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REVIEW

On osseointegration in relation to implant surfaces

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Abstract

Background: The understanding of mechanisms of osseointegration as well as applied knowledge about oral implant surfaces are of paramount importance for successful clinical results.

Purpose: The aim of the present article is to present an overview of osseointegration mechanisms and an introduction to surface innovations with relevance for osseointegration that will be published in the same supplement of *Clinical Implant Dentistry and Related Research*.

Materials and Methods: The present article is a narrative review of some osseointegration and implant surface-related details.

Results and Conclusions: Osseointegration has a changed definition since it is realized today that oral implants are but foreign bodies and that this fact explains osseointegration as a protection mechanism of the tissues. Given adequate stability, bone tissue is formed around titanium implants to shield them from the tissues. Oral implant surfaces may be characterized by microroughness and nanoroughness, by surface chemical composition and by physical and mechanical parameters. An isotropic, moderately rough implant surface such as seen on the TiUnite device has displayed improved clinical results compared to previously used minimally rough or rough surfaces. However, there is a lack of clinical evidence supporting any particular type of nanoroughness pattern that, at best, is documented with results from animal studies. It is possible, but as yet unproven, that clinical results may be supported by a certain chemical composition of the implant surface. The same can be said with respect to hydrophilicity of implant surfaces; positive animal data may suggest some promise, but there is a lack of clinical evidence that hydrophilic implants result in improved clinical outcome of more hydrophobic surfaces. With respect to mechanical properties, it seems obvious that those must be encompassing the loading of oral implants, but we need more research on the mechanically ideal implant surface from a clinical aspect.

KEYWORDS
implant surface, osseointegration, titanium

1 | ON OSSEOINTEGRATION

Direct bone anchorage of metallic implants was discovered by Brånemark in 1962 and after some animal experiments was applied clinically for oral implants in 1965. The development of directly bone-anchored implants has meant a breakthrough in possibilities to treat partially or totally edentulous individuals. The term osseointegration was coined by Brånemark in 1976 and then defined as a direct contact between implants and bone at the resolution level of the light microscope.[1]

Initially, incorporation of titanium implants was seen as a simple wound healing phenomenon which was regarded as possible due to the assumed benign tissue reactions to the material, possibly even encompassing some sort of chemical attachments of the implants.[2] However, based on findings from later research, these initial ideas about titanium as a unique material have been questioned. Firstly, it was demonstrated that other metals, such as titanium alloys, tantalum and niobium as well as various ceramic materials, were likewise capable of osseointegration.[3] Secondly the notion of titanium being bioinert without any adverse tissue reactions was questioned.[4] Donath and colleagues[4] described that titanium was far from bioinert, but instead capable of eliciting immune responses when placed in tissues. Donath and colleagues concluded that osseointegration was but a foreign body reaction where the tissues aimed at embedding the titanium material in bone as a mode of protection for nearby tissues. They claimed that any foreign material placed in bone will be rejected, dissolved, resorbed, or demarcated with a dense layer of bone to protect nearby tissues (Figure 1). What is seen as osseointegrated materials is the latter body defense of demarcation, which develops on the condition that the implant remains relatively immobile (some initial movements in the micron range are tolerated).

Today, Donath's opinion has been verified by many researchers.[5–8] Recent studies have indicated that CP titanium results in elevated immune responses.[9,10] Osseointegration has a novel definition: "osseointegration is a foreign body reaction where interfacial bone is formed as a defense reaction to shield off the implant from the tissues."[11] The fact that oral implants nowadays are being regarded as foreign bodies does not at all imply a criticism to their clinical usage. In contrast, CP titanium is a very good material for body implants and has resulted in that very good clinical longevity has been proven for oral implants up to about 25 years in retrospective clinical studies and, if only in clinical cases, been found to work for at least 50 years in situ.[12,13] Other metallic materials than CP titanium and titanium alloys have mainly been used in orthopedics, such as stainless steels and cobalt-chrome-molybdenum alloys.

Osseointegrated oral implants have been demonstrated to fare very well. In a recent overview,[14] it was reported that five different types of implant surfaces had been documented for more than 10 years. These surfaces were turned (machined), titanium plasma sprayed (TPS), blasted, SLA (sandblasted and acid-etched) and anodized ones. They all demonstrated a failure rate of within 5% at 10 years or more of follow-up.

2 | EVOLUTION OF DENTAL IMPLANT SURFACES

The properties of an implant surface have since long been identified to be one important factor to achieve and maintain osseointegration.[15]

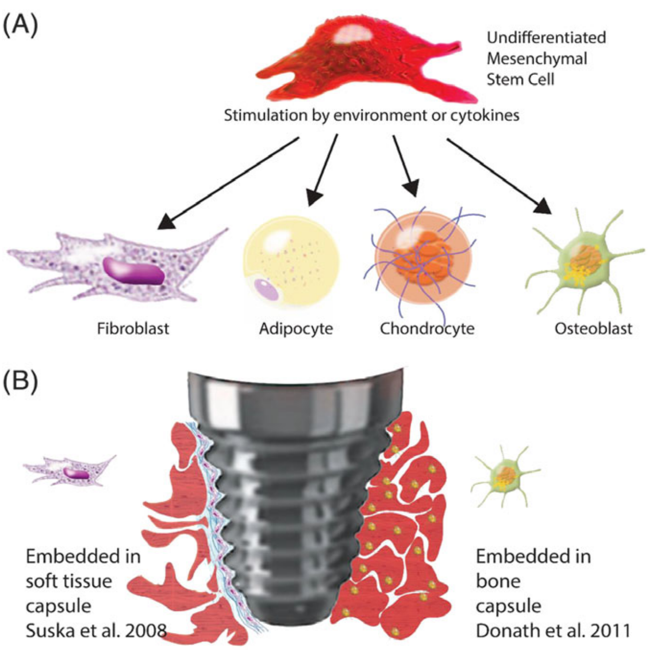

FIGURE 1 The primitive undifferentiated mesenchymal stem cell is the mother of many different connective tissue cells. One possible development is the fibroblast that ensures a soft tissue embedment of foreign-body implants to protect nearby tissues; another development is the osteoblast that establishes bone tissue as a protective layer around foreign-body titanium implants

Implant surface properties can be divided into its topographical, chemical, mechanical, and physical properties. Several of these factors interact with each other and are not easily evaluated separately, for example, if the surface topography is modified, then the surface chemistry and physics are most likely to get modified as well.

3 | ROUGHNESS

In the modern implant era, that is, after the pioneering work by PI Brånemark and his team, the dental implant surfaces have been modified from the turned relatively smooth surface to the dominating moderately rough surfaces of today. Further, surface roughness modifications have been performed at different resolution, variations at the μm and at the nanometer levels. The reason for this work has been a desire to speed up the bone healing process in order to provide a strong primary stability that can create possibilities for an early loading time. The μm roughness is supposed to provide better biomechanical interlocking and the nm roughness provides more adhesion sites for the initial proteins that will come in contact with the implant surface and be of potential importance for the continuing bone healing process.

During the 1980s, attempts were made with some additive techniques to create a rougher surface, such as the TPS technique and, later, hydroxyapatite coatings (HA). Thus, titanium particles or HA particles were added on the implant surface. The profiles of such surfaces are characterized by a convex or bumpy appearance. These very rough surfaces failed to demonstrate good enough results in terms of implant loss and significant amount of marginal bone resorption after a couple of years, and therefore, disappeared rather rapidly from the market.[16,17]

From the 1990s, the dominating technique to achieve a moderately rough surface has been a subtractive technique. The surface has been roughened by removing material or reorganizing the superficial surface layer using blasting, blasting plus etching or oxidization techniques. Etching alone removes the marks from the underlining machining technique such as turning or milling, but seldom provides a significantly increased roughness in the micrometer scale.[18] Thus, the etching process transfers an anisotropic surface (eg, a specific direction in the surface structure created by the fabrication method) to an isotropic surface (no specific direction of the surface irregularities can be observed), but also provides a submicron roughness.

Today, the dominating roughness on well-documented dental implants is an isotropic and moderately rough surface produced by the removal of materials or reorganization of the outermost surface layer. An example of the latter surface is the TiUnite (Nobel Biocare AG, Zürich, Switzerland) implant (Figure 2), where the oxide thickness is increased and the border between the titanium crystals is broken up by an anodizing process. TiUnite was launched in 2001 and since then, it has been one of the most sold dental implant surfaces worldwide. The clinical outcome has, in general, been very favorable and a recent meta-analysis has demonstrated that TiUnite has a significantly lesser probability for implant failure when compared with a turned surface.[20] In another newly published paper, oxidized surfaces were found to have the lowest probability for failure when compared to other moderately rough surfaces, minimally surfaces, and rough surfaces.[14]

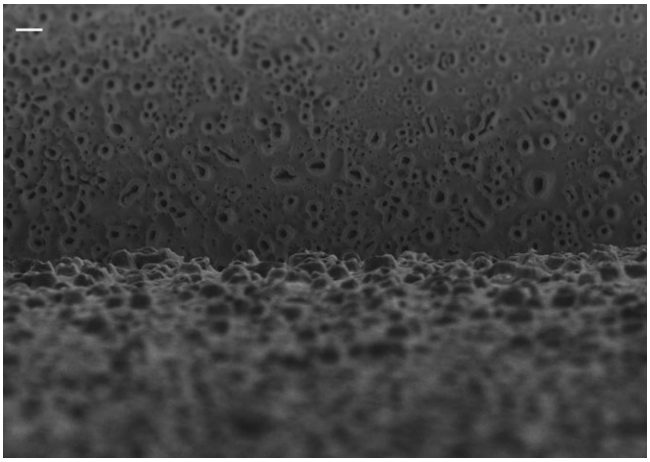

FIGURE 2 The anodized TiUnite implant has, in a recent study, displayed significantly fewer 10-year failures than any other implant surface that has been followed up long term.[14,19] The scale bar indicates 10 μm

4 | NANOSTRUCTURES

Nanostructures can be applied on an implant with the use of nano-sized HA or TiO_2 particles attached to the surface, but research has demonstrated that nanostructures can also spontaneously appear.[21] It seems that some type of etching or oxidation in combination with water, saline, or electrolyte will reorganize the grain borders by removing impurities and forming TiO_2 nanostructures instead. The density of these nanostructures will differ depending on the machining method and implant material. Several in vitro[22,23] and in vivo experiments[24,25] have demonstrated more bone cells to attach and proliferate and stronger bone tissue incorporation when implants are provided with these nanostructures. However, the literature is full of contradictions and the clinical importance is yet unknown.

5 | SURFACE CHEMICAL COMPOSITION

HA-coated surfaces became popular during the 1990s. The hypothesis behind this surface modification was the possibility to achieve a chemical bond between the coat and the bone due to the chemical similarities between the bone itself and the foreign material. The term "bioactive material" was used to indicate the presence of such bonds. However, these theories were not verified and HA-coated implants of the first generation were withdrawn due to unacceptable marginal bone loss.[17] Today, a bioactive surface likely refers to a particular possibility to enhance and speed-up the bone healing process after implantation. In various experimental studies, several ions incorporated in the implant surface, such as Ca, P, Sr, F, NaOH and Mg, have provided a strong bone response.[26–34] It should be noted that almost every technique to modify the surface roughness also alters the surface chemistry. Etching will leave different ions on the surface depending on the acid used, sandblasting will leave remnants of the blasting material, and oxidized surfaces will be chemically influenced by the electrolyte used. Thus, it is possible to improve both the chemical and topographical properties by selecting a certain manufacturing technique.

6 | PHYSICAL PROPERTIES (CRYSTALLINITY AND HYDROPHILICITY)

Titanium dioxide may have three different structures: rutile, which is the most common form; a tetragonal crystal, which is an anatase form that is also a tetragonal structure; and brookite, which is an orthorhombic structure.

The effects of the various titanium crystalline structures are unclear. in vitro studies have indicated different results. McAlarney and colleagues[35] found that the crystallinity of titanium oxide may influence protein adhesion and thus, may be important for the healing process. However, Wheelis and colleagues[36] in a newly published study could not find any effect on the long-term viability of preosteoblasts and fibroblasts.

By itself, titanium is normally hydrophilic, that is, the contact angle with a drop of water on the surface is below 90 degrees. However, a majority of common commercial implant surfaces have been found to be hydrophobic.[37] This may be due to various fabrication techniques and contaminations, for example, carbon and wrapping materials.

Different procedures can create a super hydrophilic surface; a contact angle close to 0 degrees. On such a surface a drop of water or blood will immediately spread and wet the surface. To achieve a super hydrophilic surface cleaning with plasma treatment, irradiation with UV-light are common methods. Experimental studies have shown some advantages of such surfaces in vitro[38,39] and in vivo[25,40,41] experiments; however, information on the durability of a super hydrophilic surface is often lacking and the clinical advantages of super hydrophilicity alone are unknown.

7 | MECHANICAL PROPERTIES

Example of mechanical properties may be hardness and resistance to evolution of microcracks. Mechanical aspects of the implant surface are so far the least investigated property. Partly this can be explained by the mechanical behavior is closely related to the other, above mentioned, properties and to the difficulties to quantitative measure and characterize this factor. However, the hardness of the titanium itself has been developed during the years. At the infancy of modern implant production titanium grade 1 was the dominating material. Today, the market is dominated by CP titanium grade 4 or alloys such as Ti6Al4V or TiZr. The major difference between grade 1 and grade 4 titanium is the slightly increased amounts of Fe and O, this very small increase has a profound impact on the hardness of the material. Likewise Ti6Al4V and TiZr are much harder than grade 1 Ti. The improved material hardness has been utilized, for example, to produce implants with a mechanical resistance to fractures even for small diameter implants.

CONFLICT OF INTEREST

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