Development of Implant Stability During Early Healing of Immediately Loaded Implants

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Purpose: To monitor the development of stability of immediately loaded implants during early healing. **Materials and Methods:** A total of 90 interforaminally placed implants with an alkali-treated surface were considered. The stability of each implant was examined at placement and 1, 2, 3, 4, 5, 6, 8, and 10 weeks after the surgery using resonance frequency analysis (RFA) and damping capacity measurement. The development of implant stability, focusing on the decrease in stability (as measured by implant stability quotient [ISQ]) and the interplay of primary (ISQ0) and secondary implant stability, was evaluated. The implants were divided into three groups based on primary stability: group L (ISQ0 < 68), group M (ISQ0 68 to72), and group H (ISQ0 > 72). Stability curves for each group were created and analyzed statistically. Implant stability measurement results gained with RFA and damping capacity were compared employing the Wilcoxon paired test, correlation coefficients, and regression analysis. The threshold for statistical significance was set at P < .05. **Results:** The most pronounced decrease in ISQ values occurred 1 week after implant placement (mean decrease of 2.2 ISQ). During the 10-week experiment, mean ISQ rose by 5.5 in group L and by 1.3 in group M and dropped by 1.8 in group H (P < .001). The coefficient of determination $R^2 = 0.06$ showed a weak dependence of RFA on the damping capacity (P < .001). **Conclusions:** Implants with low primary stability showed a significant increase in stability during healing. In contrast, implants with high primary stability lost some stability over time. Int J Oral Maxillofac Implants 2012;27:619–627.

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

Implant stability is considered one of the most important parameters in implant dentistry. It affects the healing and successful osseointegration of implants. Its importance is further increased when employing modern treatment protocols, ie, accelerated treatments such as immediate loading.

Implant stability (total stability) is usually divided into two stages: primary stability (implant stability reached during implant placement) and secondary stability (implant stability after healing). Primary implant stability has been proven to be a mechanical phenomenon, whereas secondary stability is a result of biologic events (osseointegration).[1] The proportion of biologic and mechanical components varies during the healing period. At the time of implant placement, implant stability is based solely on the mechanical component. During the healing period, mechanical stability decreases, whereas biologic stability increases.[2] Finally, for an osseointegrated implant, stability relies entirely on the biologic component. This implies that an implant that has been loaded after a healing period resists masticatory forces by means of biologic stability, whereas an immediately loaded implant is immobile immediately after insertion only as a result of mechanical stability.

According to conventional opinions, overall implant stability increases during the healing process.[2,3] However, this appears to be a rather simplified view of the complex healing process.[4] More precisely, implant stability increases during healing only in implants with low primary stability, whereas in implants with high primary stability, a decrease in stability is observed.[4] Therefore, the primary stability affects the development of stability during the healing process.[4] However, this pattern of implant stability development was

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demonstrated with a delayed-loading protocol.[2,3] For immediately loaded implants, the stability curve may follow a different course as a result of the functional loading of implants during the healing period.[5] There is a need for larger studies to confirm this finding.[6,7]

Several methods have been proposed to determine implant stability noninvasively in clinical practice, but only two of them—measurement of the damping capacity and resonance frequency analysis (RFA)—have been considered sufficiently valid.[8,9] The only commercially available device utilizing damping capacity measurement is the Periotest device (Siemens). The determination of implant stability with this device is determined by tapping on a rod abutment and recording its contact time, which is considered to be a function of implant mobility. The result is displayed using numeric values ranging from –8 to +50, referred to as Periotest values (PTVs). The lower the value, the greater the stability.

The most reliable noninvasive method to measure implant stability is RFA. This method was introduced by Meredith et al in 1996.[10] The RFA principle is predominantly used in devices of the Osstell series, with the wireless Osstell being its most recent modification. A magnet on an aluminum metal rod (SmartPeg) is screwed into the implant. After it receives a signal from the device, vibrations in two perpendicular directions are produced. Because the resonance frequency is directional, the highest and the lowest values are presented simultaneously. If the numeric difference between the values is greater than three units, both values are displayed.[2] Higher resonance frequencies correspond to higher implant stability. The resonance frequencies are transformed into implant stability quotients (ISQs), which range from 0 to 100.

Numerous studies have investigated the development of implant stability during the healing period. Some have recorded implant stability only at placement and compared it with the stability obtained after healing is complete.[11] However, this does not provide an accurate record of how implant stability is established. Longitudinal monitoring of implant stability has provided data indicating that implant stability is not established in a linear fashion. In the case of a slow increase in biologic stability and a rapid decrease in mechanical stability, a transient decrease in overall stability during healing occurs. This phenomenon has been termed a "dip" (or "drop" or "gap") in stability.[12,13] In principle, it is caused by the loss of mechanical stability when not sufficiently compensated by the growing biologic stability.

The existence and pattern of the stability dip are probably influenced by a variety of factors, such as the quality of bone, final insertion torque, and implant design, especially its surface. In some studies, no dip was reported, while other studies have reported differences in its timing, duration, and depth.[2,5,6–8,12–18] Understanding this issue is crucial for accelerated loading protocols.

The aims of the present prospective clinical study were, in light of previous research,[4] (1) to monitor the development of implant stability in immediately loaded implants during the initial healing period, (2) to investigate how primary stability affects stability post-healing, (3) to compare measurements of implant stability obtained with RFA and damping capacity, and (4) to determine mutual relationships between selected insertion parameters (type of bone, final insertion torque, and primary stability). The experiment was conducted using implants with an alkali-treated surface, a surface that shows signs of bioactivity.

MATERIALS AND METHODS

Eighteen Caucasian subjects (7 women and 11 men; mean age 57.2 ± 9.7 years) requesting an implant-supported fixed full-arch denture in the mandible were enrolled in the study. No dropouts were observed. Between October 2009 and June 2010, 90 implants were consecutively placed according to the "Teeth in 6 Hours" concept. This concept is based on the insertion of five implants in the interforaminal area of the mandible, 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.[4] All procedures were performed at the Department of Dental Implantology, University Hospital in Hradec Kralove, Czech Republic. The local ethics committee officially approved the design of this study. All patients were informed about the nature of the study and their participation, and written consent according to the Helsinki Declaration of 1994 was granted by every participant.

The inclusion criteria were based upon the patient's current stable medical condition and the ability to withstand the stress of a dental implant surgery. Patients with metabolic bone disease, unstable systemic conditions such as uncontrolled diabetes or untreated hypothyroidism, and those who smoked more than five cigarettes a day were not included.

Surgical Procedure

All surgical procedures were performed under local anesthesia in an outpatient setting by the same surgeon (AS). 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 placed in healed extraction sockets at least 6 months

after extraction. After a mucoperiosteal flap was raised, both mental nerves were identified and the alveolar crest was contoured as required. Then five self-tapping, screw-form implants with a sandblasted and acid- and alkali-treated surface (Bio, Impladent Straight STI-BIO-C, Lasak Ltd) were inserted at regular intervals into the interforaminal region according to the manufacturer's protocol. All implants were 3.7 mm in diameter and 16 mm in length. The final drill diameter was 3.0 mm; a tap was not used. The final torque of the implants was measured using a torque wrench (torque control device, Lasak Ltd). The bone type was classified using Lekholm and Zarb standards based on the subjective evaluation of the surgeon.

A 4-mm-high abutment for screw-retained prostheses was attached to every implant and was tightened to 35 Ncm using a torque wrench. The wounds were then sutured. Tiaprofenic acid (300 mg) was recommended three times a day for pain relief. An abutment-level impression was taken immediately using a polyaddition type of silicone impression material in a modified preformed plastic impression tray. A fixed screw-retained provisional prosthesis that extended to the second premolars was fabricated. The prosthesis was delivered and functionally loaded within 6 hours. Oral hygiene instructions were given and the patients were scheduled for regular follow-up visits.

Implant success criteria consisted of (1) no clinically detectable implant mobility, (2) no pain or any subjective sensation, (3) no recurrent peri-implant infection, and (4) no progressive peri-implant bone loss.

Measurement of Implant Stability and Marginal Bone Loss

The stability of each implant was measured at baseline and 1, 2, 3, 4, 5, 6, 8, and 10 weeks after the surgery using the Osstell and Periotest devices. All measurements were performed by an experienced surgeon (TB).

At each follow-up visit, the Osstell device was used initially. The provisional prosthesis and abutments were removed and the SmartPeg was screwed to each implant and tightened to approximately 5 Ncm. The transducer probe was aimed at the small magnet on top of the SmartPeg at a distance of 2 to 3 mm and held stable during the pulsing time until the instrument beeped and displayed the ISQ value. If two ISQ values were displayed simultaneously, their mean value was recorded. Measurements were taken twice in the buccolingual direction as well as in the mesiodistal direction. The mean of all measurements was rounded to the nearest whole number and was regarded as representative of the ISQ. The abutments were then screwed back on the implants and tightened to 35 Ncm; thereafter, measurements using the Periotest device were performed. The stylus was positioned perpendicular to the abutment in a buccolingual direction as apically as possible. Measurements were repeated until the same value was obtained twice in succession. This value was recorded. Then the provisional prosthesis was reinserted.

Values acquired at baseline (ISQ0 for RFA and PTV0 for damping capacity) corresponded to primary stability. Values obtained at the follow-up visits were marked by the relevant week of the measurement (ie, ISQ1 to ISQ10 and PTV1 to PTV10). A digital panoramic radiograph was obtained according to the user's manual and by the same technician after the last measurement, ie, 10 weeks postplacement. Progressive peri-implant bone loss was defined as a mean of the mesial and distal bone loss exceeding 1 mm at 10 weeks after the surgery; it was measured independently by two surgeons (AS, DK). On the radiograph, bone resorption was measured from the implant-abutment interface to the first visible bone-to-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. The distance between the peaks of the threads (1.0 mm) served as a known standard to compensate for any radiographic distortion.

Statistical Analysis

Statistical analysis was carried out using Statistica software. The Wilcoxon paired test, correlation coefficients, and regression analysis were employed. The statistical significance of all tests was defined as $P < .05$. A dip in stability was defined as a significant drop in implant stability in one or several consecutive weeks, followed by a significant increase.

Statistical analysis of the entire cohort of implants was accomplished and the development of stability (as compared with ISQ0) was evaluated. For this purpose, the implants were divided into three groups: those with low primary stability (ISQ0 < 68, group L); those with moderate primary stability (ISQ0 68 to72, group M); and those with high primary stability (ISQ0 > 72, group H). Stability curves were created for each group and evaluated statistically.

RESULTS

One implant (1.1%) was removed after 8 weeks because of mobility. Ten weeks postplacement, all remaining implants were classified as successful. With regard to bone type, 33.3% of implants were placed in type 1 bone, 45.6% were placed in type 2 bone, and 21.1% were placed in type 3 bone. The mean (± standard deviation [SD]) final insertion torque was 61.3 ± 11.5 Ncm (6 implants with 31 to 40 Ncm, 12 implants with 41 to 50 Ncm,
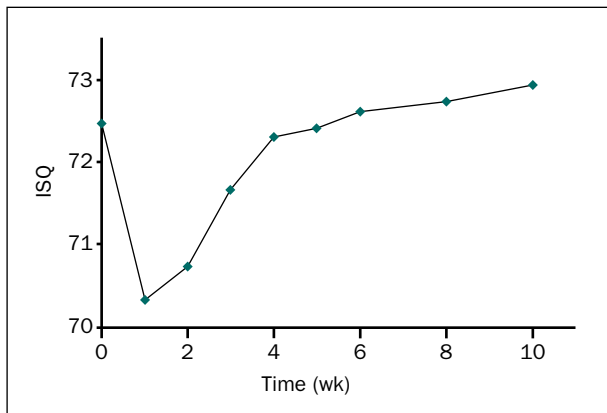
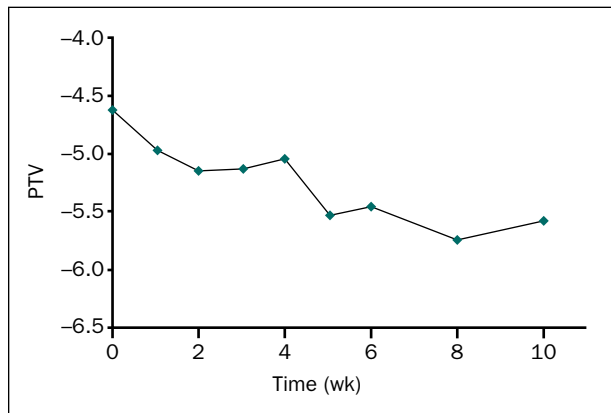Fig 1 Mean ISQ values during the study period.

Fig 2 Mean PTVs during the study period.

Table 1	Mean ISQs and PTVs (± SDs) During the Study Period								
	Time (wk)								
Value	0	1	2	3	4	5	6	8	10
ISQ	72.5 ± 5.5	70.3 ± 6.2	70.7 ± 5.8	71.7 ± 5.4	72.3 ± 4.9	72.4 ± 4.4	72.6 ± 4.1	72.7 ± 3.6	72.9 ± 3.1
PTV	−4.6 ± 1.3	−5.0 ± 1.1	−5.1 ± 1.3	−5.1 ± 1.5	−5.0 ± 1.3	−5.5 ± 1.6	−5.4 ± 1.2	−5.7 ± 1.1	−5.6 ± 1.1

26 implants with 51 to 60 Ncm, 33 implants with 61 to 70 Ncm, and 13 implants with 71 to 80 Ncm). The mean (± SD) primary stability, as measured with RFA, was 72.5 ± 5.5 ISQ (2 implants with 51 to 60 ISQ, 6 implants with 61 to 65 ISQ, 25 implants with 66 to 70 ISQ, 31 implants with 71 to 75 ISQ, 19 implants with 76 to 80 ISQ, and 7 implants with 81 to 85 ISQ). The mean primary stability (± SD) as measured via damping capacity was −4.6 ± 1.3 PTV (1 implant with 0 to −1 PTV, 14 implants with −2 to −3 PTV, 51 implants with −4 to −5 PTV, and 24 implants with −6 to −7 PTV). A correlation between the final insertion torque and bone type was confirmed ($r = -0.63$, $P < .001$). A correlation between bone type and ISQ0 was not confirmed ($r = -0.07$, $P > .05$), and there was no correlation between final insertion torque and ISQ0 ($r = 0.02$, $P > .05$). On the other hand, correlations between bone type and PTV0 ($r = 0.43$, $P < .001$) and between final insertion torque and PTV0 ($r = -0.40$, $P < .001$) were confirmed.

Stability curves created from the ISQs and PTVs are presented in Figs 1 and 2, and stability values are presented in Table 1. While a dip in stability was not detected by damping capacity, it was obvious and statistically significant as measured with RFA. The most pronounced dip in ISQs occurred 1 week after implant placement, with a mean decrease of 2.2 (range, −7 to +4, $P < .001$). The ISQs rose significantly every week until the fourth week ($P < .001$, $P < .05$, $P < .001$, and $P < .001$, respectively). The closest value to ISQ0 was reached at 5 weeks postplacement, and the ISQs then rose continuously but insignificantly until the end of the experiment. While ISQ10 was not significantly different from ISQ0, PTV10 was significantly lower than PTV0 (mean difference, 0.96 PTV, $P < .001$).

The coefficient of determination describing the dependence of ISQ on PTV values was $R^2 = 0.06$ ($P < .001$). Thus, the strength of this relationship was rather low, but it remained statistically significant (Fig 3).

A multiple regression model was used in which ISQ10 was a dependent variable and ISQ0, density, and torque were independent variables ($R^2 = 0.637$). According to this analysis, only ISQ10 was dependent on ISQ0 ($P < .001$), while ISQ0 was not related to density or torque ($P > .05$).

Fifteen implants were included in group L, 29 implants in group M, and 46 implants in group H. Stability curves for each of these groups are shown in Fig 4, and the respective stability values are shown in Table 2. The stability dip was most significant at 1 week postplacement in all groups, when it reached 3.5 ISQ in group L, 1.8 ISQ in group M, and 2.0 ISQ in group H ($P < .001$). The stability dip was greater in group L than in groups M and H ($P < .01$). During the 10-week experiment, implant stability rose by 5.5 ISQ in group L and by
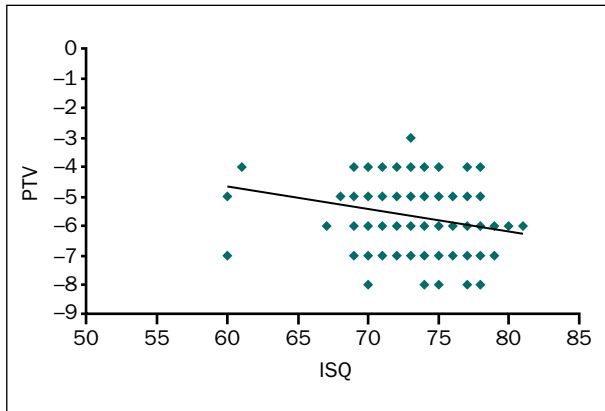
Fig 3 Regression of ISQs on PTVs. The correlation was weak ($R^2 = 0.06$) but significant ($P < .001$).
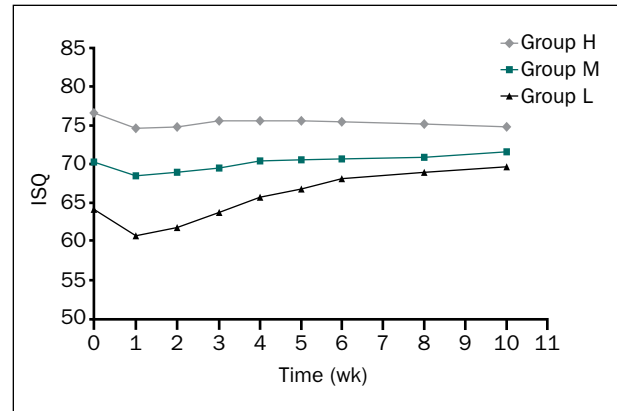

Fig 4 Development of implant stability (in ISQ) in relation to primary stability. Group H: ISQ0 > 72; group M: ISQ0 68 to 72; group L: ISQ0 < 68.

Table 2	Mean ISQs (± SDs) in Each Group During the Study Period								
	Time (wk)								
Group	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**
Group H	76.6 ± 3.1	74.7 ± 3.5	74.8 ± 3.1	75.6 ± 3.0	75.7 ± 2.6	75.5 ± 2.3	75.4 ± 2.3	75.2 ± 2.6	74.8 ± 2.7
Group M	70.2 ± 1.5	68.4 ± 2.7	68.9 ± 2.9	69.6 ± 2.5	70.3 ± 3.0	70.4 ± 3.2	70.6 ± 3.3	70.8 ± 2.5	71.5 ± 1.3
Group L	64.1 ± 3.8	60.7 ± 4.3	61.7 ± 4.5	63.7 ± 4.2	65.6 ± 4.3	66.7 ± 3.5	68.0 ± 3.5	68.9 ± 2.9	69.7 ± 2.8

Fig 5 Development of stability in a failed implant, which was removed 8 weeks post-placement.
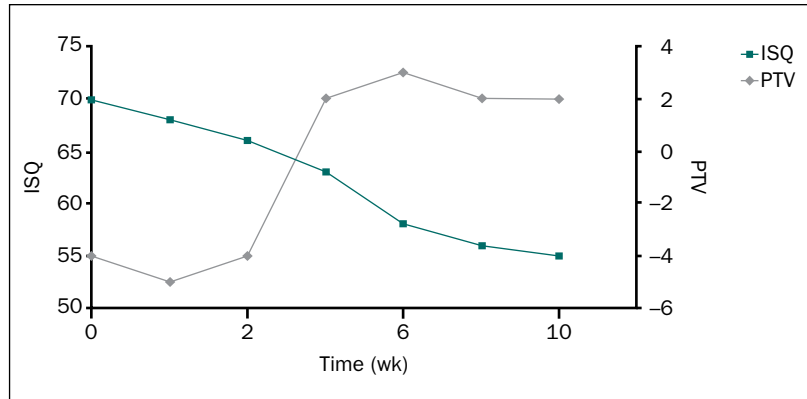
1.3 ISQ in group M and dropped by 1.8 ISQ in group H ($P < .001$). Differences between the three groups were highly significant ($P < .001$).

The progression of ISQs and PTVs in the only failed implant is shown in Fig 5. The implant was inserted in type 3 bone with an insertion torque of 60 Ncm. During the first 6 weeks after placement, this implant did not show any signs of failure and all performed measurements were free of pain. However, 8 weeks after placement it was not possible to remove the abutment without causing pain, and the implant was removed from its bone bed, with the site anesthetized locally.

DISCUSSION

The present study was designed to accomplish, as much as possible, standardized experimental conditions. The implants were inserted in the interforaminal area of the mandible, where compact bone prevails. All implants featured the same length, diameter, and surface properties.

In the present study, high values for insertion torque were achieved as a result of the bone quality in the anterior mandible, the implant design, and the omission of tapping. A high final insertion torque may be useful

for immediate implant loading[17] and can contribute to safe manipulation with the implant during the healing period. Insertion torque can be measured easily and is considered to be an indirect indicator of primary implant stability.[19] However, the present study observed a correlation of insertion torque with PTV only; a correlation between final insertion torque and ISQ could not be confirmed.

Any dip in implant stability has fundamental clinical importance for immediately loaded implants. If the stability decreases below a critical level during the healing process, a functionally loaded implant cannot withstand masticatory forces, becomes mobile, and fails. There is a considerable lack of agreement regarding the parameters of the dip in postinsertion stability. Studies that have demonstrated this dip in stability have usually observed it between the second and eighth weeks following implant placement.[5,13–15,20–24] The maximum stability drop was detected during the third or fourth week postplacement[13–15,20,21] and ranged from 2 to 12 ISQs below the baseline ISQ.[5,13]

However, some studies did not observe this decrease in stability.[6,25] These differences in results may be related to variations in the design of implants employed, especially variations in surface properties.[24,26,27] A time dependence of implant stability, without the initial decline, has been observed in association with rapid increases in bone-implant contact. This feature is typical for fluoride-treated or alkali-treated, ie, potentially bioactive, surfaces.[25,28] Accelerated formation of bone-to-implant contact contributes to a faster increase in biologic stability. This biologic process compensates for any decrease of mechanical stability and ensures consistency in stability over time, without the drop during the healing period.[25] Geckili et al measured the stability of titanium grit–blasted dental implants with and without fluoride treatment longitudinally in a comparative study.[12] Implants were inserted interforaminally in the mandible and were followed for 24 weeks. Implants without fluoride treatment showed a statistically significant drop in ISQ (mean, 4.9 units) in the first 2 weeks after implant placement. This change was statistically insignificant in the second group of implants, suggesting that fluoride modification of the implant surfaces may enhance the osseointegration process.[12] Similar trends were observed with fluoride-treated implants in other studies.[2]

The results are ambivalent for the widely used SLA (sandblasted, large-grit, acid-etched; Straumann) and SLActive surfaces, despite the unquestionably positive effect of both surfaces on osseointegration.[29] Sim and Lang detected a continuous increase in ISQs without signs of a dip in implants with an SLA surface during a 12-week period after implant placement.[2] Valderrama et al came to similar conclusions.[18] On the other hand, Schätzle et al detected a dip in stability in palatal implants with SLA and SLActive surfaces.[29] However, features of the stability curve were different for both surfaces, suggesting a tendency for the SLActive surface to contribute to a decreased healing time. Han et al also detected a period of reduced stability, but without any difference between SLA and SLActive surfaces.[16] ISQs decreased by 3 to 4 units during healing and reached the lowest values in the third week. Following this, the ISQs increased steadily up to the 12th week. Lai et al detected a dip in stability between weeks 2 and 6 for implants with the SLA surface.[13] Depression of the curve was significant and reached 12 ISQs.

The results of some studies were very difficult to interpret, and several authors therefore consider RFA to be a controversial method.[30] Abrahamsson et al detected neither a dip in stability nor a significant difference in development of ISQs between implants with the SLA surface and implants with a turned surface during a 12-week experiment in Labrador dogs, although the degree of bone-to-implant contact was significantly higher at the SLA surface.[8]

The present study confirmed a dip in stability between the first and fourth week postplacement. The ISQs did not change significantly after the fifth week. On average, the maximum dip was only 2.2 ISQ. Comparison with the aforementioned studies indicates that depression of the curve was relatively shallow and subsided rapidly. This could be explained by the alkali-treated surface Bio, which is potentially bioactive.[25] The three-dimensional macro-, micro-, and nanostructured Bio surface may significantly enhance the surface reactivity with the surrounding ions, amino acids, and proteins, which modulate the initial cellular events at the cell-implant interface.[25] In addition, the wettable, hydrophilic Bio surface enhances the establishment of good contact between the blood clot and the implant. It rapidly induces adsorption of calcium and phosphate ions on contact with the ions of the blood plasma.[25] This mechanism can accelerate the formation of a stable bone-implant interface.[25] Hence, it can be hypothesized that the dip in stability was minimized by the effect of the highly textured and hydrophilic Bio surface, which accelerated the acquisition of biologic stability.[25,31]

The parameters of the dip can be influenced by factors other than surface properties and implant macrodesign as well, eg, timing of functional loading or bone type.[20] Zhou et al compared immediately loaded with delayed loaded SLA implants and discovered that the ISQs for immediately loaded implants were significantly higher. The maximum stability dip was reached at 2 weeks postsurgery, while in delayed loaded implants this dip was observed 2 weeks later.[5] Implants in types 1 and 2 bone showed higher implant stability than implants inserted into type 3 bone.[5]

In the present study, the anatomical conditions were uniform, distinguishing this study from most other studies.[13,15,21–24] Implants were inserted only in the anterior mandible and loaded immediately. Functional loading could have promoted bone formation and maturation around the implants, making the surrounding bone stronger.[20] All these factors may have influenced the unusual timing of the stability dip.

Several authors have studied the effect of primary implant stability on the development of overall stability during healing. It was demonstrated that stability changes are mainly dependent on primary implant stability.[2] In a 12-week clinical study, Nedir et al found that ITI implants with ISQ0 < 60 exhibited a stability increase, whereas implants with ISQ0 between 60 and 69 exhibited decreased stability after 8 weeks.[7] The implants returned to their initial stability values at the end of the 12-week period. Implants with ISQ0 > 69 exhibited decreased stability during the first 4 weeks, after which they maintained stability. In a similar longitudinal study, West and Oates employed the same type of implants and divided them into two groups (ISQ0 < 56 and ISQ0 > 56).[32] During the first 16 weeks, implants in the first group maintained a lower ISQ than the implants in the second group. Thereafter, the differences were statistically insignificant; both groups maintained a value of 61 ISQ. Similarly, Friberg et al stated that the stability of implants placed in softer bone would "catch up" over time with implants placed in denser bone.[19] A study conducted by Simunek et al showed a significant increase in stability for implants with low primary stability (ISQ0 < 68), while high-primary-stability (ISQ0 > 72) implants lost some stability over time.[4] Balshi et al came to the same conclusions.[20] Limiting values of ISQ 68 and 72 were chosen with consideration of the results of a previous investigation of the same research group. This research revealed that, within an ISQ range of 68 to 72, stability alterations during the healing period are minimal.

The present study confirmed most previously published results. When ISQ0 and ISQ10 values were compared, group L, with the lowest primary stability, presented a significant increase in ISQs (average increase of 5.5 ISQ, $P < .001$). On the other hand, group H implants, with high primary stability, demonstrated a significant drop in stability (on average, 1.8 ISQ, $P < .001$). Group M implants, with moderate primary stability, presented a mild but a significant increase in stability (on average, 1.3 ISQ, $P < .001$), in contrast to an earlier study conducted by the same research group.[4] This minor discrepancy may be a result of the arbitrary classification of the primary stability into three intervals.

When analyzing the dip in implant stability with respect to primary stability, the observed dip in stability was significantly more pronounced in group L

than in the other two groups. Group L had less bone-to-implant contact initially, such that the same pattern of remodeling could reduce the percentage of bone-to-implant contact more significantly than for group H. Very similar results were observed in implants with the SLA surface by Barewal et al.[14] Implants in type 4 bone had significantly lower primary stability and showed a significantly greater dip in stability than implants in types 1, 2, or 3 bone.

The development of implant stability in all three groups was characterized by an initial drop in stability, which was most pronounced at 1 week after implant placement. An increase in implant stability followed. It could be hypothesized that this phenomenon is caused by an unusually fast decrease in stability as a result of the implant design or the above-average bone mineralization in the anterior mandible, combined with a rapid onset of osseointegration of the acid- and alkali-treaded implant surface. To confirm this hypothesis, further studies are necessary. Further developments, consisting of a stability increase in groups L and M over the initial values and a drop in implant stability in group H to below the initial value, could be explained by an overall trend of achieving a common level of secondary implant stability.[4] This trend could be influenced by the biologic response of variously mineralized bone to the immediate loading.

Contradictory results have been reported on the comparability of RFA and damping capacity measurements. Cehreli et al performed a meta-analysis and reached the conclusion that there is no correlation between both methods.[33] Determination of the damping capacity is considered to be more susceptible to clinical variables influencing the measurements and less precise.[34,35] On the other hand, several animal experiments, human cadaver studies, and clinical studies showed moderate to strong correlation of both methods.[19,36,37] Some in vitro experiments with the Osstell and Periotest devices found a linear association between measurements, with high statistical correlation coefficients of −0.9 and −0.8.[38,39] However, in the present study, dependence of ISQ on PTV was rather low ($R^2 = 0.06$, $P < .001$). An explanation could be sought in the specific conditions of the anterior mandible, which typically consists of highly mineralized bone. In comparison to Osstell, the Periotest device applies a much greater force to the implant-bone interface; therefore, based on the bone quality, the sensitivity of each technique can be different.

Opinions regarding the mutual relationships between bone type, final insertion torque, and primary implant stability are not uniform. Nearly the same number of studies confirms or denies a correlation of the primary stability with bone type.[2,8,29,30,33,40–42] The present study did not confirm a correlation between

the type of bone and ISQ0 or between the final insertion torque and ISQ0. However, the damping capacity measurements revealed a significant effect of these parameters on the primary implant stability that was, nevertheless, not very marked. This may be a result of the high bone quality in the anterior mandible, where high insertion torque can be achieved. A noncontact magnetic pulse of the ISQ device might not be able to distinguish the relatively strong interface stiffness of implants. An intense mechanical tapping device such as the Periotest might not necessarily be influenced as strongly by the high-quality bone. If these implants had been placed in lower quality bone, the discrepancy between the devices might have been lessened or absent. A relationship between the final insertion torque and the bone type ($r = -0.63$, $P < .001$) was demonstrated, which is in agreement with other studies.[43]

The predictive validity of RFA in detecting the failing implant in the present study should be questioned.[2] The prevailing opinion is that ISQ values under 50 should be considered critical.[5] A decrease in ISQ values of 20 or more indicates an already disintegrated implant, rather than a disintegrating one.[9] Only one implant failed in the present study. The RFA values dropped from the initial 70 ISQ to 55 ISQ prior to the implant's removal. The decrease was linear and had begun as early as the first week postplacement. Such a stability curve should warn the clinician of possible implant failure. It cannot be ruled out that the repeated implant manipulation during the experimental period contributed to the implant's failure. The contribution of the actual Periotest measurement cannot be ruled out either.

In formulating particular conclusions, the authors of this study are aware of its limitations. The sample size is small. The relationships between insertion torque, PTV, and ISQ might have been distorted by the inclusion of only the homogenous anterior mandible area. Statistical conclusions are also affected by the patient dependency of the data, as the sample included more than one implant per patient. The criteria for dividing implants into three groups were purely arbitrary and may have influenced the statistical outcomes. Finally, postplacement panoramic radiographs were not obtained; thus, a precise relationship between the implant and the alveolar crest could not be confirmed.

CONCLUSIONS

With consideration of the present evaluation of alkali-treated immediately loaded implants in the anterior mandible, the following conclusions may be drawn:

1. Longitudinal measurement of implant stability using RFA demonstrated a dip in stability in the period between the first and fourth weeks post-placement. The mean dip in stability was 2.2 implant stability quotients (ISQs) and reached its peak 1 week after implant placement. No dip was detected when stability was measured via damping capacity.
2. Implants with low primary stability (ie, ISQ < 68) showed a significant increase in stability during the healing period, while implants with high primary stability (ISQ > 72) lost some stability over time.
3. A correlation between measurement of implant stability using resonance frequency analysis and damping capacity was rather low but still significant.
4. It was confirmed that the bone type correlates with the final insertion torque, but only damping capacity measurement revealed a significant effect of these parameters on the primary stability of an implant.

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