Monitoring Osseointegration : A Review

Dr Mohit Kamra
Reader, Deptt. of Prosthodontics

Dr. Rajnish Jain
Reader, Dept. of Conservative Dentistry

Dr Preeti Choudhary
Reader, Deptt. of Pedodontics

Swami Devi Dyal Dental College, Barwala, Punchkula, Haryana

Abstract

Micromotion at the interface has already been shown to influence tissue differentiation and excessive micromotion compromises implant osseointegration, since it prevents contact between the bone and the implant surface. The use of an ultrasonic tool would avoid problems in the osseointegration process resulting from mechanical micromotions.

The longevity of dental implants depends on osseointegration, which provides load-bearing capacity without putting the prosthesis at risk from micromotions at the implant-bone interface. Bone microstructure has usually been assessed by obtaining samples invasively and analyzing them with conventional histomorphometric methods. Improvements in high-resolution image acquisition systems have enabled non-invasive assessment of bone morphology and a more precise 3-D evaluation by means of "virtual biopsies", permitting bone assessment in regeneration or remodeling processes. [1]

Key Words : Boneimplant interactions, osseointegration, implant stability.

Introduction

Bone is a unique structural material. Its physical and mechanical properties mimic both natural materials such as wood and man-made materials including polymers.

Its mechanical properties can be directly correlated to its complex structure and it should therefore be described as an anisotropic material (Carter & Beaupre, 2001). In contrast many man-made polymers have a uniform structure in all directions and can thus be considered homogenous materials.

Bone's unique property is its ability to form new bone and to remodel existing bone. This is especially important in its response to applied mechanical stresses (Carter et al, 1998).[2]

The degree of osseomechanical integration of dental implants is acutely sensitive to their mechanical environment. Bone, both as a tissue and structure, adapts its mass and architecture in response to loading conditions. Therefore, application of predefined controlled loads may be considered as a treatment option to promote early maturation of bone/implant interface prior to or in conjunction with crown/ prosthesis attachment.

Stiffness of the tissueimplant interface and implant-supporting tissues are considered as the main determinant factors in osseointegration .While the structure and heterogeneity of mineralization affects the stiffness of bone.

Bone Mechanobiology

The interaction between mechanical signals and biological processes in cells and tissue is studied in mechanobiology. Mechanical load may influence cell proliferation, differentiation and metabolism and therefore have a crucial role in live tissue growth, adaptation, regeneration and bioengineering. Mechanobiology combines experimental biological techniques (in vitro and in vivo models) and computerized techniques (mathematical and computer models) to create interactions between mechanics and biology.Van der Meulen described skeletal mechanobiology as "the science that studies the mechanical forces that modulate morphological and structural fitness of skeletal tissue, i.e., bone, cartilage, ligament and tendon"[1]. Three developments have led to major advances in bone mechanobiology in recent years: a) computer models of structures, allowing analysis of the effects of physical force on the complex bone geometry; b) molecular biology, permitting detection of gene expression and protein synthesis after applying different mechanical forces, and c) novel imaging technology, revealing the micro- and nanostructural characteristics of tissue. Real high-resolution images can serve as a source of data for generating Finite Element (FE) computer programs, providing a more accurate simulation of different biomechanical load situations compared with conventional FE. The study of bone biomechanics is relevant to bone physiopathology (e.g., osteoporotic state or fracture risk), bone-biomaterial interface (e.g., periimplant healing), and bone regeneration (e.g., distraction histogenesis and fracture healing). Unlike traditional biomechanical methods, computerized micro-FE models (μFEs) can simulate the different biomechanical properties of bone (compression, tension, shearing or fatigue) and do not require the destruction of samples.[1]

Timing of osseointegration

While it has been demonstrated that excessive mobility may cause fibrous tissue formation and lead to failure of osseointegration (Huiskes et al. 1997; Lioubavina- Hack et al. 2006), in order to limit the micromotion and achieve primary stability of the implant, a slightly undersized osteotomy is usually prepared for press-fitting of the implant. However, a _60 mm gap between the implant and host bone has been noted under microscopic investigations (Futami et al. 2000; Colnot et al. 2007), and depending on the extent of injury to the host bone, this gap may later extend to 100500 mm (Eriksson et al. 1984). Therefore, this gap is filled with blood and forms a water layer incorporated with hydrated ions on the implant surfaces immediately after implant placement (Park & Davies 2000; Berglundh et al. 2003).

The small proteins adsorbed on the surface are subsequently replaced by larger proteins based on the 'Vroman effect'. Although different implant surface properties may affect the composition and conformational states of the binding proteins, the biological aggregates on the surface interact with the cell extensions, cell membrane, membrane- bound proteins or receptors, and initial cell attachment eventually establishes on the implant surface (Kasemo & Gold 1999). The interface area is first occupied by red blood cells, inflammatory cells, and degenerating cellular elements, then is gradually replaced with spindle-shaped or flattened cells, concurrent with initiation of osteolysis on the host bone surface until day 3 (Futami et al. 2000). Osteoblasts begin to attach and deposit collagen matrix at this stage (Meyer et al. 2004).Early bone formation is not evident until days 57 (Berglundh et al. 2003; Colnot et al. 2007) and is consistent with the sequence of appositional matrix deposition and calcification from the lamina limitans of

host bone onto the implant surface (Marco et al. 2005). Most of the interfacial zone is occupied by provisional matrix rich in collagen fibrils and vasculature, and woven bone can be observed around the vascular areas by day 7 (Berglundh et al. 2003). Through continuous deposition, trabecular bone fills the initial gap and arranges in a three-dimensional (3D) network at day 14 (Franchi et al. 2005).The de novo formation of primary bone spongiosa offers not only a biological fixation to ensure secondary implant stability (Ferguson et al. 2006) but also a biological scaffold for cell attachment and bone deposition (Franchi et al. 2005). After 28 days, delineated bone marrow space and thickened bone trabeculae with parallelfibered and lamellar bone can be found within the interfacial area. After 812 weeks, the interfacial area appears histologically to be completely replaced by mature lamellar bone in direct contact with titanium (Berglundh et al. 2003).

The measurement of osseointegration.

Osseointegration is associated with intimate and long-lasting contact between bone and the alloplastic tooth root replacement material. While there is yet no generally accepted device or method for the objective clinical assessment of osseointegration, techniques used for this purpose include:

Manual Percussion And Mobility Tests: This is by far the most common clinical technique to assess implants. Typically, successfully functioning implants are immobile and exhibit a clear, ringing sound when percussed, while failing implants tend to be mobile and elicit a dull sound. Admittedly subjective and insensitive to small changes in state, these are nevertheless useful "go/no-go" tests for osseointegration, both initially (before loading) and for periodic follow-up assessment. Unlike histologic alternatives, they are minimally invasive and nondestructive.

Histology: The defining histologic characteristic of osseointegration is the direct apposition of bone to the alloplastic surface with no interposing fibrous tissue at the light microscopic level. This result has been found in humans and in several animal models, although the amount of bone at the interface varies with the animal species and implant type, as well as the site and other factors. No specific amount of bone contact has been adopted as a standard for osseointegration.

Other Destructive Techniques: Many other approaches have been suggested to overcome the limits of the qualitative clinical examination: electron microscopic studies, conventional histology, the optical chamber technique, and various bio-mechanical methods such as torque, push-out,and pull-out testing. Whatever their strengths and weaknesses, all share the disadvantage of being destructive; they are therefore unsuitable for use in human patients and incapable of producing true longitudinal data in any species

Radiographic Techniques: Radiography, which is noninvasive and widely available, can be used to monitor the physical manifestations of implant osseointegration and failure to approximately 0.5 mm resolution with conventional techniques, or to 0.1 mm with digital subtraction radiography. However, functional osseointegration depends upon phenomena at and within the thin layer of interfacial soft tissue, which cannot be resolved by the usual clinical radiographic techniques, especially on buccal and lingual surfaces masked by the radiopaque implant.

Pre-clinical biomechanical assessments for osseointegration

Tensional test

The interfacial tensile strength was originally measured by detaching the implant plate from the supporting bone (Kitsugi et al.1996). Branemark later modified this technique by applying the lateral load to the cylindrical fixture (Branemark et al.1998) .However, they also addressed the difficulties of translating the test results to any area-independent mechanical properties.

Push-out/pull-out test

The 'push-out' or 'pull-out' test is the most commonly used approach to investigate the healing capabilities at the boneimplant interface (Brunski et al. 2000; Kempen et al. 2009). In the typical pushout or pull-out test, a cylinder-type implant is placed transcortically or intramedullarly in bone structures and then removed by applying a force parallel to the interface. The general loading capacity of the interface (or interfacial shear strength) can be measured by dividing the maximum force by the area of implant in contact with the host bone (Berzins et al. 1997). 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 (Brunski et al. 2000).

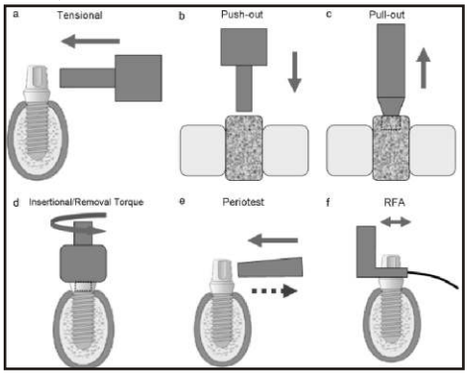

Fig. 1. Biomechanical assessments for oral implant osseointegration (a) tensional test, (b) push-out test, (c)pull-out test, (d) insertional/removal torque test, (e) Periotest, and (e) resonance frequency analysis (RFA).

Removal torque

The removal torque refers to the torsional force necessary for unscrewing the fixture and was first investigated by Johansson et al. (1998). The removal torque value was recorded using a torque manometer calibrated in Newton-centimeters (Ncm). This technique primarily focuses on interfacial shear properties. However, the results may be affected by implant geometry and topography (Meredith et al. 1997; Yeo et al. 2008).

Combination of push-out/pull-out and removal torque

This combinational trial was introduced by Branemark et al. (1998) by applying torsional force until reaching the maximum torque and then pulling the implant out. In this investigation, the removal torque was related to the interfacial bonding capability, and the pull-out strength was related to the shear properties from the implant-supporting structure.

Impulse Testing : Impulse testing is a long-established, highly developed method of structural analysis used throughout the engineering disciplines, particularly in the aerospace and aeronautical fields. In conventional impulse testing, one or more accelerometers are attached to the structure to be tested. The accelerometers also are connected to a recorder that measures acceleration as a function of time. The structure then is percussed with a calibrated hammer, and the acceleration time history, or ATH, is recorded by each accelerometer. The ATH is a sine wave of decreasing amplitude, and the rate of the decrease is related to the damping characteristics and

stiffness of the structure. The greater the rate of decreasing amplitude, the stiffer the structure is. The frequency analyzer converts accelerometer signals from the time domain to the frequency domain using a mathematical algorithm called a fast Fourier transform, or FFT. This method provides a "signature reading" of the tested structure in its free state.

non-invasive and radiation-free methods, magnetic resonance imaging (MRI) is a very attractive modality that could provide clinical evaluation of trabecular bone architecture and quality.[3]

The techniques most commonly used today for monitoring implant stiffness are the Periotest and resonance frequency analysis (RFA), both of which involve

.The tolerated micromotional threshold has been found to lie somewhere between 50 and 150 μm , beyond which the healing of the bone tissue and its intergrowth into porous implants are compromised. A review of the experimental literature indicates that it is not the absence of loading, but the absence of excessive micromotion at the implant-bone interface that is critical for

Current biomechanical assessments for dental implant osseointegration

Methodology	Destructive	Clinical use	Property investigated	Parameters
Tensional test	Yes	No	Lateral resistance Branemark et al. (1998), Kitsugi et al. (1996)	Maximal lateral load
Push-out/pull-out	Yes	No	Interfacial shear Berzins et al. (1997), Brunski et al. (2000)	Maximal force Interfacial stiffness
Removal torque	Yes	No	Interfacial shear Johansson et al. (1998), Meredith et al. (1997)	Loosening torque Torque load
Cutting resistance/	No	Yes	Interfacial shear Friberg et al. (1995), O'Sullivan et al. (2000)	Torque load Peak Insertional torque
Periotest	No	Yes	Damping Aparicio et al. (2006), Schulte & Lukas (1993)	Periostest value (PTV)
Resonance frequency analysis	No	Yes	Vibration/damping Friberg et al. (1999), Meredith et al. (1997), Turkyilmaz et al. (2009)	Implant stability quotient (ISQ)

Discussion

Cancellous bone microarchitecture in the mandible can influence the success of dental implant osseointegration.Astudy aimed to explore the feasibility of two-dimensional (2D) high resolution magnetic resonance imaging (MRI) for the evaluation of trabecular bone architecture and to compare architecture parameters derived from MR images between different areas in the mandible, and between sex and dental status. Osseointegration of endosteal dental implants is a continuous remodelling process dependent on biomechanical properties. Biomechanical properties are determined not only by bone mineral content and bone mineral density (BMD) but also by trabecular microarchitecture. Because dental implants are placed mainly in contact with the cancellous bone, a knowledge of the latter microarchitecture in different areas of the mandible, as well as differences regarding sex and dental status, may improve the understanding of the higher failure rate aetiologies in some situations. Dual energy X-ray absorptiometry (DXA) is a standard technique for osteoporosis assessment but it does not give any information on trabecular micro-architecture. Optical and electron microscopy and microradiography of bone biopsies give access to an accurate analysis of trabecular bone microarchitecture but cannot be used on a large scale because of their invasive character. Among possible

stimulating the implant mechanically and measuring its mechanical response. These data can be measured from time to time to monitor the stiffness of the implant in the bone tissue. A review of the RFA and Periotest techniques indicated that neither of these methods identify the bone/interface characteristics or provide a quantitative evaluation of bone tissue integration.The results of these techniques depend on features such as the characteristics of the bone tissue and the implant sink depth, but neither of these methods has a minimum value to determine a prognosis of implant failure. In fact, the literature reports that, to date, no clinical tool exists to evaluate the amount of osseointegration and stability around dental implants, but only to monitor changes in the stiffness of an implant in bone during healing.Ultrasonic technique have been developed to evaluate the stability of dental implants, taking into account the quantity of bone ingrowth in the surface pores of implants, unlike the principle of the current devices, which measure an implant's response to mechanical stimuli that attempt to cause micromovements.

The mechanical stimulus employed in the evaluation of implant stability must be of an extremely low-amplitude to avoid jeopardizing the process of osseointegration, since micromotions of the implant may cause the formation of fibrous tissue at the tissue-implant interface, preventing the microstructural fusion of bone and implant

osseointegration .

Results have shown that firstly, clinically nonintegrated implants exhibit a nonlinear stiffness when subjected to an external bias load, whereas integrated implants show no such behavior. Second, among integrated implants, the value of dynamic stiffness is roughly proportional to the amount of bone in contact with the implant. Similar findings apply (though at lower significance levels) to the dynamic damping coefficient.[4]

A study was designed to determine the effect of time on the biomechanical integration of cylindrical dental implants in the mandible and maxilla. IMZ dental implants was placed bilaterally in the endentulous maxillae and mandibles Pullout tests were used to assess biomechanical integration at intervals from 2 to 24 weeks. This study indicated that there is a time-dependent, progressive increase in pullout force to 24 weeks. The forces were consistently higher for the mandible than the maxilla. Moreover, there was no correlation between the intraoperative stability of the implant and the postoperative pullout force.[5]

A vitro study indicates that the surface chemical composition and topography of the porous structure leads to good cytocompatibility. Consequently, osteoblasts proliferate smoothly on the entire implant including the flat surface, embossed region, exposed area of the pores, and interconnected channels. In conjunction

with the good cytocompatibility, the superelastic biomechanical properties of the porous NiTi scaffold bodes well for fast formation and ingrowth of new bones, and porous NiTi scaffolds are thus suitable for clinical applications under load-bearing conditions.[6]

Histometric Analysis of immediate loading according to the dependency of bone formation-resorption upon the biomechanical stress-strain of bone investigations clarified that the micromotion of less than 30 μm at the implant-bone interface did not interfere with the osteogenesis and new bone growth at the implant-bone interface.[7]

Micromotion at the interface has already been shown to influence tissue differentiation and excessive micromotion compromises implant osseointegration, since it prevents contact between the bone and the implant surface.The use of an ultrasonic tool would avoid problems in the osseointegration process resulting from mechanical micromotions.

Summary

The ability to monitor osseointegration and the life expectancy of an implant is a valuable diagnostic and clinical tool that has far-reaching consequences on implant dentistry.Biomechanical testing may be a more suitable indicator to evaluate the dynamic changes of osseointegration than any single structural parameter. However, biomechanical testing, such as push-out and pull-out measurements, is destructive and only available for preclinical use . Therefore,the clinical value of non-destructive measurements, such as resonance frequency analysis (RFA) or damping characteristics (Periotests technique, Siemens, Bensheim, Germany), are still limited due to the lower resolution and higher variability during examinations . Hence, integration of peri-implant structure may be necessary to predict the interfacial properties. However, further confirmation through pre-clinical and clinical models is still needed for investigating the mechanism involved in osseointegration and bone regeneration associated with oral implants.

References

1. Jorge Cano , Julián Campo. High resolution image in bone biology II. Review of the literature. Med Oral Patol Oral Cir Bucal. 2008 Jan1;13(1):E31-5.
2. Neil Meredith; Review of Implant Design, Geometry and Placement Applied Osseointegration Research - Volume 6, 2008.
3. L Choël, D Last, F Duboeuf. Trabecular alveolar bone microarchitecture in the human mandible using high resolution magnetic resonance imaging. Dentomaxillofacial Radiology (2004) 33, 177-182.
4. Lance C. Ramp, Robert L Jeffcoat Dynamic Behavior of Implants as a Measure of Osseointegration.Int .J Oral Maxillofac Implants; 2001;16:637645.
5. Kraut RA, Dootson J,Biomechanical analysis of osseointegration of IMZ implants in goat mandibles and maxillae. Int J Oral Maxillofac Implants. 1991;6(2):187-94
6. BioLiu X, Wu S, Yeung KW. Relationship between osseointegration and superelastic biomechanics in porous NiTi scaffolds.Biomaterials 2011 Jan;32(2): 330-8
7. Kawahara, Haruyuki ; Kawahara, Dai ; Osseointegration under Immediate Loading: Biomechanical Stress-Strain and Bone Formation-Resorption. Implant Dentistry: March 2003 - Volume 12 - Issue 1 - pp 61-68.