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Measurement of Dental Implant Stability by Resonance Frequency Analysis— Review of the Literatures

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Abstract

Dental implant treatment is getting more and more popular and be an excellent option for prosthetic restoration with high success rates. Implant stability is essential for a good outcome and a prerequisite for osseointegration. The clinical assessment of osseointegration is based on mechanical stability rather than histological criteria, considering primary stability and secondary stability. The aim of this report is to review the literature on Resonance Frequency Analysis (RFA) as a method for measuring dental implant stability. All searches include experimental and clinical research published between 1996 and 2014. The studies reviewed demonstrate the usefulness of RFA as a non-invasive method to assess implant stability.

Key words: Resonance frequency analysis, Dental implant stability.

Introduction

In 1969, Brånemark et al. defined osseointegration as "the direct, structural, and functional con-tact between live bone and the surface of a functionally loaded implant". The first clinical report on dental implants, published a few years later, clarified that establishment and maintenance of osseointegration depends on the capacity of the tissues for healing, repair, and remodeling.[1] Shortly afterwards, Schröeder et al. defined this bone-implant union as a "functional anchylosis".[2]

Osseointegration is accepted as a histological term denoting direct bone apposition on the implant surface with no interposition of soft tissue. Clinical assessment is based on mechanical rather than histological criteria of stability considering primary and secondary stability[3]. Primary stability is the absence of

mobility in the bone bed upon insertion of the implant and depends on the quantity and quality of bone, surgical technique and implant design. Secondary stability depends on bone formation and remodeling at the implant-bone interface and is influenced by the implant surface and the wound-healing time[4]. The clinical definition of implant osseointegration considers the level of stable marginal bone and absence of mobility in the bone. Therefore, the diagnosis is based on radiographic and mechanical stability criteria.

Methods for measurement of dental implant stability

Invasive test:

(1) Biopsy - in animal experiments
(2) Removal torque test - in animal experiments
(3) Pull-through and push-through test - in animal experiments

Noninvasive test:

(1) Tapping
(2) Radiographic methods
(3) Cutting resistance measurement
(4) Reverse torque
(5) Periotest
(6) Resonance frequency analysis (RFA)

Invasive and non-invasive clinical tests are available to objectively assess implant mechanical stability. Invasive tests are largely used in experimental studies. Most commonly used methods among the non-invasive methods include the radiographic images, Periotest and RFA. Peri-implant radiolucent areas and marginal bone height can be identified on X-ray, although only mesio-distal changes are detected. Sundén et al.[5] stated that high-quality radiography is necessary to optimize the irradiation geometry, density and contrast. The Periotest® system (Periotest®, Siemens) was originally designed to quantify signs of stress resorption by the periodontal ligament surrounding the tooth, as a measure of mobility[6]. It is a hand-held device with a metal bar that is attracted to the tooth by an electromagnet, giving an audible signal and showing the measurement digitally on a scale from -8 (low mobility) to 50 (high mobility) PTV units. However, this has been criticized for its lack of resolution, poor sensitivity and its susceptibility to being influenced by the operator[43].

After the first studies on RFA by Meredith et al.[7] in 1996, Integration Diagnostics AB (Savedalen, Sweden) launched the Osstell® system in 2000. Researchers at the University of Taipei (Taiwan) (8) also developed an RFA system, the Implomates® (Bio TechOne) system.

In the initial studies published by Meredith et al.[3, 7], the units of measurement used were kilohertz in a range from 3,500 to 8,500 kHz. The Implant Stability Quotient (ISQ) was subsequently developed, converting kHz units to ISQ values on a scale of 1 to 100, with high values indicating high stability. The Osstell® system now features the Osstell Mentor® and Osstell ISQ®, a type of electronic tuning fork that automatically converts kHz to ISQ values. It is a portable, hand-held device that emits signals repeated by a transducer that is screwed directly into the implant or trans-epithelial abutment with a force of 5-10 Ncm, calculating the resonance frequency (in ISQ values) from the response signal. The objective of the present report is to review studies on the use of RFA to measure dental implant stability.

Material and methods

The first studies on RFA as a method for measuring stability appeared in 1996. The literature on RFA were published between 1997 and 2014. The key words used for the search

were dental implant, resonance frequency analysis, stability. It was started with an online search of the PubMed (MedLine) database, to detect scientific studies.

Results

After the on-line database search, 273 published studies were found, constituting the initial study sample. The first studies of RFA appeared in 1996 but there was little scientific research (around 3% of the total) over the next five years. Scientific interest in this area grew considerably in 2005, when studies accounted for 18% of all studies on RFA, and this level was maintained in 2006. There was further increase in 2007 (27% of the total), and this trend continued in the first two months of 2008. The largest number of articles on RFA appeared in the field of oral surgery and dentistry (72%), followed by dental engineering (27%), general surgery (13%), biophysics (11.6%), and psychology (7.7%).

The following articles were selected on the basis of the H index (H index = 21). Table 1 shows:

author, year of publication, type of study (clinical or experimental), number of references, objectives, material and methods, and conclusions. Table 2: Scientific work from January 2007 to February 2008. The 10 RFA studies of clinical interest selected were published in the two journals with highest impact: Clinical Oral Implants Research and the International Journal of Oral & Maxillofacial Implants. Table 3: Recent scientific work and literature review from 2008 to 2014.

Discussion

According to these findings, Resonance Frequency Analysis as a technique for measuring dental implant stability has attracted considerable scientific interests in recent years, with a constant increase in the volume of scientific research and studies published in prominent journals. The studies selected reflect the effectiveness of RFA as a method for measuring dental implant stability.

There are three points need to be dressed out for RFA according to the literature reviews:

First of all, Meredith et al.[3] and Sennerby et al.[12] both concluded that resonance frequency was a highly effective qualitative method and proposed its use to assess implant stability in 1998. In 2002, Huang et al.[13] reached similar conclusions after evaluating implant behavior in different types of bone. Using RFA, the stability of implants was even found to improve over time in soft bone[14], and no differences in stability were observed between different bone types at week 5[15]. However, O'Sullivan et al.[16] compared insertion torque and bone properties in a cadaver study and obtained high values for all bone types except type IV; this was in line with the findings of Boronat et al.[17], who reported higher ISQ values for implants inserted in areas of more compact bone. Other authors used RFA to determine the effects of immediate or early loading[18-20] or assess changes in stability over time[21]. Consequently, resonance frequency is really an effective method to evaluate osseointegrated condition for implants in various types of bone, although the accuracy of the RFA may be doubted and needs to be re-confirmed when gingiva was impinged or alveolar bone was covered[19].

Secondly, resonance frequency can also be measured at any time during the process[22], allowing implant failure to be diagnosed at an

Table 1. Articles selected on the basis of the H index (n = 21)

AUTHOR	OBJECTIVES	MATERIAL AND METHODS	CONCLUSIONS
Meredith et al. 1996[7] In vitro 115 References	Critically analyze radiographic and Periotest methods	- Aluminium blocks implants - Polymethyl blocks implants	Close correlation between RFA and exposed implant height and rigidity.
Meredith et al. 1998[9] In vitro 84 References	Analyze Periotest and Dental Fine Test techniques	Concepts of primary and secondary stability	RFA quantitative method more effective
Meredith et al. 1998[9] In vitro 27 References	Compare different methods for evaluating implant stability	Analysis of electronic methods and RFA	Clinical applications of electronic methods for stability diagnosis discussed
Sennerby et al. 1998[12] 1998 32 References	Analyze need to develop new methods for measuring stability	Correlation between implant failure and bone properties	Reasonance frequency possible method for determining stability
Huang et al. 2002[13] In vitro 28 References	Evaluate implant behavior under different bone conditions	- 3D model of finite elements developed - Implants in different types of bone - RFA	RFA a possible diagnostic tool to determine implant stability
Friberg et al. 1999[14] In vivo 73 References	Compare RFA and insertion torque during implantation	Classification of edentulous maxillary bone types according to site RFA at surgery at 8 months and 1.5yrs	Stability improves over time even in soft bone
Barewal et al. 2003[15] In vitro 32 References	Assess stability changes at initial phases of osseointegration using RFA	- 27 ITI SLA implants - 4 bone types - RFA measurements each week up to 10th week	At 5 weeks, no differences in stability among bone types
O'Sullivan et al. 2002[16] In vitro 47 References	Compare primary stability between different implant designs	- 52 human cadaver implants - RFA and removal torque (RT) - Different bone qualities	High RFA and removal torque values obtained, indicating very hard bone- implant interface (except for bone type IV)
Glauser et al. 2004[18] In vivo 35 References	Analyze RFA measurements in immediate and early loaded implants	- 81 Bränemark implants - RFA: during implant insertion surgery, at 1, 2, 3, 6 and 12 months	Very low RFA values at 2 months appear to indicate future risk of failure
Olsson et al. 2003[19] In vivo 31 References	Evaluate stability of immediate and early loaded implants for edentulous maxillary teeth	- 10 patients with 6 or 8 Ti-Unite implants - RFA measurements: at surgery and implant placement	Despite limited number of case, early loaded maxillary implants possible in 6 or 8 cases

Table 1. Articles selected on the basis of the H index (n = 21) (Cont.)

AUTHOR	OBJECTIVES	MATERIAL AND METHODS	CONCLUSIONS
Nedir et al. 2004[20] In vivo 22 References	- Evaluate RFA for diagnosis of mobile and stable implants - Determine predictive ISQ values for osseointegration - RFA predictability in immediate load (IL) and delayed load (DL) implants	- Immediate load (IL) and delayed load (DL) ITI implants - RFA: at 1, 2, 4, 6, 8, 10, 12 weeks	These data can help the surgeon to choose load protocol and establish healing phases
Friberg et al. 1999[21] In vivo 69 References	- Assess stability changes using RFA - Assess changes in marginal bone using radiography	- 3 different types of Bränemark implants inserted in a single surgical operation - RFA measurements at 2, 6, 15 and 30 weeks	Early diagnosis of implant failure possible (very low RFA values)
Meredith et al. 1997[22] In vitro 69 References	Measure RFA stability during surgery and compare results with histomorphometric measurements	- Implants in rabbit tibia - RFA on transepithelial abutment - Histomorphometric analysis	- RFA measurement possible at any time - Stability changes related to increased bone rigidity
Balleri et al. 2002[23] In vivo 30 References	Measure stability using RFA during loading period	- 45 implants in 45 patients - RFA and Rx during year of loading - Different locations, lengths, and bone levels	ISQ values at 1yr in 57-82 range indicate implant success
Sul et al. 2002[35] In vitro 50 References	Observe whether oxidative properties of implants improve osseointegration at 6 wks	- 48 TiUnite implants in rabbit tibia - RFA and removal torque at 6 wks	- Oxidative properties of TiUnite implants improve bone tissue response
Rasmusson et al. 1999[36] In vitro 28 References	Study effects of barrier membranes and onlay grafts on stability	- 18 implants in 9 rabbits - 2 groups (with and without membrane) - RFA, removal torque, and histological analysis	No improvement in stability with use of nonresorbable membranes
Rocci et al. 2003[37] In vivo 26 References	Evaluate histological analyses of TiUnite implants	- 5 implants extracted from 5 patients - Immediate loading - RFA. - Inserted in posterior mandibular area	This type of implant highly integrated in both hard and soft tissue
Calandriello et al. 2003[38] In vivo 25 References	Evaluate stability of immediately loaded implants	- 50 Bränemark implants in posterior areas - RFA y RX during 1 year	In posterior regions, immediate loading a highly effective treatment option for type IV bone

Table 1. Articles selected on the basis of the H index (n = 21) (Cont.)

AUTHOR	OBJECTIVES	MATERIAL AND METHODS	CONCLUSIONS
Bischof et al. 2004[39] In vivo 24 References	- Determine factors affecting RFA - Monitor changes in first 3 months - Evaluate differences between immediate and delayed loading of implants	- ITI implants - 2 groups: immediate loading (IL) and delayed loading (DL) - RFA every 2 weeks - Different variables	- Initial stability measured by RFA affect by bone quality and location - No differences between IL and DL after 3 months
Nkenke et al. 2003[40] In vitro 23 References	Determine relationship between stability, bone density, and histological analysis	- 48 human cadaver implants - RFA, insertion torque, and Periotest	Stronger relationship between RFA and histomorphometric than Periotest parameters
Glauser et al. 2005[41] In vivo 22 References	Describle TiUnite surface at immediate loading in different locations	- 102 maxillary and mandibular Bränemark implants - RFA, torque, and radiography at 1, 6 and 12 months	High level of success (97.3%) with immediately loaded TiUnite implants

Table 2. Articles published between January 2007 and Feburary 2008 selected using H index (n = 10)

AUTHOR	OBJECTIVES	MATERIAL AND METHODS	CONCLUSIONS
Cannizzaro et al. 2007[24] In vivo	Compare conventional sinus augmentation (particulate bone) with new internal sinus block inlay graft technique	- Control group: block graft implants - Test group: particulate bone graft implants - RFA and Periotest measurements: 6-12 months	- Similar stability levels in both groups - Block graft technique is an effective option for sinus augmentation
Ozkan et al. 2007[25] In vivo	Compare stability and marginal bone levels in atrophied mandibular implants using bone augmentation and non-graft bone implant techniques	- Control group: 18 non-graft bone implants - Test group: 17 graft implants placed 4 months previously - RFA measurements at 1, 4 and 12 months - Radiographic monitoring	No differences in RFA-measured stability between graft and non-graft implants
West et al. 2007[26] In vivo	Evaluate changes in stability between immediate and delayed load implants Compare 2 implants designs for extraction sockets	- Control group: 11 delayed load implants - 2 experimental groups: 28 standard and tapered implants - RFA measurements every 2 weeks up to 24th week	Similar levels of stability attained for both standard and tapered implants in extraction sockets

Table 2. Articles published between January 2007 and Feburary 2008 selected using H index (n = 10)(Cont.)

AUTHOR	OBJECTIVES	MATERIAL AND METHODS	CONCLUSIONS
Lang et al. 2007[27] In vivo	Compare use of standard, cylindrical, and tapered Straumann implants for immediate placement in extraction socket	- 9 study centers: randomized clinical trial - 208 immediate load implants - RFA measurements: at surgery, 1, 2, 6 and 12 weeks	SLA Straumann cylindrical and tapered implants can both be used in extraction socket
Cannizzaro et al. 2007[28] In vivo	Evaluate success/failure of immediately loaded transmucosal implants in edentulous superior maxilla	- 202 implants (53 immediately loaded). - RFA measurements: at surgery and 12 months after insertion	Immediate loading of transmucosal maxillary implants a predictable treatment option
Huwiler et al. 2007[30] In vivo	Monitor RFA measurements in relation to bone characteristics during early phase of osseointegration	- 23 Straumann SLA implants - RFA measurements: at 1, 2, 3, 4, 5, 6, 8, and 12 weeks	ISQ values of 57-70 indicate stability. No predicttive RFA values for implant success
Ito et al. 2008[31] In vitro	Observe possible correlation between RFA and histology (BIC)	- 24 pig implants - RFA measurements: at 1, 2 and 4 weeks - Histological analysis	No correlation between RFA and BIC, whose values only increased in bone around the neck of the implant
Al-Nawas et al. 2008[32] In vitro	Evaluate osseointegration conditions in animal trial and for loaded implants with different surfaces	- 196 implants - 6 surface types - Histological analysis - RFA measurements	Benefit of rough surfaces histologically proven
Karl et al. 2008[33] In vivo	Evaluate RFA of ITI implants using retrospective clinical analysis	- 385 ITO implants - RFA measurements at 12 weeks in superior maxilla and at 6 weeks in inferior maxilla - Variables: length, diameter, and location	Repeated RFA measurement appears to facilitate diagnosis of implants with limited stability. Specific effect of variables unclear.
Verdonck et al. 2008[34] In vitro	Monitor implant stability during placement and at osseointegration stage in irradiated and non-irradiated bone-	- 120 implants placed in pigs - RFA measurements: at 8, 16, and 24 weeks	Negative effect of irradiation on bone vascularization and implant stability confirmed

early stage. Very low RFA values at 2 months appear to indicate risk of future implant failure, while ISQ values of 57-82 at 1 year indicate implant success[23]. Articles in Table 2 represent a small sample of the abundant ongoing research. In 2007, various authors examined the use of bone augmentation techniques for sinus elevation[24] and mandibular atrophy treatment[25], using RFA to test implant stability in regenerated zones. In relation to different implant designs and their

Table 3.

Author	Objectives	Materials and methods	Conclusions
Boronat López A. 2008[45] stability	Measure the implant quotient (ISQ) values during the osseointegration period, and determine the factors that affect implant stability.	- RFA was performed in 24 patients - 64 implants. - 52 type II bone, 12 type III. - RFA was used on the day of implant placement and consecutively once a week for 8 weeks and at week 10.	- The mean ISQ of all measured implants was 62.6. - The lowest mean stability measurement was at 4 weeks for all bone types (60.9). - Gender was found to be significant ($p < 0.05$); women showed higher implant stability than men. - Higher ISQ values for anterior implants than posterior fixtures ($p < 0.05$).
González-García R 2011 Aug[46]	Predictability of the resonance frequency analysis in the survival of dental implants placed in the anterior non-atrophied edentu lous mandible.	- 70 complete mandibular edentulism patients underwent dental implant rehabilitation. - 68 dental implants within the interforaminal region and subsequent placement of an overdenture. - Primary implant stability was measured by means of RFA on the day of the implant insertion and at the time of the healing abutment placement in a two-stage surgical procedure.	- No statistical differences in terms of primary and secondary implant stability measured by RFA exists between 3.75 mm and 4.25 mm diameter implants in the conventional implant two-stage surgical procedure in patients with non-atrophied edentulous mandible being re-stored with an overdenture. - No statistical association between RFA and the implant insertion torque was observed for endosseous dental implant placement at the first surgical stage.
Manuel N 2013[42] Review	Review the influence of surface morphology on the primary stability of dental implants.	- PubMed databases were explored from 1994 up to and including April 2012. - Three clinical and seven experimental were included - Using the insertion and removal torque tests and resonance frequency analysis using implant stability quotient values.	- Rough-surfaced implants have significantly higher success rates compared with dental implants with smooth surfaces. - However, the question "Is there a connection between implant surface roughness (micro-design) and primary stability?" remains unanswered.
Tang Y. 2014[44] Review	Review and analyze critically the current available literature in the field of RFA, and to also discuss based on scientific evidence, the prognostic value of RFA to detect implants at risk of failure.	- Using the PubMed database to find all the literature published on "Resonance frequency analysis for implant stability" till date. - Articles discussed in vivo or in vitro studies comparing RFA with other methods of implant stability measurement and articles discussing its reliability were thoroughly reviewed and discussed.	Resonance frequency analysis could serve as a non-invasive diagnostic tool for detecting the implant stability of dental implants during the healing stages and in subsequent routine follow up care after treatment.

behavior in specific clinical situations, West et al.[26] and Lang et al.[27] used RFA to demonstrate the similar stability of cylindrical and tapered implants in immediate implants inserted into extraction sockets, while Cannizzaro et al.[28] was able to show that immediate loading of trans-mucosal maxillary implants is a successful treatment option. Consequently, RFA seems to be able to apply to different designs of implants for diagnosing the osseointegrated condition. However, the effectiveness of RFA values in clinical situation when used in various designs of implants may need more research to verify.[28]

Thirdly, RFA was also used to determine whether implant length and diameter influence primary stability[29], leading to the conclusion that ISQ values were not significantly related to implant length or diameter. Bone biology and osseointegration in implantation continue to attract considerable scientific interest. Huwiler et al.[30] applied RFA at early stages of osseointegration and reported that ISQ values of 57-70 indicates stability. Using in vitro histomorphometric analysis, Ito et al.[31] found no correlation between bone-implant contact (BIC) and RFA, while Al-Nawas et al.[32] confirmed the benefits of a rough implant surface for increased RFA-measured stability. Karl et al.[33] compared the different locations of mandibular and maxillary ITI implants and found a significant correlation between these variables. They also observed that RFA measurements can identify unstable implants. Verdonck et al.[34] carried out experimental studies using RFA to determine the stability of implants placed in irradiated bone and found that irradiation had an adverse effect on bone vascularization and hence on implant stability.

In summary, the methods and results of recent studies and literature reviews are showed in Table 3 (2008-2014). As evidenced by this review, objective assessment using the RFA method has made it possible to quantitatively and qualitatively analyze the stability of various types of implants and examine their behavior under different bone and loading conditions.

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利用回音頻率分析法來測量人工植牙穩定性的文獻回顧

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摘 要

人工植牙治療越來越普及而且人工植牙贋復體也具有很高的成功率，但是人工植牙的穩定性一直都是骨整合的先決條件。骨整合的臨床評估是基於機械穩定性而非組織標準，尤其是人工植牙的初期穩定度更是重要。這一篇報告的目的是在於回顧利用回音頻率分析法當成是來測量人工植牙穩定性的方法，涵蓋所有1996到2014年之間的文獻回顧其中包括實驗端和臨床端。這些文獻回顧的結果證實了回音頻率分析法的確是一個測量人工植牙穩定性的有效方法。

關鍵詞：回音頻率分析法，人工植牙穩定性。

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