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Implant stability measurement of delayed and immediately loaded implants during healing.

A clinical resonance-frequency analysis study with sandblasted-and-etched ITI implants

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Abstract: The purpose of the present study was (1) to measure the primary stability of ITI implants placed in both jaws and determine the factors that affect the implant stability quotient (ISQ) determined by the resonance frequency method and (2) to monitor implant stability during the first 3 months of healing and evaluate any difference between immediately loaded (IL) implants and standard delayed loaded (DL) implants. The IL and DL groups consisted of 18 patients/63 implants and 18 patients/43 implants. IL implants were loaded after 2 days; DL implants were left to heal according to the one-stage procedure. The ISQ was recorded with an Osstell® apparatus (Integration Diagnostics AB, Gothenburg, Sweden) at implant placement, after 1, 2, 4, 6, 8, 10 and 12 weeks. Primary stability was affected by the jaw and the bone type. The ISQ was higher in the mandible (59.8 $\pm$ 6.7) than the maxilla (55.0 $\pm$ 6.8). The ISQ was significantly higher in type I bone (62.8 $\pm$ 7.2) than in type III bone (56.0 $\pm$ 7.8). The 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. The influence of bone type was leveled off and bone quality did not affect implant stability. The resonance-frequency analysis method did not reveal any difference in implant stability between the IL and DL implants over the healing period. Implant stability remained constant or increased slightly during the first 4–6 weeks and then increased more markedly. 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 no difference in implant stability between the IL and DL procedures over the first 3 months. IL short-span bridges placed in the posterior region and full arch rehabilitation of the maxilla with ITI sandblasted-and-etched implants were highly predictable.

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-Gulden, Bensheim, Germany) or the Dental Fine Tester (Kyocera, Kyoto, Japan). 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. 1996, 1997a; Heo et al. 1998, Meredith, 1998; Rasmussen et al. 1998, 1999a, 1999b, 2001; Friberg et al. 1999a, 1999b). 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® equipment (Integration Diagnostics AB, Gothenburg, Sweden). This ISQ value varies on a 1–100 scale and provides information on implant stability. Classically, it has been found to vary between 40 and 80; the higher the ISQ the higher implant stability. Several authors (Meredith et al. 1997a, 1997b; Rasmusson et al. 1997, 2001; Heo et al. 1998; Friberg et al. 1999b) showed that the resonance frequency of a stable, osseointegrated implant increased with time, and they attributed this augmentation of implant stability to the interfacial bone reactions that lead to osseointegration. An increase in the stability of facial implants during the first 7 years was also measured, which 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; Meredith 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 five times 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 with machined implants.

In vivo data have evidenced that implant fixation, measured by the reverse-torque test, decreases during the initial 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 the remodeling phase of necrotized bone, followed by a neoapposition phase (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 N cm. After 2 weeks, the reverse torque decreased down to 84 and 88 N cm, respectively, whereas after 8 weeks it increased up to 200 and 213 N cm, and reached 285 and 301 N cm 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 N cm down to 20 and 19 N cm, respectively, while after 8 weeks it increased up to 30 N cm. Since this fixation reduction might correspond to a decrease in implant stability, it was speculated that the RFA method might be as sensitive as the reverse-torque method. It would be possible to put into evidence the modifications that are taking place at the bone–implant interface during the initial weeks after implant placement in terms of an ISQ decrease.

Recently, immediate loading (IL) 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), where the aim is 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), whereas short-span bridges in the mandible and in the maxilla have scarcely been documented (Jaffin et al. 2000; Glauser et al. 2001). Although IL protocols have been predictable (Chiapasco et al. 1997; Jaffin et al. 2000; Szmukler-Moncler et al. 2000a) 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. 1998; Massei et al. 2001; Testori et al. 2001, 2002) histology, little is known regarding 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 occur during healing as evidenced by the reverse-torque test. Subsequently, the RFA method might provide information on the possible distinct healing patterns between IL and delayed loaded (DL) implants during the initial weeks of healing. The healing pattern of the IL implants would be perceived by a distinct evolution of implant stability during this critical period. It would be characterized either by a slower healing process for IL implants because of the exerted stress, translating into a pronounced decrease of implant stability during the initial weeks followed by an increase; or by faster healing because of the biomechanical stimulation, translating into a rapid increase of 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 as the torque test method and (3) to evaluate the 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 financial affordability. 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 & Zarb (1985) or requiring an augmentation procedure were excluded. The achievement of primary stability determined clinically by finger pressure on the implant mount was a prerequisite to participate in the study.

Surgical and prosthetic procedures

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

The IL group consisted in 18 patients (nine males and nine females) with a mean age of 57.1 ± 17.1 years. Following an 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 an impression with Impregum Penta® (3M Espe AG, Seefeld, Germany) was taken. The latter was sent to the laboratory for the preparation of an acrylic resin metal-reinforced temporary prosthesis. Within 2 days, the prosthesis was placed, the occlusal screws were hand-tightened by applying a moderate torque and covered with Fermit® (Ivoclar-Vivadent AG, Schaan, Lichtenstein). The fixed partial dentures were maintained out of occlusion through dynamic occlusion checking with a 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 units bridges relying on two to three implants and four full-arch bridges relying on five to six 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, the implant length varied from 8 to 13 mm, and length was determined according to the available bone height only. In the mandible, a security margin of 2 mm above the mandibular canal was taken into account. In the maxilla, sinus perforation of 1–2 mm was tolerated during the drilling sequence (Nedir et al. 2003), in this case the patient was given a nasal spray (Locabioatal, Servier SA, Meyrin, Switzerland), two sprays × 4/day for 7 days, in addition to Amoxibasan® 750 mg (Schönenberger Pharma, Schönenwerd, Switzerland), 3 cps/day during 5 days. 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 obtain 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. If 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), and 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 perpendicular 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, three hypotheses have been put forward: (1) the RFA method is able to detect an increase in implant stability during the healing phase of ITI implants, which 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, which 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. The 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 two groups. The ANOVA with the *post hoc* Tukey HSD test for pairwise comparison was used for more than two groups. When the distribution was non-parametric, the Mann–Whitney *U*-test (comparing two groups) or the Kruskal–Wallis ANOVA test (comparing more than two groups) was used. For repeated measurements, the two-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 ($n = 63$), as shown in Table 1, and the difference was not statistically significant. The ISQi of the DL and IL implants in both the mandible and the maxilla showed no statistically significant difference (Table 1). Subsequently, all implants were pooled for further analysis of the parameters governing implant primary stability.

The ISQi of the mandibular and maxillary implants was 59.8 ± 6.7 ($n = 45$) and 55.0 ± 6.8 ($n = 61$); the difference between jaws was significant (Table 1). Implant localization did not affect the ISQi significantly (Table 2). Bone quality affected implant stability significantly; the latter was higher in type I bone and lower in type III bone. Pairwise comparison showed that only primary stability in type I and type III was statistically different (Table 3).

The implant diameter did not affect the ISQi (Table 4). Implant length was not a parameter influencing primary stability (Table 5). Subsequently, the effect of implant deepening could be investigated by pooling all implant lengths together (Table 6). The ISQi of the Std (8, 10, 12 mm) and the Esth (9, 11, 13 mm) implants were not statistically different (Table 6).

Implant stability after 12 weeks

The mean ISQf of the DL and IL implants was 60.3 ± 4.8 and 60.3 ± 6.8 (Table 1); the difference was not statistically significant. 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; the difference between jaws was significant (Table 1). Implant localization (Table 2), implant diameter (Table 4) or implant length (Table 5) did not affect implant stability. Bone type that did influence implant primary stability did not affect implant stability after 12 weeks (Table 3).

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 1); the difference was not statistically different. 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.

Over the 3-month survey, the mean ISQ of the IL and the DL implants increased when compared with the mean ISQi as shown in Fig. 1; implant stability at 12 weeks only was significantly higher. Both groups displayed the same increasing trend (Fig. 1), and no statistically significant difference between the groups could be measured at any time point. Both $f(t)$dISQ 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 Fig. 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 $f(t)$dISQ curves fitted a polynomial quadratic equation with a high correlation level (mandible, $r^2 = 0.95$; maxilla, $r^2 = 0.93$), as shown in Fig. 2.

Failed implants

Over the 3-month survey period, two 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 could be 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 (types 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 with type III. Our data are in line with those obtained with Brånemark implants, where implant stability was higher in the mandible than in the maxilla (Meredith et al. 1997a; Friberg et al. 1999a; Balleri et al. 2002), higher in denser bone (Friberg et al. 1999a, 1999b), while implant length did not affect implant stability (Meredith et al. 1997a, 1997b; Friberg et al. 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 with the anterior region (Saadoun & LeGall 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; the wider implants were not 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. 1997a, 1997b) i.e. the method is in the 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 the mean ISQi significantly 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), macrogeometry and implant design should alter implant primary stability, therefore a distinct ISQi value was expected for the ITI implants of distinct design when compared with Brånemark implants. The mean ISQi for the present ITI implants was 57.4 ± 6.8, varying between 42 and 72; in the maxilla, it was 55.0 ± 6.8, comparable to the primary stability reported for

Table 1. **Implant stability in function of the loading protocol (IL and DL) and the jaw (mandible and maxilla)**

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

The mean implant stability quotient (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 during the healing period was also tested for statistical significance. These statistical analyses have been performed in all forthcoming tables.
IL, immediately loaded; DL, delayed loaded; ISQi, ISQ measured at implant placement; ISQf; ISQ registered after 12 weeks; dISQ, ISQ variation.

Table 2. **Implant stability in function of implant position, at implant placement, after 3 months as well as variation of implant stability during this period**

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

ISQi, implant stability quotient measured at implant placement; ISQf, ISQ registered after 32 weeks; dISQ, ISQ variation.

Table 3. **Implant stability in function of bone type, at implant placement, after 3 months as well as variation of implant stability during this period**

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

*or ** refer to the corresponding statistically significant groups. ISQi, implant stability quotient measured at implant placement; ISQf, ISQ registered after 32 weeks; dISQ, ISQ variation.

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**

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

ISQi, implant stability quotient measured at implant placement; ISQf, ISQ registered after 32 weeks; dISQ, ISQ variation.

Table 5. **Implant stability in function of implant length, at implant placement, after 3 months as well as variation of implant stability during this period**

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

ISQi, implant stability quotient measured at implant placement; ISQf, ISQ registered after 32 weeks; dISQ, ISQ variation.

Table 6. Implant stability in function of implant deepening, at implant placement, after 3 months as well as variation of implant stability during this period

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

ISQ, implant stability quotient measured at implant placement; ISQf, ISQ registered after 32 weeks; dISQ, ISQ variation.

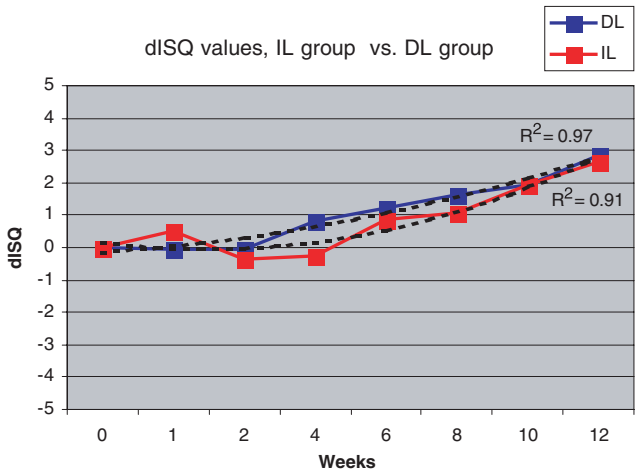

Fig. 1. Evolution of implant stability between implant placement and 3 months for the immediately loaded (IL) and delayed loaded (DL) groups. The curves are similar, the mean implant stability quotients (ISQs) remained stable over the first 4 weeks and then started to increase; statistical significance 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.

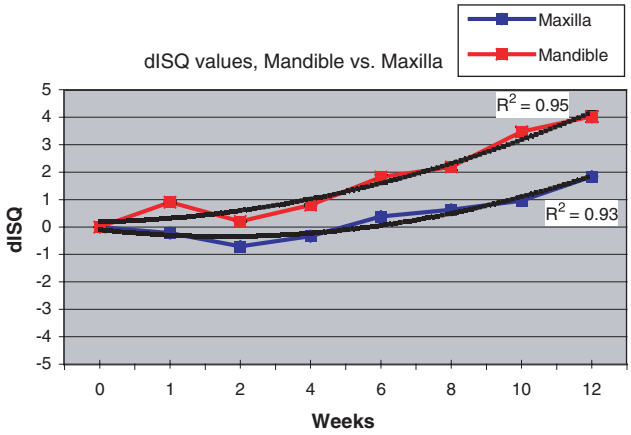

Fig. 2. Evolution of implant stability between implant placement and 3 months for implants placed in the mandible and in the maxilla. In the mandible, implant stability did not change significantly over the first 4 weeks and then increased significantly. In the maxilla, the increase in implant stability 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. dISQ, implant stability quotient variation.

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, Rasmusson 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 achieve similar primary stability. Primary stability seems less affected by implant design than by local bone quality. Therefore, it seems 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 the bone quality rather than by the very local interaction between the implant and the contacting bone.

After 12 weeks of healing, the parameters governing the ISQ were further investigated. The mean ISQf in the mandible was still higher than in the maxilla but the difference between bone type, which was a determinant for the ISQi, was 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 than mandibular implants, as for Brånemark implants (Meredith et al. 1997a, 1997b; Meredith 1998; Friberg et al. 1999a, Glauser & Meredith 2001), especially because leveling out was found for the various bone qualities.

During 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. Friberg et al. (1999a) followed the 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 increase. It is tempting to attribute this discrepancy to the distinct surface states (machined vs. SLA) and their subsequent reactions at the interface (Godfredsen et al. 2000; Bernard et al. 2003; Szmukler-Moncler et al. 2003). However, Meredith et al. (1997b) also found an increase in implant stability for machined surfaces after 2 and 4 weeks, which leveled out after 6 weeks.

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 stresses one of the limitations of the RFA method that requires fixation of the transducer to the implant.

Three hypotheses 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 and (3) it would detect a difference between the IL and DL implants that might correspond to distinct healing patterns. The RFA method revealed a significant increase in implant stability as hypothesized, which should correspond to some healing events in the supporting bone. However, what is exactly measured by the Osstell® remains unclear. The ISQ value does not correspond to implant osseointegration because implants with distinct bone–implant contacts (25.5% vs. 52.3%) may lead to a similar implant stability (Rasmusson et al. 2001). Conversely, implants with similar implant–bone contacts may lead to dissimilar ISQ scores (Rasmusson et al. 1999a). In addition, the ISQ value does not reflect implant anchorage because implants of similar anchorage may display distinct implant stability values (Rasmusson et al. 1999a). It seems that the RFA method does not provide information on the bone–implant interface as the torque-test method does (Godfredsen et al. 2000; Bernard et al. 2003; Szmukler-Moncler et al. 2003), but rather on the overall bone–implant complex. This would explain why the RFA method did not reveal a significant decrease in implant stability during the initial weeks of healing, while the torque-test method was able to seize the early events of remodeling after implant placement (Claes et al. 1976; Wilke et al. 1990; Brånemark et al. 1997). Accordingly, the lack of discrimination between the IL and DL implants during the healing phase is not supportive of similar healing patterns. At best, it might suggest that loading during healing does not affect the overall supporting bone. An investigation of the healing patterns of IL and DL implants requires, therefore, longitudinal histological evaluations.

Long DL periods have been advocated in the past because the surrounding bone was thought to have no load-bearing capacity until completion of bone remodeling (Albrektsson et al. 1981; Roberts et al. 1989). Implant stability did not decrease significantly during healing, which might mean that a constant load-bearing capacity can be maintained at any stage of healing despite the interfacial remodeling. Accordingly, there might not be a critical period during the initial weeks of healing where loading should be avoided, as this might be extrapolated from the torque-test that showed a decrease in implant fixation followed by an augmentation (Claes et al. 1976; Wilke et al. 1990; Brånemark et al. 1997).

One IL and one DL implant failed, and no difference in survival rates was found between the two loading protocols. Both implants were 8 mm long placed in type 3 bone, leading to a failure rate of 10% for this implant length category. Nevertheless, the 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. Although based on a limited number of cases, these preliminary data showed that IL short-span bridges with ITI SLA implants might be as predictable as DL ones. Based on a 1-year follow-up, our study confirms that failures occur within the initial 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 the jaw and bone type. After 3 months, the effect of bone was leveled out but still the ISQ in the mandible was significantly higher. Over a 3-month period, the RFA method did not reveal any decrease in implant stability either in 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 implant healing patterns.

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Résumé

Les buts de l'étude présente étaient 1) de mesurer la stabilité primaire d'implants ITI placés dans les deux maxillaires et de déterminer les facteurs qui affectaient le quotient de stabilité implantaire (ISQ) déterminé par la méthode de fréquence de résonance, 2) d'enregistrer la stabilité implantaire durant les trois premiers mois de guérison et d'évaluer les différences entre les implants immédiatement mis

en charge (IL) et les implants avec charge retardée (DL). Les groupes IL et DL comprenaient respectivement 18 patients/63 implants et 18 patients/43 implants. Les implants IL ont été mis en charge après deux jours et les DL ont eu un temps de guérison sans charge suivant le processus standard. L'ISQ a été enregistré à l'aide d'un appareil Osstell® lors du placement de l'implant et après une, deux, quatre, six, huit, dix et douze semaines. La stabilité primaire était affectée par la mâchoire et le type d'os. L'ISQ était plus important dans la mandibule (60 ± 7) que dans le maxillaire (55 ± 7). L'ISQ était significativement plus important dans l'os de type I (63 ± 7) que dans l'os type III (56 ± 8). La position de l'implant, sa longueur, son diamètre et sa profondeur (les implants Esthetic plus) n'avaient pas d'influence sur la stabilité primaire. Après trois mois, le gain de stabilité était plus important dans la mandibule que dans le maxillaire. L'influence du type osseux était réduite et la qualité osseuse n'influençait pas la stabilité implantaire. La méthode RFA ne montrait aucune différence dans la stabilité implantaire entre les implants IL et DL durant la période de guérison. La stabilité implantaire restait constante ou augmentait légèrement durant les quatre à six semaines et augmentait ensuite de manière plus marquée. Un implant DL et un IL ont échoué, les deux avaient une longueur de 8 mm et étaient placés dans de l'os type III. Au contrôle après une année, les taux de survie des implants IL et DL étaient respectivement de 98,4 et 97,7%. Cette étude n'a montré aucune différence dans la stabilité implantaire entre les processus IL et DL après les premiers trois mois. Les bridges courts placés immédiatement dans la région postérieure et la réhabilitation de toute l'arche dentaire au niveau du maxillaire avec des implants ITI SLA étaient hautement prévisibles.

Zusammenfassung

Das Ziel dieser Studie war: 1) die Primärstabilität von ITI-Implantaten in beiden Kiefern zu messen und die Faktoren zu suchen, die diesen Implantatstabilitätsquotienten (ISQ), bestimmt mittels Resonanzfrequenz-Analyse, beeinflussen; und 2) die Implantatstabilität während den ersten 3 Monaten der Heilphase longitudinal zu verfolgen und eventuelle Unterschiede zwischen sofort belasteten (IL) und gemäss Standardprotokoll belasteten Implantaten (DL) herauszufinden.
Die IL- und DL-Gruppen bestanden aus 18 Patienten/63 Implantaten und 18 Patienten/43 Implantaten. Die IL-Implantate belastete man nach 2 Tagen, die DL-Implantate liess man dem Standardvorgehen entsprechend einheilen. Mit einem Osstell®-Gerät bestimmte man nach der Implantation, sowie nach 1, 2, 4, 6, 8, 10 und 12 Wochen den ISQ.
Die Primärstbilität war durch den Knochentyp und die verschiedenen Kiefertypen beeinflusst. Im Unterkiefer war der ISQ höher (59.8 ± 6.7) als im Oberkiefer (55.0 ± 6.8). Ebenso war der ISQ im Knochentyp I signifikant höher (62.8 ± 7.2) als im Knochentyp III (56 ± 7.8). Implantatposition, -länge, -durchmesser und das vertiefte Setzen der Implantate (Esthetic plus) beeinflussten die Primärstabilität nicht. Nach 3 Monaten verbesserte sich die Stabilität im Unterkiefer mehr als im Oberkiefer. Wenn man den Einfluss des Knochentyps rechnerisch ausglich, hatte die Knochenqualität auf die Implantatstabilität keinen Einfluss. Die RFA-Methode zeigte zwischen den IL- und den DL-Implantaten in der Heilphase keine Unterschiede der Implantatstbilität. Die Implantate behielten ihre Stabilität oder zeigten in den ersten 4-6 Wochen eine leichte, später sogar eine markante Zunahme. Je ein DL- und ein IL-Implantat gingen verloren und wurden als Misserfolg gewertet. Beide waren 8 mm lang und in Typ III Knochen implantiert worden. In der Nachkontrolle nach einem Jahr betrug die Überlebensrate der IL-Implantate 98.4%, die der DL-Implantate 97.7%.
Diese Studie zeigte in den ersten 3 Monaten keine Unterschiede in der Implantatstabilität zwischen dem IL- und den DL-Protokoll auf. Die Prognose von sofortbelasteten Brücken mit kurzer Spannweite im posterioren Bereich und den ganzen Bogen umspannende Brücken im Oberkiefer mit ITI SLA-Implantaten konnten mit hoher Sicherheit vorausgesagt werden.

Resumen

El propósito del presente estudio fue, (1) medir la estabilidad primaria de los implantes ITI colocados en ambos maxilares y determinar los factores que afectan al cociente de estabilidad primaria (ISQ) determinado por un método de frecuencia de resonancia, (2) monitorizar la estabilidad del implante durante los 3 primeros meses de cicatrización y evaluar cualquier diferencia entre implantes de carga inmediata (IL) e implantes estándar de carga diferida (DL).
Los grupos IL y DL consistieron de 18 pacientes/63 implantes y 18 pacientes/43 implantes. Los implantes IL se cargaron a los 2 días, los implantes DL se dejaron cicatrizar de acuerdo con el procedimiento de 1 fase. Se recogió el ISQ con un aparato Osstell® al colocar el implante, tras 1, 2, 4, 6, 8, 10 12 semanas.
La estabilidad primaria se afectó por el maxilar y el tipo de hueso. El ISQ fue mas alto en la mandíbula (57.8 ± 6.7) que en el maxilar (55.0 ± 6.8). El ISQ fue significativamente mas alto en el hueso tipo I (62.8 ± 7.2) que en el hueso tipo III (56.0 ± 7.8). La posición del implante, la longitud del implante, el diámetro del implante y la profundidad del implante (implantes Esthetic plus) no afectaron a la estabilidad primaria. Despues de 3, la ganancia de estabilidad fue mayor en la mandíbula que en el maxilar. La influencia del tipo de hueso se niveló y la calidad de hueso no afectó a la estabilidad implantaria. El método RFA no reveló ninguna diferencia en la estabilidad implantaria entre los implantes IL y DL a lo largo del periodo de cicatrización. La estabilidad de los implantes permaneció constante o se incrementó ligeramente durante las primeras 4 a 6 semanas y después aumentó mas marcadamente. Un implante DL y otro IL fracasaron, ambos de 8 mm de longitud colocados en hueso tipo III. En el control de 1 año, el índice de supervivencia de los implantes IL y DL fue del 98.4 y 97.7% respectivamente.
Este estudio no mostró diferencias en la estabilidad implantaria entre los procedimientos IL y DL a lo largo de los 3 primeros meses. Los puentes cortos cargados inmediatamente colocados en la región posterior y las rehabilitaciones de toda la arcada del maxilar con implantes ITI SLA fueron altamente predecibles.

要旨
本研究は、1）上下顎に埋入したＩＴＩインプラントの初期固定を測定し、インプラントの安定性係数（ＩＳＱ）に影響を及ぼす要因を明らかにし、2）治癒期間３ヶ月中のインプラント安定性をモニターし、即時荷重（ＩＬ）インプラントと、時期を遅らせた標準の荷重（ＤＬ）インプラントの間の差異を評価することを目的に行った。
ＩＬ群とＤＬ群は、各々患者１８名／インプラント６３本と、患者１８名／インプラント４３本から構成されていた。ＩＬインプラントは２日後に荷重し、ＤＬインプラントは１回法に基づいて治癒期間を設けた。ＩＳＱはOsstell®装置を用いて、インプラント埋入時、１、２、４、６、８、１０、１２週間後に測定した。
初期固定は、顎骨と骨タイプによって影響を受けた。ＩＳＱは下顎（５９．８±６．７）が上顎（５５．０±６．８）より高かった。ＩＳＱはタイプ１の骨質（６２．８±７．２）がタイプ３（５６．０±７．８）より有意に高かった。インプラントの位置、長さ、直径と深さ（Esthetic plusインプラント）は、初期固定に影響を及ぼさなかった。３ヶ月後の安定性の増加の度合いは上顎より下顎の方が高かった。骨タイプの影響は横ばいとなり、骨質はインプラントの安定性に影響しなかった。ＲＦＡの方法では、治癒期間中にＩＬ群とＤＬ群の間にインプラント安定性の差異は認められなかった。インプラントの安定性は、最初の４－６週間は一定に維持されるか、やや増加し、その後顕著に増加した。タイプ３の骨に入れた８ｍｍ長のDLインプラントとILインプラントが各々１本ずつ失われた。１年間の経過観察で、ILとDLのインプラントの生存率は、各々９８．４％と９７．７％であった。
本研究は、最初の３ヶ月間にIL群とDL群の間にインプラントの安定性に差がないことを示した。即時荷重のＩＴＩ SLA インプラントを、臼歯部でスパンの短いブリッジを上部構造として用いた場合および上顎の全顎リハビリテーションに用いた場合、非常に高い予知性が示された。

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