CLINICAL ORAL IMPLANTS RESEARCH

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Factors influencing resonance frequency analysis assessed by Osstell™ *mentor* during implant tissue integration: II. Implant surface modifications and implant diameter

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Abstract

Objectives: To monitor the development of the stability of Straumann® tissue-level implants during the early phases of healing by resonance frequency analysis (RFA) and to determine the influence of implant surface modification and diameter.

Material and methods: A total of twenty-five 10 mm length implants including 12 SLA RN ∅4.1 mm implants, eight SLActive RN ∅4.1 mm implants and five SLA WN ∅4.8 mm implants were placed. Implant stability quotient (ISQ) values were determined with Osstell™ *mentor* at baseline, 4 days, 1, 2, 3, 4, 6, 8 and 12 weeks post-surgery. ISQ values were compared between implant types using unpaired *t*-tests and longitudinally within implant types using paired *t*-tests.

Results: During healing, ISQ decreased by 3–4 values after installation and reached the lowest values at 3 weeks. Following this, the ISQ values increased steadily for all implants and up to 12 weeks. No significant differences were noted over time. The longitudinal changes in the ISQ values showed the same patterns for SLA implants, SLActive implants and WB implants. At placement, the mean ISQ values were 72.6, 75.7 and 74.4, respectively. The mean lowest ISQ values, recorded at 3 weeks, were 69.9, 71.4 and 69.8, respectively. At 12 weeks, the mean ISQ values were 76.5, 78.8 and 77.8, respectively. The mean ISQ values at all observation periods did not differ significantly among the various types. Single ISQ values ranged from 55 to 84 during the entire healing period. Pocket probing depths of the implants ranged from 1 to 3 mm and bleeding on probing from 0 to 2 sites/implant post-surgically.

Conclusions: All ISQ values indicated the stability of Straumann® implants over a 12-week healing period. All implants showed a slight decrease after installation, with the lowest ISQ values being reached at 3 weeks. ISQ values were restored 8 weeks post-surgically. It is recommended to monitor implant stability by RFA at 3 and 8 weeks post-surgically. However, neither implant surface modifications (SLActive) nor implant diameter were revealed by RFA.

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Evaluation and assessment are integral parts of post-surgical monitoring of dental implants during healing and for follow-up visits. Successful implant installation is characterized by clinical stability and achievement of a ''functional ankylosis'' (Schroeder et al. 1976), also termed ''osseointegration'' (Brånemark et al. 1997). Mechanical or primary stability may be mediated by macro-retentions or

friction of the implant in its prepared bed, while biological stability is the result of a direct bone-to-implant contact after tissue integration (Abrahamsson et al. 2004). The latter represents a prerequisite for the functional loading and long-term stability of an oral implant (Lang 2000).

In an attempt to assess primary stability objectively, various methods have been proposed, such as the Periotest® or the Dental Fine Tester. However, the latter has been criticized because of its lack of resolution, poor sensitivity and susceptibility to operator variability (Meredith 1998a, 1998b).

In recent years, resonance frequency analysis (RFA) has been introduced to provide non-invasive and objective assessments of implant stability and to monitor stability over time (Meredith et al. 1996, 1997a, 1997b; Heo et al. 1998; Rasmusson et al. 1998, 1999, 2001; Friberg et al. 1999a, 1999b; Balleri et al. 2002; Bischof et al. 2004; Huwiler et al. 2007; Kessler-Liechti et al. 2008; Sim & Lang 2010).

The original electronic RFA device used a direct connection (wire) between the transducer and the resonance frequency analyzer. The transducer was an L-shaped cantilever beam, which was connected to the implant via a screw attachment. A piezoelectric crystal on the vertical portion of an L-shaped beam was used to stimulate the implant/transducer complex; a second piezoelectric crystal on the opposite side of the beam was used as the receiving element to detect the response of the beam.

The second more recent development is a magnetic device that uses the magnetic frequencies between the transducer (a magnetic peg) and the resonance frequency analyzer. The transducer is a metallic rod with a magnet on top that is screwed onto an implant or an abutment. The magnet is activated by a magnetic pulse of approximately 1-ms duration from a wireless probe. After excitation, the peg vibrates freely, and the magnet induces an electric voltage in the probe coil. This voltage is the measurement signal sampled by the resonance frequency analyzer. The results of an RFA are expressed as an implant stability quotient (ISQ) on a scale from 1 to 100, which represents a standardized unit of stability. Generally, the ISQ has been found to vary between 40 and 80 for clinically stable implants (Aparicio et al. 2006).

Hence, RFA is believed to be a potentially useful clinical instrument for the detection of implant tissue disintegration. Because resonance frequency has been postulated to reflect the bone anchorage of the implant (Meredith et al. 1996, 1998), RFA may be applicable in the prevention, diagnosis and prediction of implant failures (Huang et al. 2002; Sjöström et al. 2005). It has been speculated that higher ISQ values indicate greater implant stability and presumably more extensive osseointegration (Barewal et al. 2003). To validate this statement, monitoring of resonance frequency should reveal the events during early healing.

While the original RF analyzer was subjected to a variety of inconsistencies, and hence yielded a wide spectrum of ISQ values within a range of normality indicating implant stability (Huwiler et al. 2007), the more recent wireless probe represented a clear improvement in assessing implant stability with higher sensitivity, robustness and reproducibility (Sim & Lang 2010). Factors influencing RFA assessments have been recently identified. The bony structure of the parent bone into which the implant was installed was the most significant factor of variability, while implant length contributed to variability in a longitudinal comparison over time to a limited extent (Sim & Lang 2010). Also, the occlusal or the lateral positioning of the probe in relation to the peg did not affect the ISQ values, while buccolingual vs. mesiodistal directional assessments appear to be a source of slight variability (Park et al. 2010). Two-directional readings may, therefore, reveal more sensitive information than one-directional readings.

If RFA is able to reveal minor differences in the extent and intensity of implant stability, modifications of implant surfaces, presumably leading to greater and faster osseointegration, should be reflected in longitudinal monitoring of the healing process.

The aim of the present study was

(1) to monitor longitudinally the development of implant stability of one-stage non-submerged Straumann® tissue-level implants of identical length applying the new magnetic RFA device Osstell™ *mentor* and

(2) to evaluate longitudinally stability changes of implants with different surface characteristics and implant diameters.

Material and methods

The present study was conducted at the Department of Periodontology and Fixed Prosthodontics, School of Dental Medicine, University of Berne, following approval by the Ethical Committee of the Canton of Berne, Switzerland. Informed consent was obtained from all patients.

Subject population

Twenty-three partially edentulous patients (nine females and 14 males; mean age: 65 years; age range: 49–86 years) seeking implant therapy were included in the study. Control of periodontal disease, if necessary, was achieved by motivation and oral hygiene instruction, initial periodontal therapy consisting of scaling and root planing and periodontal surgery, if needed.

The following *inclusion criteria* had to be met:

- unremarkable medical histories; no known allergies; and no metabolic bone diseases;
- no heavy smoking ($\geq$ 10 cigarettes/day);
- full-mouth plaque scores (FMPS) and full-mouth bleeding scores (FMBS) $>25\%$ at study baseline;
- adequate quantity and quality of native bone to achieve primary implant stability; and
- indication for the installment of a tissue-level implant of 10 mm length.

The *exclusion criteria* were:

- severe bruxism or clenching habits;
- untreated periodontitis or periapical pathology;
- heavy smoking as defined by a self-declared consumption of >10 cigarettes a day; and
- self-declared pregnancy or intention to become pregnant.

Clinical procedures

In 23 patients, a total of 25 Straumann® tissue-level implants of 10 mm length

(Straumann AG, Basel, Switzerland) were inserted according to the standard procedures. Post-operative pain and edema were controlled with Mephadolor® (500 mg tablet t.i.d. for the subsequent 7 days) and Voltaren® Rapid (50 mg tablet b.i.d. for the subsequent 3 days). Patients were instructed to rinse twice daily with 0.12% chlorhexidine digluconate and to use modified oral hygiene procedures in the treated area for the first 4 post-operative weeks (Heitz et al. 2004). No provisional denture was made during the observation period.

Clinical parameters

During implant installation, the following parameters were assessed:

- Implant position.
- Implant diameter and (10 mm) implant length. The sink depth was measured by assessing the distance from implant shoulder to alveolar crest at four aspects around the implant.
- FMPSs (O'Leary et al. 1972) and FMBSs were recorded at baseline.
- Plaque index (Silness & Löe 1964), bleeding on probing (BOP) (Lang et al. 1986) and pocket probing depths of the implant were assessed 6, 8 and 12 weeks post-operatively.
- Primary implant stability was assured clinically before flap closure. At the time of suture removal as well at every subsequent observation period before fixing the Smartpeg™ onto the implant, implant stability was checked clinically.

RFA measurements

At implant installation as well as after 4 days, 1, 2, 3, 4, 6, 8 and 12 weeks post-operatively, RFA measurements were performed applying the Osstell™ *mentor* (Integration Diagnostics AB, Göteborg, Sweden) according to the manufacturer's recommendations. A Smartpeg™ for Straumann® implants was screwed onto the implants (Fig. 1). For any individual implant, the measurements were performed with the probe detecting from three different directions (e.g. from buccal, lingual and distal directions) at each observation time point. All the three ISQ values were recorded and used as a mean value for statistical analysis.

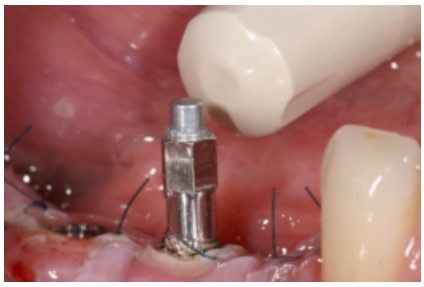

Fig. 1. Positioning of the Smartpeg™ of Osstell™ *mentor* immediately after implant installation applying a lateral positioning of the instrument (probe).

Radiographs

Before surgery, a radiographic examination was carried out by obtaining periapical radiographs and orthopantomograms. Periapical radiographs were also obtained immediately after implant installation and at cementation of the restoration.

Statistical analysis

The patient was considered as a statistical unit. The SPSS version 16 statistical software program (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Individual implant means were calculated for ISQ values. The Levene test was used to test for normality of distribution of the data. Because the data were normally distributed, ANOVA was performed for the longitudinal comparison of ISQ values and the differences in ISQ values between the SLA RN (⌀4.1 mm) implants, SLActive implants and the wide-body (⌀4.8 mm) implants, respectively. For multiple comparisons, *LSD tests* were used. The level of significance was set at $\alpha = 0.05$.

Results

A total of 25 implants were inserted in 23 patients including 12 SLA RN implants with a standard diameter of 4.1 mm, eight SLActive RN implants with a standard diameter of 4.1 mm and five SLA WN implants with a wide-body diameter of 4.8 mm. Two randomly selected SLA RN implants were excluded from the study to match the concept of one implant per patient being included in the study. The placement and implant characteristics are described in Table 1.

The post-operative wound healing of the implants was uneventful. Clinical monitoring at 6, 8 and 12 weeks post-surgically showed that probing depths of the implants ranged between 1 and 3 mm. BOP of the implants ranged between 0 and 2 surfaces/implant. Plaque scores (FMPS) were <20% in all patients. All implants were clinically stable, and no mobility was present. All were considered as successful implantations throughout the 12 weeks of the study.

The mean ISQ values obtained at each time point are presented in Table 2. The differences in the ISQ values among SLA RN implants, wide-body implants and SLActive implants did not reach statistical significance for any of the observation periods.

SLA RN 4.1-mm-diameter implants

At implant installation, the ISQ values ranged from 64 to 78, with a mean value of 72.6 (SD ± 4). The longitudinal development of the ISQ values of the SLA RN 4.1-mm-diameter implants is depicted in Fig. 2. The mean ISQ values were unchanged at baseline, 4 days and 1 week, and then decreased to a mean value of 71.5 at 2 weeks. The mean lowest value of 69.9 was reached at 3 weeks and at 4 weeks (70.2). Following this, the mean ISQ values increased to 73.8 and 75.2 at 6 and 8 weeks, respectively. Between 8 and 12 weeks, the mean ISQ value increased to 76.5. However, for the one-factor ANOVAs, no significant mean differences across time were observed ($P = 0.15$). These longitudinal changes in the mean ISQ values represented variations within a range of means of 69.9–76.5.

SLActive implants

At implant installation, the individual ISQ values ranged from 65.3 to 81.3, with a mean value of 75.7 (SD ± 5.4). The longitudinal development of the RFA of the SLActive implants is depicted in Fig. 2 as well. It shows that the mean ISQ values of the SLActive implants decreased to 72.8, 73.4 and 72.7 after 4 days, 1 and 2 weeks, respectively. At week 3, again, a lowest value of 71.4 was reached. Following this, the mean ISQ values increased to 73.5, 75.2, 76.2 and 78.8 at weeks 4, 6, 8 and 12, respectively. However, for the one-factor ANOVAs, no significant mean stability differences across time were observed ($P = 0.082$). These longitudinal changes in the mean ISQ values represented variations within a range of means of 71.4–78.8.

Table 1. **Information about the implants placed ($n = 23$ evaluated patients)**

Jaw implanted		Implant position		Implant surface		Implant diameter (mm)		Implant length (mm)		
Maxilla	Mandible	Posterior	Anterior	SLA	SLActive	4.1	4.8	8	10	12
11	12	22	1	15	8	18	5	8	12	3

Table 2. **Mean ISQ values of the three groups at each time point**

Time	SLA RN ($n = 10$)		SLActive ($n = 8$)		WB ($n = 5$)		Significance
	Mean	SD	Mean	SD	Mean	SD	
Baseline	72.6	4	75.7	5.3	74.4	7	0.426
4 days	72.3	3.4	72.8	5.7	70.4	8.7	0.765
1 week	72.7	4.9	73.4	4.5	71.9	5.7	0.862
2 weeks	71.5	6.6	72.7	6.5	70.8	8	0.874
3 weeks	69.9	6.1	71.4	5.2	69.8	6.7	0.834
4 weeks	70.2	7.1	73.5	4.6	72.9	7.5	0.495
6 weeks	73.8	6.8	75.2	3.1	75.4	4.3	0.806
8 weeks	75.2	5.7	76.2	2.7	76.9	4.4	0.77
12 weeks	76.5	6.5	78.8	3.2	77.8	4.6	0.664
Significance	0.15		0.082		0.513		

ISQ, implant stability quotient.

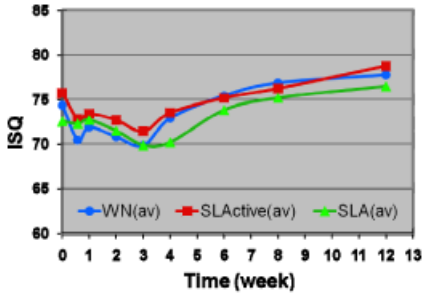

Fig. 2. Diagram visualizing the mean (av) ISQ values for all the three types at all observation periods: blue WN: wide-neck (diameter 4.8 mm) SLA Straumann® implants ($n = 5$), red SLActive: regular neck (diameter 4.1 mm) chemically modified SLA Straumann® implants ($n = 8$) and green SLA RN: regular-neck (diameter 4.1 mm) SLA Straumann® implants ($n = 10$).

Wide-body 4.8-mm-diameter implants

At implant installation, the individual ISQ values ranged from 65.3 to 81.3, with a mean value of 74.4 (SD ± 7). The longitudinal development of the RFA of the wide-body 4.8-mm-diameter implants is also depicted in Fig. 2. The mean ISQ values of the wide-body (∅4.8 mm) implants decreased to 70.4, 71.9 and 70.8 after 4 days, 1 and 2 weeks, respectively. At week 3, again, the lowest value of 69.8 was reached. Following this, the mean ISQ values increased to 72.9, 75.4 and 76.9 at weeks 4, 6 and 8, respectively. From 8 to 12 weeks, the mean ISQ value increased to 77.8. However, for the one-factor ANOVAs, no significant mean stability differences across time were observed ($P = 0.513$). Again, these longitudinal changes in the mean ISQ values represented variations within a range of means of 70–78.

From Fig. 2, it is evident that the overall patterns of change in mean the ISQ values during early healing for the three groups of implants were consistent. The mean ISQ values decreased for both SLActive and WB implants by values of approximately 4.5 from 4 days to 3 weeks and increased for both implant groups by about 7.7 from 3 to 12 weeks. The mean ISQ values decreased for SLA implants by about 2.7 from 4 days to 3–4 weeks and increased by about 6.6 from 3–4 weeks to 12 weeks.

Cross-sectionally, there were no statistically significant differences in the mean ISQ values between any of the three implant types at any observation period.

Discussion

The development of clinical, preferably non-invasive diagnostic instruments with high sensitivity and reproducibility to detect early changes in implant stability during tissue integration of dental implants was desirable in the light of the propagation and the increasing popularity of implants placed immediately into extraction sockets and/or early loading protocols. In this respect, RFA appeared to present several promising applications, such as the determination of an adequate healing period as a result of a proper bone-to-implant interface sufficient to carry a functional load (Rasmusson et al. 1999, 2001; Rocci et al. 2003).

It has been suggested that RFA is related to the stiffness of the implant in the surrounding bony tissues, and this should correspond to histological results (Gedrange et al. 2005). In viable bone, stiffness also depends on the time of healing, because bone forms and remodels toward the implant surfaces as a result of the osseointegration healing process (Abrahamsson et al. 2004). Hence, an increase in implant stability values with time may probably reflect bone apposition and remodeling in the implant–bone interface.

The purpose of this study was to evaluate the longitudinally stability changes of implants with different surface characteristics and implant diameters applying the novel magnetic RFA device Osstell™ *mentor*. The results of the present study indicated that a normative ISQ range appeared between 64 and 81 at the time of implant installation. During the incorporation phase of the implants up to 12 weeks, the ISQ values varied slightly within the range of values that were encountered at the time of implant installation. The lowest ISQ value found for an individual implant was 55 and the highest ISQ value was 84.

These results are in agreement with a number of other clinical studies. In one study, RFA yielded a mean ISQ value of 68, a value that was indicative of achievement of high primary implant stability (Glauser et al. 2004). In another study, a cut-off ISQ value for adequate implant stability of ISQ ≥ 47 was proposed to indicate implant stability (Nedir et al. 2004). Furthermore, ISQ values for successfully osseointegrated implants varied between 57 and 82, with a mean of 69 after 1 year of loading (Ersanli et al. 2005). Moreover, various ISQ values have been presented for implants in the maxilla and in the mandible (Balleri et al. 2002; Barewal et al. 2003; Bischof et al. 2004; Balshi et al. 2005).

A recent, well-controlled animal study related ISQ values obtained during early tissue integration to the direct bone-to-implant contact as revealed in sequential histological preparations (Abrahamsson et al. 2009). The ISQ values from 2-h post-implant installation to 4 days, 1, 2, 4, 6, 8 and 12 weeks post-installation varied very little and were between 59 and 64. They failed to correlate with histological parameters for osseointegration and hence were not suitable to predict the period of adequate osseointegration for an implant to be functionally loaded. Neither were ISQ values able to identify the bone maturation process from woven bone to parallel fiber, lamellar bone. Moreover, RFA was not successful in determining the histologically well-documented difference in bone-to-implant contact over time between a turned and a moderately rough (SLA) implant surface. Hence, the correlation between the quality of osseointegration and RFA remains unclear (Abrahamsson et al. 2009).

As mentioned before, RFA is supposed to reflect the stiffness of the implant in the surrounding bone, even though it may not represent a true value for bone-to-implant contact. As such, a few aspects may affect the normative ISQ values.

Although some of these factors, such as bone morphology of the surrounding alveolar process and implant length, have been studied in a recently published report (Sim & Lang 2010), the present study evaluated the ISQ values during early osseointegration of two implant surface chemistries and two different diameters of implants with identical brand, length and configuration. Both bone morphology and implant length affected the ISQ values significantly, while the direction of the application of the probe on the magnetic peg did not (Sim & Lang 2010). Bone density and cortical bone thickness were also identified as influencing factors in a recent animal study (Su et al. 2009). In the present study, only implants of the same length were installed. Furthermore, the bone morphology of the recipient sites corresponded for almost all implants to Type II rather than Type III or IV (Lekholm & Zarb 1985). This, in turn, means that a standardized situation allowed an assessment of the two variables tested in the present study.

In analyzing the mean ISQ values for various observation periods, it was evident that all implants yielded a decrease in ISQ values within the first 3 weeks after installation. Both WB (∅4.8 mm) and SLActive implants reached the lowest value at 3 weeks, while for SLA RN implants, this was identified both after 3 and 4 weeks. Following this, the ISQ values increased to values observed previously at the time of implant installation and beyond. From 8 to 12 weeks, the incremental increase in ISQ values was smaller and they remained in a steady state.

The initial decrease in the ISQ values within the first 3 weeks is in agreement with the results of other studies (Barewal et al. 2003; Crismani et al. 2006; Huwiler et al. 2007; Valderrama et al. 2007). These findings suggest the existence of an interval between primary and secondary stability during which the mobility of the implant may increase. Using a bone chamber model (Berglundh et al. 2003) and studying the sequence of wound healing events surrounding dental implants, it was demonstrated that in areas of primary mechanical stability at the pitch of the implant threads, osseointegration first occurred after bone resorptive processes, thereby dismantling mechanical stability for a short period of time. This, in turn, means that bone resorptive processes will yield to bone appositional processes during early healing phases (Abrahamsson et al. 2004).

After installing dental implants into a prepared bony implant site, primary stability of the implant obtained during surgical placement is purely mechanical in nature (Cochran et al. 1998). Blood clots in the spaces between the implant surfaces and the pristine bone, and the organization of an early granulation tissue after 4 days are observed. On a moderately rough (SLA) surface, this tissue will give rise to contact osteogenesis (Davies 1998) with an ''osteocoating'' of the implant surfaces, thereby starting the processes of biological stability. During the first weeks of healing, bone modeling and remodeling take place adjacent to the implant surface. Subsequently, the woven bone opposite to the implant surface will remodel to form, in the first 2–4 weeks, a functionally oriented parallel-fiber bone within an osteogenic implant surface (Abrahamsson et al. 2004). It may be speculated that the decrease in the ISQ values within the first 3 weeks represented relaxation of the primary stability as a result of biological changes associated with early bone healing (Glauser et al. 2003). Subsequently, the process of osseointegration documented by contact osteogenesis in animal studies after 2–4 weeks (Abrahamsson et al. 2004; Cornellini et al. 2004) and the maturation of bone into lamellar bone, thus providing secondary implant stability may be reflected in the increased ISQ values during the latter phase tissue integration.

In the present study, the results for both implant diameters (∅4.1 mm and ∅4.8 mm) and for both surfaces (SLA and SLActive) were analyzed separately. The longitudinal changes of the ISQ values presented similar patterns for SLA RN implants, SLActive implants and WB implants. Moreover, the range of ISQ values during all observation periods did not differ significantly among the three types of implants. This, in turn, means that the implant diameter is not a significant factor affecting ISQ values. This is in agreement with a previous study (Bischof et al. 2004), which demonstrated that implant diameter did not contribute to the variability of ISQ values during the first 12 weeks. However, the results of the present study do not agree with a postulated notion of a larger bone-to-implant contact resulting in improved implant stability by the use of wider diameter implants (Langer et al. 1993; Renouard et al. 1999; Polizzi et al. 2000).

The results of the present study also failed to document significant differences in ISQ values between SLA and SLActive (SLA: sandblasted, acid etched vs. SLActive: chemically modified sandblasted, acid etched) implants at any of the observation periods.

This is in agreement with a recent study (Valderrama et al. 2007) in which ISQ values of 17 SLA implants and 17 SLActive (Straumann®) implants were monitored over 12 weeks. In that study, the type of implant surface did not reveal any significant differences in ISQ values either in early healing or over time. It may be speculated that either no differences exist in the extent of implant stability between the two implant surfaces in the early phase of healing or that the RFA may not be sensitive enough to detect minute differences. Moreover, the possibility of underpowered studies has to be realized.

Certainly, the sample size of the present study was not calculated to specifically compare the two Straumann® surfaces, because no comparative data are available from previous studies.

In summary, the results of the present study indicated ISQ values in the range of 55–84 representing homeostasis and implant stability during healing. The longitudinal changes of the ISQ values showed almost the same patterns for SLA RN, SLActive and WB (Straumann®) implants. The range of ISQ values during all observation periods did not differ significantly among these three types of implants. All implants yielded a decrease in ISQ values after installation, and the lowest ISQ value was obtained at approximately 3–4 weeks post-surgically. ISQ values were recovered at 8 weeks post-surgically. Hence, it is suggested that RFA be performed at implant installation, 3 weeks post-surgery and at 8 weeks post-surgery before taking an impression in order to monitor functionality and successful tissue integration of dental implants.

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