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Effect Of Various Implant Surface Treatments On Osseointegration - A Literature Review

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Abstract
The osseointegration rate of dental implants is related to their composition and surface roughness. Rough-surfaced implants favour both bone anchoring and biomechanical stability. Osteoconductive calcium phosphate coatings promote bone healing and apposition, leading to the rapid biological fixation of implants. The different methods used for increasing surface roughness or applying osteoconductive coatings to the dental implants are reviewed. Surface treatments, such as titanium plasma-spraying, grit-blasting, acid-etching, anodization or calcium phosphate coatings, and their corresponding surface morphologies and properties are described. Most of these surfaces are commercially available and have proven clinical efficacy (>95% over 5 years). The precise role of surface chemistry and topography on the early events in dental implant osseointegration remain poorly understood. Still, there has been a growing demand for implants with better surface features, therefore the topography of the implant surfaces can now be manipulated at a wide range of length scales, down to the nano level.The aim of this article was to review the literature on the various surface treatments of dental implants and their potential effects on the performance of dental implants.

Key Words
Dental Implants, Titanic , Osteoconduction

Introduction

Osseointegration, the direct structure-function adhesion between bone and implant surface, is a prerequisite for the long-term success of dental implants. Albrektsson et al[1] suggested the following as the six most important factors for establishing reliable osseointegration: implant material, implant design, surface quality, bone status, surgical technique and loading conditions. Of these, surface structure is the most critical factors influencing the clinical outcome of implants.

The surface quality of an implant depends on the chemical, physical, mechanical and topographical properties of its surface. Several implant surface modifications have been used to improve the quantity and quality of the bone-to-implant interface. Surface composition and roughness are parameters that may play a role in implant-tissue interaction and osseointegration. Still, there has been a growing demand for implants with better surface features and consequently better osseointegration, therefore the topography of the implant surfaces can now be manipulated at a wide range of length scales, down to the nano level. In the light of the continuing development of new dental implants, this review focuses on the different surfaces and methods that aim to accelerate the osseointegration of dental implants.

Controlling The Bone Implant Interface By Biomaterial Selection And Modification

Different approaches are employed to obtain desired outcomes at the bone implant interface. As a general rule, an ideal implant biomaterial should present a surface that will not disrupt, and that may even enhance, the general processes of bone healing, regardless of implantation site, bone quantity and bone quality.[2]

As described by **Ito et al**. the approaches to alter implant surfaces can be classified as physicochemical, morphologic or biochemical.[3]

Physicochemical Method

It mainly involves the alteration of surface energy, surface charge, and surface composition with the aim of improving the bone-implant interface. The method employed is the Glow discharge treatment, in which materials are exposed to ionized inert gas, such as argon. During collisions with substrate, high energy species "scrub" contaminants from the surface, thereby unsaturating surface bonds and increasing surface energy. This higher surface energy will then influence adsorption of biomolecules, which in turn affects subsequent cell and tissue behaviour. However improved interactions with bone have not been demonstrated.[4]

Morphological Methods

It mainly deals with alteration of surface morphology and roughness to influence cell and tissue response to implants. Many animal studies support that bone ingrowth into macro rough surfaces enhances the interfacial and shear strengths.[5] In addition; surfaces with specially contoured grooves can induce contact guidance, whereby direction of cell movement is affected by morphology of substrate. The added advantage is that this method prevents the epithelial down growth on dental implants.[6, 7]

Implant surfaces have been classified on different criteria, such as roughness, texture and orientation of irregularities.

(A) **Wennerberg and coworkers**[8] have classified implant surfaces based on the surface roughness as:

1. Minimally rough (0.5-1 μm)
2. Intermediately rough (1-2 μm)
3. Rough (2-3 μm)

(B) Based on texture obtained, the implant surface can be divided as:

1. Concave texture (mainly by additive treatments like hydroxyapatite (HA) coating and titanium plasma spraying)
2. Convex texture (mainly by subtractive treatment like etching and blasting)

(C) Based on the orientation of surface irregularities,[9] implant surfaces are divided as:

1. Isotropic surfaces: have the same topography independent of measuring direction.
2. Anisotropic surfaces: have clear directionality and differ considerably in roughness.

Advantages of increased roughness:

1. Increased surface area of implant adjacent to bone.
2. Improved cell attachment to bone.
3. Increased bone present at implant interface.
4. Increased biochemical interaction of implant with bone.

Different methods have been described in the literature that increases the surface roughness, such as:

1. Blasting
2. Chemical etching
3. Porous surfaces
4. Plasma-sprayed surfaces
5. Ion-sputtering coating
6. Anodized surface

1. Blasting:

Blasting implant surface with particles of various diameters is one of the frequently used methods of surface alteration. Ceramic particles are projected through a nozzle at high velocity by means of compressed air. Depending on the size of the ceramic particles, different surface roughness can be produced on titanium implants. The blasting material should be chemically stable, biocompatible and should not hamper the osseointegration of implants. Various ceramic particles have been used, such as alumina, titanium oxide and calcium phosphate particles.

Alumina (Al_2O_3) is frequently used as a blasting material and produces surface roughness. However, the blasting material is often embedded into the implant surface and residue remains even after ultrasonic cleaning, acid passivation and sterilization. Alumina is insoluble in acid and is thus hard to remove from the titanium surface. In some cases, these particles have been released into the surrounding tissues and have interfered with the osseointegration of the implants.[10]

Titanium oxide is also used for blasting titanium dental implants. Titanium oxide particles with an average size of 25 μm produce a moderately rough surface in the 1-2 μm range on dental implants.[11, 12]

A third possibility for roughening dental implants consists of using a biocompatible, osteoconductive and resorbable blasting material. Calcium phosphates such as hydroxyapatite, beta-tricalcium phosphate and mixtures have been considered useful blasting materials. These materials are resorbable, leading to a clean, textured, pure titanium surface.[13]

2. Chemical etching:

Etching with strong acids such as HCl, H_2SO_4, HNO_3 and HF is another method for roughening dental implants. Acid-etching produces micro pits on implant surfaces with sizes ranging from 0.5 to 2 μm in diameter. Acid- etching has been shown to greatly enhance osseointegration. Immersion of titanium implants for several minutes in a mixture of concentrated HCl and H_2SO_4 heated above 100°C (dual acid-etching) is employed to produce a microrough surface. This type of surface promotes rapid osseointegration while maintaining long-term success over 3 years. It has been found that dual acid etched surfaces enhance the osteoconductive process through the attachment of fibrin and osteogenic cells, resulting in bone formation directly on the surface of the implant.

Another approach involves treating titanium dental implants in fluoride solutions. Titanium is very reactive to fluoride ions, forming soluble TiF_4 species. The surface produced has microrough topography. This chemical treatment of the titanium created both a surface roughness and fluoride incorporation favourable to the osseointegration of dental implants.[2, 4, 10]

3. Porous surfaces:

These are produced when spherical powder of the metallic/ceramic material becomes a coherent mass within the metallic core of the implant body. These are characterized by pore size, shape, volume and depth, which are affected by the size of the spherical particles and the temperature and pressure of the sintering chamber. Pore depth depends on the size of the particles (44 to 150 μm) and their concentration per unit area, as well as on the thickness of the applied coating (usually 3,000 μm). A pore depth of 150 to 300 μm appears to be the optimal size for bone ingrowth and maximum contact with the walls of the pore[14, 15]

Advantages of this method are as follows:

- A secure 3D interlocking interface with bone is observed.
- Short healing time.
- Provide space, volume for cell migration and attachment and thus support contact osteogenesis.[2]

In the future, porous-coated implants could be impregnated with growth factors and act as delivery vehicles because of increased surface volume.[16]

4. Plasma-sprayed surfaces:

Plasma-spraying is a technique in which hydroxyapatite (HA) ceramic particles are injected into a plasma torch at high temperature approximately 15,000-20,000 K and projected on to the surface of the titanium where they condense and fuse together, forming a film. Plasma-sprayed coatings can be deposited with a thickness ranging from a few micrometers to a few millimetres. In order to obtain mechanical retention of the coating, the surface of the metallic implant must be roughened, e.g. by means of gritblasting, when using this method.

The plasma-spraying method has disadvantages, however, such as the porosity of the coating and residual stress at the substrate/coating interface, as well as drastic changes in the composition and crystallinity of the initial calcium phosphate Plasma-sprayed HA -coated dental implants have also been associated with clinical problems. One of the major concerns with plasma-sprayed coatings is the possible delamination of the coating from the surface of the titanium implant and failure at the implant-coating interface despite the fact that the coating is well-attached to the bone tissue. The discrepancy in dissolution between the various phases that make up the coating has led to delamination, particle release and thus the clinical failure of implants. Loosening of the coating has also been reported, especially when the implants have been inserted into dense bone.[10, 13]

For all of the above reasons, the clinical use of plasma sprayed HA-coated dental implants is limited.

5. Ion-sputtering coating:

It is the process by which a thin layer of HA can be coated onto an implant substrate. This is performed by directing a beam of ion onto an HA block that is vaporized to create plasma and then recondensing this plasma onto the implant.[2]

6. Anodized surface:

Micro- or nano-porous surfaces may also be produced by potentiostatic or galvanostatic anodization of titanium in strong acids (H_2SO_4, H_3PO_4, HNO_3, HF) at high current density (200A/m2) or potential (100 V). The result of the anodization is to thicken the oxide layer to more than 1000nm on titanium. When strong acids are used in an electrolyte solution, the oxide layer will be dissolved along current convection lines and thickened in other regions. The dissolution of the oxide layer along the current convection lines creates micro or nano-pores on the titanium surface. Anodization reduces modifications in the microstructure and the crystallinity of the titanium oxide layer. The anodization process is rather complex and depends on various parameters such as current density, concentration of acids, composition and electrolyte temperature.

Anodized surfaces result in a strong reinforcement of the bone response with higher values for biomechanical and histomorphometric tests in comparison to machined surfaces.[10, 17]

Future trends in dental implant surfaces

The future trends concern the modifications of surface roughness at the nanoscale level for promoting protein adsorption and cell adhesion, biomimetic calcium phosphate coatings for enhancing osteoconduction and the incorporation of biological drugs for accelerating the bone healing process in the peri-implant area.

Surface roughness at the nanoscale level

The arrival of nanotechnology has opened new opportunities for the manipulation of implant surfaces. It is believed that implant surfaces could be improved by mimicking the surface topography formed by the extracellular matrix (ECM) components of natural tissue. These ECM components are of nanometre scale with typical dimensions of 10-100 nm. Cell attachment, proliferation, and differentiation are responsive to nano-scale features such as pillars or grooves prepared, for example, using nanolithography. Nanopatterned surfaces may also provide better adhesion of the fibrin clot that forms right after implantation, facilitating the migration of osteogenic cells to the material surface. Alumina/zirconia nanocomposites offer an example of how nanotechnology offers an attractive path to the development of new implant materials but ceramics, even nanocomposite ceramics, will not replicate the unique combinations of mechanical properties of tooth tissues as they are, for example, much stiffer and wear-resistant.[10]

Recently, it has been shown that a possible path to combining high strength and toughness in a ceramic material is to take advantage of the transformation toughening mechanisms in nanozirconia-alumina materials. These materials consist of a dispersion of a small amount of tetragonal ZrO_2 particles (typically around 200 nm in size) in an Al_2O_3 matrix.

Despite conflicting reports regarding the effect of ceramic coatings and micro- and/or nano-topography on the osseointegration of dental implants, the prevailing philosophy is that they may significantly influence the bone growth and attachment to implant surfaces and ultimately improve the success of dental implants and the rapid return to function (i.e. mastication). There is an urgent need for more fundamental research in this area that would combine both in vitro and in vivo studies and ultimately lead to appropriate clinical application.[18]

Incorporation of biologically active drugs into dental implants

The surface of titanium dental implants may be coated with bone-stimulating agents such as growth factors in order to enhance the bone healing process locally. Members of the transforming growth factor (TGF-β) superfamily, and in particular bone morphogenetic proteins (BMPs), TGF-β1, platelet-derived growth factor (PDGF) and insulin-like growth factors (IGF-1 and 2) are some of the most promising candidates for this purpose. Another possibility may be the adjunction of a plasmid containing the gene coding for a BMP. This possibility is limited due to the poor efficacy of inserting plasmids into the cells and the expression of the protein. In addition, overproduction of BMPs by cells might not be desirable after the bone healing process. The surface of implants could also be loaded with molecules controlling the bone remodelling process. Incorporation of bone antiresorptive drugs, such as biphosphonates, might be very relevant in clinical cases lacking bone support, e.g. resorbed alveolar ridges. Biphosphonate incorporation on to titanium implants increased bone density locally in the peri-implant region. Plasma-sprayed HA-coated dental implants immersed in pamidronate or zoledronate demonstrated a significant increase in bone contact area. The main problem lies in the grafting and sustained release of antiresorptive drugs on the titanium implant surface. Due to the high chemical affinity of biphosphonates for calcium phosphate surfaces, incorporation of the antiresorptive drug on to dental implants could be achieved by using the biomimetic coating method at room temperatures.[10, 19, 20]

Conclusion

There are a number of surfaces commercially available for dental implants. Most of these surfaces have proven clinical efficacy (>95% over 5 years). However, the development of these surfaces has been empirical, requiring numerous in vitro and in vivo tests. The exact role of surface chemistry and topography on the early events of the osseointegration of dental implants remain poorly understood. The various methods of modifying the implant surface have been listed, and these techniques have greatly influenced the quality of clinical service in implant prosthodontics. Furthermore, comparative clinical studies with different implant surfaces are rarely performed. The future of dental implantology should aim at developing surfaces with controlled and standardized topography or chemistry.

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