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Dental Implants: The Surface Modifications: A Brief Review

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Abstract

AIM- *Osseointegration occurs around the screw threaded implants through the tissue on growth or through a direct apposition between the tissue and the implant surface. The alternative methods of the implant-tissue attachments, based on the tissue ingrowth into roughened or three-dimensional surface layers, yield higher bone metal shear strength and decreased implant loosening. The surfaces of a dental implant have been modified in several ways to improve its biocompatibility and speed up osseointegration. Literature says that any surface modification provides a good surface for osseointegration of the implant when the surface roughness is about 0.44 - 8.68 µm. It is also said that acid etching and coating are the most preferred methods for creating good roughness of the implant surface. This article reviews the surface modifications of dental implants for the achievement of better success rates. Various methods are used to modify the topography or the chemistry of the implant surfaces which includes acid etching, anodic oxidation, blasting, treatment with fluoride, and calcium phosphate coating. These modifications provide a faster and a stronger osseointegration. A positive effect of various surface modifications is also illustrated in this review.*

Keywords: *Morphological modifications, surface coatings, biochemical methods, additive methods, subtractive methods.*

Introduction

The goal of research in the field of implantology is to design the implants that bring about controlled and rapid integration into the surrounding tissues. Events that leads to the stability of an implant takes place mainly at the tissue–implant interface. Formation of the tissue-implant interface is complex process and requires a number of factors which includes the implant-related factors, such as materials, shapes, topography, and surface chemistry and the mechanical loading, surgical technique. Patient factors such as the quantity and quality of bone also matters. The bone implant interface can be controlled by the selection and modification of the biomaterial from which is made. These include morphological, physiochemical and biochemical methods. The morphological methods involve alterations in the surface morphology and roughness, such as hydroxyapatite coating or blasting and etching. The physiochemical methods involve modification of the surface energy, the surface charge and the surface composition. The biochemical surface modification endeavours to utilize the current understanding of the biology and the biochemistry of the cellular function and differentiation.[1] The aim of the present review is to briefly describe the various implant surface modifications and the advantages of various surface modification procedures.

Surface Topography of Implant Surface

Two surface characteristics are commonly cited as an important determinant for tissue responses.[2] One which is the topographic or the morphological features of the implant while the other is the chemical properties. Independent studies of the topographic and chemical properties are confounded as the methods used to alter the surface morphology mostly leads to changes in surface chemistry.[3] In the newer methods for altering the surface characteristics, great attention has been focused on the changes in surface roughness and chemistry.[4] The surface topography describes surface of implants as “rough” or “smooth”. Compared to smooth surfaces, textured implants surfaces exhibit more surface area for integrating with bone via osseointegration process. Textured surface also allows ingrowth of the tissues. Surface topography can produce orientation and guide locomotion of special cells and has the ability to directly affect shape and function of them.

Surface topography can be classified as

A) Sykaras and coworkers5 have classified implant surfaces as:

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

B) Based on texture obtained

- Concave texture (mainly by additive treatments such as hydroxyapatite coating and titanium plasma spraying)
- Convex texture (mainly by subtractive treatment such as etching and blasting).

C) Based on orientation of irregularities

- Isotopic surfaces: It has the same topography independent of measuring direction
- Anisotropic surfaces: It has clear directionality and differs considerably in roughness.[6]

Surface Modifications

By increasing the surface roughness, an increase in the osseointegration rate and the biomechanical fixation of titanium implants have been observed. The implant modifications can also be achieved either by additive or subtractive methods.

The additive methods employed the treatment in which other materials are added to the surface, either superficial or integrated, and categorized into coating and impregnation, respectively. While impregnation implies that the material/chemical agent is fully integrated into the titanium core, such as calcium phosphate (CaP) crystals within titanium oxide (TiO2) layer or incorporation of fluoride ions to surface, the coating on the other hand is addition of material/agent of various thicknesses superficially on the surface of core material.

The coating techniques can include:

- Titanium plasma spraying (TPS)
- Plasma sprayed hydroxyapatite (PSHA) coating
- Alumina coating, and
- Biomimetic CaP coating.

Meanwhile, the subtractive techniques are the procedure to either remove the layer of core material or plastically deform the superficial surface and thus roughen the surface of core material.

The common subtractive techniques are:

- Large-grit sands or ceramic particle blasts
- Acid etch, and
- Anodization.

The various approaches for surface modifications are classified mainly into 3 categories:

a) Morphological

b) Physiochemical

c) Biochemical

Morphological: These procedures involving physical treatment generally result in rough or smooth surfaces which can enhance the adhesion, proliferation, and differentiation of cells. Include grinding, blasting, machining, and polishing.

Biochemical: A chemical treatment, either using acids or using alkali solution of titanium alloys, in particular, is normally performed not just only to alter the surface roughness but also to modify the composition and to induce the wettability or the surface energy of the surface. Methods of surface modification of titanium and its alloys by chemical treatment are based on chemical reactions occurring at the interface between titanium and a solution done to alter surface roughness and composition and enhance wettability/surface energy. This includes chemical treatment with acids or alkali, hydrogen peroxide treatment, sol-gel, chemical vapor deposition, and anodization

Physiochemical: As for physical treatment of implant surfaces such as plasma spray or thermal spray, it is often carried out on the outer coating surface to improve the esthetic of the material and its performance. In addition, ion implantation, laser treatment and sputtering, alkali/acid etching, and ion deposition are also utilized.

Description Of Various Methods

Turned or Machined and Blasted Dental Implant Surface

In initial studies, screw shaped implants were prepared with different surface topographies as machined and blasted surfaces and the topography was measured by using a confocal laser scanning profilometer, their surface roughness being characterized by using height and spatial descriptive patterns.8 In implant research, the term ‘machined surface’ is often used as a description of a turned, milled or sometimes a polished surface.[9]

Blasting with particles of various diameters is one of the frequently used method of surface alteration.[10] It is mainly done by Al_2O_3 and TiO_2 with particle size ranging from small, medium to large grit. Roughness depends upon particle size, time of blasting, pressure and distance from the source of particle to the implant surface.[11] The turned surface has an average roughness of 0.96µm and an average peak spacing of 8.6µm. Blasting the implant screws with 25-75µm alumina particles results in an isotropic surface with average height deviations of 1.1 and 1.5µm respectively. Blasting with 250µm alumina particles results in a less isotropic surface and an average height deviation of about 2.0µm8.

Several commercial implant systems are machined with the turning process and the surface roughness which is achieved with the 250µm blast particles is comparable to that of some commercial plasma sprayed and hydroxyapatite coated implants.[12] A series of investigations have demonstrated a firmer bone fixation of the implant with an average surface roughness (sa) of 1-1.5µm than those of smoother implants with an average surface roughness of 0.6µm.

Advantages:

- Studies have shown that it allows adhesion, proliferation and differentiation of osteoblasts.[13]
- Has been found that fibroblasts adhere to the surface with difficulty and hence could limit soft tissue proliferation.[14]
- Increase bone formation.

Chemical Etching

Metallic implant is immersed into an acidic solution, which erodes its surface, creating pits of specific diameter and shape.[15] Concentration of acidic solution, time and temperature are factor determining the result of chemical attack and microstructure of the surface.

a) Dual acid etched technique:16 Proposed to produce a micro texture rather than macro texture.

Advantages:

- Higher adhesion and expression of platelet and extracellular genes.
- Helps in colonization of osteoblasts at the site.
- Promote osseointegration.

b) Sandblasted and acid etched:

Sand and grit blasting are used to modify the implant surface by using titanium oxide and alumina particles. 25µm particles of TiO_2 are used to grit the blast. The large grit sandblasting particles are corundum 0.25- 0.5mm and the medium grit particles are 250-500µm in size. Acid etching can be done by using an HCL/H_2SO_4 mixture or by pickling in 2% HF/10%HNO_3. These processes leave pits and craters. In addition to the surface roughness, sand blasting and acid etching can remove the surface contaminants and increase the surface reactivity of the metal.[17]

Sand blasted and acid etched surfaces have a hydrophobic surface and the new SLA active implants have a hydrophilic surface which shows a stronger bone response. These have an sa of 1.75µm and a developed surface area ratio of 143%, which is indicative of the high density of the peaks than are seen in the SLA implants.[18] The original Branemark turned pure Ti implants had an surface area of 0.9µm and a developed surface area ratio of 34%. The different etching processes also may lead to the formation of Titanium hydrides (TiH2 TiH3, TiH4 or a combination which needs investigation) and the replacement of hydride by oxygen results in the slow transformation of the implant surface, resulting in nanometre sized particles of titanium on the surface. The nano roughness may be important in the protein adhesion, immediately after the implant placement.[18]

Advantages:

- Increase the rate and amount of the bone formation
- Enchanced alkaline phosphatase specific activity.
- Increased osteocalcin production.
- Increased transforming growth factor beta and prostaglandin E2.

c) Porus Surfaces

These are produced when spherical powder of metallic/ceramic material becomes coherent mass with the metallic core of implant body.5 These are characterized by pore size, shape, volume and depth which are affected by size of spherical particles and the temperature and pressure of the sintering chamber.

Advantages:

- A secure 3-D interlocking interface with bone
- Predictable and minimal crestal bone remodeling
- Short healing time
- Provide space, volume for cell migration and attachment and thus support contact osteogenesis.

d) Flouride Surface Treatments

Jimbo et al[19] showed the surface hydrophilicity of the implants when they were treated with fluoride containing acids. Based on biomechanical and histomorphometric data, the fluoride modified titanium implants demonstrated a firmer bone anchorage than the unmodified implants, after a short healing period. The formation of fluoridated HA and flourapatite in the calcified tissues has been demonstrated.

Advantages:

- Increased seeding rate of the apatite crystals.
- Increased stimulation of the osteoprogenitor cells.
- Increased alkaline phosphatase activity and
- Increased incorporation of newly formed collagen into the bone matrix.

e) Anodised Surface Implants

Oxidation process can be used to change the characteristic of oxide layer and make it more biocompatible. Anodized surface implants are implants which are placed as anodes in galvanic cells, with phosphoric acid as the electrolyte and current is passed through them. The surface oxides grow from the native state of 5nm to approximately 10,000nm.18 This results in a surface with micropores of variable diameter and demonstrates lack of cytotoxicity and increased cell attachment and proliferation.

Advantages:

- Increased cell attachment and proliferation.
- More Biocompatible.

Surface Coatings

a) Hydroxyapatite (HA) coatings

CaP coatings, mainly composed by HA, have been used as a biocompatible, osteoconductive, and resorbable blasting materials. The idea behind the clinical use of HA is to use a compound with a similar chemical composition as the mineral phase of the bone to avoid connective tissue encapsulation and promote peri-implant bone apposition. For this matter, CaP coatings disclose osteoconductive properties allowing for the formation of bone on its surface by attachment, migration, differentiation, and proliferation of bone-forming cells. In the resorbable ones, following implantation, the release of CaP into the peri-implant region increases the saturation of body fluids and precipitates a biological apatite onto the surface of the implant.[20] This layer of biological apatite might contain endogenous proteins and serve as a matrix for osteogenic cell attachment and growth and, therefore, improve osseointegration. Plasma sprayed hydroxyapatite (PSHA) coatings are the most commonly found among the commercially available CaP coatings.

HA coatings on implant surface are carried by various methods:

- Plasma spraying (PSHA): The stream of the HA powder is blown through a very high temperature flame that partially melts and ionizes the powder, which emerges from the flame, hitting the metallic surface which has to be coated. This method uses carrier gas which ionizes the forming plasma and superheats the particles of HA, which undergo partial melting and are propelled towards the surface which has to be coated, producing around 50μm thick coatings. The most stable of the plasma sprayed calcium phosphate coatings is flourapatite. The plasma sprayed HA coatings rely on the mechanical interlocking between a grit blasted or etched metallic surface and ceramic for physical integrity during the implant placement.[21]

- The vacuum deposition/sputtering techniques: These techniques include ion beam sputtering, radiofrequency sputtering (a radiofrequency magnetic sputtering apparatus with a base pressure of 10-6 mbs ; the sputtering is performed in a mix of argon and reactive gases to obtain a desired HA stoichiometry) and pulsed laser deposition.[22]
- The sol gel and dip coating method: In this technique, the coating is fired at 800-900ºC to melt the carrier glass to achieve its bonding to the metallic substrate. The precursor of the final product is placed in the solution and the metal implant which has to be coated is dipped into the solution and is withdrawn at a prescribed rate. It is then heated to create a more dense coating.
- Electrolytic process: Electrophoresis and electrolytic deposition are two processes that deposit HA out of a bath of proper chemistry. The porous surface materials can be uniformly coated and the original composition of the ceramic can be maintained.[1]

Advantages:

- HA coating can lower the corrosion rates of same substrate alloys.
- HA coating can be credited with enabling to obtain improved bone implant attachment.
- Have higher success rates in maxilla.
- Being osteoconductive in nature, more bone deposited is noted.

b) Nanotitania Coatings

Nanotitania coatings were prepared during a study by using the sol-gel technique. Commercially available tetra isopropyl orthotitanate was dissolved in absolute ethanol. Ethyleneglycol monoethylether, deionized water and fuming HCl 37% were dissolved in ethanol. The two solutions were mixed rapidly and stirred effectively for 3 minutes. The coating sol was aged at 0°C for 24hours before the Ti substrates were dip coated and the substrate was withdrawn at 0.30mm/s. The coated substrates were heat treated at 500°C for 10minutes, cleaned ultrasonically in acetone for 5 minutes and dried at ambient temperature.[23]

Advantages:

- Increased feature density and a large feature coverage area as compared to the nano-HA implants.
- Presented more binding sites for the protein cell attachment and for increased bone contact.

c) Peptide coatings

This involves the coating of titanium implant surface with synthetic arginylglycylaspartic acid (RGD) peptides that contain binding sites for integrin receptors.[24]

d) Antibiotic coatings

Antibiotics such as cephalothin, carbenicillin, amoxicillin, cefamandol, tobramycin, gentamicin, and vancomycin can bind to calcium-based coatings of implants, as well as be released from it. This antibiotic-releasing coating also retains its antimicrobial properties.[25]

e) Growth factor coatings

The implant surface can be coated with various bone formation stimulating agents to accelerate angiogenesis and bone formation around implants. These growth factors coating the implant can be bone morphogenetic proteins (BMPs), transforming growth factor b1 (TGF-b1), vascular endothelial growth factors (VEGFs), platelet-derived growth factors (PDGFs), or insulin-like growth factors (IGFs). BMPs can be directly incorporated into the implant surface, or they can be incorporated via the use of a plasmid containing the BMP-encoding gene.[26]

f) Bone modulating agent coatings

The implant surface can also be coated with bone remodelling associated agents like bisphosphonates. Bisphosphonates have a great chemical affinity for calcium phosphate molecules and thus can be incorporated via the biomimetic coating procedure. Bisphosphonates can also be coupled with RGD peptides and chemically absorbed on titanium to produce synergistic osteogenic effects.[27]

Conclusion

Despite the fact that implant have excellent survival rate, still implant failures still occur in some patients. These kinds of patients remain a challenge in dental implantology and requires a quick need for surface biomodifications of implant surfaces for better osseointegration after implant insertion. The main goal for research on surfaces modifications is to facilitate the long term bone-implant interface contact and the ability of implant to be placed in fresh extraction sockets and newly grafted sites. Therefore, the research on surface modifications always has a positive influence and has proven to be more advantageous.

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