Scientific Works. Series C. Veterinary Medicine. Vol. LXVII (2), 2021
ISSN 2065-1295; ISSN 2343-9394 (CD-ROM); ISSN 2067-3663 (Online); ISSN-L 2065-1295

METHODS FOR DETERMINING OSSEOINTEGRATION OF ENDOSSEOUS DENTAL IMPLANTS - REVIEW

Mihaela MINCU[1], Elvira GAGNIUC[1], Roxana BUDEI[2], Manuella MILITARU[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Veterinary Medicine Bucharest, 105 Splaiul Independentei, District 5, Bucharest, Romania
[2] CMI Roxana Eliss Budei, 4 Eforiei Street, District 5, Bucharest, Romania

Corresponding author email: mihaelam_mincu@yahoo.com

Abstract

The dental implant is currently the treatment of choice for dental restoration in edentulous patients. The success of implantation is represented by the dental implant osseointegration. An important indicator of osseointegration is the primary stability (represents the direct mechanical contact between the dental implant and the bone tissue) and secondary stability (appears when regenerative processes and bone remodeling around the implant occur). The gold standard for determining the stability of the implant is histomorphometric analysis, this being a direct and objective method. The method is mainly used in experimental animal studies. Currently, non-invasive methods are used to monitor human subjects. They have the disadvantage that they are indirect methods (e.g.: radiography, cutting torque test, periotest) or they are subjective (e.g.: Percussion test). Till now, no universally accepted non-invasive method has been discovered to directly and objectively quantify the stability of the dental implant.

Key words: *dental implants, implant stability, RFA (Resonance Frequency Analysis), osseointegration.*

INTRODUCTION

Currently, the dental implant is the treatment of choice for dental restoration in edentulous patients (Antonio et al., 2011). The success of implantation is represented by the ability of osseointegration of the implant in the body (Satwalekar et al., 2015).
Branemark and associates first promoted, in 1969, the concept of osseointegration, defining it as the direct structural and functional connection between living bone tissue and the implant surface (Branemark, 1985), and in the following years they published study reports on dental implants and osseointegration (Branemark, 2001).
In 1987 Albrektsson and Jacobsson stated that tests are generally used to indicate, not to verify, the osseointegration process.
Several factors participate in the osseointegration process, each of them having an important role. These factors refer to: the type of implant and its external architecture, the roughness of the implant, its surface or coating, the biocompatibility of the implant, the mechanical properties and physical characteristics of the implant, the place of insertion of the implant, the quality and quantity of bone in which the implant will be inserted, the surgical technique, long-term implant maintenance (Parithimarkalaignan & Padmanabhan 2013)
The stability of the implant has an important role to assure the success of implantation and osseointegration.
Two stages of implant stability can be identified: primary stability and secondary stability (Sennerby & Meredith, 1998) (Table 1).

Table 1 - Factors that may influence the stability of the dental implant

Type of stability	Factors
primary stability	- bone quality - the surgical technique - the design and the surface of the dental implant (the external architecture, the material, the length, the diameter, the surface characteristics of the dental implant)
secondary stability	- primary stability - the surface of the dental implant - the reactivity of the peri-implantar tissue

Primary stability refers to the lack of mobility when establishing the mechanical contact between the implant and the bone cortical area and depends on certain factors such as: bone quality, surgical technique, the implant design and the surface of the implant (the external architecture, the material, the length, the diameter, the surface characteristics of the implant) (Sennerby et al., 1991, Quesada - Garcia et al., 2009, Konstantinovic 2015).

Secondary stability occurs when regenerative processes and bone remodeling around the implant occur. Secondary stability usually refers to a period of 3-6 months postimplant-tation, although the response of peri-implantar tissue to the trauma produced can take place over a period of up to 18 months (Sennerby & Meredith, 1998; Huang et al., 2002; Nedir et al., 2004; Lang, 2007). Secondary stability depends on factors such as: the primary stability, the implant surface and the reactivity of the peri-implantar tissue which takes into account the period of bone remodeling and healing (Cannizzaro et al., 2007; Huwiler et al., 2007; Atsumi et al., 2007).

Liubavinac- Hack N. and colab. and L. Molly appreciate that primary stability is essential in determining secondary stability and further in determining the correct operating time of the implant (Lioubavina et al., 2006; Molly, 2006).

It is important that in order to predict the long-term evolution of osseointegration, the stability of the implant can be quantified at certain periods of time, by measurable procedures. (Atsumi et al., 2007).

In order to be able to clinically evaluate the patient, certain mechanical indicators of implant stability and less histological criteria are used (these being used especially in animal studies being the gold standard for determining osseointegration), as stated by Meredith, in 1998 (Meredith, 1998).

This article aims to analyze/expose/identify invasive, non-invasive methods that can directly or indirectly demonstrate, subjectively or objectively, the presence of the phenomenon of osseointegration.

METHODS OF EVALUATION OF THE IMPLANT STABILITY

Currently, both invasive and non-invasive methods are used to determine osseointegration. (Swami et al., 2016) as listed in Table 2.

Table 2 - Methods used in assessing implant stability

Invasive methods	Noninvasive methods
1. histomorphometric analysis *2. tensional test* *3. push-out/pull-out test* *4. removal torque test (RTT)* *5. circularly polarized light microscopy* ***6.*** *reverse torque test /implant loosening test*	1. the implantologist's perception 2. percussion test 3. radiographic analysis 4. cutting torque resistance analysis (CRA) 5. periotest 6. resonance frequency analysis (RFA) 7. insertion torque resistance measurement 8. measurement of the lateral mobility

Invasive methods

Invasive methods refer to a series of tests generally performed on experimental animal model, some of these tests being rarely used on human patients due to the invasiveness of the method. (Atsumi et al., 2007; Brunski, 2006).

Histomorphometric analysis - represents the gold standard for determining the stability of the implant. The method consists of biopsy of bone tissue and microscopic examination by specific techniques.

Currently it is made only on experimental animal model. For human patients, this method is no longer accepted due to the invasive nature necessary to perform the biopsy that provides data on the stability of the implant (Kastala 2018).

Tensional test - at the beginning, the measurement was performed by detaching the implant from the bone support in which it had been inserted. Afterwards, the methodology was modified, applying lateral loads on the implant. Even though improvements have been made to the method, there are difficulties in interpreting the results, these being directly influenced by the characteristics of the insertion substrate. (Meenakshi et al., 2013)

Push-out/pull-out test is the method that evaluates the healing capacity of bone tissue at the interface with the cylindrical implant without a threaded surface (Brunski, 2006). It is a method that measures shear strength by applying a load parallel to the bone tissue/implant interface (Meenakshi et al., 2013).

Removal torque test is the method that was proposed by Roberts and his collaborators in

1984, and will later be developed and experimented by Johansson and Albrektsson (Atsumi, 2007). The method consists in removing the implant after the healing period to determine osseointegration (Atsumi et al., 2007).

Sullivan et al., have speculated, following their experiment, that any removal torque value (RTV) above 20Ncm may indicate implant osseointegration (Sullivan et al., 1996). This method is limited to animal studies (Atsumi et al., 2007).

Circularly polarized light microscopy can provide information about the inorganic and organic structure of different materials, information that cannot be provided by other methods (Bromage et al., 2003).

A number of studies use this method on an experimental animal model to evaluate osseointegration in the early stages of osseointegration (7, 21 and 42 days), following the collagen fibers orientation patterns. A certain type of orientation of these fibers has been observed which at a certain moment may indicate the maturation of collagen fibers and the increase of bone resistance in the peri-implantar area (Munhoz et al., 2015)

Reverse torque test/ implant loosening test was the most commonly used method to measure the secondary stability of the implant. Implants showing mobility during this test should be considered for removal. This method is no longer used, as testing can lead to microcracks at the implant interface with the bone, which can lead to implant loss. (Sullivan D.Y. et al., 1996).

Non-invasive methods

Non-invasive methods are used in the clinical evaluation of human subjects (Gupta & Padmanabhan T.V., 2011; Meredith, 1998).

The implantologist's perception it is a simple method of assessing primary stability. It is based on the implantologist's perception when he inserts the implant. It has the disadvantage that it is a subjective method related to the surgeon's experience. The method cannot be reproduced or quantified (Swami et al., 2016).

Percussion test consists in evaluating the tonality of the sound emitted by touching a metal object by an inserted implant or by an abutment attached to the implant.

The method has proven to be ineffective as it is a subjective method that depends entirely on the human factor performing the test and does not have the ability to consistently discriminate sounds based on specific criteria. (Meredith, 1998; Al-Jetaily & AlFarraj Al-dosari, 2011).

Radiographic analysis is the most widely used non-invasive method. It can be used at any stage of post-implant healing and is useful to observe the lesions that may occur following implantation, but also to evaluate quantitatively and qualitatively the peri-implantar bone tissue. (Da Cunha, 2004).

The disadvantages of the method are represented by: visibility limitation in the case of conventional panoramic exposures, distortions of the radiographic image, bone loss at the interface with the implant is identified late (Da Cunha, 2004) and cannot accurately indicate the stability of the implant (Atsumi et al., 2007).

Another commonly used method is **computed tomography**. The method is used for planning the implantological treatment, determining the bone density, identifying the local pathological processes, but also for following the osseointegration (Ritter et al., 2014; Wang et al., 2013).

Regarding to **cutting torque resistance analysis** (CRA), the method was developed by de Johansson and Strid and later improved by Friberg. The amount of unit volume of bone removed by current fed electric motor and is measured by controlling the hand pressure during drilling at low speed. This energy is correlated with bone density and primary stability. It has the disadvantage that it cannot assess secondary stability or the potential for implant loss.

Periotest is a type of device developed to be able to quantitatively measure the movement of the tooth. Subsequently, the manufacturer recommends the use of this device to measure with high precision the mobility of the implant in the situation where no problems identifiable by radiological examination were detected (Drago, 2000).

The values recorded by the periotest depend directly on the characteristics of the peri-implantar tissue (bone, if the implantation was successful, or fibrous tissue, if the implant is compromised). The disadvantage of this method is given by the fact that the value obtained is correlated with the direction and position of the excitation determined by the device (Tricio et al., 1995). The value of the read parameters sometimes differs from the real value of the existing biomechanical parameters (Caulier et al., 1997; Derhami et al., 1995).

Resonance frequency analysis (RFA) is one of the most commonly used methods in assessing the stability of the dental implant, being considered a non-destructive and non-invasive method (Meredith et al., 1996; Feng et al., 2015).

This method uses the principle of vibrations. The interpretation of the recorded response is based on the assumption that the resonant frequency is directly related to the rigidity of the bone-implant interface and the surrounding tissue (Zanetti et al., 2018).

Basically, the method targets 3 variables: implant rigidity/stability, implant/bone interface rigidity and peri-implantar bone tissue rigidity (Bavetta et al., 2019).

The higher the frequency resonance, the stronger the implant bone interface, indicating osseointegration (Satwalekar, 2015). Over time, obtaining low values may be associated with marginal bone loss and/or implant mobility, most often indicating the possibility of implant loss (Friberg et al., 1999; Barewal et al., 2003; Sjostrom et al., 2005; Lundgren et al., 2004).

Thus, by this method, the implants with risk of loss can be identified, but it can be considered as a method that indicates if the stability of the implant allows the subsequent prosthesis. (Gallucci et al., 2004; Glauser et al., 2004; Meredith et al. 1997; Kramer et al., 2005).

Resonance Frequency Analysis (RFA) is affected not only by bone tissue characteristics, but also by the effective implant length, diameter, and surface characteristics. This is the reason why no established normative base on RFA is available yet (Zanetti et al., 2018).

Insertion torque resistance measurement is the method that measures the torsional resistance that occurs during implantation. Torque resistance during implantation depends on dental implant characteristics (implant material, surface, architecture) and on bone tissue characteristics (resistance and density) (Ostman P., 2005; Boronat-Lopez A. et al., 2006; Konstantinovic, 2015).

A disadvantage of this method is that its result is influenced by the type of implant and the amount of fluid in the insertion pocket at the time of implantation. Also, the method does not take into account the force with which the implant is inserted（Ostman P. et al., 2005; Boronat-Lopez A. et al., 2006）.

Measurement of the lateral mobility applies to implants that may show a rotational movement, but which are stable to lateral movement (buccal-lingual or mesial-distal) and may have a favorable prognosis in terms of osseointegration (Konstantinovic et al., 2013; Sennerby et al., 2002).

Research and development methods

Further methods are being researched and constantly developed that can demonstrate, directly or indirectly, the presence of the osseointegration phenomenon. These methods include: *Implatest conventional impulse testing, Highly nonlinear solitary waves method, Electro-mechanical impedance method and Micro motion detecting device.*

CONCLUSIONS

The experimental animal model is indispensable in studies in the field of implantology because they allow in-depth cellular research that cannot be performed on human subjects due to the invasiveness of the research methods involved.

The newly discovered methods are initially tested on animal models and will be tested on human subjects after demonstrating their safety and efficiency.

So far, no universally accepted non-invasive method has been discovered to directly and objectively quantify the stability of the dental implant.

A non-invasive, fast, simple test to quantify implant osseointegration and stability is extremely necessary in current implantology.

REFERENCES

Albrektsson T. and Jacobsson M. *Bone-metal interface in osseointegration,* 1987, The journal of prosthetic dentistry, Vol 57, No5, 597-607

Al-Jetaily S., AlFarraj Al-dosari A. *Assessment of Osstell and Periotest systems in measuring dental implant stability (in vitro study)* The Saudi Dental Journal, 2011, 23, 17-21

Antonio A.A., Oliveira Neto P., de Santis E., Caneva M., Botticelli D., Salata L.A., *Comparisons between Bio-Oss® and Straumann® Bone Ceramic in immediate and staged implant placement in dogs mandible bone defects*, Clinical Oral Implants Reasearch, 2011, 1-8

Atsumi M., Park S.H., Wang H.L. *Methods used to assess implant stability: Current status* International Journal of Oral Maxillofacial Implants 2007 Vol 22, 743-54

Barewal RM, Oates TW, Meredith N, Cochran DL. *Resonance frequency measurement of implant stability in vivo on implants with a sandblasted and acid□etched surface*. International Journal Oral Maxillofacial Implants 2003; 18:641-651.

Boronat-Lopez A., Penarrocha-Diago M., Martinez-Cortissoz O., Minguez-Martinez I., *Resonance frequency analysis after the placement of 133 dental implants*. 2006, Med Oral Path Oral Cir Bucal 11(3):272-6

Branemark P-I, Zarb GA., Albrektsson T. *Tissue-Integrated Prostheses* 1985 Chicago:Quintessence

Brånemark R., Brånemark P-I, Rydevik B, Myers R. R. *Osseointegration in skeletal reconstruction and rehabilitation: A review*, 2001 Journal of Rehabilitation Research and development, Vol 38, No2, 175-181

Bromage T.G., Goldman H.M., McFarlin S.C., Warshaw J, Boyde A and Riggs C.M *Circularly Polarized Light Standards for Investigations of Collagen Fiber Orientation in Bone*, 2003, The Anatomical Record (PART B: NEW ANAT.) 274B:157–168

Brunski J. *Push out (pull), tensile and reverse torque tests of bone implant interfaces,* 2006, Clin Oral Implant Res ;1:33-40

Cannizzaro G., Leone M., Esposito M.. *Immediate functional loading of implants placed with flapless surgery in the edentulous maxilla: 1-year follow-up of a single cohort study.* 2007, International Journal of Oral Maxillofacyal Implants. Vol 22:87-95.

Caulier, H., Naert, I., Kalk, W., Jansen, J.A., 1997. The relationship of some histologic parameters,radiographic evaluations, and Perio□test measurements of oral implants: an experimental animal study. Int. J. Oral Maxillofac. Implants 12, 380–386.

Da Cunha HA, Francischone CE, Filho HN, de Oliveira RC. *A comparison between cutting torque and resonance frequency in the assessment of primary stability and final torque capacity of standard and TiUnite single-tooth implants under immediate loading.* International Journal of Oral Maxillofacial Implants 2004;19:578-85.

Derhami, K., Wolfaardt, J.F., Faulkner, G., Grace, M., 1995. Assessment of the Periotest device in baseline mobility measurments of craniofacial implants. Int. J. Oral Maxillofac. Implants 10, 221–229.

Drago, C.J., 2000. A prospective study to assess osseointegration of dental endosseous implants with the Periotest instrument. Int. J. Oral Maxillofac. Implants 15, 389–395.

Feng SW, Chang WJ, Lin CT, Lee SY, Teng NC, Huang HM, *et al.* Modal damping factor detected with an impulse-forced vibration method provides additional information on osseointegration during dental implant healing. Int J Oral Maxillofa Implants 2015;30:1333-40

Friberg B, Sennerby L, Gröndahl K, Bergström C, Bäck T, Lekholm U, *et al. On cutting torque measurements during implant placement: A 3-year clinical prospective study.* Clin Implant Dent Relat Res 1999;1:75-83.

Glauser R, Sennerby L, Meredith N, et al. *Resonance frequency analysis of implants subjected to immediate or early functional occlusal loading. Successful vs. failing implants*. Clinical Oral Implants Research 2004;15: 428-434.

Gupta RK., Padmanabhan TV. *Resonance frequency analysis*. Indian Journal of Dental Resarch 2011;22:567-73.

Huang H.M., Lee S.Y., Yeh C.Y., Lin C.T. *Resonance frequency assessment of dental implant stability with various bone qualities: a numerical approach.*2002 Clinical Oral Implants Research. Vol 13:65-74.

Huwiler M.A., Pjetursson B.E., Bosshardt D.D., Salvi G.E., Lang N.P. *Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation.* 2007 Clinical Oral Implants Research. Vol 18:275-80.

Kastala V.H., *Methods to measure implant stability*, 2018, Journal of Dental Implant, 8, 3-8

Konstantinovic V, Todoroviý V, Laziý V. *Possibilities of reconstruction and implant-prosthetic rehabilitation following mandible resection*. Vojnosanit Pregl 2013; 70(1): 80-5.

Konstantinovic V.S., Ivanjac F., Lazic V., Djordjevic I., *Assessment of implant stability by resonant frequency analysis* 2015, Vojnosanit Pregl, 72(2): 169-174

Kramer FJ, Dempf R, Bremer B. *Effificacy of dental implants placed into fifibula-free flflaps for orofacial reconstruction.* Clin Oral Implants Res 2005;16:80-88.

Lang N.P., Tonetti M.S., Suvan J.E., Pierre Bernard J., Botticelli D., Fourmousis I., *Immediate implant placement with transmucosal healing in areas of aesthetic priority. A multicentre randomized controlled clinical trial I. Surgical outcomes* 2007. Clinical Oral Implants Research. Vol 18:188-96.

Lioubavina-Hack N., Lang NP., Karring T. *Significance of primary stability for osseointegration of dental implants.* Clincal Oral Implants Res 2006 Vol 50, No.7 17:244

Lundgren S, Andersson S, Gualini F, Sennerby L. *Bone reformation with sinus membrane elevation: A new surgical technique for maxillary sinus floor augmen□tation*. Clinical Implant Dental Relat Res 2004;6:165-173.

Meredith N, Alleyne D, Cawley P. *Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis*. Clinical Oral Implants Resarch 1996;7:261-267.

Meredith N. *Assessment of implant stability as a prognostic determinant.* International Journal of Prosthodontics 1998;11:491-501.

Molly L. *Bone density and primary stability in implant therapy*. Clin Oral Implants Res 2006;17 Suppl 2:124-35

Munhoz F.L., Della-Casa M. S., Sesma N., Martins D.M.F.S, Filho L.G.F and Bromage T.G. *Analysis of the Early Stages of Osseointegration in Two Surface Dental Implants:Pilot Study* 2015, Dentistry Vol 5, 322

Nedir R., Bischof M., Szmukler-Moncler S., Bernard J.P., Samson J. *Predicting osseointegration by means of implant primary stability*.2004, Clinical Oral Implants Research. Vol 15:520-8.

Ostman P., Hellman M., Sennerby L., *Direct Implant Loading in the Edentulous Maxilla Using a Bone Density-Adapted Surgical protocol and Primary Implant Stability Criteria for Inclusion.* 2005, Clin. Implant Dental Relat. Res 7 supl 1:60-9

Parithimarkalaignan S. and Padmanabhan T.V. *Osseointegration: An Update* 2013 Journal Indian Prosthodont Society , Vol 13, No1, 2-6

Quesada- Garcia M.P., Prados-Sancez E., Olmedo-Gaya M.V., Munoz-Soto E., Gonzales-Rodriguez M.P., Vallecillo-Capilla M., *Mesurement of dental implant by resonance frequency analysis: A review of the literature* 2009, Medicina Oral Cir Bucal 1.14(10) 538-46

Ritter L, Elger MC, Rothamel D, Fienitz T, Zinser M, Schwarz F, et al. *Accuracy of peri-implant bone evaluation using cone beam CT, digital intra-oral radiographs and histology*. Dentomaxillofac Radiol 2014;43.

Satwalekar P., Nalla S., Reddy R, Chowdary S. G., *Clinical evaluation of osseointegration using resonance frequency analysis,* The Journal of Indian Prosthodontic Society, 2015, 15

Sennerby L, Meredith N. Analisi della Frequenza di Risonanza RFA). *Conoscenze attuali e implicazioni cliniche. In: Chiapasco M, Gatti C, editors. Osteointegrazione e Carico Immediato.* Fondamenti Biologici e Applicazioni Cliniche. Milano: Mason,Spa; 2002. p.1932.

Sennerby L. *Resonance frequency analysis for implant stability measurements*. A review. Integr Diagnostic Update 2015;1:1-11.

Sennerby L., Ericson L.E., Thomsen P., Lekholm U., Astrand P. *Structure of the bone-titanium interface in retrieved clinical oral implants,* 1991, Clinical Oral Implants Research. Vol 2:103-11.

Sennerby L., Meredith N. *Resonance frequency analysis: Measuring implant stability and osseointegration*. Compendium of Continuing Education in Dentistry 1998 Vol 8, 19:493

Sjostrom M, Lundgren S, Nilson H, Sennerby L. *Monitoring of implant stability in grafted bone using resonance frequency analysis. A clinical study from implant placement to 6 months of loading.* International Journal Oral Maxillofacial Surgery 2005;34:45-51.

Sullivan DY, Sherwood RL, Collins TA, Krogh PH. *The reverse torque test: a clinical report.* Int J Oral Maxillofac Implants 1996; 11(2): 179-85.

Swami V, Vijayaraghavan V, Swami V. *Current trends to measure implant stability.* The Journal Indian Prosthodontic Society 2016;16:124-30.

Tricio, J., Van Steenberghe, D., Rosenberg D., Duchateau, L., *Implant stability related to insertion torque force and bone density: an in vitro study*. J. Prosthet. Dent. 1995, 74, 608–612.

Wang D, Künzel A, Golubovic V, Mihatovic I, John G, Chen Z, et al. *Accuracy of peri-implant bone thickness and validity of assessing bone augmentation material using cone beam computed tomography*. Clinical Oral Investigation 2013;17:1601-9.

Zanetti, E.M.; Ciaramella, M.; Calì, M.; Pascoletti, G.; Martorelli, M.; Asero, R.; Watts, D.C. Modal analysis for implant stability assessment: Sensitivity of this methodology for different implant designs. *Dent. Mater.* **2018**, *34*, 1235–1245.

Zanetti, E.M; Calì, M.; Pascoletti, G.; Bignardi C; Franceschini G. Clinical Assessment of Dental Implant Stability During Follow-Up: What Is Actually Measured, and Perspectives 2018, Biosensors 8, 68

Bavetta G., Bavetta G., Randazzo V., Cavataio A. Paderni C., Grassia V., Dipalma G.,1 Gargiulo Isacco C., Scarano A., De Vito D., Cantore S., Ballini A and Inchingolo F, 2019 Clinical Study:A Retrospective Study on Insertion Torque and Implant Stability Quotient (ISQ) as Stability Parameters for Immediate Loading of Implants in Fresh Extraction Sockets Hindawi BioMed Research International Volume 2019, Article ID 9720419

Meenakshi S, Raghunath N, Raju SN, Srividya S, Indira PN. Implant stability a key determinant in implant integration. Trends Prosthodont Dent Implantol 2013;4:28-48.