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Methods to Measure Implant Stability

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Review Article

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Abstract: Osseointegration" as formulated by Alberktson is crucial for implant survival and success. Osseointegration is a measure of implant stability. Measuring implant stability helps to arrive at decisions as to loading of an implant, allows choice of protocol on a patient to patient basis and provides better case documentation. Various methods are developed to assess implant stability. A successful implant reflects good bone to implant contact and is determined by implant stability both primary and secondary. Implant stability is achieved at two different stages – primary and secondary. Primary implant stability and Secondary stability are influenced by many factors such as the mechanical properties of bone tissue at implant site and remodelling of bone and tissue around the implant. Implant stability has been confirmed to affect the process of osseointegration and therefore is essential to understand the methods to measure implant stability and factors influencing.

Keywords: Osseointegration,primary stability,secondary stability,RFA.

INTRODUCTION

Osseointegration is a measure of implant stability [1, 2]. A successful implant reflects good bone to implant contact and is determined by implant stability both primary and secondary. Primary stability is attained by mechanical engagement of implant within cortical bone [1, 2]. This depends on bone density, surgical technique and implant geometry. Secondary stability results from regeneration and remodelling of bone and tissue around the implant, that is influenced by primary stability, bone maturation, remodelling and bone density with time [1, 2].

Primary stability has been identified as a prerequisite to achieve osseointegration and is positively associated with secondary stability [3]. The attainment of direct contact between implant and living bone influences implant stability at the time of surgical insertion and in the lack of micromotion during the healing period [4]. Implant stability is the absence of clinical mobility which also suggests osseointegration [5]. Measuring implant stability is essential for evaluating the long term success of implant.

METHODS USED TO ASSESS IMPLANT STABILITY

Measuring implant stability through various techniques could assist the clinician in an optimal treatment plan and support decisions regarding implant loading protocols on a patient to patient basis and provides better case documentation.

Various methods are developed to assess implant stability such as histologic analysis, radiographs, percussion test, reverse torque test, cutting torque resistance analysis, periotest and RFA(resonance frequency analysis) device [2, 6, 7]. Historically, the gold standard method to evaluate osseointegration was histologic analysis. Later, implant stability and osseointegration are clinically determined by tactile perception, radiographs, percussion test, reverse torque test, cutting torque resistance analysis, periotest and RFA.

Histologic analysis is not widely used though it is clinically accepted due to unnecessary biopsies required for implant stability assessment. Radiographic analysis is a non invasive method that can be performed at any stage of healing yet changes in radiographic bone level cannot precisely indicate implant stability. Percussion tests provide a ringing sound as a sign of good osseointegration and are not reliable as they provide poor qualitative information [4, 6].

Cutting torque resistance analysis utilizes energy that correlates to bone density further determining implant stability. It cannot assess the secondary stability and is not frequently used as a diagnostic aid as the lower limit value that denotes potential failure of implant has not been established [6-8].

Friberg B *et al.*, evaluated the jaw bone quality at implant placement with cutting torque measurements and to compare these values in different regions in mandibles and maxillae to identify implants at risk for failing [8]. Cutting torque measurements performed for a minimum of 3 years by comparing cutting torque values of maxillae and mandibles and of different jaw regions revealed that cutting torque values correlated with radiographically, clinically assessed bone quality scores. Conversely it was not possible to identify sites at risk for future implant losses or to determine a lower limit value of cutting torque in order to achieve successful implant integration [8].

Reverse torque test proposed by Roberts *et al*., gives information on degree of bone to implant contact of any given implant and is not widely used as it can provide information as to all or none outcome (osseointegrated or failed) and it cannot quantify the degree of osseointegration [6, 7, 9].

Sullivan DY assessed the relation between Reverse torque analyses to failure on implants. Clinical analysis after reverse-torque testing and loading, revealed that there is no increase in failure rates with no failure rates between values of 45 and 58 Ncm. Reverse-torque testing at 20 Ncm appears to be a safe, reliable method for verifying osseointegration with pure titanium screw-shaped implants [9].

Modal analysis measures the natural frequency or displacement signal of a system in resonance. It is performed in two models: theoretical and experimental. The experimental or dynamic modal analysis has been used to quantify degree of osseointegration and implant stability. Dental mobility checker developed by Aoki and Hirakawa utilizes same principle as impact hammer method and provides measurements for osseointegrated implants. It has certain disadvantages such as difficulty in double tapping and the application of small force to an implant immediately after placement may jeopardize the process of osseointegration [6, 7].

Kaneko T evaluated the sensitivity of pulsed oscillation waveform to analyse the mechanical vibrational characteristics of the bone implant bone interface using forced excitation of a steady state wave and the sensitivity was low in the direction for which a normal load was applied to the bone, reflecting a mechanical difference of the surrounding bone and/or the interface. Therefore, it is desirable that the assessment by the vibrational test is done in the direction, for which a shearing load is applied. They stated that the minimum average thickness of soft interface layer distinguishable from a hard interface depends on load directions and positions [10].

Kaneko T *et al*., introduced a simple acoustoelectric technique for in vivo assessment of the interfacial rigidity between a dental root implant and the bone surrounding it. This method is based on estimating the frequency (10 to 150 KHz) and amplitude of the vibration of the implant induced by a small pulsed force. Application of the force to the implant and detection of the vibrational signal from the implant are performed by lightly touching it with two fine needles connected with piezoelectric elements [11].

Dental Periotest has been thoroughly studied and advocated as a reliable method to determine implant stability. Readings of -8 to + 50 are interpreted. Successfully integrated implants have yielded a wide range of periotest values. These variations suggest that for implants there is no absolute value that is considered acceptable. Periotest cannot diagnose a borderline case or an implant in the process of osseointegration [6, 7, 12].

Olivé J, Aparicio C assessed the use of Periotest method as a measure of osseointegrated oral implant stability and suggested that the Periotest value of an oral implant is an objective and easily applied criterion for stability assessment. Since osseointegration is achieved gradually over time, this test may assist the clinician in deciding whether to extend the healing period before loading fixtures that seem clinically and radiologically integrated but give borderline Periotest values [12].

Olsen S *et al*., introduced a novel computational method for real-time preoperative assessment of primary dental implant stability which allows fast and fully automatic structural analysis during preoperative planning for dental implant surgery. This method integrates a fully automatic fast finite element solver within the framework of new concepts in computer-assisted preoperative planning for implant surgery. The resulting displacements were measured and compared with those predicted by numerical analysis during planning. The results show that fast structural analysis can be integrated with surgical planning software allowing the initial axial implant stability to be predicted in real time during planning. It is believed that such a system could be used to select patients for immediate implant loading and, when further developed, will be of use in other areas of preoperative surgical planning [13].

Limitation of these methods therefore lead to the development of other diagnostic tests that are non-invasive, clinically applicable, user friendly and reliable to measure implant stability such as the Resonance Frequency Analysis Device.

Meredith and coworkers in 1996 first described the resonance frequency analysis for implant stability measurement which is commercially available as Osstell, Implomates, Penguin. This technique measures the resonance of a transducer that is attached to implants to correlate with micromobility or displacement which in turn is determined by the bone density. The RFA technique provides clinically relevant information about the state of the implant –bone interface at any stage after implant placement. It can be used as an additional parameter to support decision making during implant treatment and follow up [7].

COMPARING VARIOUS MEASURES TO ASSESS IMPLANT STABILITY

To evaluate the bone quality and degree of osseointegration of an implant various methods have been proposed. These include histology, histomorphometry and removal torque analysis. In course of time the limitations of invasiveness and inaccuracy were overcome by designing non-invasive devices like Periotest and Resonance frequency analysis device. These are used to assess clinically the implant stability over a long term period, yet periotest values do not always precisely correspond to biomechanical parameters. Unlike the periotest values the RFA values strongly correlate with changes in implant stability during osseous healing and failure of implants.

Evaluation of the reliability of Osstell TM and Periotest devices in assessing implant stability revealed that both devices are non –invasive ,reliable showed strong association to each other in assessing implant stability and can be used in the long term follow up of implant integration [14].

Correlation between implant stability quotient and bone-implant contact was assessed utilizing RFA device stating that a significant positive correlation exists between the RFA and BIC values and more bone contact with implant surface implies higher implant stability [15].

Analysis with a purpose of simulating the influence of parameters like implant length, bone quality, bone loss and quality of transducer fixation on resonance frequency analysis and damping capacity measurements utilizing periotest and osstell mentor devices respectively revealed that both reacted similarly to different parameters of implant stability. Good correlation between periotest and RFA values were observed only when bone loss values were not considered [16].

Investigations on the sensitivity and reliability of OSSTELLTM compared to Periotest system in implant stimulated conditions revealed significant correlation between osstell and periometer instruments [17].

Evaluation whether resonance frequency (RF) analysis combined with modal damping factor (MDF) analysis provides additional information on osseointegration during dental implant healing status revealed that RF combined with MDF provides additional information on dental implant healing status. MDF analysis can detect changes in the implant/bone complex during the healing period even in implants with higher RF values [18].

RESONANCE FREQUENCY ANALYSIS SIGNIFICANCE

Resonance frequency analysis (RFA) is one of such techniques which is most frequently used nowadays and works under the basic vibrational theory that is used to design transducer. The transducer could be excited using a steady state, swept frequency waveform and its response measured to determine the stiffness of an implant in the surrounding tissues. The technique originally used an L-shaped transducer that was screwed to an implant and excited over a range of frequencies. Response of the frequency was analyzed. With the first flexural resonance of beam, amplitude and phase of received signal changes.

Four generations of RFA have been introduced so far. The first generation device was based on a measuring element transducer placed on implant/abutment and then connected to a measuring unit with a wire. Second generation device analyses frequency response utilizing the magnetic technology. The third generation device was designed to overcome drawbacks of first and second generation RFA devices like the different transducers that had to be calibrated. Third generation system was provided with a small battery driven system, which enables quick and simple measurements and chair side interpretation.

The first commercially available RFA equipment is OSSTELLTM, followed by OSSTELL AB, then OSSTELL Mentor and the most recent version of RFA is OSSTELL ISQ which utilizes a smart peg and a wireless probe attached to the device. The smart peg has a small magnet attached at its top that is excited by magnetic pulses generated from a probe. The activated peg induces electric volt into probe that is sampled by the magnetic RFA device.

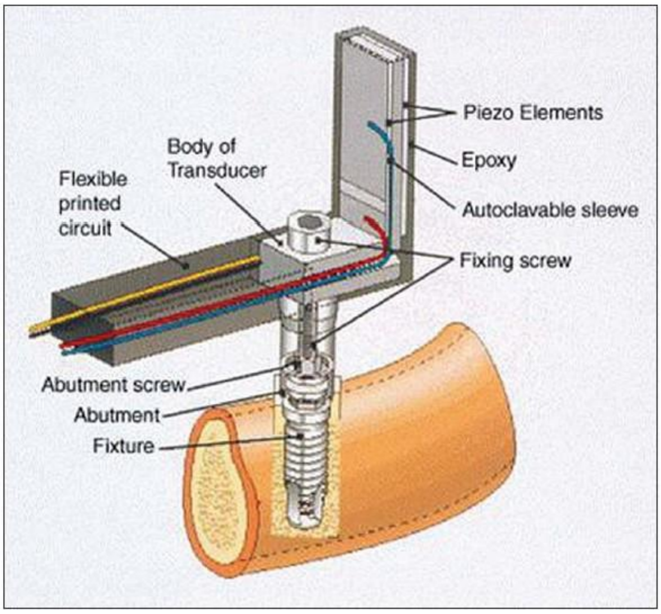

Fig-1: Electronic Resonance Frequency Analysis

Implant stability was determined under various surrounding bone conditions by Huang HM et al and concluded that RFA could serve as non-invasive diagnostic tool for detecting implant stability during different healing stages in different bone densities [19].

Clinical trials to determine whether RFA can be integrated into routine clinical evaluation supported the need for a tool such as RFA to evaluate dental implant stability prior to loading [20]. Changes in implant stability measured using both the devices magnetic RFA device and with electronic RFA device correlated significantly during the healing period [21].

Clinical trials were conducted to evaluate the prognostic accuracy of RFA measurements to determine optimal threshold value for predicting failure risk of immediately loaded implants. RFA values can merely indicate that inserted implant is clinically stable but may provide a false sense of assurance in contemplating an immediate implant restoration. To overcome the low sensitivity of RFA as a prognostic tool a combination of clinical parameters, radiographic evaluation should also be considered prior to immediate loading [22].

IMPLANT STABILITY USING OSSTELL

Resonance frequency analysis allows the assessment of implant stability by measuring implant oscillation frequency on bone. Meredith et al 1998 described the non-invasive method of assessing implant stability utilizing the RFA device OSSTELL. OSSTELL devices have been designed since 1999 by the Integration Diagnostics Ltd, Sweden. Within the last decade, numerous generations of osstell devices have evolved to improvise the implant stability measurements viz., OSSTELL ™, OSSTELL Mentor, OSSTELL ISQ.

It is a non-invasive diagnostic technique that uses a piezoelectric transducer. It emits a sinusoidal signal within a specific frequency meant to make the implant vibrate. Implant's resistance to vibration is measured by the device and transformed into ISQ value. Implant Stability Quotient Value (ISQ) is measured on a scale within 0-100, 100 being the maximum and 0 lowest stability values.

The last and latest generation of this device was developed in 2009, OSSTELL ISQ, It includes a new control unit with a probe connected to it by means of a cable. Its use is progressively extending to register the implant stability measurement due to the ability of device to reproduce accurate values without intra and inter observer variability. The Osstell measurements are highly reliable and is alone sufficient to assess the status of implant success.

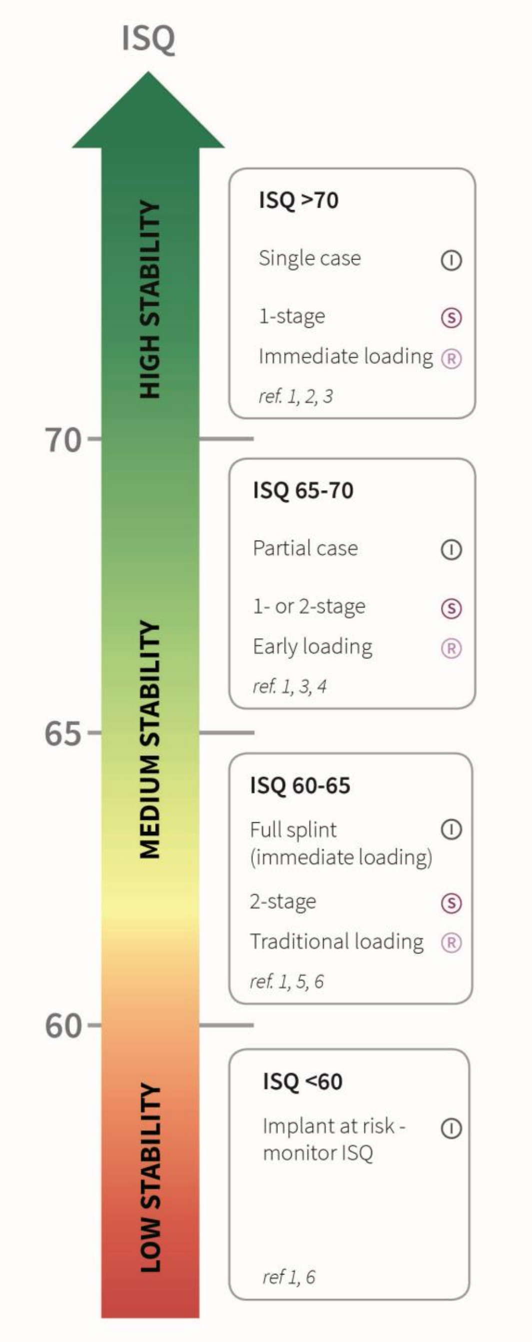

Fig-2: Implant Stability Quotient Scale (WWW.OSSTELL.COM)

Nedir R *et al*., evaluated the implant primary stability as a means of predicting osseointegration. However they stated that all implants with an ISQi >49 osseointegrated when left to heal for 3 months. All implants with an ISQi >54 osseointegrated when immediately loaded. For implants with low ISQi values, decrease in implant stability should alert the practitioner to take precautionary measures. For implants with high ISQi values, reduction of implant stability during first 12 weeks of healing can be considered as a common event [23].

A safe threshold RFA value for planning immediate implant restoration was analyzed stating that implant stability values after 8 weeks showed a better accuracy in predicting implants and optimum cut off value for detecting implant stability was ISQ of 60.5 [24].

Primary stability of implants was assessed through RFA using OSSTELL^{TM} and OSSTELL Mentor devices to analyze the comparibility and reproducibility of these devices stating that Osstell underestimates implant stability relative to Osstell Mentor score.[25] Clinical trials on efficacy of OSSTELL ISQ concluded the almost perfect repeatability, reproducibility and highly reliability with one measurement [26].

Evaluated the ISQ values using OSSTELL Mentor during implant integration in immediately and non-immediately loaded implants concluded that RFA using OSSTELL Mentor may offer an objective method to determine the implant stability and for immediate loading [27].

Comparibility and reliability of OSSTELL Mentor and OSSTELL ISQ in measuring implant stability was estimated and the mean values of ISQ for OSSTELL ISQ and OSSTELL Mentor were 72.87 and 72.04 respectively, suggesting perfect concordance, reproducibility and repeatability between these devices [28].

Both at insertion and after healing successful implants showed significantly different ISQ values as compared to implant failures or implants with prolonged healing. However, overlapping ISQ distributions at implant insertion demonstrated that there was no correlation among the data that could be used to predict successful osseointegration. The prognostic value of ISQ values were ambiguous [29].

CONCLUSION

The RFA technique has been extensively used in clinical research for the last two decades though there are many techniques to measure implant stability. Nonetheless, from available literature, there is still a lack of precise information on the correlation between ISQ values and the short- and long-term implant outcomes. Different authors have attempted to establish thresholds for primary and secondary stability and highlighted the factors influencing to predict higher risks for implant failure. Only repeated measurements over a longer period of time would have clinical significance and prognostic value.

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