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Assessment of Implant Stability: Methods and Recent Advances

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Authors' contributions

This work was carried out in collaboration between all authors. Author AS designed and performed literature search, reviewed the related articles, and wrote the first draft of the manuscript. Authors PD and SS study performed literature search and reviewed the article. All authors read and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Achieving primary stability is of greatest importance, at the time of implant placement. A rigid fixation of implant within the host bone, in absence of micromotion is the most critical factor for successful osseointegration. Over the years, several authors have reported various methods in literature to monitor implant stability, which include, tapping the abutment with a metallic instrument, histomorphometry test, removal torque test, cutting torque test, radiography, periotest, and resonance frequency analysis. Resonance frequency analysis (RFA) offers a clinical, objective way to measure stability and presumed osseointegration of implants. The review focuses on different methods used to assess implant stability and recent advances in this field.

Keywords: Implant stability; resonance frequency analysis; dental implants; RFA.

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ABBREVIATIONS

1. *ISQ - Implant stability quotient*
2. *RFA - Resonance frequency analysis*

1. INTRODUCTION

Dental implants represent one of the most successful treatment modalities in dentistry. However, failures do occur in the range from 5 to 8% for routine procedures and up to 20% in major grafting cases after at least 5 years of function [1,2]. The majority of implant losses may be explained as biomechanically induced failures, since low primary implant stability, low bone density, short implants and overload have been identified as risk factors [1,3]. Hence, achievement and maintenance of implant stability are pre-conditions for a successful clinical outcome with dental implants.

Implant stability plays a vital role for successful osseointegration. It may be defined as the capacity of implant to withstand loading in axial, lateral and rotational direction [4]. Implant stability serves as an indirect indication for osseointegration, and the clinical perception of implant stability is often related to the rotational resistance during placement of dental implant [5].

Dental implant stability can be divided into primary and secondary components. Primary stability refers to the mechanical bracing of the implant in bone and absence of any micro-movement, while secondary stability refers to successful osseointegration of the implant with the surrounding bone [6].

Achieving Primary stability is of utmost importance, at the time of implant placement. A rigid fixation of implant within the host bone, in absence of micro-motions is the most critical factor for successful osseointegration [7,8]. If an implant is not sufficiently stable at the time of implant placement, micro-motions may occur, normal healing process may then be disrupted and a fibrous tissue capsule may form, resulting in clinical mobility and subsequent implant failure.

Primary stability arise because of the compression of bone, it is associated with the mechanical engagement of implant with the surrounding bone. It depends upon many factors with includes quantity and quality of local bone; implant related factors like length, diameter, form and surface characterization; and the surgical procedure followed i.e. drill size in relation to implant size, pre-tapped or self-tapping implants [6,9,10]. Modification of bone quality and quantity by use of grafts or augmentation procedure can be done, but for majority, quality of bone is one parameter on which a clinician has little control. Thus, design of implant and surgical procedure followed are the only two parameters, where a clinician has control [9]. Using a smaller size drill in diameter than implant, causes development of compressive stress around implant- tissue interface, resulting in local compression of bone when implant is inserted. Such stresses are beneficial in terms of attaining good primary stability, but if these stresses reaches sufficiently high levels than it may result in local ischemia of bone and necrosis [10].

In addition to it, changes in implant stability after insertion due to regeneration and remodeling of bone at implant tissue interface is considered to be secondary stability. Secondary stability has been shown to increase 4 weeks after implant placement, and up to this time i.e. about 2-3 weeks after implant placement, lowest stability is expected [11,12]. Secondary stability is a biological stability, it involves regeneration and remodeling of bone and tissue around the implant after insertion. It depends upon primary stability, bone formation and remodeling. At the time of implant placement, there is a sparse bone to implant contact. With time, newly formed bone will fill the voids at intersurface zone and grows into implant surface irregularities. Complete bone-implant contact rarely occurs and clinically observed osseointegration corresponds to approximately 80% of bone contact. Though, more than 60% of bone-implant contact is considered to be adequate for implant stability [6,13].

There are various methods which have been suggested in literature to measure implant stability. In early days, it was proposed that osseointegration could be assessed by tapping the implant or/and an abutment with a metallic instrument. The aim of the test was to determine the resonance and damping of implant from the audible ringing produced. A clearly ringing “crystal” sound indicates successful osseointegration, whereas a “dull” sound may indicate no osseointegration. However, this method is subjective and have poor sensitivity to discriminate the resonance frequency, damping and amplitude of tone produced [10,12].

2. METHODS

A number of authors have published various methods which can be broadly classified under two groups i.e. destructive and non-destructive methods (Fig. 1). Destructive Method Includes: Histomorphologic research, Tensional test, Push-out/pull-out test and Removal torque test. These methods are invasive methods and are not suitable of the clinical assessment. Non-destructive methods includes: Percussion test, Radiography, Cutting torque test, Periotest, and resonance frequency analysis (Table 1). These methods are non-invasive methods and can be used in clinical assessment [3,6,9,10,12].

2.1 Tensional Test

The interfacial tensile strength was originally measured by detaching the implant plate from the supporting bone. Later on it was modified by applying the lateral load to the cylindrical implant fixture. However, there were difficulties in translating the test results to any area-independent mechanical properties [14].

2.2 Histological and Histomorphometric Analysis

Histomorphometric method, quantitatively assesses the bone contact and bone area within threads. This technique generally requires a light microscope with microvid computers. Ultrastructural studies are mostly performed on the decalcified specimens sectioned for transmission electron microscopy. But due to the invasive and destructive nature of this techniques, its use has only limited to non-clinical and experiments studies [10,15].

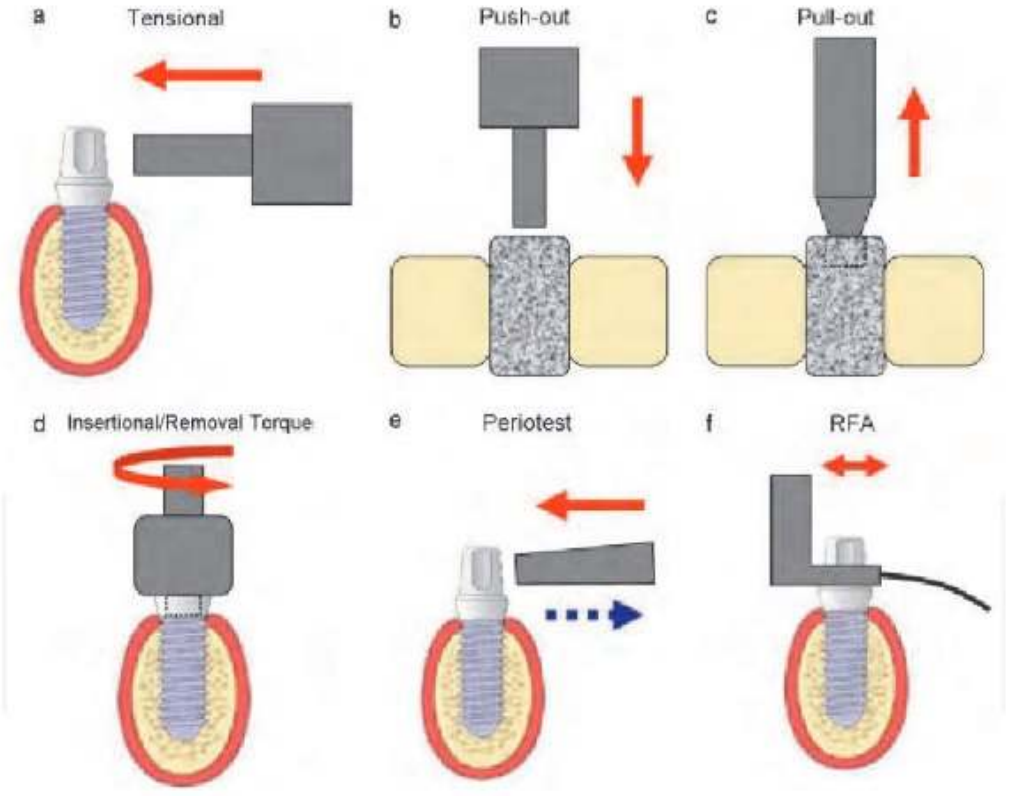

Fig. 1. Stability analyses for oral implant osseointegration from Chang, P. C., Lang, N. P. & Giannobile, W. V. (2010). "Evaluation of functional dynamics during osseointegration and regeneration associated with oral implants." Clinical Oral Implants Research 21: 1-12. (a) tensional test, (b) push-out test, (c) pull-out test, (d) insertional/removal torque test, (e) Periotest, and (e) resonance frequency analysis

2.3 Push-out/Pull-out Test

In a typical pushout or pull-out test, a cylinder-type implant is placed transcortically or intramedullarly in bone and then removed by applying a force parallel to the interface. The maximum load capability (or failure load) is defined as the maximum force on the force–displacement. However, the push-out and pull-out tests are only applicable for non-threaded cylinder type implants, whereas most of clinically available fixtures are of threaded design, and their interfacial failures are solely dependent on shear stress without any consideration for either tensile or compressive stresses [14,16].

2.4 Removal Torque Analysis

In this technique, osseointegration is tested at second stage surgery. During the test, a counter clock wise (reverse) torque is applied to implant up to level of 20 Ncm as removal torque value of clinically osseointegrated implant ranged from 45 to 48 Ncm [12]. Osseointegrated implants resist this torque, while failed implants unscrew. However, torque load can result in plastic deformation, even at low levels of torque, and implant surface in the process of osseointegration may fracture under the applied torque stress [10,14,17].

This test is considered one of the most crude test as it gives little information about implant bone interface and provides result only by all or none rule i.e. ossteointegrated or failed, thereby not able to discriminate the degree of bone healing or bone formation around implants.

2.5 Cutting Resistance Analysis/ Insertion Torque Measurement

The cutting resistance refers to the energy required in cutting of a unit volume of bone, and the energy has been shown to significantly correlate with bone density. The major limitation is that it does not give any information on bone quality until osteotomy site is prepared. Furthermore, it has been highlighted that longitudinal data cannot be collected to assess bone quality changes after implant placement [12].

Insertional torque is measured during the fixture tightening procedure. Both these measurements consider the lateral compression force and friction at the interface during implant insertion and are mainly influenced by the tolerance of the fixture thread design. Insertion torque values have been used to measure the bone quality in various parts of the jaw during implant placement [9]. The technique is not non-invasive, since it involves measurement of torque created while cutting a thread in a hole in bone. However, it cannot assess the secondary stability by new bone formation and remodeling around the implant. So it cannot collect longitudinal data to assess implant stability change after placement [14,15].

Table 1. Destructive and non-destructive methods to measure implant stability

Type	Method
Destructive methods	• Histomorphologic Research • Tensional test • Push-out/pull-out test • Removal torque test
Non destructive	• Percussion test • Radiography • Cutting torque test while placing implants, • Periotest • Resonance frequency analysis(RFA)

2.6 Radiography

There are various radiographic assessment methods which provide information regarding the quantity and quality of local bone before placing the implant fixture. It is probably one of the most widely used tool not only for preoperative assessment but also helpful in predicting implant stability and assessment of abutment fit. The objective of radiograph is to identify peri- implant radiolucencies and assessment of marginal bone loss [10].

However, there are limitations such as image is two dimensional, image resolution is not good and standardized X-rays are difficult to achieve, making quantitative measurements much more difficult and challenging. In addition, it is difficult to perceive changes in the bone structures and morphology of the implant-bone interface unless over 30% bone loss occurs. Although the accuracy of the diagnosis is low, radiography is the major method used clinically to evaluate osseointegration and implant stability because of its convenience. It is a non-invasive procedure and can be performed at any stage [15].

2.7 Periotest®

Periotest®, Siemens AG, Benshein, Germany (Fig. 2) is an electronic device which quantitatively measures the damping characteristics or dynamic tissue recovery process after loading, to assess osseointegration. Periotest® was originally devised by Dr. Schulte [18] to measure tooth mobility was designed to assess damping characteristics of periodontal ligament surrounding a tooth by calculating contact time between the test subject and percussion rod, thereby establishing its mobility. This instrument has been widely used to measure implant stability. Periotest value (PTV) is marked from -8 (low mobility) to +50(high mobility). PTV of -8 to -6 is considered good stability. A healthy implant surrounded by bone will exhibit stiffness characterstics as compared to a tooth supported by periodontal ligament (Table 2) [10].

Fig. 2. Illustration showing periotest device

Table 2. Interpretation of PT value range

PT value range	Interpretation
-8 to 0	Good Osseointegration, implant can be loaded
1 to 9	Clinical examination required, implant loading not recommended
10 to 50	Insufficient Osseointegration, implant loading not recommended

In periotest an electronically controlled rod weighting 8 g taps implant 4 times/sec at an constant speed for 4 seconds at a velocity of 0.2 m/s0. The rod is decelerated when it touches the implant. The greater the implant solidity, the higher the deceleration and thus higher the damping effect of the surrounding tissues. After tapping the spot, rod recoils, a faster recoil indicates increased damping [19].

Periotest® can measure all surfaces such as the abutment or prosthesis, but the rod must make contact at a correct angle and distance. Meredith [10] demonstrated that number of important variables, including angulation, striking point and abutment length, may influence the accuracy of this technique. If the perpendicular contact angle is larger than 20 degrees, or if the parallel contact angle is larger than 4 degrees, the measured value is invalid. Also, the rod and the test surface must maintain 0.6-2.0 mm distance and if the distance is over 5 mm, the measured value may be insignificant [20].

Periotest® has a limited use as a clinical diagnostic aid, since there is lack of resolution, poor sensitivity and more over results may be influenced by to position and direction of percussion rod. The most failing point of this method is that the percussing force on the implant may deteriorate the stability in poor initial stability implants [14].

2.8 Resonance Frequency Analysis (RFA)

In 1996, Meredith suggested a non-invasive method of analyzing peri-implant bone by connecting an L shaped transducer to an implant in an animal study. The transducer provides a high frequency mechanical vibration and record the frequency and amplitude of the signal received. The resonance frequency was thus defined as the peak of frequency- amplitude plot and converted to a value representing stiffness of bone implant interface [21].

The experimented resonance frequency analysis system was commercially produced as Osstell® (Osstell AB, Göteborg, Sweden). A measurement of Osstell® is displayed as implant stability quotient (ISQ) from 1 to 100, Where 100 signifies the highest implant stability. Osstell® was later followed by Osstell® Mentor, and Osstell® ISQ (Fig. 3) [6,10].

RFA uses the principle of resonance frequency, in which, when a frequency of audible range is repeatedly vibrated onto an implant, the stronger the bone implant interface, higher the frequency. The first RFA device utilized stainless steel or titanium and comprised of an offset cantilever beam with peizoceramic elements. One beam was vibrated by one element with a typical frequency of 5 to 15 kHz with the help of

frequency response analyser and personal computer and second piezoelectric element, measured response of the beam. In general, ISQ values for successful implants are reported from 57 to 82 ISQ. With development of the product, wired transducer of Osstell device was replaced by wireless aluminum rod with magnets (smartpeg) Fig. 4, which allows non- contact measurements in this device the magnet attached to smartpeg is excited with magnetic pulses (Fig. 5) [6,10,12].

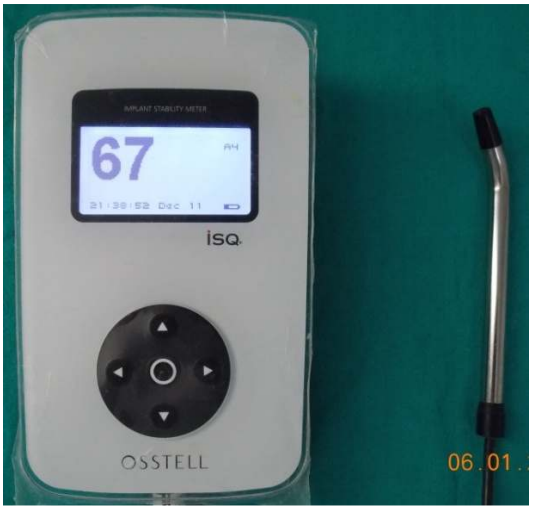

Fig. 3. Osstell ISQ from Osstell AB, Sweden

Fig. 4. Smartpeg type 47

The magnetic resonance analyzers (Osstell mentor and Osstell ISQ): Resonance frequency of 3.5 kHz and 8.5 kHz formed by magnetic field is converted to ISQ values. Its transducer, smartpeg has a magnetic top and is fixed to implant fixture or abutment by screw below. The probe releases magnetic resonance frequency, which activates magnetic smartpeg. The activated magnetic peg vibrates and the alternative magnetic field resulting from the activated magnetic smartpeg induce electric volt into probe coil and this electric volt is sampled by magnetic resonance frequency analyzer (Figs. 6-8) [12,15].

3. FACTORS DETERMINING OSSTELL MEASUREMENTS (Table 3)

3.1 Primary Implant Stability

3.1.1 Factors related to bone

Bone density is a major determinant of Osstell measurement. There is a positive correlation between ISQ units and bone density, with insertion torque measurements and with quantitative CT [22,23]. The properties of the marginal bone influences Osstell measurements, studies have observed a positive correlation between cortical bone thickness and ISQ values [24]. Similarly, research has documented a positive correlation between the height of the crestal cortical bone and ISQ values [25].

Fig. 5. Smartpeg fixed to implant and measurement is made in non contact manner with Osstell ISQ

3.1.2 Implant factors

The influence of implant length and diameter on Osstell measurements is not clear and seems to vary between studies. Though, most researchers have not found implant surfaces to impact on ISQ measurements [26]. However, Rompen et al.

[27] showed that surfaced-modified implants maintained stability, whilst machined implants experienced a decrease in stability during the early healing period. Glauser et al. [28] compared machined and oxidized implants using an immediate loading protocol and found more decrease in stability for machined implants during the first 3 months post-loading.

3.1.3 Surgical technique

The use of technique to create increased lateral compression during insertion seems to result in higher stability. This may be due to undersized preparation before placing the implant, wider implants or the use of tapered implant [9].

3.2 Secondary Stability

3.2.1 Time dependence

The resonance frequency increases with time as a function of an increased stiffness resulting from new bone formation and remodelling. However, if the primary stability of an implant is very high, subtle changes in stiffness may not be evident [26,27].

Friberg and co-wokers [29] reported that all implants placed in the edentulous maxilla, irrespective of initial stability, tended to reach a similar level of stability at the time of abutment connection (6– 8 months later) and after 1 year in function. This is in line with a clinical study by Sennerby et al. [26], where implants in soft bone with low primary stability showed a marked increase in stability compared with implants in dense bone. The data indicate that healing and remodelling process of soft trabecular bone seems to result in an increased stiffness of the peri-implant bone.

3.2.2 Marginal bone resorption and presence of defects

Sennerby et al. [26] demonstrated a negative correlation between radiographic bone loss and ISQ measurements. Turkyilmaz and co-workers [23] found a negative correlation between increased marginal bone loss around mandibular implants and decreased implant stability over the first 6 months following implant placement. No such correlation was observed between the 6-month and the 12-month study period. The authors suggested that the effect of bone loss was compensated for by an increased interfacial stiffness resulting from bone formation and remodelling from 6 to 12 months.

3.3 Use and Interpretation of Clinical ISQ Measurements

Research has shown that ISQ measurements can provide the clinician with valuable information about the present state of bone-implant interface. Together with clinical/radiographic findings it seems like as the technique can be used to support decision-making during implant treatment and follow-up with regard to healing times, loading protocol and identification of implants at risk for failure.

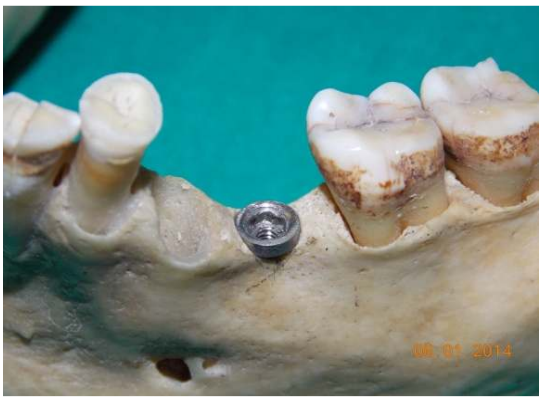

Fig. 6. Showing internal threads of dental implant placed in jaw bone

Its highlighted in literature that primary implant stability depends upon many factors such as local bone quality and quantity, implant morphology, and surgical technique followed [3,10]. As implant length, width, surface and number of threads are very specific for a particular implant system, therefore RFA values are not comparable for different implant systems [6,30]. These values should be individually determined for each implant system, and are in a similar pattern for a particular implant system in a specific clinical situation. Further, several clinicians have suggested that there is no definite ISQ cutoff values to differentiate implant failure and success and it can be explained through the local factors such as bone quality and quantity, surgical technique and morphology of implants, which are not similar in different patients and in different regions of oral cavity [31,32]. Though, low ISQ values are considered to be a factor precipitating implant failure [32], however, Tozum et al. [33] and Glauser et al. [34], suggested that marked and progressive decline in ISQ values is associated with failed implants. Thus, RFA measurements only have predictive values for stability when used repeatedly over a longer period of time.

Figs. 7, 8. Showing implant stability measurements made using RFA device in buccolingual and mesiodistal direction

Table 3. Showing factors influencing implant stability

Factors affecting primary stability	• Bone quantity and quality • Surgical technique, including the skill of the surgeon • Implant (eg, geometry, length, diameter, surface characteristics)
Factors affecting secondary stability	• Primary stability • Bone modeling and remodeling • Implant surface conditions

Table 4. Advantages and disadvantages of methods used to measure implant stability

Method	Advantages	Disadvantages
Histologic analysis	• Good objectivity	• Destructive and Invasive method • Limited to Non-clinical/ Experimental studies
Percussion test	• Non-invasive • No costly equipment • Easy to use	• Not Reliable method - Subjective method • Depends upon clinician perception
Radiographs	• Non-invasive (apparently) • Easy to use	• Not a Reliable method (generally 2D) • Quantitative measurements difficult
Removal Torque	• No costly equipment • Easy to use	• Osseointegraton is tested in second stage only • Can cause fracture or /and plastic deformation • Provide result only in osseoingration or/ failed implant (all or none rule)
Cutting resistance	• Reliable method • High Correlation between Cutting Resistance and bone quality • Detect bone density	• Can only be used during surgery
Periotest	• Non Invasive • Quantitative method • Can be used clinically • Can be used repeatedly	• Poor Sensitivity (as compared to RFA) • Lack of resolution (as compared to RFA) • May affect implant stability (when used during implant placement)
RFA	• Non Invasive • Can be used clinically • Quantitative method • Fair amount of predictability • Can be used repeatedly	• Expensive Equipment • No Critical value to suggest implant success or/ failure

4. CONCLUSION

To date no definite method has been establish to measure implant stability accurately with fair amount of reliability (Table 4). Though, clinical measurement of implant stability can be evaluated with resonance frequency analysis with fair amount of predictability. The theoretical basis of resonance frequency analysis is based on sound foundation; still there are uncertain issues such as critical value that can suggest success or failure of a particular implant system. Hence, further research is needed to establish higher reliability of the currently discussed methods.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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