ORIGINAL ARTICLES

DAMPING CAPACITY ASSESSMENT VERSUS RESONANCE FREQUENCY ANALYSIS IN THE DETERMINATION OF DENTAL IMPLANT STABILITY

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REZUMAT
Acest articol îşi propune să facă o trecere în revistă a studiilor clinice referitoare la rolul capacităţii de amortizare (tehnica Periotest) şi analizei frecvenţei de rezonanţă (tehnica RFA) în determinarea stabiliteii implantelor dentare şi în detectarea celor cu risc de mobilizare. Ambele tehnici de investigare sunt metode de testare intraorală non-invazivă şi sunt influenţate de parametri ca densitatea oselor maxilare, inserarea implantelor la maxilar sau mandibulă, lungimea stâlpului implantar sau înălţimea porţiunii supracrestale a implantului. Rezultatele studiilor sugerează că valori ridicate înregistrate prin tehnica RFA şi scăzute înregistrate prin tehnica Periotest indică implant dentare cu o evoluţie favorabilă, în timp ce valorile scăzute/in scădere ale tehnicii RFA sau valorile ridicate/in creştere ale tehnicii Periotest indică pierdere de os marginal perimplantar. Totuşi, măsurările singulare, folosind oricare dintre cele două tehnici, au o valoare clinică limitată. Datorită volumului limitat al cercetării ştiinţifice pe acest subiect, este nevoie de mai multe studii clinice care să investigeze valoarea de prognostic a tehnicilor RFA şi Periotest, în detectarea pierderii în timp a stabilităţii implantare.

Cuvinte cheie: stabilitate implantară, Periotest, analiza frecvenţei de rezonanţă, interfaţa implant-os

ABSTRACT
This paper presents a review of the clinical literature on the damping capacity assessment (Periotest technique) and resonance frequency analysis (RFA technique) in the determination of dental implant stability and the prognostic value of each technique to detect implants at risk for failure. Both techniques are non-destructive intraoral testing methods and seem to be influenced by factors such as bone density, implant insertion on upper or lower jaw, abutment length and supracrestal implant length. Data suggest that high RFA and low Periotest values indicate successfully integrated implants and that low/decreasing RFA and high/increasing Periotest values indicate marginal bone loss. However, single readings using any of the techniques are of limited clinical value. Due to the limited number of clinical reports found, the prognostic value of the RFA and Periotest techniques in predicting loss of implant stability has yet to be established in more clinical studies.

Key words: implant stability, Periotest, resonance frequency analysis, implant-bone interface

INTRODUCTION

The resonance frequency analysis (RFA – using the Osstell™ device) and the damping capacity assessment (Periotest™ technique) are the non-destructive intraoral testing methods for assessing implant stability. Another technique – the insertion torque measurements – only assess conditions at the time of implant insertion.¹

One of the most important parameters for the short- and long-term clinical functioning of an implant is considered to be the development of a firm implant-bone interface.² The contact between bone and implant surface and its characteristics are influenced by the different implant geometries and surfaces as well as various host site conditions.²
Although the technical approach to implant stability of each device (Osstell™ and Periotest™ instruments) differs substantially, both methods seem to be useful in the long-term follow-up of dental implant integration. From the peri-implant bone loss point of view, it can be stated that the techniques are both suitable to detect a decrease in implant stability.

Today, RFA is frequently used in clinical research to monitor implant stability. The RFA technique may detect bone loss earlier than Periotest™ method. Due to its higher reproducibility, RFA has replaced, in some cases the Periotest™ technique, which has been developed for a similar purpose. It is known that, at this moment, it is not recommended to entirely rely on Periotest™ or RFA measurements against radiographic diagnosis of the peri-implant bone situation follow-up.

The destructive methodologies, such as removal torque assessment, pullout and pushout techniques, may be of value as research techniques, but they are of limited value in clinical use, owing to ethical concerns associated with the invasive nature of such methodology.

The aim of this article is to define and characterize the RFA and Periotest™ techniques as methods for testing the implant/bone interface and to analyze their validity, clinical significance and prognostic value for assessing implant stability.

Resonance Frequency Analysis

Resonance frequency analysis (RFA) is a non-invasive and non-destructive quantitative measurement of implant integration by assessing changes in implant stability over time. RFA measurements have documented healing changes along the implant–bone interface by measuring the increase/decrease in stiffness of the implant/bone interface. RFA also has been used to determine whether implants are sufficiently stable to receive the final restoration or to be loaded and to identify “at-risk” implants.

RFA was first proposed by Meredith et al. (1996). The original electronic technique used an L-shaped transducer that was screwed to an implant or its abutment and a direct connection (wire) between the transducer and the resonance frequency analyzer. The transducer beam was then excited over a range of frequencies, from 5 to 15 kHz. A frequency response analyzer subsequently analyzed the response of the beam. At the first flexural resonance of the beam, there was a marked change in amplitude and in phase of the received signal. The resonance frequency can thus be identified in a plot of frequency (Hz) against amplitude (V).

At the beginning, prototype instruments used in a number of studies indicated the results in Hz. One disadvantage of the technique is the fact that each transducer has its own genuine RF and that the RF of the same implant varies between transducers. A linear relation was found between abutment length and RF, and measurements with different transducers and implants with different abutment lengths have to be calibrated before submitting the data to statistical analysis.

The first commercial version of the RFA technique (Osstell™, Integration Diagnostic AB, Göteborg, Sweden) used transducers that were calibrated by the manufacturer. Before performing RFA, a registration of the implant length was needed. RF measurements were now expressed as the implant stability quotient (ISQ) with values from 1 to 100. These are based on the underlying and calibrated RF of the transducer used.

More recently, the commercial instrument was modified; it is now wireless and makes use of a magnetic peg – Smartpeg – attached to an implant or abutment (Mentor™, Integration Diagnostic AB, Göteborg, Sweden) (Fig. 1). The peg is excited and the RF is expressed electromagnetically as ISQ units (the magnetic pulse technique).
values (PTVs) on a scale of −8 (low mobility) to 50 (high mobility).

The technique has also been used to determine implant mobility, and typical values obtained were defined as ranging from −5 to +5, thus representing a narrower range over the scale of the instrument than for tooth mobility measurements. A stable implant will exhibit different stiffness characteristics compared with those of teeth that are connected by a periodontal ligament.

Figure 2. The Periotest™ instrument and its working principle.

MATERIAL AND METHODS

An online search for studies in English language was performed, using Medline and PubMed data bases, focusing on high level evidence publications. We found 214 papers, from 1983 to 2008, based on the following search terms: implant stability, implant mobility, periosteal, resonance frequency analysis.

From the 214 papers that matched the criteria, only 54 most relevant were selected and reviewed (20 on RFA, 30 on Periotest and 4 on both RFA and Periotest techniques).

RESULTS

For the RFA Technique

Resonance frequency (RF) was determined by the stiffness of the bone–implant complex as demonstrated by performing repeated measurements of implants placed in self-curing resin. A linear relationship was found between exposed implant heights, which indicated that vertical implant placement, marginal bone height/loss and abutment height influence RF.10

Measurements of 56 implants in the maxilla of nine patients demonstrated an increase of RFA values from placement to abutment connection for all but two implants, that were judged as having failed.10 Moreover, measurements of 52 implants in this nine patients after at least 5 years in function in the maxilla revealed a significant relation between effective implant length (abutment length and bone loss) and RF, indicating an increase in stiffness of the bone–implant complex with time, except for the implants that failed.

A correlation between cutting resistance at implant placement and primary RF values was reported for maxillary implants. Repeated measurements indicated that all implants reached similar RF values at abutment connection and after 1 year of loading, irrespective of initial stability at the time of insertion.14

In a study on one-stage implants in dense mandibular bone, RFA showed small changes over a 15-week period of time. A small and significant decrease in RFA values was observed. However, this could be explained by marginal bone loss and an increase in effective implant length.7

More recently, some studies using the Osstell™ technique have demonstrated higher stability in maxillary than in mandibular bone.8,15-19

A correlation was observed between bone quality (Lekholm & Zarb index 1985) and ISQ values in some studies,16,17,19 while other studies failed to demonstrate such a correlation.20

The influence of gender, implant diameter and implant location on RFA values was documented as well19. In that study, decreasing ISQ values were recorded with increasing implant lengths, which may be explained by the fact that long implants may have a reduced diameter in the coronal direction. In a study with 106 ITI implants placed in mandibular and maxillary bone, implant position, length, diameter and vertical position (sink depth) did not affect the ISQ values.16

It has been postulated that implants with low ISQ values yielded more marked increases in ISQ values with time than implants with high ISQ values,7,8,14,16,21-23 indicating that differences in RFA values between implants may diminish with time. It may be speculated that similar bone densities will result with time as a consequence of remodelling and adaptation to function.

Studies on one-stage and immediately loaded implants have demonstrated an initial decrease of ISQ values that appeared to increase within the following 2–3 months,8,15,17 reflecting changes in the bone/implant interface during the process of osseointegration.24
A relation between marginal bone loss and RFA was observed for mandibular implants, and changes in ISQ values were reported between implant insertion and a 6-month follow-up, but not between the 6- and the 12-month follow-up.25

Results for the Periotest Technique

Inter-operator and inter-instrument variability has been studied extensively.26,30 A linear relationship between contact time and PTVs resulted for implants assessed in vitro and in vivo, indicating the robustness of the instrument.26,33

Both in vitro and in vivo studies indicated a linear relationship between the vertical distances from the striking point to the first bone contact on the PTVs. It was, therefore, concluded that single Periotest™ measurements do not allow any prognosis for the stability of an implant, but that an individual implant may and should be measured repeatedly during follow-up.29,33,34

A mathematical model illustrating the effect of various geometric and clinical parameters on the PTV was developed. This model was validated in an in vitro experiment.35 The results showed that PTVs were sensitive to the position on which the Periotest™ impacted on the abutment and hence, depended on the angulations of the hand piece. A change in position of 1 mm in striking height may produce a difference in PTVs between 1 and 2.26,36-38 As the outcome of Periotest™ measurements is influenced by the distance from the striking point to the first bone contact, it is evident that the placement of the implant in vertical dimension, abutment height, the level of marginal bone loss and the striking position on the abutment-implant are critical factors for accuracy and/or reproducibility. Clinical studies using various implant systems have demonstrated significantly lower PTVs in mandibular than in maxillary bone, indicating higher stability in the former than in the latter location.36,39-41

A relation between marginal bone loss and RFA was postulated by some authors,42 others only described this for the maxilla26,36,37,41 and another group of authors did not find any correlations.38,44,45

Evaluating four different implant surfaces in an animal model, neither a correlation between PTVs and marginal bone height nor between PTVs and bone contacts as determined histologically was found.40 A comparison between screw-shaped implants subjected to excessive occlusal load and implants subjected to plaque accumulation in primates led to the result that some, but not all excessively loaded implants showed signs of clinical mobility while all implants with plaque accumulation were stable after 18 months. The PTVs correlated with the marginal bone loss and degree of bone–implant contact. However, for the clinically stable implants, no correlation could be demonstrated.47

The Periotest™ instrument was also evaluated to measure implant mobility in a controlled in vitro model.48 The range of mobility as determined by the Periotest™ instrument in vivo was –6 to +2. The authors concluded that clinically stable implants were not completely immobile as revealed by PTVs, but yielded a range of mobility.

Time elapsed since implant insertion appears to influence implant stability. This is sustained by the fact that lower PTVs are usually encountered with increasing time of follow-up.26,37,38,40,44,49,50 Decreasing PTVs were observed up to the fifth year of follow-up for 213 mandibular implants used for the retention of overdentures. This was interpreted as ongoing remodelling and stiffening of the interface following implant placement.40

Discussion

RFA Technique

To monitor the outcome of implant insertion and determine the prognostic value of RFA in predicting loss of implant stability, 75 one-stage implants in the edentulous mandible were evaluated over time.7 One implant showed decreasing ISQ values from 2 to 15 weeks, the observation time at which clinical mobility was evident. Another patient within the same study yielded three of five implants that showed a dramatic decline in ISQ values from 2 to 6 weeks postoperatively, when the implants were loaded with a relined denture. Unloading of these implants resulted in recovery of two and maintained stability of one implant. Hence,
the results seemed to indicate that RFA might identify the loss of implant stability.

A more recent study (2007) assessed ISQ values at the time of implant insertion of ITI implants (Straumann, Basel, Switzerland) and at 1, 2, 3, 4, 5, 6, 8 and 12 weeks thereafter. One implant lost clinical stability after 3 weeks. At this time, the ISQ had declined significantly from 70, 69 and 68 to 45. However, the loss of clinical stability was coincidental to the low ISQ, but not to be predicted by RFA. In the remaining 16 implants of identical length, sink depth and diameter in nine patients, the ISQ at the time of placement did not correlate with a micro-CT analysis of the bone density or the bone trabecular connectivity of the parent jawbone. ISQ values decreased slightly after 2–4 weeks and increased thereafter to the levels of the time at implant insertion or higher, reflecting the changes observed at the bone/implant interface during the process of osseointegration. It has to be noted that in the reported study, the numerical value of the implant having lost stability after 3 weeks (ISQ=45) was only marginally outside the range of the ISQ values reported for all the other implants at all observation periods.

In a longitudinal study on immediate loading, RFA was performed on 72 stable implants and compared with nine implants that had lost stability during a period of 1 year. Both groups of implants showed a high degree of initial stability documented by an ISQ=70. The implants losing stability showed a continuous decrease in ISQ values until clinical failure was evident. The mean ISQ value was statistically lower for the group with implants having lost stability (ISQ=52) than for the group with stable implants (ISQ=68). The lower the ISQ value was after 1 month of immediate loading, the higher was the risk for future loss of stability. The risk for loss of stability was 18.2%, if ISQ values were between 49 and 58.

In a study on implant stability in grafted maxillae, only a tendency towards lower initial ISQ values was found for 17 implants that lost stability during the study (ISQ=54.6) compared with 195 implants that remained stable (ISQ=62).

Comparing immediately loaded ITI implants with implants loaded after 3 months of healing, the RFA technique was judged to be an unreliable methodology for the identification of mobile ITI implants. However, implant stability was reliably determined for implants with an ISQ>47. The insensitivity of detecting unstable implants was explained by the nature of the RFA technique, which appears to determine stability as a function of stiffness. Mobile implants display extremely low stiffness and hence, the first resonance frequency may not be identifiable, resulting in false increased ISQ values, that may correspond to the second resonance frequency.

A prospective pilot study was done in order to investigate differences in changes in implant stability and crestal bone height, between loaded and unloaded dental implants, at four months after placement. In the test group, 20 implants were placed in the anterior region of the mandible, in 10 patients. They were connected with a Dolder bar within 10 days and placed into function immediately. In the control group, 21 implants were placed in the anterior region of the mandible, in a 2-stage procedure, in 12 patients. In both groups, measurements of the RF were made at the time of placement and repeated 4 months after placement.

In the early loading group, the mean change of ISQ was $-0.08 \pm 0.77$ and the mean bone loss was $0.69 \pm 0.15$ mm. In the unloaded group, the mean change in ISQ was $1.33 \pm 1.65$ and the mean bone loss was $0.53 \pm 0.18$ mm. There was no statistically significant difference across the 2 treatment groups. When gender was included as a factor, the changes in stability and bone loss were statistically smaller among female than among male patients.

The absence of differences in implant stability found between the 2 treatment groups or over the 4-month period within either group is inconsistent with other studies, where a slight decrease in stability for the majority of 75 machined Brånemark implants, placed in anterior mandibles with high bone density was found. When using 127 implants in 20 patients, it was showed that, when the primary stability is high at placement, the ISQ is more likely to be stable over time. These differences may be a result of different types and designs of implant used, or may simply reflect the small sample size that was used in each study.

The lack of published normative values or baseline data for ISQ makes comparisons difficult. However, it is useful to compare changes in bone-implant interface stiffness over time. The ISQ values provided by the Osstell™ instrument are determined by the stiffness of the bone-implant interface and by the distance from the transducer to the first bone-implant contact (reflecting any change in bone level). Consequently, to know whether a change of ISQ over time is the result of bone loss, a change in the bone-implant interface or a mixture of both, the change in bone height needs to be known. However, since there is no published standard or ratio between bone loss and ISQ, it is not possible to know if the changes in ISQ are the result of bony crest changes or of a change in the interface stiffness. Thus, the only conclusion that can be drawn from this study is that
early loading does not adversely affect the stability of
dental implants placed in dense bone.52

**Periotest Technique**

Evaluating PTVs of eight implants that lost
stability after prosthesis placement, six of eight
implants showed PTVs of +4 or higher as determined
at the time of abutment connection. All eight implants
demonstrated PTVs from +13 to +30 at the time of
loss of stability. Nine other implants with high initial
PTVs (+3 to +8) were left unloaded for at least 4
months. This resulted in a decrease of PTVs (final
measurements were from 0 to +5). In addition, two
cases demonstrated high PTVs at the time of loss of
implant stability. Derived from single case reports, the
data suggest that high PTVs at abutment connection
may indicate questionable osseointegration and may
suggest increased risk for loss of stability if loaded.
However, the level of evidence remains anecdotal and
precludes the prognostic value of the Periotest™.38

When evaluating PTVs of four different implant
systems after an average of 22.5 months after
placement, 14 of 204 implants lost stability, with all
those yielding positive PTVs. Also, significantly higher
PTVs were found than for stable implants, except for
the ITI implants in the maxilla.41

In a sequential study on 40 patients, evaluating
PTVs after implant abutment connection, prosthetic
impression, placement of the prosthesis and 6 and
12 months after occlusal loading, The Periotest™
instrument was able to identify 64% of the non-
integrated implants at abutment connection and
12 months after occlusal loading. However, PTVs
recorded at abutment connection failed to predict
loss of implant stability at 12 months of functional
loading.53

In an attempt to validate PTVs and other clinical
and radiographic parameters for the detection of
alveolar bone loss around 32 cylindrical implants
in 16 patients, it was demonstrated that radiographs
disclosed pathological loss of alveolar bone at the
bone–implant contact area, while other parameters
including Periotest™ assessments did not.54

**CONCLUSIONS**

1. Although extensively used in clinical research
as one parameter to monitor implant stability,
it has to be realized that RFA is affected by
factors such as bone tissue characteristics
and implant sink depth, diameter and surface
characteristics.
2. Research indicates that implants yielding high
ISQ values during follow-up appear to maintain
stability. Low or decreasing ISQ values may
indicate a developing instability.
3. No established normative range of ISQ
values is available as yet. Consequently, a
single determination of the ISQ value does
not define bone/interface characteristics or
provide a quantitative evaluation of bone
tissue integration.
4. At the present time, the prognostic values for
developing implant instability and the validity
and relevance of RFA for clinical use have to
be questioned. Further research is needed to
establish threshold ranges for implant stability
and for implants at risk for losing stability, for
different implant systems.
5. Although the Periotest™ instrument has
been extensively evaluated in experimental
and clinical research, prognostic value to
detect loss of implant stability cannot be
documented. A variety of factors, such as the striking position (abutment length,
supracrestal implant length) and location
within the jaw (mandible/maxilla), have been
shown to influence the PTVs.
6. It is evident that negative PTVs indicate stability of
implants, while high and positive PTVs may
suggest loss of stability. Such increases in PTVs
are often realized after the fact, indicating a
high specificity of the Periotest™, but a low
sensitivity.
7. Owing to a variety of factors, the
reproducibility of assessments is questionable.
Single readings of Periotest™ determinations
are of limited clinical value and have not
been demonstrated to reflect the nature of
the bone/implant interface. By performing
repeated measurements of the same implant
over time, implant stability may be confirmed.
8. The Osstell instrument seems to be more
precise than Periotest, whose values appear to
be more susceptible to clinical conditions.

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