Implant stability measurement of delayed and immediately loaded implants during healing. A clinical RFA study with SLA ITI implants

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Abstract

Resonance frequency has been recently introduced to measure implant stability. An implant stability quotient (ISQ) is obtained that usually varies in the 40-80 range. The purpose of the present clinical study was, 1) to measure the primary stability of ITI implants placed in both jaws and determine the factors that affect the ISQ, 2) to monitor implant stability during the first 3 months of healing and evaluate any difference between immediately loaded (IL) implants and implants left to heal according to a 1-stage delayed loading (DL) protocol. Primary stability was affected by the jaw and the bone type. The ISQ was higher in the mandible (59.8 ± 6.7) than the maxilla (55.0 ± 6.8). The ISQ was significantly higher in type I bone (62.8 ± 7.2) than in type III bone (56.0 ± 7.8). Implant position, implant length, implant diameter and implant deepening (Esthetic plus implants) did not affect primary stability. After 3 months, the gain in stability was higher in the mandible than in the maxilla, 4.1 vs. 1.9 units. The influence of bone was leveled off and bone quality did not affect any more implant stability. Over the monitored period, implant stability remained constant or increased slightly during the first 4-6 week and then increased more markedly. The RFA method did not reveal any difference in implant stability between the IL and DL implants over the healing period. Most implants were rehabilitated with cemented prosthesis, this prevented monitoring of implant stability after definitive prosthesis placement. One DL and IL implant failed, both were 8 mm long placed in type III bone. At the 1-year control, the survival rate of the IL and the DL

implants was 98.4 and 97.7 %, respectively. This study showed that immediately loaded short-span bridges placed in the posterior region and full arch rehabilitation of the maxilla with ITI SLA implants can be as predictable as corresponding prosthesis loaded after 3 months.

Introduction

Primary implant stability has been identified to be a prerequisite to achieve osseointegration (Brånemark et al. 1977, Adell et al. 1981, Albrektsson et al. 1981). In addition, it has been proposed that primary stability may be a useful predictor for osseointegration (Meredith 1998). In the past, objective measurements of the primary stability have been proposed with several methods like the Periotest (Siemens-Gulder, Bensheim, D) or the Dental Fine Tester (Kyocera, Kyoto, J). However, the latter have been criticized because of their lack of resolution, poor sensitivity and susceptibility to operator variables (Meredith 1998). Recently, resonance-frequency analysis (RFA) has been introduced to achieve an objective measurement of implant primary stability and to monitor implant stability in the long term (Meredith et al. 1996a, 1997a, 1998, Heo et al. 1998, Friberg et al. 1999a, 1999b, Rasmussen et al. 1998, 1999a, 1999b, 2001). With this method, implant stability is measured either by determining the resonance frequency of the implant-bone complex stiffness or by reading an implant stability quotient (ISQ) value derived from the resonance frequency given by the Osstell apparatus (Integration Diagnostics AB, Gothenburg, S). This ISQ value varies on a 1-100 scale and provides information on implant stability. Classically, it has been found to vary between 40 to 80, the higher the ISQ the higher implant stability. Several authors (Meredith et al. 1997, Heo et al. 1998, Friberg et al. 1999b, Rasmusson et al. 1997, 2001) showed that the resonance frequency of a stable, osseointegrated implant increased with time, they attributed this augmentation of implant stability to the interfacial bone reactions that lead to osseointegration. An increase in stability of facial implants during the first 7 years was also measured, that was attributed to

corticalization of the surrounding bone (Heo et al. 1998). Similarly, crestal bone loss and loss of implant stability could be correlated (Meredith et al. 1997b, 1998) while loss in implant stability could be detected before subjective clinical observation (Friberg et al. 1999a). However, all these data documenting the method have been obtained with Brånemark implants; so far, no clinical data have been published with ITI implants. With the latter implants, implant stability might be different since implant primary stability is the result of the interaction between implant design, the biomechanical properties of the local bone and the implant bed preparation technique (Meredith 1998). In addition, the increase in implant stability during the healing phase might be higher for ITI implants because Bernard et al. (2003) showed that after 3 months of healing in the dog mandible, the anchorage of 10 mm long textured ITI implants was 5 time stronger than equivalent 10 mm long machined implants. Therefore, it was of interest to evaluate, 1) if the primary stability of ITI implants, as measured by the resonance frequency method, would be comparable to Brånemark implants, 2) if the stronger implant fixation measured at ITI implants with the reverse-torque method (Bernard et al. 2003) would be reflected by the RFA method in terms of a significant increase in implant stability after the achievement of osseointegration when compared to machined implants.

In vivo data have evidenced that implant fixation, as measured by the reverse-torque test, decreases during the first weeks of healing and then increases progressively with time (Claes et al. 1976, Wilke et al. 1990, Brånemark et al. 1997, 1998, Baker et al. 1999). This reduction in anchorage might correspond to remodeling of bone necrotized during the drilling sequence prior to subsequent neo-apposition (Brånemark et al. 1985, Roberts et al. 1989). Wilke et al. (1990) inserted

titanium plasma sprayed (TPS) and sandblasted-and-etched (SLA) implants in the sheep tibia with a pre-determined torque of 100 Ncm. After 2 weeks, the reverse torque decreased down to 84 and 88 Ncm respectively, whereas after 8 weeks it increased up to 200 and 213 Ncm, and reached 285 and 301 Ncm after 12 weeks. Similarly, for machined implants placed in the rat tibia, Brånemark et al. (1997) reported a torque decrease following 2 and 4 weeks of healing, from 24 Ncm down to 20 and 19 Ncm respectively, while after 8 weeks it increased up to 30 Ncm. Since this fixation reduction might correspond to a decrease in implant stability, it was speculated that the RFA method might be sensitive enough, as the reverse-torque method, to put into evidence the modifications that take place at the bone-implant interface during the first weeks after implant placement and that might lead to a decrease in implant stability.

Recently, immediate loading became an issue extensively addressed by researchers and clinicians (Sagara et al. 1993, Chiapasco et al. 1997, Piattelli et al. 1998, Jaffin et al. 2000, Szmukler-Moncler et al. 2000a , 2000b , Massei et al. 2001, Testori et al. 2001, 2002, Romanos et al. 2002) with the aim to minimize the interval between surgery and prosthetic rehabilitation. Most IL clinical studies reported on treated edentulous mandibles (Schnitmann et al. 1990, Tarnow et al. 1997, Testori et al. 2001, 2002), short-span bridges in the mandible and in the maxilla have been scarcely documented (Jaffin et al. 2000, Glauser et al. 2001). Although IL protocols have been predictable (Chiapasco et al. 1997, Szmukler-Moncler et al. 2000a, Jaffin et al. 2000) and osseointegration has been demonstrated in animal (Sagara et al. 1993, Piattelli et al. 1998, Szmukler-Moncler et al. 2000b, Romanos et al. 2002) and human (Piattelli et al. 1997, Ledermann et al. 2001, Massei et al. 2001, Testori et al.

2001, 2002) histology, little is known on the dynamics of the interfacial events that lead to osseointegration when healing occurs under loading. It was hypothesized that the RFA method might be sensitive enough to follow the early interfacial reactions that are occurring during healing as evidenced by the reverse-torque test. Subsequently, the RFA method might provide information on possible distinct healing patterns between IL and DL implants during the first weeks of healing, e.g. a longer healing process for IL implants because of the loaded situation or a faster healing because of the biomechanical stimulation. The healing pattern of the IL implants would be perceived by a distinct evolution of implant stability during this critical period, e.g. a more pronounced decrease of implant stability during the first weeks because of the exerted stresses followed by an increase in implant stability or no decrease in implant stability because of the stimulation.

The aim of the present clinical study was therefore, 1) to generate RFA data with ITI implants and determine the parameters governing the ISQ values at implant placement, 2) to evaluate the capacity of the RFA method to follow the early interfacial events the same way the torque test method, 3) to evaluate possible changes in implant stability during the healing phase when implants are submitted (IL group) or not submitted (DL group) to loading.

Material and Methods

Patients enrollment criteria

Two groups of patients were enrolled in the present study, the first group was treated with DL implants whereas the second group was rehabilitated with IL implants. Patient assignation to a group was performed before surgery, according to the esthetic concern and personal availability. The patients belonging to the IL group were informed of the possible additional risks of the procedure and signed an informed consent. Patients with type IV bone according to the classification of Lekholm and Zarb (1985) or requiring an augmentation procedure were excluded. Achievement of primary stability determined clinically by finger pressure on the implant mount was a pre-requisite to participate to the study.

Surgical and prosthetic procedures

The DL group consisted in 18 patients (10 males and 8 females) with a mean age of 56.1 ± 13.6 years. Following a classical 1-stage procedure, 43 SLA ITI implants (Straumann AG, Waldenburg, CH) were placed, 23 (53 %) in the maxilla and 20 (46 %) in the mandible, without pre-tapping. After a delayed loading period of 3 months in both jaws, the abutments were tightened at 35 Ncm, and the patients received their definitive prosthesis following the classical prosthetic steps. The patients were rehabilitated by 2 single crowns and 20 short-span bridges of 2-3 units supported by 2-3 implants. All implants passed the 1-year control.

The IL group consisted in 18 patients (9 males and 9 females) with a mean age of 57.1 ± 17.1 years. Following an immediate loading (IL) protocol, 63 SLA ITI implants were placed, 38 (60 %) in the maxilla and 25 (40 %) in the mandible. A crestal flap was elevated and implants were placed, without pre-tapping. After surgery, standard

impression copings were press fitted into the implants and impression with Impregum Penta® (3M Espe AG, Seefeld, D) was taken. The latter was sent to the laboratory for preparation of an acrylic resin metal-reinforced temporary prosthesis. Within 2 days the prosthesis were placed and screwed, the occlusal screws were covered with Fermit® (Ivoclar-Vivadent AG, Schaan, FL). The fixed partial dentures were maintained out of occlusion through dynamic occlusion checking with an 0.2 mm occlusion paper. Full occlusion was maintained in the cross-arch bridges, following a balanced occlusion scheme. The implants supported 15 short-span 2-4 unit bridges relying on 2-3 implants and 4 full arch bridges relying on 5-6 implants. After 3-4 months of loading, the definitive prosthesis was delivered. All implants passed the 1-year control.

In both groups, implants of Ø 4.1 and Ø 4.8 mm were inserted according to the available ridge width. In both groups, implant length varied from 8 to 13 mm, length was determined according to the available bone height only. In the mandible, a security margin of 2 mm was considered above the mandibular canal, in the maxilla sinus perforation of 1-2 mm was tolerated (Nedir et al. 2003). Esthetic plus (Esth) implants (implants placed deeper with an additional mm of bone anchorage gained at the neck level) were placed to meet esthetic requirements but not to get an additional mm of bone anchorage. In the posterior area, the mean implant length was 9.8 and 10.4 mm for the DL and IL groups, respectively. During surgery, implant sites were categorized following the classification of Lekholm & Zarb (1985) into type I (7.6 %), type II (61.3 %) and type III (31.3 %); sites with soft bone of type IV were excluded from the study.

Implant stability measurement

Implant primary stability was first assessed by finger pressure exerted on the implant-mount. When clinically stable, implant stability was further measured by resonance frequency. The ISQ value at implant placement was blindly recorded and did not influence the surgical or prosthetic treatment. The ISQ was measured by an Osstell apparatus with a commercially available transducer (type L4F5) adapted to ITI implants. The transducer was maintained perpendicular to the implant and was hand-screwed into the implant body as recommended by the manufacturer. The ISQ was measured at implant placement (ISQi); the jaw, implant position, implant Ø, implant length and bone quality were recorded to evaluate the parameters governing the ISQi. The ISQ was further registered after 1, 2, 4, 6, 8, 10, and 12 weeks (ISQf), the ISQ variation (dISQ) between implant placement and the last time point was also measured. To perform the measurements at the DL implants, the cover screw was removed at each time point, the transducer was placed perpendicularly to the mesio-distal direction and was hand-screwed. For the IL implants, the temporary prosthesis was unscrewed to receive the transducer as previously described.

Success criteria

The success criteria proposed by Buser et al. (1997) and Cochran et al. (2002) were followed at each recall. They included : 1) absence of clinically detectable implant mobility, 2) absence of pain or any subjective sensation, 3) absence of recurrent peri-implant infection, 4) absence of continuous radiolucency around the implant at

the 12-week time point, after 6 and 12 months.

Statistical analysis

Hypothesis

In this study, 3 hypothesis have been put forwards, 1) the RFA method is able to detect an increase in implant stability during the healing phase of ITI implants, that might correspond to the achievement of osseointegration, 2) the RFA method is able to detect a decrease in implant stability within the first 4-6 weeks of healing like the torque method, at least for the DL implants, 3) the RFA method is able to put into evidence a difference in implant stability during the healing phase between the IL and the DL implants, that might be related to distinct bone healing patterns.

To determine the factors that are affecting the ISQi, the ISQf and the dISQ, the above mentioned variables were tested. Normality of the groups was tested with the Shapiro-Wilk W test; when normality was found, the t-test for independent variables was used to compare 2 groups. The ANOVA with the post-hoc Tukey HSD test for pairwise comparison was used for more than 2 groups. When the distribution was non-parametric, the Mann-Withney U test (comparing 2 groups) or the Kruskal-Wallis ANOVA test (comparing more than 2 groups) was used. For repeated measurements, the 2-tailed paired samples t-test was used when normality was found, and for non-parametric data the Wilcoxon rank test was applied. Statistical significance was set at 5 %.

Results

Primary implant stability

The mean ISQi of the DL and IL implants was 56.8 ± 6.6 (n = 43) and 57.2 ± 7.0 (n= 63), respectively, as shown in table I, the difference was not statistically significant (p = 0.74). In the mandible, the ISQi of the DL and IL implants was 59.2 ± 6.4 (n = 20) and 60.3 ± 6.8 (n= 25) respectively, the difference was not statistically significant (p = 0.58) as shown in **table I**. In the maxilla, the ISQi of the DL and IL implants was 54.7 ± 6.0 (n = 23) and 55.2 ± 6.4 (n= 38) respectively, the difference was not statistically significant (p = 0.79) as shown in **table I**. Because the 2 groups had similar primary stability, the ISQi of all implants were pooled for further analysis.

The ISQi of the mandibular and maxillary implants was 59.8 ± 6.7 (n = 45) and 55.0 ± 6.8 (n = 61), respectively. The primary stability of the mandibular implants was higher than the maxillary implants, the difference between jaws was highly significant (p = 0.0003) as shown in **table I**. The ISQi of the implants placed in the anterior and the posterior regions was 58.2 ± 8.4 (n = 23) and 56.7 ± 6.3 (n = 83) respectively, the difference between the sectors of the oral cavity was not significant (p = 0.35). No further difference was found for the sub-groups either in the mandible (p = 0.55) or in the maxilla (p = 0.48) as shown in **table II**. Similarly, no difference was found between the premolar and molar areas either in the mandible (p = 0.20) or in the maxilla (p = 0.48) as shown in **table II**. The ISQi of the implants placed in type I bone was 62.8 ± 7.2 (n = 8), in type II it was 56.9 ± 5.9 (n = 65) and in type III

it was 56.0 ± 7.8 (n = 33). The difference was statistically significant (p = 0.039), pairwise comparison showed that primary stability in type I and type III only were statistically different (**table III**). In the maxilla, a difference could be found between type I and II (p = 0.009), type I and type III (p = 0.009) but not between type II and III (p = 0.06) as shown in **table III**.

The ISQi of the Ø 4.1 mm implants was 57.4 ± 6.6 (n = 90), for the wider implants of Ø 4.8 mm it was 55.3 ± 8.0 (n = 16), the difference was not statistically significant (p = 0.26). No difference was found either in the mandible (p = 0.16) or in the maxilla (p = 0.37) as shown in **table IV**. The ISQi of the 8 mm long implants was 57.8 ± 7.0 (n = 20), the 9 mm had an ISQi of 57.3 ± 6.7 (n = 6), the 10 mm had 56.1 ± 6.1 (n = 24), the 11 mm had 57.9 ± 5.0 (n = 28), the 12 mm had 57.6 ± 9.6 (n = 14) and the 13 mm had 55.1 ± 8.2 (n = 14). The difference between groups was not significant (p = 0.81), no difference was found either in the mandible (p = 0.85) or maxilla (p = 0.06) sub-groups as shown in **table V**. Since implant length was not affecting the ISQi value, the effect of implant deepening could be investigated by pooling all implant lengths together (**table VI**). The ISQi of the Std (8,10, 12 mm) implants was 57.3 ± 7.4 (n = 59), for the Esth (9, 11, 13 mm lengths) implants it was 56.8 ± 6.1 (n = 47), the difference between groups was not significant (p = 0.97). No difference was further found either in the sub-groups of the mandible (p = 0.96) or the maxilla (p = 0.06) as shown in **table VI**

Implant stability after 12 weeks

The mean ISQf of the DL and IL implants was 60.3 ± 4.8 and 60.3 ± 6.8, respectively, as shown in **table I**, the difference was not statistically significant (p = 0.58). Therefore, implants of both groups were pooled for further analysis. The ISQf of the mandibular and maxillary implants was 63.9 ± 6.0 and 57.9 ± 6.0, respectively. The primary stability in the mandibule was higher than in the maxilla, the difference between jaws was significant (p = 0.04) as shown in **table I**. The ISQf of the implants placed in the anterior and the posterior regions was 59.3 ± 6.7 and 60.4 ± 5.9 respectively, the difference between sectors was not significant (p = 0.94) as shown in **table II**. No further difference was found either in the mandible (p = 0.08) or in the maxilla (p = 0.11) as shown in **table II**. Similarly, no difference was found between the premolar and molar areas either in the mandible (p = 0.56) or in the maxilla (p = 0.74). The ISQf of the implants placed in type I bone was 60.7 ± 3.6, in type II it was 60.1 ± 5.8 and in type III it was 60.6 ± 7.2. The difference was not statistically significant (p = 0.08) as shown in **table III**.

The ISQf of the 4.1 mm Ø implants was 60.3 ± 5.9, for the wider implants of Ø 4.8 mm it was 59.4 ± 7.1, the difference was not statistically significant (p = 0.15) as shown in **table IV**. The ISQf of the 8 mm long implants was 60.2 ± 5.1, the 9 mm had 59.2 ± 5.1, the 10 mm had 61.6 ± 6.1, the 11 mm had 60.3 ± 5.9, the 12 mm had 60.6 ± 6.7 and the 13 mm had 57.2 ± 5.1. The difference between groups was not significant (p = 0.25), no further difference was found for the sub-groups either in the mandible (p = 0.74) or in the maxilla (p = 0.70) as shown in **table V**. Since implant length was not affecting the ISQf value, the effect of implant deepening could be investigated by pooling all implant lengths together. The ISQf of the Std (8,10, 12 mm) implants was 60.9 ± 5.9, for the Esth (9, 11, 13 mm lengths) implants,

it was 59.2 ± 6.2, the difference between the groups was not significant (p = 0.15). In the mandible, however, the difference was statistically significant (p = 0.03) as shown in **table VI.**

Variation of implant stability over the healing phase

The variation of implant stability after 3 months of healing was 2.7 ± 5.6 for the IL group and 3.1 ± 5.3 for the DL group (**table I**), the difference was not statistically different (p = 0.54). After implant pooling, the increase in stability was higher for the implants placed in the mandible, 4.1 ± 6.0 vs. 1.9 ± 4.8, the difference was statistically significant (p = 0.04).

Over the 3-month survey, the mean ISQ of the IL and the DL implants increased when compared to the mean ISQi as shown in **figure 1**; implant stability at 12 weeks only was significantly higher. Both groups displayed the same increasing trend (fig 1)**,** no statistically significant difference between the groups could be measured at any time point. Both $f(t)_{ISQ}$ curves fitted a polynomial quadratic equation with a high correlation level (DL, $R^2 = 0.97$; IL, $R^2 = 0.91$). The mean ISQ of the mandibular and maxillary implants increased as shown in **figure 2**. For the maxillary implants, the ISQ increase was statistically significant after 12 weeks only; for the mandibular implants, the ISQ increase was statistically significant after **6 weeks and later**. The difference in dISQ between the mandibular and maxillary implants was significant after 10 and 12 weeks only. Both $f(t)_{ISQ}$ curves fitted a polynomial quadratic equation with a high correlation level (Mandible, $R^2 = 0.95$; Maxilla, $R^2 = 0.93$).

Failed implants

Over the 3-month survey period, 2 implants became mobile and were removed, both were 8 mm long placed in type 3 bone, no implant failed afterwards. In the DL group, the failure occurred after 2 weeks, the ISQi was 48 and the ISQ at failure was 43. In the IL group, the failure occurred after 4 weeks, the ISQi was 53 and the ISQ measured at failure was 46. At the 1-year control, the survival rate of the IL and the DL implants was 98.4 and 97.7 %, respectively.

Discussion

The ISQi of the IL and DL groups were not statistically different therefore the 106 implants were pooled. Six variables that might affect implant primary stability were investigated, they were the jaw (mandible vs. maxilla), the sector of the oral cavity (anterior vs. posterior region, premolar vs. molar area), type of bone (type I-III), implant diameter (4.1 vs. 4.8 mm), implant length (8-13 mm) and implant deepening (Std vs. Esth). Only the jaw and the bone type were found to affect primary stability. Implants placed in the mandible were more stable than in the maxilla, as well as implants placed in type I bone when compared to type III. Our data are in line with those obtained with Brånemark implants, implant stability was higher in the mandible than in the maxilla (Meredith et al. 1997a, Friberg et al. 1999a, Balleri et al. 2002) and in denser bone (Friberg 1999a, 1999b) and implant length did not affect implant stability (Meredith et al. 1997, Friberg 1999b, Balleri et al. 2002). It

has been suggested that bone quality, and subsequently implant stability, is poorer in the posterior area and this might explain the lower success rates reported in the posterior area when compared to the anterior region (Saadoun et al. 1992, Lazzara et al. 1996). Although the ISQi was lower in the posterior region of both the mandible and the maxilla, the differences were not significant. Several authors suggested the use of wider diameter implants to increase primary stability because of a larger bone-implant contact with cortical bone (Langer et al. 1993, Renouard et al. 1999, Polizzi et al. 2000), however the RFA method did not confirm this clinical assumption because the wider implants did not prove to be more stable. It has been suggested that the resonance frequency was related to the effective length of an implant above the bone level (Meredith et al. 1997) i.e. the method is in capacity to detect small variations between the transducer level and the first bone-implant contact. Accordingly, implant deepening of the Esth implants was expected to increase significantly the mean ISQi over the Std implants because of the 1 mm reduction between the highest bone level and the transducer; nonetheless, the ISQi of the groups did not differ.

According to Meredith (1998), macro-geometry and implant design should alter implant primary stability, therefore a distinct ISQi value was expected for the ITI implants of distinct design when compared to Brånemark implants. The mean ISQi for the present ITI implants was 57.4 ± 6.8, varying between 42 to 72; in the maxilla, it was 55.0 ± 6.8, comparable to the primary stability reported for Brånemark implants placed in the maxilla (Meredith et al. 1997a) where a mean of 54 has been reported. O'Sullivan et al. (2000) compared the primary stability of implants of various designs like the MkII, the MKIV, the Osseotite and the TiOblast implants

placed in the maxilla of human cadavers. They did not find a statistically significant difference between implants despite differences in peak torque insertion. Similarly, Rasmuson et al. (2001) failed to measure any difference in primary stability between Brånemark and Astra implants placed in the dog mandible. Surprisingly, it appears that a large variety of implants are achieving a similar primary stability; moreover, implant length does not increase implant stability. Implant primary stability seems less affected by implant design than by the local bone quality. Therefore, it is possible that the RFA method measures the stiffness in bending of the overall bone-implant complex rather than the local stiffness at the bone-implant interface. Probably, the measured resonance frequency of the complex is over-weighted by bone quality rather than by the very local interaction between the implant and the surrounding bone.

After 12 weeks of healing, the parameters governing the ISQ were further investigated. The mean ISQf at the mandible was still higher than in the maxilla but the difference between bone type, that was determinant for the ISQi, were leveled out. The latter may be explained by bone densification of the soft bone surrounding the implants. For Brånemark implants, Friberg et al. (1999b) reported a similar leveling out tendency between bone qualities after 1 year. All other parameters did not further affect implant stability.

The dISQ during the healing phase was significantly higher in the mandible than in the maxilla, 4.1 vs. 1.9. This was unexpected since implant stability of implants placed in the maxilla with a lower ISQ was foreseen to increase more readily that mandibular implants, as for Brånemark implants (Meredith et al. 1997, 1998, Friberg

et al. 1999a, Glauser & Meredith 2001), specially because leveling out was found for the various bone qualities. The highest increase in ISQ was found for the Esth implants placed in the mandible (+ 7.0), the reason for that is unknown.

Over the healing period, the mean ISQ in the mandible and in the maxilla remained stable or slightly increased during the first 4-6 weeks and then started to increase more noticeably. In the mandible, implant stability increased sooner and more markedly than in the maxilla. Friberg et al. (1999a) followed implant stability of 75 Brånemark implants placed in the mandible of 15 edentulous patients after 1, 2, 6 and 15 weeks, implant stability was found to decrease rather than to increase. It is tempting to attribute this discrepancy to the distinct surface states (machined vs. SLA) and their subsequent reactions at the interface, i.e. micro-mechanical coupling at the textured implant interface (Godfredsen et al. 2000, Szmukler-Moncler et al. 2003) vs. tight bone juxtaposition without adhesion for machined implant interface (Sennerby et al. 1992, Brånemark et al. 1998, Bernard et al. 2003, Szmukler-Moncler et al. 2003). Bernard et al. (2003) reported a large difference in anchorage between Brånemark and ITI textured surfaces, reaching a factor x 5 for implants of 10 mm in length. The latter might explain the increase in stability for the textured implants and the decrease for the machined ones. Similarly, Baker et al. (1999) in a push-out test compared the Osseotite and the machined surfaces after 1 to 8 weeks of healing in the cortical bone of the rabbit tibia. Between surfaces a noticeable difference could be evidenced, the anchorage of the machined implants decreased during the first 4 weeks and later slightly increased whereas the anchorage of the Osseotite surface did not decrease, it remained constant over this period and increased after 3 weeks. Therefore, the increase in resonance frequency might

indeed correspond to bone ingrowth and mechanical interlocking at the interface. This interpretation, however, contrasts with a previously published work of Meredith et al. (1997b) where implant stability of machined Brånemark implants placed in the rabbit tibia was followed over the healing period up to 160 days. Despite the machined nature of the surface, the authors found an increase in implant stability after 2 and 4 weeks that leveled out after 6 weeks. Taking into consideration the species factor (Roberts et al. 1988), this would correspond to an augmentation of implant stability after 6 and 12 weeks in the human. The difference between the clinical and the experimental data with Brånemark implants is unknown. However, since the animal data with the Brånemark implants match our clinical results with ITI implants, an increase in implant stability because of the surface state (machined vs. textured) seems unlikely.

In the maxilla of 9 patients treated with 61 implants, Friberg et al. (1999b) observed an improvement of implant stability after 8 months, at abutment connection, that further increased after 12 months, at the 1-year loading milestone. No information, however, was provided on the period between implant placement and abutment connection. In our study, evolution of implant stability after the first 3 months and until the first annual control could not be followed for all implants because most rehabilitations were cemented instead of screw-retained, due to the higher costs of the screw-retained prosthesis (Nedir et al. 2003) and in agreement with the ITI philosophy for prosthetic management (Belser et al. 2000). This prevented serial implant monitoring in the longer term when in function. This stresses one of the limitations of the RFA method that requires fixation of the transducer to the implant.

Three hypothesis have been set forth in this study,1) the RFA method would be able to detect an increase in implant stability that might correspond to osseointegration, 2) it would detect a decrease in implant stability at least for the DL implants as detected by the torque-test method, 3) it would detect a difference between the IL and DL implants that might correspond to distinct healing patterns. The RFA method detected a significant increase in implant stability as hypothesized, that should correspond to some healing events in the supporting bone. Meredith et al. (1997) reported in an experimental study in the rabbit tibia that an increase in bone implant contact was accompanied by an increase in resonance frequency. However, one cannot conclude that the RFA method is able to assess the level of osseointegration. Rasmussen et al. (2001) compared machined Brånemark implants and blasted Astra implants in the dog mandible. They found after 4 months of healing distinct bone-implant contacts, 25.5 % for the Brånemark and 52.3 % for the Astra ($p < 0.05$), but no statistically significant differences in resonance frequency. In contrast, these authors (Ramsmusson et al. 1999a) previously compared simultaneous and delayed placement of Brånemark implants in grafted sites of the rabbit tibia. The total bone-implant contact was similar, after 8 weeks (25.6 % vs. 33.9 %), 16 weeks (32.2 % vs. 39. 6 %) and 24 weeks (45.9 % vs. 50.3 %), but implant stability was different at each time point. Noteworthy, implant stability measured by the RFA method cannot either be related to the degree of implant anchorage as measured by the torque test. Rasmusson et al. (1999a) compared simultaneous and delayed placement of Brånemark implants in grafted sites of the rabbit tibia. After 24 weeks, the torque was similar (56.2 vs. 61.8 Ncm) whereas implant stability was significantly higher for the delayed group. Therefore, it might be that, as suggested above when discussing the primary implant stability, the RFA

method does not provide information on the very interfacial bone-implant events as the torque-test method does (Gotfredsen et al. 2000, Szmukler-Moncler et al. 2003) but rather on the overall bone-implant complex. This would explain the increase in resonance frequency with time without however getting a simple relationship between the ISQ value and either the level of osseointegration or the degree of implant anchorage in bone. This, in turn, would also explain why the RFA method did not reveal a decrease in implant stability during the first weeks of healing as hypothesized while the torque-test method was able to seize the early events of remodeling (Claes et al. 1976, Wilke et al. 1990, Brånemark et al. 1997) after implant placement (Brånemark et al. 1985, Roberts et al. 1989).

In the past, long delayed periods have been advocated because it was supposed that the surrounding bone had no load-bearing capacity until completion of bone remodeling (Albrektsson et al. 1981, Roberts et al. 1989). The present RFA results showed that implant stability did not decrease significantly at any time point. This may, therefore, demonstrate that a constant load-bearing capacity can be maintained at any stage of healing despite interfacial remodeling. This finding might provide a supportive explanation for the unexpected high predictability of IL (Schnitman et al. 1990, Chiapasco et al. 1997, Tarnow et al. 1997, Testori et al. 2001, 2002) and early loading protocols as short as 6-8 weeks (Lazzara et al. 1998, Testori et al. 2002, Cochran et al. 2002) or even 3 weeks (Røynesdal et al. 2001). Accordingly, there might not be a critical period during the first weeks of healing where loading should be avoided, as this might have been extrapolated from the decrease in implant anchorage prior to augmentation (Claes et al. 1976, Wilke et al. 1990, Brånemark et al. 1997).

The RFA method did not discriminate between the IL and DL implants as hypothesized, both groups displayed similar evolution curves without decrease in implant stability. This might support an equal predictability for IL and DL protocols as far as bone support is considered. Because the RFA method seems to measure the overall bone support rather than the interfacial bone-implant events, similar healing patterns at both groups cannot be deducted. At best, it might suggest that the loading regimen does not affect the overall supporting bone. Comparison of the healing patterns of IL and DL implants requires therefore a longitudinal histological evaluation.

In this study, one IL and one DL implants failed, no difference in survival rates was found between the 2 loading protocols. Noteworthy, both implants were 8 mm long placed in type 3 bone, leading to a failure rate of 10 % for this implant length category. Nevertheless, conclusion that shorter implants have a tendency to fail more than longer ones cannot be drawn because of the reduced number of failures and implants. In a previous study involving 528 implants (Nedir et al. 2003), the short 8 mm ITI implants were not at higher risk when submitted to classical or early loading protocols. Studies with a larger number of implants should address the relevant use of short implants when immediately loaded. Although based on a limited number of cases, these preliminary data showed that immediately loaded short-span bridges with ITI SLA implants might be as predictable as delayed loaded ones. Based on a 1-year follow-up, our study confirms that failures happen within the first months of function. Further failures because of the IL loading protocol are not to be expected once osseointegration has been achieved.

In conclusion, data with the RFA method have been obtained for ITI implants at implant placement and during healing up to 12 weeks. Implant stability varied according to jaw and bone type. After 3 months, the effect of bone was leveled out but the still the ISQ at the mandible was significantly higher. Over a 3-month period, the RFA method did not reveal any decrease in implant stability either at the DL or the IL groups. This might explain why IL protocols may be as predictable as DL ones. The mean ISQ remained stable or slightly increased during the first 4-6 weeks and then increased more noticeably. A correlation between the interfacial events and implant stability could not be evidenced, therefore, no conclusion could be drawn on the similarity or dissimilarity of the IL and DL implants healing patterns.

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Captions

Table 1.

Implant stability in function of the loading protocol (IL and DL) and the jaw (mandible and maxilla). The mean ISQ at implant placement and after 3 months is given as well as the change in implant stability over this period. Statistical significance has been tested between groups at placement and at 3 months; variation of implant stability over the healing period was also tested for statistical significance. These statistical analysis have been performed in all forthcoming tables.

Table 2.

Implant stability in function of implant position, at implant placement, after 3 months as well as variation of implant stability over this period.

Table 3.

Implant stability in function of bone type, at implant placement, after 3 months as well as variation of implant stability over this period. The stars (* or **) refer to the corresponding statistically significant groups.

Table 4.

Implant stability in function of implant diameter, at implant placement, after 3 months as well as variation of implant stability over this period.

Table 5.

Implant stability in function of implant length, at implant placement, after 3 months as well as variation of implant stability over this period.

Table 6.

Implant stability in function of implant deepening, at implant placement, after 3 months as well as variation of implant stability over this period.

Fig 1.

Evolution of implant stability between implant placement and 3 months for the IL and DL groups. The curves are similar, the mean ISQs remained stable over the first 4 weeks and then started to increase, statistical significance was reached after 12 weeks only. The black discontinued lines are the polynomial quadratic fitting curves, the correlation levels (R^2) between the observed and calculated curves are also given.

Fig 2.

Evolution of implant stability between implant placement and 3 months for implants placed in the mandible and in the maxilla. In the mandible, implant stability did not change significantly over the first 4 weeks and then increased significantly. In the maxilla, the increase in implant stability was more moderate than in the mandible, statistical significance was reached after 12 weeks only. The black discontinued lines are the polynomial quadratic fitting curves, the correlation levels (R^2) between the observed and calculated curves are also given.

Fig 1.

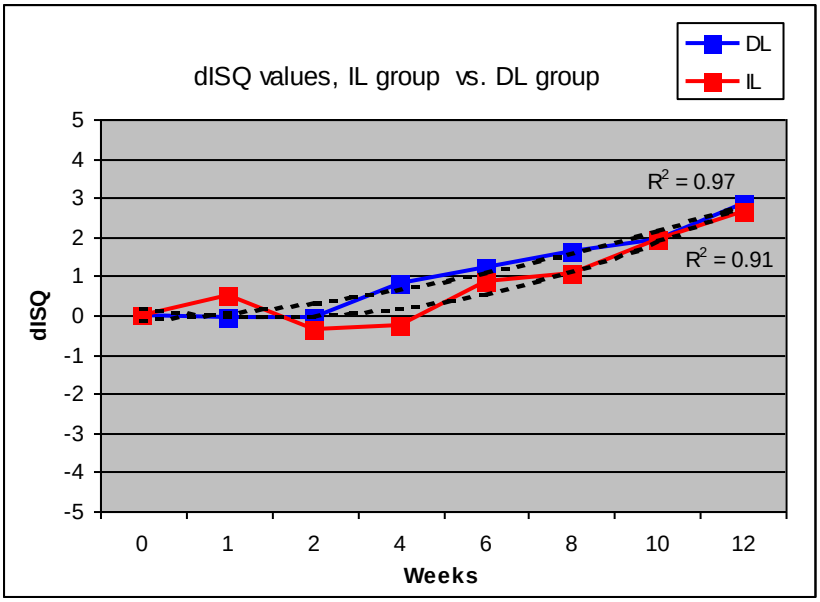
dISQ values, IL group vs. DL group
DL
IL
R^2 = 0.97
R^2 = 0.91
dISQ
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
4
6
8
10
12
Weeks

Fig 2.

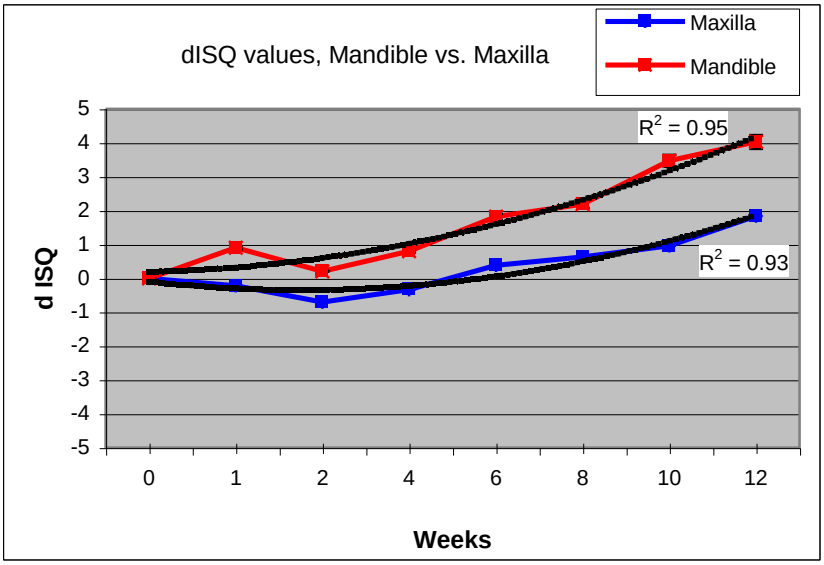
dISQ values, Mandible vs. Maxilla
Maxilla
Mandible
R^2 = 0.95
R^2 = 0.93
d ISQ
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
4
6
8
10
12
Weeks

Table 1

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance dISQ (paired)	Statistical significance between groups
DL group, Max & Md	n = 43	56.8 ± 6.6	p = 0.74	60.3 ± 4.8	3.1 ± 5.3	p = 0.001, S	p = 0.58
IL group, Max & Md	n = 63	57.2 ± 7.0	NS	60.3 ± 6.8	2.7 ± 5.6	p = 0.005, S	NS
All implants	n = 106	57.4 ± 6.8		60.3 ± 6.1	2.9 ± 5.5	p = 0.001, S	
Mand, DL group	n = 20	59.2 ± 6.4	p = 0.58	62.5 ± 5.2	3.6 ± 5.4	p = 0.01, S	p = 0.58
Mand, IL group	n = 25	60.3 ± 6.8	NS	65.2 ± 6.4	4.5 ± 6.6	p = 0.002, S	NS
Max, DL group	n = 23	54.7 ± 6.0	p = 0.79	58.3 ± 3.4	2.6 ± 5.3	p = 0.02, S	p = 0.59
Max, IL group	n = 38	55.2 ± 6.4	NS	57.0 ± 4.9	1.5 ± 4.6	p = 0.03, S	NS
Mand, IL & DL group	n = 45	59.8 ± 6.7	p = 0.0003	63.9 ± 6.0	4.1 ± 6.1	p = 0.01, S	p = 0.04
Max, IL & DL group	n = 61	55.0 ± 6.8	S	57.9 ± 6.0	1.9 ± 4.8	p = 0.006, S	S

Table 2

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance d ISQ (paired)	Statistical significance between groups
Anterior, Mand & Max	n = 23	58.2 ± 8.4	p = 0.35	59.3 ± 6.7	1.1 ± 4.9	p = 0.28, NS	p = 0.94
Posterior, Mand & Max	n = 83	56.7 ± 6.3	NS	60.4 ± 5.9	3.3 ± 5.4	p < 0.0001, S	NS
Anterior, Mand	n = 4	66.3 ± 6.6	p = 0.055	68.8 ± 3.6	2.5 ± 7.0	-	p = 0.08
Posterior, Mand	n = 41	59.1 ± 6.4	NS	63.8 ± 5.8	4.3 ± 6.0	p < 0.0001, S	NS
PM, Mand	n = 19	60.8 ± 7.1	p = 0.12	64.1 ± 5.4	3.3 ± 5.7	p = 0.02, S	p = 0.59
Mol, Mand	n = 22	57.7 ± 5.5	NS	63.1 ± 6.1	5.1 ± 6.2	p = 0.001, S	NS
Anterior, Max	n = 19	56.5 ± 7.9	p = 0.20	57.4 ± 5.3	0.8 ± 4.5	p = 0.28, NS	p = 0.11
Posterior, Max	n = 42	54.3 ± 5.3	NS	57.3 ± 4.0	2.4 ± 4.7	p = 0.002, S	NS
PM, Max	n = 33	54.6 ± 4.3	p = 0.48	57.4 ± 4.0	2.0 ± 4.5	p = 0.01, S	p = 0.74
Mol, Max	n = 9	53.2 ± 8.2	NS	56.8 ± 4.3	3.6 ± 5.4	p = 0.08, NS	NS

Table 3

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance d ISQ (paired)	Statistical significance between groups
Bone type I	n = 8	62.8 ± 7.2 *	p = 0.04	60.7 ± 3.6	- 1.6 ± 4.7	p = 0.4, NS	p = 0.08
Bone type II	n = 65	56.9 ± 5.9	S	60.1 ± 5.8	2.8 ± 4.8	p = 0.0001, S	NS
Bone type III	n = 33	56.0 ± 7.8 *		60.6 ± 7.2	4.0 ± 6.8	p = 0.003, S	
Bone type I, Mand	n = 3	62.3 ± 11.0	-	60.0 ± 6.1	- 2.3 ± 5.5	-	
Bone type II, Mand	n = 25	59.8 ± 5.1	p = 0.77	64.2 ± 5.3	4.1 ± 4.8	p = 0.01, S	p = 0.25
Bone type III, Mand	n = 17	59.2 ± 8.1	NS	64.5 ± 6.8	5.1 ± 7.4	p = 0.11, NS	NS
Bone type I, Max	n = 5	63.0 ± 5.5 * / **	p = 0.005	61.8 ± 1.5	- 1.2 ± 4.1	p = 0.55, NS */**	p = 0.02
Bone type II, Max	n = 40	55.0 ± 5.7 *	S	57.4 ± 4.3	1.9 ± 4.2	p = 0.01, S *	S
Bone type III, Max	n = 16	52.6 ± 6.0 **		56.1 ± 4.5	2.8 ± 6.1	p = 0.11, NS **	

Table 4

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance d ISQ (paired)	Statistical significance between groups
Ø 4.1 mm, Mand & Max	n = 90	57.4 ± 6.6	p = 0.26	60.3 ± 5.9	2.6 ± 4.9	p < 0.0001, S	p = 0.15
Ø 4.8 mm, Mand & Max	n = 16	55.3 ± 8.0	NS	59.4 ± 7.1	4.2 ± 7.4	p = 0.04, S	NS
Ø 4.1 mm, Mand	n = 36	60.5 ± 6.6	p = 0.16	64.7 ± 5.1	4.0 ± 5.1	p < 0.0001, S	p = 0.15
Ø 4.8 mm, Mand	n = 9	57.0 ± 6.7	NS	61.6 ± 8.1	4.6 ± 8.7	p = 0.15, NS	NS
Ø 4.1 mm, Max	n = 54	55.4 ± 5.7	p = 0.37	57.1 ± 4.4	1.7 ± 4.5	p = 0.007, S	p = 0.74
Ø 4.8 mm, Max	n = 7	53.0 ± 9.8	NS	56.7 ± 4.9	3.7 ± 6.0	p = 0.15, NS	NS

Table 5

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance d ISQ (paired)	Statistical significance between groups
8 mm, Mand & Max	n = 20	57.7 ± 7.0		60.2 ± 5.1	1.4 ± 4.2	p = 0.18, NS	
9 mm, Mand & Max	n = 6	57.3 ± 6.7		59.2 ± 9.1	1.8 ± 3.1	p = 0.20, NS	
10 mm,Mand & Max	n = 24	56.1 ± 6.1	p = 0.81	61.6 ± 6.1	5.3 ± 6.3	p = 0.0004, S	p = 0.25
11 mm, Mand & Max	n = 28	57.9 ± 5.0	NS	60.3 ± 5.9	2.4 ± 4.9	p = 0.02, S	NS
12 mm, Mand & Max	n = 14	57.6 ± 9.6		60.6 ± 6.7	2.6 ± 6.2	p = 0.10, NS	
13 mm, Mand & Max	n = 14	55.1 ± 8.2		57.2 ± 5.1	1.9 ± 4.9	p = 0.19, NS	
8 mm, Mand	n = 10	60.4 ± 7.0		62.9 ± 5.5	1.7 ± 4.8	p = 0.33, NS	
9 mm, Mand	n = 1	69		76	7	-	
10 mm, Mand	n = 17	58.5 ± 4.8	p = 0.85	64.2 ± 4.9	5.8 ± 6.9	p = 0.003, S	p = 0.74
11 mm, Mand	n = 7	59.9 ± 4.4	NS	66.9 ± 4.1	7.0 ± 4.4	p = 0.006, S	NS
12 mm, Mand	n = 6	60.4 ± 10.0		59.7 ± 8.4	0.8 ± 4.2	p = 0.65, NS	
13 mm, Mand	-	-		-	-	-	
8 mm, Max	n = 10	55.2 ± 6.3		57.6 ± 3.2	1.1 ± 3.8	p = 0.41, NS	
9 mm, Max	n = 5	55.0 ± 4.0		55.8 ± 4.2	0.8 ± 1.9	p = 0.40, NS	
10 mm, Max	n = 7	51.0 ± 5.8	p = 0.06	55.3 ± 3.7	4.3 ± 5.1	p = 0.07, NS	p = 0.70
11 mm, Max	n = 21	57.2 ± 5.1	NS	58.1 ± 4.7	0.9 ± 4.1	p = 0.35, NS	NS
12 mm, Max	n = 4	50.5 ± 2.6		58.0 ± 5.3	2.6 ± 5.3	-	
13 mm, Max	n = 14	55.1 ± 8.2		57.0 ± 5.0	1.9 ± 4.9	p = 0.18, NS	

Table 6

	Sample size	ISQi (primary stability)	Statistical significance between groups	ISQf (12 weeks)	d ISQ (ISQf-ISQi)	Statistical significance d ISQ (paired)	Statistical significance between groups
Std, Mand & Max	n = 58	57.2 ± 7.4	p = 0.97	60.9 ± 5.9	3.4 ± 5.9	p < 0.0001, S	p = 0.15
Esth, Mand & Max	n = 48	57.0 ± 6.1	NS	59.2 ± 6.2	2.2 ± 4.6	p = 0.002, S	NS
Std, Mand	n = 37	59.5 ± 6.9	p = 0.93	63.2 ± 5.7	3.5 ± 6.2	p = 0.002, S	p = 0.03
Esth, Mand	n = 8	61.0 ± 5.2	NS	68.0 ± 5.0	7.0 ± 4.1	p = 0.002, S	S
Std, Max	n = 21	53.1 ± 5.9	p = 0.06	56.9 ± 3.8	3.5 ± 5.3	p = 0.009, S	p = 0.60
Esth, Max	n = 40	56.2 ± 6.2	NS	57.4 ± 4.7	1.2 ± 4.2	p = 0.08, NS	NS