

Osseointegration: An Update

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Abstract Osseointegration, defined as a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant, is critical for implant stability, and is considered a prerequisite for implant loading and long-term clinical success of endosseous dental implants. The implant–tissue interface is an extremely dynamic region of interaction. This complex interaction involves not only biomaterial and biocompatibility issues but also alteration of mechanical environment. The processes of osseointegration involve an initial interlocking between alveolar bone and the implant body, and later, biological fixation through continuous bone apposition and remodeling toward the implant. The process itself is quite complex and there are many factors that influence the formation and maintenance of bone at the implant surface. The aim of this present review is to analyze the current understanding of clinical assessments and factors that determine the success & failure of osseointegrated dental implants.

Keywords Bone–Metal interface · Endosseous implants · Mechanical interlock · Implant stability

Introduction

Osseointegration is defined as a time dependent healing process whereby clinically asymptomatic rigid fixation of

alloplastic materials is achieved, and maintained, in bone during functional loading (Zarb & Albrektsson,) [1, 2]. Histologic appearance resembled a functional ankylosis with no intervention of fibrous or connective tissue between bone and implant surface.

The successful outcome of any implant procedure is mainly dependent on the interrelationship of the various components of an equation that includes the following [3]:

1. Biocompatibility of the implant material
2. Macroscopic and microscopic nature of the implant surface & designs [4]
3. The status of the implant bed in both a health and a morphologic (bone quality) context
4. The surgical technique per se [5, 6]
5. The undisturbed healing phase [7]
6. Loading conditions

The challenge confronting the clinician is that these several factors must be controlled almost simultaneously, if a predictably successful outcome is to be expected.

Research Background

In clinical experiences it has been demonstrated that the implants were anchored in bone without intervening fibrous tissue, while the experimental data point to an osseointegration even at the ultrastructural level. Collagen filaments approaching the titanium oxide surface and separated only by a 20–40 nm thick Proteoglycan layer [8] have been observed. Studies on the importance of controlling the surgical technique [5, 9] have demonstrated that bone tissue is much more sensitive to heat than previously believed. Eriksson and Albrektsson found that subjecting newly inserted titanium implants to a temperature elevation

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of 47 °C significantly disturbed their subsequent integration in the bone bed. Haraldson has measured bite force levels in patients with osseointegrated dental implants and found that these were similar to levels measured in dentate patients with the same extension of the dentition. Branemark [10] and Adell et al. [11] and Lekholm et al. [12], have examined soft tissue reactions to the mucosa-penetrating abutments and found a healthy gingival reaction with very few inflammatory cells. The bacteriological investigation revealed only about 3 % of the microflora contained potentially dangerous bacteria such as spirochetes. Till date, no other dental implant system has been so thoroughly evaluated from both an experimental and clinical point of view.

Branemark and Albrektsson [13] evaluated the outcome of all implants inserted during 1 year and then followed up for 5 years and found an implant success rate of 96.5 % in the mandible. This improved success rate compared to the data published by Adell et al. [14] reflects a true improvement in the outcome, attributed to meticulous surgical and prosthodontic techniques.

Materials and Methods

Stages of Osseointegration

Direct bone healing, as it occurs in defects, primary fracture healing and in Osseointegration is activated by any lesion of the pre-existing bone matrix. When the matrix is exposed to extra cellular fluid, noncollagenous proteins and growth factors are set free and activate bone repair [15]. Once activated; osseointegration follows a common, biologically determined program that is subdivided into 3 stages:

- Incorporation by woven bone formation;
- Adaptation of bone mass to load (lamellar and parallel-fibered bone deposition);
- Adaptation of bone structure to load (bone remodeling).

Clinical Assessments for Osseointegration

Many methods have been tried to clinically demonstrate osseointegration of an implanted alloplastic material.

These are [16]:

1. Performing a clinical mobility test and finding that the implant is mobile is definite evidence that it is nonintegrated. The presence of clinical stability cannot be taken as conclusive evidence of osseointegration
2. Radiographs demonstrating a apparently direct contact between bone and implant have been cited as evidence of osseointegration

Radiolucent zones around the implant are a clear indication of its being anchored in fibrous tissue, Whereas the lack of such zones is not evidence for osseointegration. The reason for this is that the optimal resolution capacity of radiography is in the range of 0.1 mm whereas the size of a soft tissue cell is in the range of 0.01 mm; thus a narrow zone of fibrous tissue may be undetectable by radiography

3. The use of a metal instrument to tap the implant and analyze the transmitted sound may, in theory, be used to indicate a proper osseointegration. However, there is no typical “sound diagram” defined for the osseointegrated implant in contrast to the implant anchored in fibrous tissue. Therefore, clinical tests of implant interfacial arrangements are only capable of roughly indicating the true tissue responses

Osseointegration is also a measure of implant stability, which can occur at 2 different stages: primary and secondary. Primary stability of an implant mainly comes from mechanical engagement with compact bone. Secondary stability, on other hand, offer biological stability through bone regeneration and remodeling. The former is a requirement for secondary stability. The latter, however dictates the time of functional loading.

Implant stability, an indirect indication of osseointegration, is a measure of the clinical immobility of an implant. Currently; various diagnostic analyses have been suggested to define implant stability standardized radiographs, cutting torque resistance test, modal analysis and, Resonance frequency analysis (RFA).

Presently, clinical application of RFA [17] includes establishing (1) a relationship between exposed implant length and resonance values or ISQ values [18]; (2) differential inter and intra arch ISQ values for implants in various location; (3) prognostic criteria for long term implant success; (4) diagnostic criteria for implant stability [19].

The evaluation of implant stability using RFA machines such as Osstell and Implomates still has some uncertain issues.

It is clinically being used without much conclusive data on the bone –metal interface & resonance frequency values. Further research is needed to establish higher reliability of these diagnostic devices.

Factors That Determine Success and Failure of Osseointegrated Implants

Osseointegration is the basis of a successful endosseous implant. The process itself is quite complex and there are many factors that influence the formation and maintenance of bone at the implant surface. To fully understand what influences osseointegration, it is important first to examine

more closely the interface, the traits of a surface that allow for biocompatibility, and the common surfaces used and studied such as titanium oxide and hydroxyapatite.

Bone-Implant Interface [20]

Osseointegration is a striking phenomenon in which bone directly opposes the implant surface without any interposing collagen or fibroblastic matrix. Numerous studies have all concluded that the strength of an osseointegrated implant is far greater than that of a fibrous encapsulated implant. Also, the strength of the interface between bone and implant increases soon after implant placement (0–12 weeks). This strength may in fact be related to the amount of bone surrounding the implant surfaces. Other factor that may affect the strength of the interface is biophysical stimulation and time allowed for healing. Studies have shown that measurable increases in bone implant interactions take place for at least 3 years.

Implant Biocompatibility [21]

Commercially pure titanium is widely used as an implant material as it is highly biocompatible, it has good resistance to corrosion, and no toxicity on macrophages or fibroblasts, lack of inflammatory response in peri-implant tissues and it's composed of an oxide layer and has the ability to repair itself by reoxidation when damaged. Another material used for implants, Titanium -6 Aluminum-4 Vanadium (Ti-6AL-4 V) alloy exhibits soft tissue reactions very similar to those reported to cp Ti [22, 23].

Titanium Oxide

When Ti (Titanium) or Ti alloys are exposed to air or normal physiologic environments, there is a reaction with the oxygen that causes an oxide layer to be formed. Usually the oxide is in the form of TiO_2 . The oxide layer protects against corrosion. Calcium and phosphate ions have been found in the oxide layers, which suggest that there is an active exchange of ions at the bone implant interface.

In addition, porous surfaces have been shown to enhance ionic interactions, initiate a double physical and chemical anchor system and augment load bearing capacity. Also, porous surfaces can increase the tensile strength via growth of bone three dimensionally as well as increased healing rates. The majority of commercially available implants are covered via plasma spraying. Titanium plasma spraying [24, 25] involves molten droplets being sprayed in a powder form onto the implant surface at high temperatures. Thus, an increased surface area is obtained, increased bone contact is achieved and the ability to form a 3 dimensional interconnection is enhanced. The disadvantage of Titanium

plasma spraying is the risk of scaling and cracking due to the high processing temperatures. Also, there is a risk of abraded material being implanted into the bone-implant interface. The amount of melting of the plasma sprayed titanium contributes to this abrasion. That is, the more the melting, the more abrasion resistant the surface.

HA coatings have the advantage of increasing surface area, decreasing corrosion rates, and accelerating bone formation via faster osteoblast differentiation. Also, due to the enhanced biomechanics HA coated implants are better able to withstand loads. Other advantages of HA include the more organized bone pattern and higher degree of mineralization at the interface, as well as increased bone penetration (which improves fixation). The bone bonding capabilities of HA make it a very desirable surface and probably the most reliable surface up to date.

Implant Surface Characteristics

The Surface Quality will determine tissue reaction to an oral implant. Surface quality may be divided into three categories: (1) Mechanical properties, (2) Topographic properties [26] (3) physiochemical properties.

Mechanical Properties

Mechanical properties of implant surfaces relate to potential stresses in the surface that may result in increased corrosion rate and wear relating to the hardness of the material. Wear is related to the strength of the material, but also to the surface roughness. One technique to minimize the wear is ion implantation.

Topographic Properties

The surface topography relates to the degree of roughness of the surface and the orientation of the surface irregularities. The chemical composition of the implant interface on the implant surface was shown to affect initial cell attachment. This has stimulated great interest on implant surface modification as a way to accelerate the rate of osseointegration.

Surface Roughness

Depending on the scale of the features and based on the proposal of Wennerberg and Albrektsson, surface roughness can be divided into four categories:

- Smooth surfaces: Sa value $<0.5 \mu\text{m}$ (e.g. polished abutment surface).
- Minimally rough surfaces: Sa value 0.5 to $<1.0 \mu\text{m}$ (e.g. turned implants).

- moderately rough surfaces: Sa value 1.0 to <2.0 μm (e.g. most commonly used types).
- Rough surfaces: Sa value ≥ 2.0 μm (e.g. plasma sprayed surfaces).

Moderate roughness and roughness is associated with implant geometry, such as screw structure, and macroporous surface treatments. Previous studies demonstrated that this type of roughness [27] allowed for bone ingrowth and provided mechanical interlocking shortly after implant placement. Higher Bone implant contact [28] (BIC) and removal torque force suggested enhanced secondary stability compared to smooth and minimally rough implants.

There are two main theories regarding the influence of implant surface microtopography on peri-implant tissue formation—(1) the surface energy and (2) the distortional strain. The smaller grain size on the surface results in higher surface energy, which is more favorable for cell adherence.

Furthermore, potential drawbacks of roughening the implant surface include problems with periimplantitis and a greater risk of ionic leakage.

Physical Characteristics

Refer to factors such as surface energy and charge. A surface with a high energy has an affinity for adsorption. In other words, an oral implant with high surface energy may show stronger osseointegration.

Glow discharge treatment results in high surface energy as well as implant sterilization.

A practical way to measure the surface energy is contact angle measurements, a method also determines whether a surface is hydrophobic or hydrophilic (wettability of the surface).

Implant Bed

A healthy implant host site is required. However, in the clinical reality; the host bed may have suffered from previous irradiation and osteoporosis, to mention some undesirable states for implantation. Previous irradiation need not be an absolute contraindication for the insertion of oral implants. However, it is preferable that some delay is allowed before an implant is inserted into a previously irradiated bed. Furthermore, some 10–15 % poorer clinical results must be anticipated after a therapeutic dose of irradiation. Because of vascular damage, at least in part. One attempt to increase the healing conditions in a previously irradiated bed is by using hyperbaric oxygen, as a low oxygen tension definitely has negative effects on tissue repair.

Smoking has been reported to yield significantly lower success rates with oral implants. The mechanism behind

this lowered success is unknown, but vasoconstriction may play a role.

Other common clinical host bed problems involve osteoporosis and resorbed alveolar ridges. Such clinical states may constitute an indication for ridge augmentation with bone grafts.

In jaws with insufficient bone volume for implant installation, a grafting technique has been recommended in order to increase the amount of hard tissues. To create more alveolar bone without grafting, a new surgical technique was tested, relying on the biologic principle of guided tissue regeneration. It is of great value in situations with insufficient alveolar bone volume.

Surgical Technique

Minimal tissue violence at surgery is essential for osseointegration. This objective depends on continuous and careful cooling while surgical drilling is performed at low speed.

If too violent a surgical technique is used, frictional heat will cause a temperature rise in the bone and the cells that should be responsible for bone repair will be destroyed. However, the critical time/temperature relationship for bone tissue necrosis is around 47 °C applied for 1 min.

Loading Conditions

The primary factor for success at the time of placement is achieving primary stability. Any micromotion during initial phases of bone healing will cause a lack of integration. Failure is most often caused by overloading due to transmucosal forces of removable appliance over the implant site.

Any attempt to keep a patient functioning with fixed provisional restoration during the healing phases of treatment, will allow for easier patient management.

If immediate loading at the time of final definitive implant placement is to be considered, not only should the initial stability be extremely tight, but control of the occlusion on the provisional interim restoration must be adjusted and monitored carefully through the initial healing period.

Recent Innovations in Dental Implant Technology to Enhance Osseointegration

1. Use of computer aided radiographic treatment planning & surgical guide fabrication using advanced computer aided design/computer aided manufacturing software
2. Implant surfaces with hydrophilic properties that promote osteoconduction of new bone growth
3. Use of recombinant human growth factors on the implant surface or as a part of the placement

- Surface chemistry modifications to accelerate bone growth (fluoride modified titanium oxide surface)

Conclusion

The endosseous dental implant has become a scientifically accepted and predictable treatment for completely and partially edentulous patients. Successful osseointegration is a prerequisite for functional dental implants. The osseointegration is a complex process that can be influenced by many factors relating to the surface topography, biocompatibility, and loading conditions all play an important role in osseointegration.

Titanium and its alloys are the materials of choice clinically, because of their excellent biocompatibility and superior mechanical properties. The combined effect of surface energy, surface roughness, and topography on implant determines its ultimate ability to integrate into the surrounding tissue. Surface modification technologies involve preparation with either an additive coating or subtractive method. Cell migration, adhesion, and proliferation on implant surfaces are important prerequisites to initiate the process of tissue regeneration, while modifications of the implant surface by incorporation of biologic mediators of growth and differentiation may be potentially beneficial in enhancing wound healing following implant placement.

Technology is constantly advancing, newer, better surfaces are being researched and tested. Modified titanium surfaces may show promising results in the future.

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