionally loaded. Oral hygiene instructions were given and the patients were scheduled for regular recall appointments.

The impression for the definitive prosthesis was made after 4 months of healing. For those patients for whom an impression was made in September 2006 or later, the measurement with the Osstell device was repeated for each implant. The measured values were recorded and denoted as tISQ. After confirming passive fit of the construction and correcting the occlusion, a definitive cantilevered prosthesis that extended to both first molars was fabricated and delivered within 2 weeks after taking the impression. A digital panoramic radiograph (Planmeca ProMax) was obtained immediately after fixation of the definitive prosthesis according to the manufacturer's recommendation and was done by the same technician.

Measurement of Marginal Bone Loss

Marginal bone loss was determined at all implants at which the absolute value of the difference between pISQ and tISQ exceeded 5 units. The measurement of bone loss was conducted independently by the two surgeons on the patient's digital panoramic radiographs. On the radiograph, bone levels were measured from the implant-abutment interface to the first visible bone-implant contact. The implant-abutment interface was used as a reference point, because the implants were normally placed with the implant-abutment connection at the level of the alveolar crest (Fig 1). The distance between the thread peaks (1.0 mm) served as a known standard to calculate the exact bone loss on the mesial and distal sides of the implants. These measurements were rounded to the nearest 0.1 mm. With these data, the mean marginal bone resorption was determined for each implant. However, if the radiograph did not clearly reproduce the exact bone level, the implant was excluded from the cohort.

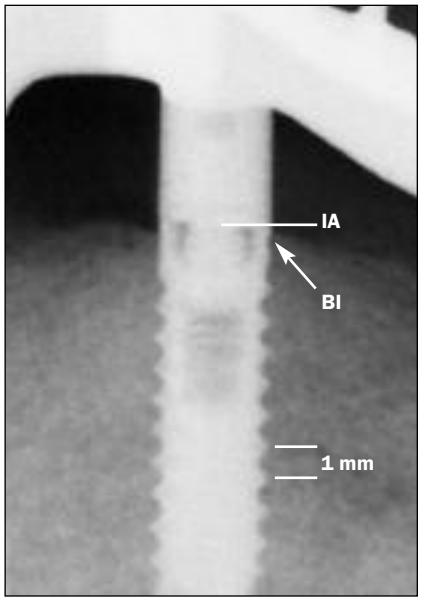

Fig 1 Method used to measure marginal bone level. First visible bone-implant contact (BI) was measured relative to the reference point at the implant-abutment interface (IA). The distance between the thread peaks is 1.0 mm and served as a known standard.

Statistical Analysis

The difference between posthealing stability (after 4 months of loading) and primary stability (tISQ – pISQ) was denoted as ΔISQ. The linear regression line, calculated from the plot of ΔISQ versus pISQ, was used to determine a pISQ value at which ΔISQ attains a value of zero. With respect to this value and to the unpublished results of a previous investigation, the implants were further divided into three study groups: those with low primary stability (pISQ < 68), those with moderate primary stability (pISQ 68 to72), and those with high primary stability (pISQ > 72). Statistical analysis was employed to verify the main working hypothesis that the immediately loaded implants with higher primary stability would lose some of their stability during healing, whereas the implants with lower primary stability would gain stability during healing.

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

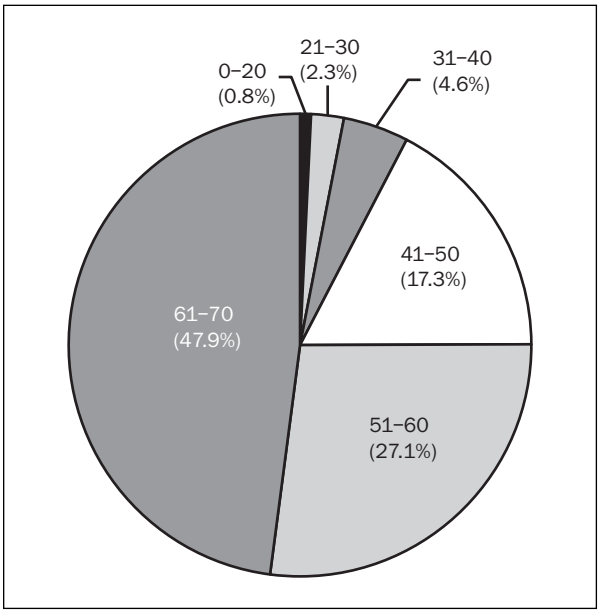

Fig 2 Final torque (Ncm).

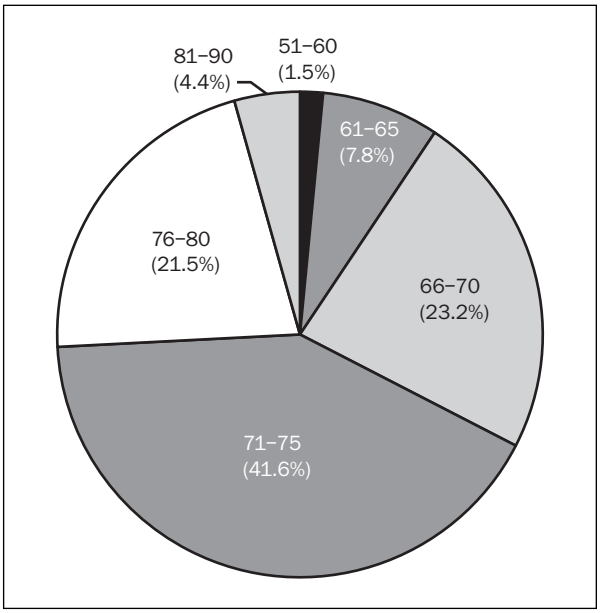

Fig 3 Primary stability (in ISQ) of the implants.

In addition, the dependence of marginal bone loss on pISQ, on final torque, and on ΔISQ was evaluated. Additional working hypotheses were that pISQ, similar to the final torque, is positively correlated with marginal bone loss, while ΔISQ is negatively correlated with marginal bone loss.

Statistical analysis was carried out using Statistica software (Statsoft Inc). The Student *t* test, one-way analysis of variance, and Spearman nonparametric correlation coefficient were employed to test the hypotheses. The statistical significance of all tests was defined as $P < .05$.

RESULTS

A total of 940 dental implants placed in 188 patients (84 men and 104 women; mean age 54.3 ± 9.4 years) was initially considered for this investigation. However, Osstell measurements showed an invalid Bode diagram for 22 implants, and these implants were therefore excluded from the cohort. Thus, the remaining 918 implants were considered for statistical analysis. The majority (97.2%) of implants were 3.7 mm in diameter, whereas only 2.8% of implants were 5.0 mm in diameter. A large majority of implants (82.2%) were 16 mm long; 9.3% were 14 mm long, 3.8% were 12 mm long, 3.8% were 18 mm long, and 0.9% were 10 mm long. With regard to bone type, 37.5% of implants were placed in type 1 bone, 40.4% were placed in type 2 bone, 21.8% were placed in type 3 bone, and 0.3% were placed in type 4 bone. Of the total number of implants placed, six implants (with pISQ 61 to 79) failed to osseointegrate (two implants in one patient and one implant each in four other patients). The osseointegration rate was therefore 99.3%.

The distribution of the final torque of implants is shown in Fig 2. The mean final insertion torque for the implants was 60.2 ± 12.0 Ncm (65.7 ± 7.2 Ncm for type 1 bone, 61.9 ± 10.3 Ncm for type 2 bone, 52.3 ± 14.6 Ncm for type 3 bone, and 30.0 ± 0.0 Ncm for type 4 bone). Statistical comparison of implant insertion torque versus bone type at the site of implantation showed a highly significant relationship ($P < .001$; between type 3 and type 4 bone, $P < .05$). No significant correlation between the final torque and implant diameter was found (61.4 ± 11.4 Ncm for 3.7-mm-diameter implants, 60.8 ± 11.9 Ncm for 5.0-mm-diameter implants).

Figure 3 shows the distribution of pISQ among the surveyed implants. The recorded mean pISQ value was 72.2 ± 5.0. The mean pISQ values for each bone type were of 72.4 ± 4.9 for type 1 bone, 71.8 ± 4.9 for type 2 bone, 72.7 ± 5.1 for type 3 bone, and 71.3 ± 2.5 for type 4 bone. There was no significant difference among groups, except for a marginally significant difference between type 2 and type 3 bone ($P = .03$). Furthermore, statistical analysis disproved the dependence of pISQ on implant length: mean values for pISQ were 70.8 ± 6.1, 73.4 ± 5.3, 72.0 ± 4.4, 72.2 ± 5.0, and 71.9 ± 4.6 for implants with lengths of 10, 12, 14, 16, and 18 mm, respectively. However, the primary stability of 5.0-mm-diameter implants was significantly higher than that of 3.7-mm-diameter implants (pISQ 75.1 ± 5.2 versus 72.1 ± 4.9, respectively;

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

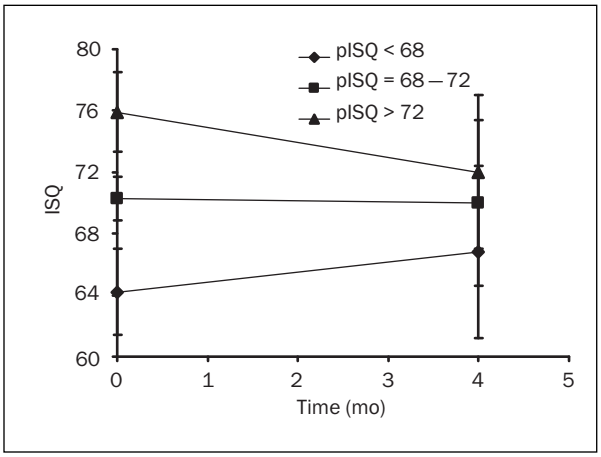

Fig 4 Implant stability over time according to the level of primary stability (see text). The decrease in ISQ for implants with high primary stability and the increase in ISQ for implants with low primary stability were highly significant ($P < .001$).

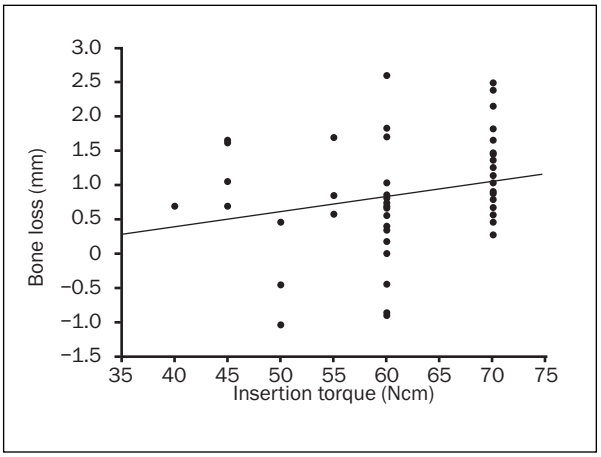

Fig 5 Marginal bone loss versus final insertion torque (R = 0.27; $P < .05$).

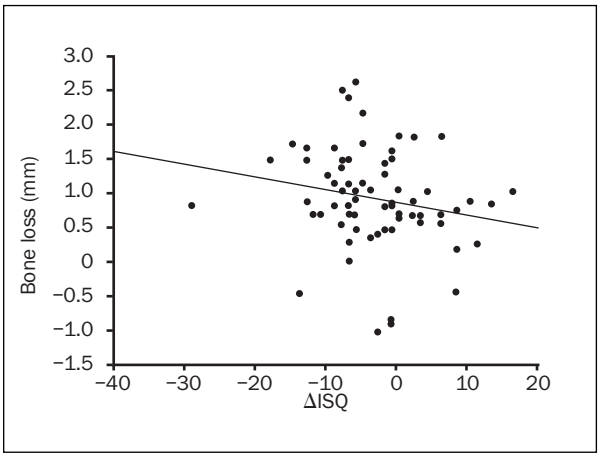

Fig 6 Marginal bone loss versus change in stability (ΔISQ) (R = −0.27; $P < .05$).

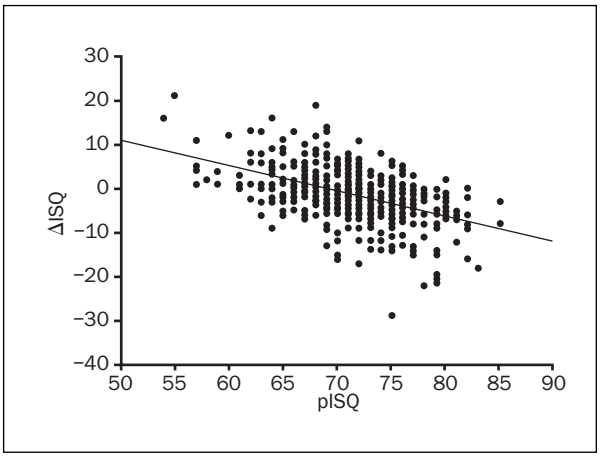

Fig 7 Change in stability (ΔISQ) versus primary stability (pISQ) (R = −0.47; $P < .01$). The regression curve indicates that ΔISQ attains zero value at a pISQ of 69.2.

$P < .01$). No significant correlation was found between pISQ and final torque (pISQ of 69.0 ± 5.9, 72.3 ± 3.7, 72.1 ± 5.1, 71.9 ± 4.9, and 72.5 ± 5.0 for a final torque of ≤ 15, 16 to 35, 36 to 45, 46 to 60, and ≥ 60 Ncm, respectively).

In this current study, the tISQ value was measured for 526 implants. Among these, 100 belonged to the low primary stability group, 189 to the moderate primary stability group, and 237 to the high primary stability group. An increase in stability was seen during the healing period in the low primary stability group (from 64.2 ± 2.8 ISQ to 66.8 ± 5.6; $P < .001$) (Fig 4). The moderate primary stability group did not exhibit any significant change in stability (from 70.3 ± 1.4 to 70.0 ± 5.4) (Fig 4). However, the high primary stability group showed a decrease in stability during the healing phase (from 75.9 ± 2.6 to 72.0 ± 5.0; $P < .001$) (Fig 4).

Marginal bone loss was measured for 76 implants and had a mean of 0.9 ± 0.7 mm (range, −1.0 to 2.6 mm). The values measured on the mesial side of the implant (0.9 ± 0.7 mm; range −0.9 to 2.9 mm) and on the distal side (0.9 ± 0.7 mm; range −1.1 to 2.9 mm) did not differ significantly.

A statistically significant relationship between primary stability and bone loss was not confirmed (Spearman nonparametric correlation coefficient, R = 0.07). However, a positive correlation was found between final torque and bone loss (R = 0.27; $P < .05$) (Fig 5). In addition, negative correlations were also found between ΔISQ and bone loss (R = −0.27; $P < .05$) (Fig 6) and between pISQ and ΔISQ (R = −0.47; $P < .01$) (Fig 7). Linear regression analysis indicated that ΔISQ attains a value of zero at a pISQ of 69.2 (Fig 7).

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

DISCUSSION

A 99.3% success rate of the implants confirmed that immediate loading of splinted implants in the interforaminal region is a viable treatment alternative. Primary stability of the failed implants did not differ significantly from that of implants that osseointegrated successfully. Measurement of RFA at the time of implant placement is therefore incapable of predicting implants with a prognosis of nonosseointegration, as described elsewhere.[22]

The topic of primary stability is currently the subject of intense scientific interest. Several authors have investigated the relationship between pISQ and other parameters, particularly the final insertion torque. Although a positive correlation between pISQ and insertion torque may initially seem probable, many authors have not found a significant relationship.[23–27] The results of the present study are in agreement with the aforementioned studies and do not support the sporadic findings of contradictory results.[28–31] However, it cannot be excluded that the discrepancies in the results were affected by the design of the implant or by local bone quality. As was also confirmed by the present study, primary stability is influenced mainly by implant diameter[30,32–36] and not by implant length.[7,30,36] This study demonstrated a highly significant relationship between final torque and bone type. However, no statistical relationship was found between final torque and implant diameter.

Several authors have studied the effect of primary stability on the development of stability during healing. The recent investigation by Karl et al assumed a general increase in stability during healing as a common phenomenon. This appears to be the somewhat confused view of the authors.[34] A few groups of authors have indicated that changes in stability during healing were mainly dependent on the initial stability level of an implant. In their 12-week clinical study, Nedir et al[22] found that ITI implants with a pISQ < 60 exhibited an increase in stability, whereas implants with a pISQ of 60 to 69 exhibited decreased stability after 8 weeks. At the end of the 12th week, the implants had returned to their initial stability values. Implants with pISQ values > 69 exhibited decreased stability during the first 4 weeks, after which they maintained consistent stability.[22] In a similar longitudinal study, West and Oates[37] employed the same type of implants and divided them into two groups (pISQ < 56 and pISQ > 56). During the first 16 weeks, implants from the first group continuously maintained a lower ISQ versus implants from the second group. Thereafter, differences were statistically insignificant. The stability of both groups remained at a value of 61 ISQ.[37] Similarly, in 1999, Friberg et al stated that the stability of implants placed in softer bone would "catch up" over time to implants placed in denser bone.[29] Balshi et al[3] and Olsson et al[38] came to the conclusion that implants with high primary stability lose part of their stability during healing, whereas implants with low primary stability have a tendency to increase their stability. The results of the present study support this theory. A significant increase in stability was recorded for the implants with low primary stability (pISQ < 68), whereas the implants with high primary stability (pISQ > 72) lost some of their stability over time. This confirms the main working hypothesis of the current investigation.

It could be further hypothesized that, in clinical practice, it may be optimal to achieve a primary stability that corresponds to the final stability value of the osseointegrated implant (ie, pISQ = tISQ; ΔISQ = 0). In this study, this pISQ value was determined by linear regression analysis to equal 69.2. This hypothetical value is probably not generally valid but is more likely specific to a particular implant system, surgical protocol, or bone type.[8]

An intraoral standardized radiograph is frequently used for exact measurements of the amount of marginal bone loss. However, unfavorable anatomical conditions frequently prevent the use of this radiographic technique in the interforaminal region of the mandible, especially in patients with an atrophied edentulous arch.[33] Consequently, panoramic radiography has been used in similar studies by other authors as an alternative.[33,39–41] In the present study, a noteworthy finding of bone gain was frequently encountered at 4 months after implant placement. Similar findings have been reported elsewhere.[42] An explanation may be found in the neck of the implant, which has a miniature thread and a chemically modified surface with signs of bioactivity. Functional stimulation of the bone by immediate loading may also play a role.[43,44]

Marginal bone loss was measured immediately after fixation of the definitive prosthesis, approximately 5 months after insertion of the implant. Bone loss could be caused by several factors, for example, surgical trauma, inadequate fit of the provisional restoration, or overloading of the implants. A detailed analysis, however, exceeds the scope of this study. The detected value of 0.9 ± 0.7 mm is acceptable.[45] No relationship was found in this study between primary stability and marginal bone loss; thus, the first of the three additional working hypotheses was not confirmed.

However, correlations were confirmed between final torque and bone loss and between ΔISQ and bone loss. Thus, the remaining two additional working hypotheses were supported. Taking the essence of these results and considering the fact that the final

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

insertion torque did not correlate to primary stability, it is possible to infer further that the use of extremely high insertion torque should be avoided. On the other hand, it is necessary to emphasize that the regression analysis indicated a weak dependence between the variables. Therefore it can be concluded that these relationships are affected by additional factors that were not examined in the analyses. The aforementioned analyses are pilot tests and require confirmation by other studies. The validity of the conclusions, therefore, is limited by the use of panoramic radiographs and by the selection of implants with a pronounced change in ISQ values during the healing period.

CONCLUSIONS

Within the limitations of the present study, it was seen that:

1. Primary stability was influenced by implant diameter and not by implant length. There was no significant relationship between primary stability and final insertion torque.
2. Implants with low primary stability showed a significant increase in stability, while implants with high primary stability showed a significantly decreased stability over time. On the basis of linear regression analysis, the change in implant stability quotient attains a value of zero at a primary implant stability quotient of 69.2.
3. A statistically insignificant relationship was found between primary stability and marginal bone loss. A positive correlation was confirmed between the final insertion torque and marginal bone loss. A negative correlation was confirmed between primary stability and change in stability during healing and between change in stability during healing and marginal bone loss.

REFERENCES

1. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont 1998;11:491–501.
2. Atsumi M, Park SH, Wang HL. Methods used to assess implant stability: Current status. Int J Oral Maxillofac Implants 2007;22: 743–754.
3. Balshi SF, Allen FD, Wolfinger GJ, Balshi TJ. A resonance frequency analysis assessment of maxillary and mandibular immediately loaded implants. Int J Oral Maxillofac Implants 2005;20:584–594.
4. Barewal RM, Oates TW, Meredith N, Cochran DL. Resonance frequency measurement of implant stability in vivo on implants with a sandblasted and acid-etched surface. Int J Oral Maxillofac Implants 2003;18:641–651.
5. 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.
6. 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.
7. Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP, Samson J. Implant stability measurement of delayed and immediately loaded implants during healing. A clinical resonance-frequency analysis study with sandblasted-and-etched ITI implants. Clin Oral Implants Res 2004;15:529–539.
8. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: Biological and biomechanical aspects and clinical implications. Periodontology 2000 2008; 47:51–66.
9. Lachmann S, Jäger B, Axmann D, Gomez-Roman G, Groten M, Weber B. Resonance frequency analysis and damping capacity assessment. Part 1: An in vitro study on measurement reliability and a method of comparison in the determination of primary dental implant stability. Clin Oral Implants Res 2006;17: 75–79.
10. Schliephake H, Hüls A, Müller M. Early loading of surface modified titanium implants in the posterior mandible: Preliminary results. Appl Osseointegration Res 2006;5:56–58.
11. Monov G, Fuerst G, Tepper G, Watzak G, Zechner W, Watzek G. The effect of platelet-rich plasma upon implant stability measured by resonance frequency analysis in the lower anterior mandibles. Clin Oral Implants Res 2005;16:461–465.
12. Ersanli S, Karabuda C, Beck F, Leblebicioglu B. Resonance frequency analysis of one-stage dental implant stability during the osseointegration period. J Periodontol 2005;76:1066–1071.
13. 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.
14. Glauser R, Ruhstaller P, Windisch S, et al. Immediate occlusal loading of Brånemark system TiUnite implants placed predominantly in soft bone: 4-year results of a prospective clinical study. Clin Implant Dent Relat Res 2005;7(suppl 1):52–59.
15. Lai HC, Zhang ZY, Wang F, Zhuang LF, Liu X. Resonance frequency analysis of stability on ITI implants with osteotome sinus floor elevation technique without grafting: A 5-month prospective study. Clin Oral Implants Res 2008;19:469–475.
16. Verdonck HWD, Meijer GJ, Laurin T, et al. Implant stability during osseointegration in irradiated and non-irradiated minipig alveolar bone: An experimental study. Clin Oral Implants Res 2008;19:201–206.
17. Calandriello R, Tomatis M. Immediate function of single implant using Brånemark system: Prospective one-year report of final restorations. Appl Osseointegration Res 2004;4:32–40.
18. Strnad J, Urban K, Povysil C, Strnad Z. Secondary stability assessment of titanium implants with an alkali-etched surface: A resonance frequency analysis study in beagle dogs. Int J Oral Maxillofac Implants 2008;23:502–512.
19. Oates TW, Valderrama P, Bischof M, et al. Enhanced implant stability with a chemically modified SLA surface: A randomized pilot study. Int J Oral Maxillofac Implants 2007;22:755–760.
20. Ellingsen JE, Johansson CB, Wennerberg A, Holmén A. Improved retention and bone-to-implant contact with fluoride-modified titanium implants. Int J Oral Maxillofac Implants 2004;19:659–666.

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

21. Lekholm U, Zarb G. Patient selection and preparation. In: Brånemark P-I, Zarb G, Albrektsson T (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:199–209.
22. Nedir R, Bischof M, Szmukler-Moncler S, Bernard JP, Samson J. Predicting osseointegration by mean of implant primary stability. A resonance-frequency analysis study with delayed and immediately loaded ITI SLA implants. Clin Oral Implants Res 2004;15:520–528.
23. Akca K, Akkocaoglu M, Commert A, Tekdemir I. Human ex vivo bone tissue strains around immediately loaded implants supporting maxillary overdentures. Clin Oral Implants Res 2005; 16:715–722.
24. da Cunha HA, Francischone CE, Filho HN, de Oliveira RCG. A comparison between cutting torque and resonance frequency in the assessment of primary stability and final torque capacity of standard and TiUnite single-tooth implants under immediate loading. Int J Oral Maxillofac Implants 2004;19:578–585.
25. Ito Y, Sato D, Yoneda S, Ito D, Kondo H, Kasugai S. Relevance of resonance frequency analysis to evaluate dental implants stability: Simulation and histomorphometrical animal experiments. Clin Oral Implants Res 2008;19:9–14.
26. Nkenke E, Michael H, Konstanze W, Martin R, Friedrich W, Klaus E. Implant stability and histomorphometry: A correlation study in human cadavers using stepped cylinder implants. Clin Oral Implants Res 14;2003:601–609.
27. Rabel A, Kohler SG, Schmidt-Westhausen AM. Clinical study on the primary stability of two dental implant systems with resonance frequency analysis. Clin Oral Investig 2007;11:257–265.
28. Friberg B, Sennerby L, Gröndahl K, Bergstrom C, Back T, Lekholm U. On measurements during implant placement: A 3-year clinical prospective study. Clin Implant Dent Relat Res 1999;1:75–83.
29. Friberg B, Sennerby L, Meredith N, Lekholm U. A comparison between placement torque and resonance frequency measurements of maxillary implants. A 20-month clinical study. Int J Oral Maxillofac Surg 1999;28:297–303.
30. Horwitz J, Zuabi O, Peled M. Resonance frequency analysis in immediate loading of dental implants [in Hebrew]. Refuat-Hapeh-Vehashinayim 2003;20:80–88.
31. Turkyilmaz I, Tozum TF, Tumer C, Ozbek EN. Assessment of correlation between computerized tomography values of the bone, and maximum torque and resonance frequency values at dental implant placement. J Oral Rehabil 2006;33:881–888.
32. Himmlová L, Dostálová T, Kácovský A, Konvicˇková S. Influence of implant length and diameter on stress distribution: A finite element analysis. J Prosthet Dent 2004;91:20–25.
33. Kessler-Liechti G, Zix J, Mericske-Stern R. Stability measurements of 1-stage implants in the edentulous mandible by means of resonance frequency analysis. Int J Oral Maxillofac Implants 2008;23:353–358.
34. Karl M, Graef F, Heckmann S, Krafft T. Parameters of resonance frequency measurement values: A retrospective study of 385 ITI dental implants. Clin Oral Implants Res 2008;19:214–218.
35. Zix J, Kessler-Liechti G, Mericske-Stern R. Stability measurements of 1-stage implants in the maxilla by means of resonance frequency analysis: A pilot study. Int J Oral Maxillofac Implants 2005;20:747–752.
36. Zix J, Hug S, Kessler-Liechti G, Mericske-Stern G. Measurement of dental implant stability by resonance frequency analysis and damping capacity assessment: Comparison of both techniques in a clinical trial. Int J Oral Maxillofac Implants 2008;23: 525–530.
37. West JD, Oates TW. Identification of stability changes for immediately placed dental implants. Int J Oral Maxillofac Implants 2007;22:623–630.
38. Olsson M, Urde G, Anderson JB, Sennerby L. Early loading of maxillary fixed cross-arch dental prostheses supported by six or eight oxidized titanium implants: Results after 1 year of loading, case series. Clin Implant Dent Relat Res 2003;5(suppl 1):81–85.
39. Kahnberg KE, Vannas-Löfqvist L. Sinus lift procedure using a 2-stage surgical technique: I. Clinical and radiographic report up to 5 years. Int J Oral Maxillofac Implants 2008;23:876–884.
40. Marchetti C, Pieri F, Corinaldesi G, Degidi M. A long-term retrospective study of two different implant surfaces placed after reconstruction of the severely resorbed maxilla using Le Fort I osteotomy and interpositional bone grafting. Int J Oral Maxillofac Implants 2008;23:911–918.
41. Nickenig HJ, Wichmann M, Schlegel KA, Nkenke E, Eitner S. Radiographic evaluation of marginal bone levels adjacent to parallel-screw cylinder machined-neck implants and rough-surfaced microthreaded implants using digitized panoramic radiographs. Clin Oral Implants Res 2009;20:550–554.
42. Botticelli D, Renzi A, Lindhe J, Berglundh T. Implants in fresh extraction sockets: A prospective 5-year follow-up clinical study. Clin Oral Implants Res 2008;19:1226–1232.
43. Hansson S. The dental implant meets bone—A clash of two paradigms. Appl Osseointegration Res 2006;5:5–17.
44. Protivinsky J, Appleford M, Strnad J, Helebrant A, Ong JL. Effect of chemically modified titanium surfaces on protein adsorption and osteoblast precursor cell behavior. Int J Oral Maxillofac Implants 2007;22:542–550.
45. Albrektsson T, Zarb G, Worthtington P. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.

© 2010 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART OF THIS ARTICLE MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.