# Predicting osseointegration by means of implant primary stability. A RFA study with delayed and immediately loaded ITI SLA implants

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## Abstract

The purpose of the present clinical study was, 1) to evaluate the Osstell as a diagnostic tool capable to differentiate between stable and mobile ITI implants, 2) to evaluate a cut-off threshold implant stability quotient value obtained at implant placement (ISQitv) that might be predictive of osseointegration, 3) to compare the predictive ISQitv of immediately loaded (IL) implants and implants loaded after 3 months (DL). Two patient groups were enrolled, 18 patients received 63 IL implants and 18 patients were treated with 43 DL implants. The ISQ was recorded at implant placement, after 1, 2, 4, 6, 8, 10 and 12 weeks. All implants passed the 1-year loading control. 2 implants failed, one DL implant with ISQ at placement (ISQi) of 48 and one IL implant with ISQi of 53. The RFA method was not a reliable diagnostic tool to identify mobile implants. However, implant stability could be reliably determined for implants displaying an ISQ $\geq$ 47. After 1 year of loading, all DL implants with an ISQi $\geq$ 49 and all IL implants with an ISQi $\geq$ 54 achieved and maintained osseointegration. By the end of 3 months, implants with ISQi < 60 had an increase of stability. Implants with ISQi 60-69 had their stability decrease during 8 weeks before returning to their initial values. Implants with ISQ > 69 had their stability decrease during the first 4 weeks before remaining stable. Although preliminary, these data might orient the practitioner to choose among various loading protocols and to selectively monitor implants during the healing phase.

# Introduction

Under defined circumstances, early and immediate loading protocols have now been recognized to be viable alternatives to the classical 1- or 2-stage delayed loading approaches (Chiapasco et al. 1997, Lazzara et al 1998, Szmukler-Moncler 1998, 2000, Jaffin et al. 2000, Roccuzo et al. 2001, Cochran et al. 2002, Glauser et al. 2001, Testori et al. 2002, Esposito et al. 2003). This means that implants might be submitted to distinct loading régimes after placement according to surgical, prosthetic and psychological considerations (Salama et al. 1995, Balshi & Wolfinger 1997, Esposito et al. 2003). Subsequently, the clinician needs reliable and supportive objective guidelines to determine on an individual basis the prognosis of a given implant, if immediately loaded, early loaded within 6-8 weeks or left classically to heal for a 3 to 6-month period. With such guidelines, the most relevant protocol amid the above mentioned ones may be chosen to meet any specific treatment and patient psychological requirement.

Primary implant stability has been identified as a prerequisite to achieve osseointegration (Branemark et al. 1977, Adell et al. 1981, Albrektsson et al. 1981). In addition, several authors suggested that primary stability may be a useful predictor for osseointegration (Meredith 1998, Friberg et al. 1999a) and that a high primary stability makes immediate loading more predictable (Szmukler-Moncler et al. 2000, Glauser & Meredith 2001). In the past, objective measurements of primary stability have been proposed by several methods like the Periotest

(Gulden, Bensheim, D) or the Dental Fine Tester (Kyocera, Kyoto, J). However, their lack of resolution, poor sensitivity and susceptibility to operator variables have been criticized (Meredith 1998). Recently, resonance-frequency analysis (RFA) has been introduced to provide an objective measurement of implant primary stability and to monitor implant stability over the healing period (Meredith et al. 1997a, 1997b, Friberg et al. 1999a, Rasmussen 2001, Bischof et al. in press) and in the longer term (Heo et al. 1998, Friberg et al. 1999b, Rasmussen et al. 2001, Balleri et al. 2002). With this method, implant stability is measured either by determining the resonance frequency of the implant-bone complex or by reading an ISQ value given by the Osstell apparatus (Integration Diagnostics AB, Gothenburg, S). Classically, the ISQ has been found to vary between 40 to 80, the higher the ISQ, the higher the implant stability. A substantial increase or decrease in implant stability could be detected with this method that otherwise could not be clinically perceived (Heo et al. 1998, Friberg et al. 1999a, 1999b). Nonetheless, evaluation of this method as a diagnostic tool capable of discriminating between stable and mobile implants has not yet been investigated, especially for ITI implants.

Implant primary stability plays a key-role in achieving osseointegration. Distinct ranges of implant primary stability have been distinguished by the resonance frequency method, (Meredith et al. 1997a, Balleri et al. 2002, Bischof et al. in press). Therefore, it was hypothesized that determination of a primary stability threshold, provided in terms of a defined threshold ISQ value, might be relevant to predict the osseointegration prognosis of a given implant. This would be in line with

the clinical studies having reported that implants placed in softer bone (Jaffin et al. 1991, Saadoun 1992, Lazzara et al. 1996) fail more often than implants placed in denser bone, and that implants located in the posterior maxilla fail more often than implants placed in the anterior mandible (Adell et al. 1981, Lazzara et al. 1996). In addition, clinical studies on IL implants showed that implants placed in type III bone failed more than implants placed in type I and II bone (Balshi & Wolfinger 1997, Glauser et al. 2001). Therefore, a second hypothesis was put forth : IL implants should require a higher primary stability to gain and maintain osseointegration than implants loaded after 3 months. Indeed, IL implants are submitted during the healing phase to higher stresses and strains than implants that are left to heal for 3 months in the mandible and the maxilla.

The purpose of the present clinical study was therefore, 1) to evaluate the Osstell as a diagnostic tool capable to discriminate between stable and mobile ITI implants, 2) to evaluate a threshold ISQ value obtained at implant placement (ISQitv) that might be predictive of osseointegration when assessed after 1 year of loading, 3) to compare the predictive ISQitv of IL and DL implants.

# Material and Methods

## Patients enrollment criteria

Two groups of patients were enrolled in the present study, the first group was treated classically with implants left to heal for 3 months, the second group had their implants immediately loaded. Patient assignation to a group was performed before surgery. Patients that were assigned to the IL group were sensitive to esthetics or function and required to be immediately rehabilitated. This treatment alternative involved additional expense for a temporary prosthesis. The patients belonging to this 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 from the study. The pre-requisite for a patient to participate in the study was achievement of primary stability for all implants, as determined clinically by exerting finger pressure on the implant mount in all directions.

## Surgical and prosthetic procedures

The DL group consisted of 18 patients (10 males and 8 females) with a mean age of 56.1 ± 13.6 years. Following a 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 classical prosthetic steps. These 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 loading control.

The IL group consisted of 18 patients (9 males and 9 females) with a mean age of 57.1 ± 17.1 years. Sixty three 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, impression copings were press fitted into the implants and impression with Impregum® (3M Espe AG, Seefeld, D) was taken. The latter was sent to the laboratory for preparation of an acrylic resin prosthesis, constructed on top of titanium synOcta posts for temporary restorations. Within 2 days the prosthesis were placed and hand-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 for the cross-arch bridges. 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 loading control.

In both groups, implants of Ø 4.1 and Ø 4.8 mm were inserted according to the available ridge width and prosthetic indication. 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). 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 clinically by finger pressure exerted on the implant-mount. If stable, the ISQ value was measured with a commercially available transducer (type L4F5, Integration Diagnostics AB, Gothenburg, S) adapted to the ITI implants. The transducer was hand-screwed into the implant, perpendicular to the mesio-distal axis as recommended by the manufacturer. The ISQi value was blindly recorded and did not further influence either the prosthetic treatment or the follow-up schedule. Implant stability was further measured after 1, 2, 4, 6, 8, 10, and 12 weeks, before being tested clinically with finger pressure in all directions. The ISQ variation (dISQ) at each time point as well as the final ISQ variation (dISQf) between implant placement and the last time point were calculated. 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 at each time point 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 after 3, 6 and 12 months of loading.

## Statistical analysis

### Repeatability of the measurements

Repeatability of the measurements was determined by measuring the relative variation of the measured ISQ based on 38 runs of 3 consecutive measurements.

### The Osstell as a diagnostic tool evaluating implant stability

Evaluation of the Osstell as a diagnostic tool able to discriminate between clinically stable and mobile implants requires determination of a cut-off value, i.e. the ISQ value that distinguishes between a mobile and a stable implant. Based on this cut-off value, the sensitivity (S), specificity (Sp), positive predictive value (PPV) and negative predictive value (NPV) have been measured for the Osstell. The sensitivity measures the probability to correctly identify as mobile the implants that are clinically mobile. The specificity measures the probability to correctly identify as stable the clinically stable implants. The PPV and NPV express the probability that

the Osstell diagnosis is correct. The PPV is the probability that an ISQ < to the cut-off value corresponds effectively to a clinically mobile implant. Clinically, it defines the probability the Osstell can successfully detect a mobile i.e. failed implant. The NPV is the probability that an ISQ > to the cut-off value corresponds effectively to a clinically stable implant. Clinically, it defines the probability the Osstell can successfully detect a stable implant. These values are determined in the following way :

1) Sensitivity = $\frac{\text{True positive results}}{\text{True positive results + False negative results}}$

2) Specificity = $\frac{\text{True negative results}}{\text{True negative results + False positive results}}$

3) PPV = $\frac{\text{True positive results}}{\text{True positive results + False positive results}}$

4) NPV = $\frac{\text{True negative results}}{\text{True negative results + False negative results}}$

where :

- a true-positive result (TP) is when the Osstell suggests implant mobility (ISQ < cut-off value) and the implant is effectively clinically mobile.
- a false-positive result (FP) is when the Osstell suggests implant mobility (ISQ <

cut-off value), however the implant is clinically stable.

- a true-negative result (TN) is when the Ostell suggests implant stability (ISQ > cut-off value) and implant stability is clinically confirmed.
- a false-negative result (FN) is when the Osstell suggests implant stability (ISQ > cut-off value) however the implant is clinically mobile.

**Evaluation of the ISQi as a predictor of osseointegration**

The ISQi was also evaluated as a predictor of implant osseointegration for IL and DL implants using the same above mentioned analysis criteria. In this case, the cut-off value is the ISQitv that predicts implant osseointegration as assessed after 1 year of loading, according to the loading protocol. The sensitivity measures the probability to correctly identify as failed the implants that are clinically mobile. The specificity measures the probability to correctly identify as osseointegrated the clinically stable implant. The PPV is the probability that an ISQi < ISQitv leads effectively to implant failure. Clinically, it defines the probability the ISQitv can successfully predict implant failure. The NPV is the probability that an ISQi > ISQitv leads effectively to implant osseointegration as assessesd after 1 year of loading. Clinically, it defines the probability the ISQitv can successfully predict implant osseointegration.

These parameters have been calculated as previously mentioned, considering that:

- a true-positive result (TP) is when the ISQi suggests the lack of implant osseointegration during the healing period (ISQi < ISQitv) and the implant is

effectively clinically mobile within 1-year of loading.

- a false-positive result (FP) is when the ISQi suggests the lack of implant osseointegration during the healing period (ISQi < ISQitv), however the implant is clinically osseointegrated at the 1-year loading control.
- a true-negative result (TN) is when the ISQi suggests implant osseointegration (ISQi > ISQitv) and implant osseointegration is clinically confirmed at the 1-year loading control.
- a false-negative result (FN) is when the ISQi suggests implant osseointegration (ISQi > ISQitv) however the implant is clinically mobile within 1-year of loading.

# Results

## Repeatability of the measurements

Among the 38 repetitive measurements, 15 (39.5 %) were identical, 17 (44.7 %) had an 1-unit discrepancy, 4 (10.5 %) had a 2-unit discrepancy and 2 (5.3 %) had a 3-unit discrepancy. The repeatability of the Osstell was 1.14 %.

## Failures

Over the 1-year loading survey period, 2 implants became mobile and were removed, one in the DL group and one in the IL group, both were 8 mm long implants placed in type III bone as shown in table 1. The DL implant failed after 2

weeks, the ISQi was 48 and the ISQ at failure was 43, the resonance frequency curve displayed a single sharp peak, characteristic of a stable implant (Meredith 1998, Rasmusson et al. 1999). The IL implant failed after 4 weeks, the ISQi was 53 and the ISQ at failure was 46, the resonance frequency curve displayed a single sharp peak, characteristic of a stable implant. Noteworthy, in the IL group, an implant rotated after 3 months during final abutment tightening at 35 Ncm, the ISQi was 53 and the ISQ before rotation was 49 with a single sharp peak. This implant was nevertheless loaded, it was connected to 2 other implants in a 5-unit bridge and remained stable over the 1-year loading period. At the 1-year loading control, the survival rate of the IL and the DL implants was 98.4 and 97.7 %, respectively.

## Evaluation of the ISQ as a diagnostic tool

At implant placement, all implants had to be clinically stable before the ISQ was measured, the ISQi varied between 42 and 72. At the other time points, the ISQ varied in the 40-77 range. The ISQ at failure of the 2 mobile implants was 43 and 46, no implant with a higher ISQ was clinically mobile. Subsequently, the cut-off ISQ value for implant stability was set as 47, meaning that an implant displaying an ISQ $\geq$ 47 should be considered as a stable implant. Based on this value, the Osstell sensitivity for determining implant stability was S = 1, Sp was 0.973, the PPV was 0.087 and the NPV was 1 (Table 2).

## Evaluation of the ISQi as a predictor of osseointegration

All DL implants that displayed an ISQi ≥ 49 at implant placement were osseointegrated at the 1-year loading follow-up. Therefore, the ISQitv for a predictable osseointegration of DL implants was 49. With a cut-off value of 49, the sensitivity for predicting osseointegration (determining implant stability after 1 year of loading) for DL implants was S = 1, Sp was 0.881, the PPV was 0.143 and the NPV was 1 (Table 2). This means that an implant with an ISQi ≥ 49 is expected to osseointegrate when loaded after 3 months in the mandible or in the maxilla.

All IL implants that displayed an ISQi ≥ 54 at implant placement were osseointegrated at the 1-year loading follow-up. Therefore, the ISQitv for a predictable osseointegration of IL implants was 54. With a cut-off value of 54, the sensitivity for predicting osseointegration for the IL implants was S = 1, Sp was 0.645, the PPV was 0.043 and the NPV was 1 (Table 2). This means that implants displaying an ISQi ≥ 54 are expected to osseointegrate when immediately loaded

## Variation of implant stability over the healing phase

Three months after placement, the ISQ's increased by 2.7 ± 5.6 units for the IL group and 3.1 ± 5.3 units for the DL group as described by Bischof et al. (in press), the difference was not statistically significant (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), as described elsewhere (Bischof et al. in press).

Implants were split into 4 groups according to their ISQi as shown in table 3 and in figure 1, a) ISQi < 50, b) ISQi = 50-59, c) ISQi = 60-69 and d) ISQi ≥ 70. Most implants with an ISQi < 60 were placed in the maxilla, whereas most implants with an ISQi ≥ 60 were placed in the mandible (Table 3). After 3 months, the mean dISQf of the “ISQi < 50” group increased by 8.5 ± 3.8, the mean dISQf of the “ISQi 50-59” group increased by 3.4 ± 5.1. The mean dISQf of the “ISQi 60-69” group increased by 1.4 ± 4.3, the mean dISQf of the “ISQi ≥ 70” group decreased by 5.1 ± 2.3. Variation of the ISQ with time for each group is shown in figure 1. The group with the lowest ISQi showed the highest increase in implant stability, the group with the highest ISQi showed the strongest decrease in implant stability. To define with more precision the ISQi range that leads to a decrease in implant stability, the “ISQi 60-69” group was split in 2 sub-groups, i) ISQi = 60-64, ii) ISQi = 65-69. Evolution of the dISQ with time is plotted for these 2 sub-groups in figure 2. The mean dISQ of the “ISQi 60-64” group decreased slightly during 6 weeks and then increased. The mean dISQ of the “ISQ 65-69” group decreased more markedly until 8 weeks and then increased until reaching the initial values. In contrast, the mean dISQ of the implant group with the highest ISQ decreased markedly during 4 weeks and then remained stable at this level. Figure 3 shows the variation in implant stability after 12 weeks as a function of the ISQi, the negative correlation was medium but highly significant ($r = -0.52$, $p < 0.05$).

# Discussion

The RFA method with the Osstell equipment has been claimed to be useful for, 1) monitoring implant osseointegration during the healing phase (Meredith 1998) and, 2) helping the clinician decide on an individual basis when to load an implant (Glauser & Meredith 2001). The implicit assumption is that implants undergoing osseointegration are supposed to increase their stability with time or at least maintain it (Meredith 1998). A second assumption is that implants having achieved a high primary stability might be loaded earlier than implants with a lower ISQi (Meredith et al. 1998). Nonetheless, no defined cut-off ISQ value has been validated until now through documented studies to determine the threshold value that discriminates between a mobile and a stable implant. Neither has a cut-off ISQ value been published so far to orient the clinician toward shorter or longer healing periods. The present study was designed to determine these values for ITI SLA implants.

Based on 38 consecutive repetitive measurements, repeatability of the ISQ values given by the Osstell was 1.14 %, comparable to the < 1 % reported by Meredith et al. (1997b) for Brånemark implants. The data collected over the 12-week healing period led to a PPV (probability of the ISQ to detect a mobile implant) as low as 0.087, meaning that only 8.7 % of the measurements supposed to indicate implant mobility (ISQ < 47) could be confirmed as clinically mobile. This proved that the ISQ values provided by the Osstell could not serve as a reliable diagnostic mean to

identify a mobile implant with accuracy. Similarly, the presence of single peak of resonance was not found to be indicative of a stable implant (Meredith 1998, Rasmusson et al. 1999) since both mobile implants displayed sharp single peaks. In contrast, the Osstell was found to be a reliable diagnostic tool capable to identify the stable implants with certainty. Indeed, no stable implant was mistaken for a mobile implant (S = 1) and all stable implants could be identified without error (NPV = 1). For the clinician that wants to rely on the ISQ to monitor implant stability, a reading of 47 or more should signify, for ITI SLA implants, that the tested implant is stable and devoid of concern, unless previous measurements gave markedly higher ISQ values.

The time period to ascertain implant osseointegration was limited to 1 year of loading. Esposito et al. (1998), in a literature review on delayed loaded implants, suggested that failure to establish osseointegration because of host related factors, i.e. bone quality and quantity, might become patent up to 1 year after loading. Afterwards, implant failure should be attributed to overloading or peri-implantitis. In addition, a survey of the literature dealing specifically with IL implants showed that failure to establish osseointegration occurs during the first 3-6 months of loading (Balshi & Wolfinger 1997, Whörle 1998, Szmukler-Moncler et al. 2000a, Testori et al. 2003). When stability is maintained afterwards, implants should be considered as osseointegrated (Corso et al. 1999, Szmukler-Moncler et al. 2000b).

In this study, the ISQitv supposed to predict successful integration was 49 for the DL implants and 54 for the IL implants. This difference between the IL and DL

groups met our second hypothesis. Distinct primary stability thresholds make sense since IL implants are submitted to higher stresses and strains, therefore they should require a higher primary stability to withstand these biomechanical constraints.

Clinically, the data suggest that implants with an ISQi $\geq$ 49 should reliably osseointegrate (NPV = 1) when they are left to heal for 3 months in the mandible and in the maxilla. These implants should require only minimal routine follow-up. On the other hand, less stable implants with an ISQi < 49 might still osseointegrate since the Sp and PPV were $\neq$ 1, nevertheless they are at higher risk and should require a tighter and more careful follow-up during the healing period. All causes of undue loading like a temporary removable prosthesis or a hard diet should be minimized. Implants with an ISQi $\geq$ 54 might be immediately loaded because they should reliably osseointegrate (NPV = 1). This does not imply, however, that implants with an ISQi < 54 do not integrate when immediately loaded, because the PPV and the Sp were $\neq$ 1. The data suggest, nevertheless, that implants with an ISQi < 54 are at higher risk and should require a tighter follow-up. Stability of the temporary prosthesis, occlusion, diet and implant stability should be regularly verified. Noteworthy, according to the ISQitv of 54 determined in this study for the IL implants, 70 out of the present 106 implants (66.0 %) might had been immediately loaded, while 21 out of the 63 IL implants (33.3 %) would have been put on a delayed loading protocol. This indicates that the number of implants

susceptible to undergo safely an immediate loading protocol when placed in type I-III bone might be higher than previously expected.

The present methodological approach is relevant to determine a ISQitv predictive of osseointegration for DL and IL implants. However, the number of failed (mobile) implants and the total number of evaluated implants are too limited to rely conclusively on these ISQitv. Nevertheless, they should be taken as indicative until better documented. The practitioner circumspect with immediate loading procedures might want to set the ISQitv for IL implants at a higher level than presently suggested, say in the 60-65 range. However, he should bear in mind that this would exclude a consistent amount of implants and patients from the benefit of immediate loading therapy. In our study, an ISQitv of 60 would have restricted immediate loading to 37 (39.4 %) implants out of 106 instead of 70 (66.0 %), while an ISQitv of 65 would have involved only 24 (22.6 %) implants out of 106. With an ISQitv of 54 required for all implants supporting a prosthesis, 10 out of the 18 patients that belonged to the IL group would have been excluded from the benefit of an immediate rehabilitation. Similarly, only 16 out the 36 patients treated in this study would have received an immediately loaded prosthesis. With a more conservative ISQitv of 60 or 65 applied to all implants supporting an IL prosthesis, only 6 or 2 out of the 36 patients, respectively, would have received an immediate rehabilitation.

An interesting observation was that one implant with an ISQ of 49 rotated when the abutment was tightened with 35 Ncm after 3 months, it was nevertheless loaded

and remained stable at the 1-year control. It has been reported that 1.9-6.9 % of ITI SLA implants might rotate when the abutment is tightened at 35 Ncm after 6-8 weeks of healing (Morton et al. 2001, Roccuzzo et al. 2001, Cochran et al. 2002). It would be interesting to investigate the clinical relevance of a correlation between ISQ values and resistance to the applied 35 Ncm torque. One might need to wait up until reaching a certain ISQ threshold before abutment tightening at 35 Ncm. The present data might suggest that a threshold value > 49 is compatible with a 35 Ncm tightening.

Implants that displayed a high ISQi had their implant stability decrease with time as shown in figures 1 and 2. Buser et al. (1998, 1999) measured high and increasing removal torques for SLA implants after 4, 8 and 12 weeks, osseointegration was also documented in these cases (Buser et al. 1999). This confirms that the RFA method does not provide a measure of implant osseointegration (Bischof et al. in press). It evaluates a given that remains to be determined with more precision; it probably deals, like the Periostest, with the stiffness of the implant-bone complex (Truhar et al. 1994), including bone quantity and bone quality (Bischof et al. in press). It appears that there is still room to develop a non-invasive method that provides a measurement of implant osseointegration instead of implant stability.

Bischof et al. (in press) showed previously that, whatever the implant diameter and implant length, the ISQ variation over the first 12 weeks of healing was similar for the IL and DL implants. Therefore, whatever the loading protocol and implant characteristics, analysis of the dISQ over time for distinct ISQi ranges might

provide relevant data for the clinician that monitors ITI SLA implants during the healing phase. These curves should allow grading the concern when implant stability is found to decrease. Implants with an ISQi $\geq$ 70 seem not to require scrutiny when implant stability decreases but then remains stable. Implants with an ISQi in the 60-65 range might remain stable or slightly decrease without leading to a tighter follow-up. Stability of the implants that have an ISQi < 60 should increase, a decrease of the ISQ value after 6 weeks of healing should warn the practitioner to put these implants under tighter scrutiny and decide on the relevance of unloading until re-gaining stability (Friberg et al. 1999a). Or if implants are non-loaded, this should urge the practitioner to consider trauma from a removable prosthesis or consider an initiating infection and investigate it clinically and radiographically. In any case, decreasing ISQ values should warrant a tighter recall schedule, thus allowing immediate implant removal if clinical mobility is detected, hence avoiding unnecessary bone resorption.

To perform the resonance frequency analysis, a transducer is fixed to the implant. This excludes from monitoring all implants that support a cemented restoration. In our private practice, cementation has been performed for 85.4 % of the implants supporting a fixed prosthesis. Subsequently, the number of implants that might benefit from implant stability monitoring with the RFA method is limited on the long-term, i.e. after cementation of the definitive prosthesis. Screw-retained prosthesis increase notably the rehabilitation costs and unless a clear advantage for monitoring implants can be identified, the cemented solution is still the simplest

and most cost-effective approach, specially with the ITI system. In this study, implants have been immediately loaded without relying on ISQ measurements (blindly recorded to avoid any bias) but on finger pressure exerted on the implant mount. Despite the lack of a graded implant primary stability evaluation, the success rate of the IL implants at 1-year was 98.4 %, comparable to standard delayed loading protocols (Nedir et al. 2003). Although relying on a limited number of patients, this high survival rate suggests that not only full cross-arch bridges might be predictably immediately loaded (Szmukler-Moncler et al. 2000a, Esposito et al. 2003, Testori et al. 2003) but posterior short-span bridges also, provided that they are maintained out of occlusion (Szmukler-Moncler et al. 2000a, Bischof et al. in press). Nonetheless, this latter indication should be better documented before being routinely offered to a large number of patients.

In private practice, time plays a critical role, Rasmusson et al. (1999) reported that implementation of the RFA method required less than 1 minute. This suggests that the method is not time-consuming. However, temporary bridge removal and re-placement, sterilization of the transducer, preparation of the equipment and data filing were not included in this evaluation, they all increase the cost of the method. In addition, the transducer is limited to a set of 60 measurements, thus making the method rather expensive.

In conclusion, repeatability of the Osstell measurements was satisfactory. The RFA method, as a diagnostic tool, was not reliable in identifying mobile implants, however implant stability could be reliably determined for implants with an ISQ $\geq$

47. All implants with an ISQi ≥ 49 osseointegrated when left to heal for 3 months. All implants with an ISQi ≥ 54 osseointegrated when immediately loaded. For implants with low ISQi values, a decrease in implant stability should alert the practitioner to submit these implants to a tighter follow-up schedule and to take additional precautionary measurements in terms of unloading until implant stability is regained or if non-loaded to check for mechanical trauma and/or infection. For implants with high ISQi values, reduction of implant stability during the first 12 weeks of healing should be considered as a common event that should not require alteration of routine follow-up.

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**Captions**

Fig 1

Evolution of the dISQ with time in function of the ISQi. Four ISQ range groups were defined, 1) ISQ < 50, 2) ISQ 50-59, 3) ISQ 60-69, 4) ISQ > 69. The dISQ increased for the 3 first groups, while implant stability decreased for the group with ISQ > 69.

Fig 2

Evolution of the dISQ with time in function of the ISQi. The ISQ 60-69 group was divided in 2 sub-groups to determine with more accuracy the ISQi range that leads to a decrease of implant stability.

Fig 3

dISQf at 12 weeks of healing in function of the ISQi. The lower ISQi increased more than the higher ones. A medium negative correlation ($r = - 0.52$) was found between dISQf and ISQi, that was significant ($p < 0.05$).

Table 1

Implant failure analysis.

FPD = fixed partial denture

Table 2

Evaluation of the Osstell as a diagnostic tool. The S, Sp, PPV and NPV have been calculated for determining implant stability and predicting osseointegration of IL implants and DL implants.

Table 3

Implant distribution in the mandible and in the maxilla according to the defined ISQi sub-groups.

Figure 1

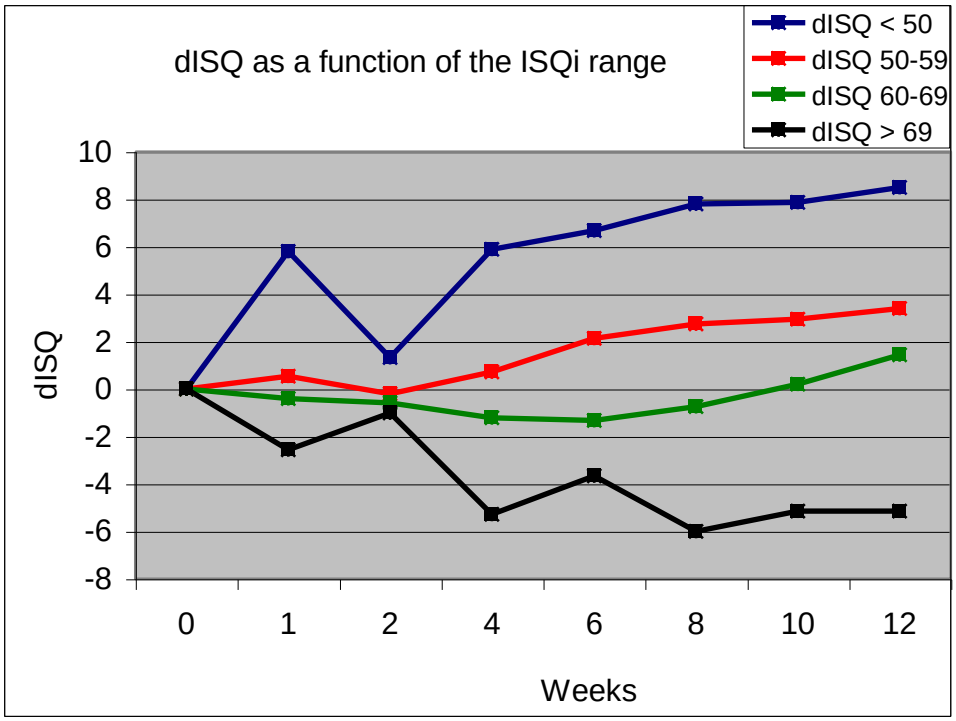


Figure 2

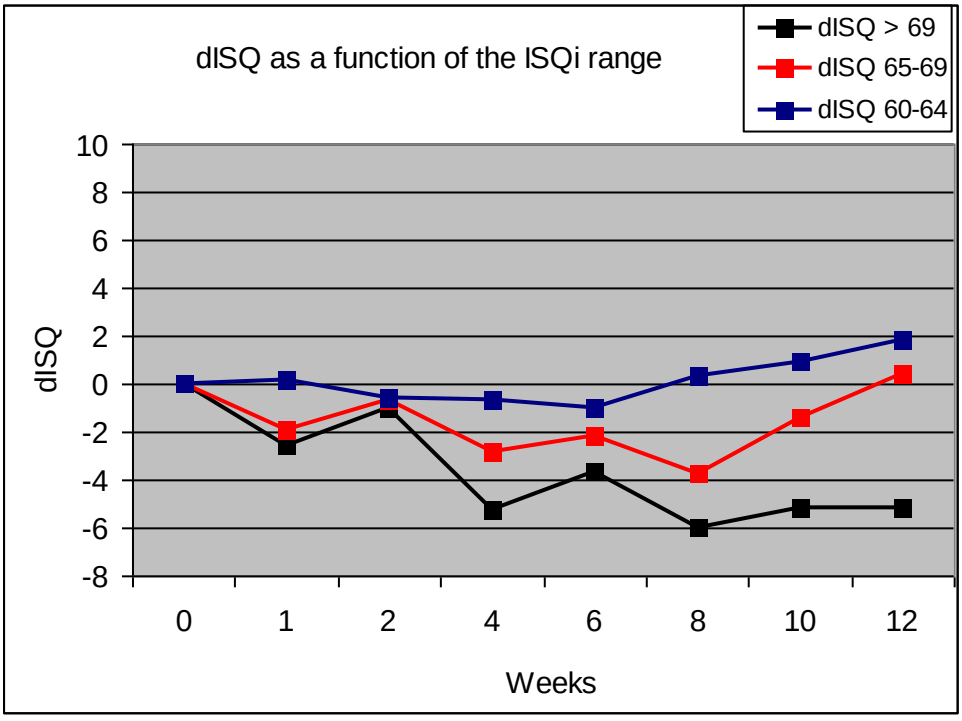

Figure 3

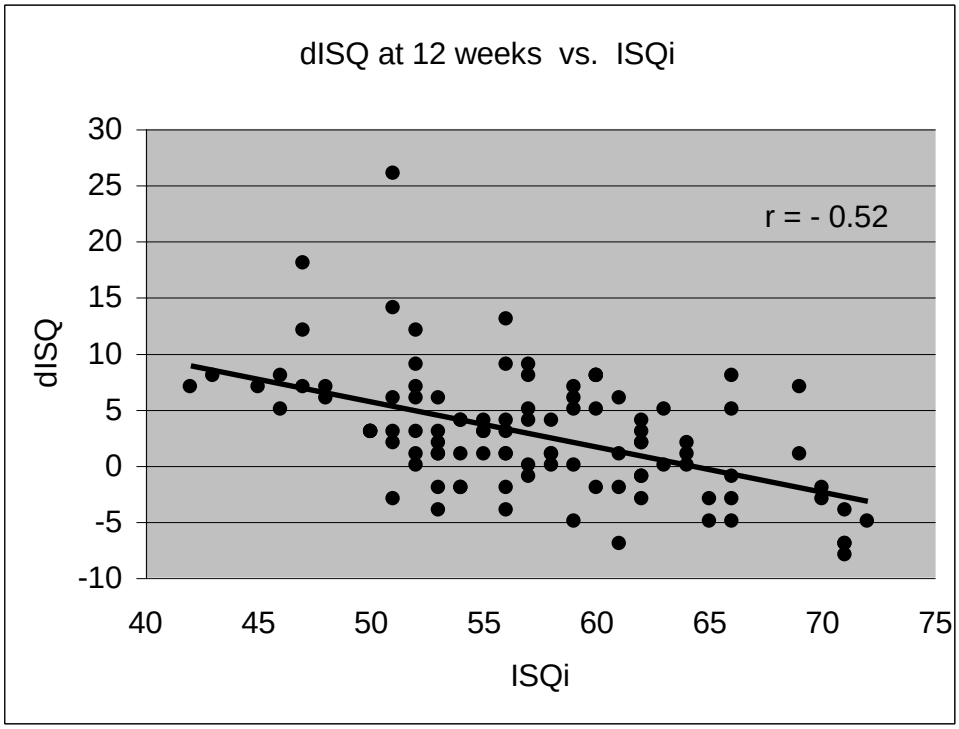


Table 1

| Group | Sex | Patient age (years) | Site | Bone type | Implant type | Implant Ø (mm) | Implant length (mm) | Rehab. type | Time of failure (weeks) | ISQi | ISQ at failure |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IL | M | 63 | 36 | 3 | SLA | 4.1 | 8 | FPD | 4 | 53 | 46 |
| DL | F | 60 | 25 | 3 | SLA | 4.1 | 8 | FPD | 2 | 48 | 43 |

Table 2

| | Diagnostic tool for determination of implant stability | Predicting osseointegration for DL implants based on ISQi | Predicting osseointegration for IL implants based on ISQi |
|---|---|---|---|
| | Cut-off ISQ = 47 | Cut-off ISQ = 49 | Cut-off ISQ = 54 |
| True positive results | 2 | 1 | 1 |
| True negative results | 742 | 37 | 40 |
| False positive results | 21 | 5 | 22 |
| False negative results | 0 | 0 | 0 |
| Sensitivity | 1 | 1 | 1 |
| Specificity | 0.973 | 0.881 | 0.645 |
| PPV | 0.087 | 0.143 | 0.043 |
| NPV | 1 | 1 | 1 |

Table 3

| ISQi interval | Number of implants | % of implants | % in the mandible | % in the maxilla | dISQf (at 12 weeks) |
|---|---|---|---|---|---|
| < 50 | n = 11 | 10.4 | 18.2 | 81.8 | 8.5 ± 3.8 |
| 50-59 | n = 58 | 53.8 | 36.8 | 63.2 | 3.4 ± 5.1 |
| 60 - 69 | n = 30 | 28.3 | 66.7 | 33.3 | 1.4 ± 4.3 |
| > 69 | n = 7 | 6.6 | 71.4 | 28.6 | - 5.1 ± 2.3 |