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Implant surface modifications: A review

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Abstract

Osseointegration is the key for long term success of endosseous dental implants. Implant surface properties like roughness, topography, energy, and composition are the major surface features that influence the process of osseointegration. Several methods have been used to optimize implant surface roughness to increase surface area thereby improving the process of osseointegration such as additive and subtractive methods. Methods used for surface modifications of endosseous dental implants are vast and continuously evolving with the recently developed technologies. This article gives an overview of various surface modifications and current trends followed in the field oral implantology.

Keywords: Additive methods, subtractive methods, photo functionalization, white coating, chitosan coating

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 [1] and the interest on surface engineering must be understood as an important and natural trend. The bone response, which means rate, quantity and quality, are related to implant surface properties [2].

The clinical success of oral implants is related to their early osseointegration. Geometry and surface topography are crucial for the short- and long-term success of dental implants. These parameters are associated with delicate surgical techniques, a prerequisite for a successful early clinical outcome [3].

Typically, integration of an implant is characterized by a series of crude clinical rules which attempt to assess the impact of the implant design and implant surface technologies. These relatively crude clinical parameters involve a lack of signs and symptoms of pathology, a lack of mobility and a radiographic assessment of the interface.

The long-term success of implant therapy is not just dependent on enhanced osseous stability. More recently, there is greater attention being addressed to the transmucosal implant or implant abutment interface [4]. Albrektsson *et al.* identified implant design and surface finish two fundamental determinants in the manipulation of osseointegration. Various surface modification procedures can improve osseointegration overtime as well as promote shorter healing processes. Implant surface modification aims to modify surface topography as well as surface energy to promote cell proliferation and growth in the local environment, thus accelerating osseointegration [5].

This paper reviews the literature on dental implant surfaces by assessing *in vitro* and *in vivo* studies to show the current perspective of implant development

Implant Surface Topography

Response of the tissues to the implant is largely controlled by the nature and texture of the surface of the implant. 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. Based on the scale of the features, the surface roughness of implants can be divided into macro, micro, and nano-sized topologies [6].

Macro-roughness comprises features in the range of millimetres to tens of microns. This scale causally relates to implant geometry, with threaded screw and macro porous surface treatments.

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The primary implant fixation and long-term mechanical stability can be improved by an appropriate macro-roughness.

Micro-roughness is defined as being in the range of 1-10 µm. This range of roughness maximizes the interlocking between mineralized bone and implant surface. The use of surfaces provided with nanoscale topographies are widely used in recent years.

Nanotechnology involves materials that have a nano-sized topography or are composed of nano-sized materials with a size range between 1 and 100 nm. Nanometre roughness plays an important role in the adsorption of proteins, adhesion of osteoblastic cells and thus the rate of osseointegration [7].

Surface topography can be classified as

a. Sykaras N *et al*. 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
    a. Concave texture (mainly by additive treatments such as hydroxyapatite [HA] coating and titanium plasma spraying)
    b. 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 [8].

Methods of Surface Treatment

The methods employed for surface modifications of implants can be broadly classified into 3 types-mechanical; chemical; and physical.

Mechanical: 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

Chemical: 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

Physical: The physical methods of implant surface modification include plasma spraying, sputtering, and ion deposition [9].

The methods can also be classified as: Additive and Subtractive

The additive methods employed the treatment in which other materials are added to the surface, either superficial or integrated. Whereas, removal of surface material by mechanical methods involved shaping/removing, grinding, machining, or blasting to create roughness are included in subtractive methods [10].

Machined

The machined implant is turned, milled, or polished. It is minimally rough, with a surface area roughness (Sa) value of 0.3–1.0 lm.The surface morphology is determined by the manufacturing tools used, the implant material, the lubricant, and the speed at which it is machined [11].

Sandblasting

The bombardment of titanium surfaces with granules of variable diameter of oxides like titanium dioxide, aluminum oxide, zirconium dioxide and silicon carbide [12].

Resorbable blast media(RBM): bone-compatible material is used as blasting media for etching the implant like Hydroxiapatite(HA),Tricalcium phosphate [13].

Acid Etched

Used to remove oxide and contamination to obtain clean and uniform surface finishes, usually this is used in combination with other treatment methods to improve the property of titanium and its alloys as in Wen., *et al*. when reported that employing (HCl+H2 SO4) and alkaline solution improves bioactivity of Tialloy [14].

Alkaline Etched

Sodium hydroxide (NaOH) treatment catalyzes the production of titanium nanostructures outward from the titanium surface. Treatment with an NaOH solution results in a sodium titanate hydrogel layer converted in an amorphous sodium titanate layer, with heat treatment at 600°C. Titanate gel layer allows HA deposition. This behaviour has also been seen with other metals, such as zirconium and aluminum [15].

Dual acid Etching

Double acid etching treats the surface with chemical or acid in sequence or combination of both. It attempts to increase the overlapped nano roughness and to create submicron and nanometre scale cavities. Compared with single acid etching, second acid etching is intended to increase the nano roughness and specific surface area [16].

Laser Etching

It is a noncontact treatment in which the implant surface is not contaminated with blasting media. Substrate material vaporizes and forms a crater. Furthermore, laser etching is a more convenient method for controlling the micro-topography of the implant surface and enhances biocompatibility of the implant surface [17].

Grit Blasting

Grit blasting, also known as abrasive blasting, is another technique which is used to create surface topographies on the implant surfaces. In grit blasting, surface of the implant is bombarded with hard dry particle or particles suspended in a liquid at high velocity. Various types of ceramic particles such as alumina, silica, etc. of different sizes can be used for grit blasting of titanium [18].

Anodization

The anodized implant undergoes anodic oxidation, an electrochemical process in an electrolyte that results in a microstructure surface with micrometre-sized open pores. This process involves passing a current through the implant as the anode with phosphoric acid as the electrolyte to form the surface oxide [11]. Anodized implant surfaces have a combination of controlled oxide texture and porosity for an enhanced biologic effect [19].

Hydroxyapatite Coating

Plasma spraying - is a method where particles, HA or Ti are projected on the surface through a plasma torch at extremely high temperature. The particles condense and fuse together on the surface thereby creating a coat. Ti plasma spraying has displayed better bone integration *in vivo* as compared to smoother implants. The advantage of plasma coating is that these coatings give implants a porous surface that bone can penetrate more readily. Thickness of less than 20µm [20].

Thermal Spraying- Thermal spraying of HAP on implant devices can be compared with plasma spray coating technique, having the advantage of high deposition rate and low cost. It can produce HA layer with thickness from 30 to 200 mm depending on the coating condition However films deposited by thermal spraying suffers from poor coating–substrate adherence and non-uniform crystallinity which reduces the lifetime of implants. Thickness of -30-200 µm [21].

Sputtering process has been shown to be a particularly useful technique for the deposition of bioceramic thin films (based on Ca/P systems), due to the ability of the technique to provide greater control of the coating's properties and improved adhesion between the substrate and the coating. The disadvantages with sputter coating is extensive time consuming, produces amorphous coatings and Ca/P ration of the coating is higher than of synthetic HA. Thickess of 05-3 µm

Magnetron sputtering- is a viable thin-film technique as it allows the mechanical properties of Ti to be preserved while maintaining the bioactivity of the coated HA [22].

Pulsed laser deposition: PLD process involves using high power laser energy to vaporize the bulk coating material from a target. The vaporized material is ejected from the target and condenses on the substrate. Repeated laser pulses will result in the deposition of the thin film as a coating on the substrate [23]. Hydroxyapatite films produces by this method have low deposition temperatures and are highly crystalline, stable and osteoinductive. Thickness of 0.05-5 mm [24].

Dip Coating involves the deposition of a wet liquid film by withdrawal of a substrate from a liquid coating medium. The complete process of film formation involves several stages. HA can be homogenously coated onto metal substrates to obtain coating thickness in the range of 0.05–0.5 mm. The coating layer is deposited on the surface of the substrate without decomposition or reaction with the metal substrate. However, this technique requires high sintering post-treatments which may induce crack formations on the surface of the substrate [25].

Sol-gel involves the formation of solid materials, mainly inorganic non-metallic materials from solution. This can be a solution of monomeric, oligomeric, polymeric or colloidal precursors. The sol–gel is a low temperature process, thus does not suffer from the implications of structural instability of hydroxyapatite at elevated temperatures. Thickness of 0.1-2.0 µm [26].

Electrophoretic deposition is a process in which particles in a suspension is coated onto an electrode under the effect of an electric field. Electrophoretic deposition of HA can be processed at room temperature or lower, which avoids problems related to formation of amorphous phases. Thickness of 0.1-2.0mm [27].

Hot isostatic pressuring is an alternative method of producing an HA coating on a Ti substrate in which pressurized gas is used to exert the required load at the desired temperature. This requires a gas-tight metal or glass encapsulation around the porous HA coated implant. In the HIP process, pressure andtemperature are applied to the workpiece simultaneously. Thickness of 0.2-2.0mm [28].

Ion Beam assisted deposition a vacuum deposition process based on the combination of ion beam bombardment and physical vapor deposition. The major characteristic of IBAD is the bombardment with a specific energy ion beam during coating deposition. a wide atomic intermixed zone between the coating material and the substrate can be created, assisted by the bombardment with energetic ions during deposition. This creates a strong adhesion of the coating to the substrate. Thickness is less than 0.03 µm [29].

Photo functionalization

UV treatment of dental implant surfaces enhances bioactivity and osseointegration by altering the titanium dioxide on the surface. By promoting interactions of cells and proteins to the implant on a molecular level, UV light is believed to enhance the osteoconductivity [30].

Fluoride Treated

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. The increased seeding rate of the apatite crystals, the stimulation of the osteoprogenitor cells, an increased alkaline phosphatase activity and the incorporation of newly formed collagen into the bone matrix are the reported effects of the fluoride modification [31].

Nanoparticle Compaction

Compaction of nanoparticles on the implant surface conserves the chemistry of the underlying surface while changing or modifying the chemistry and structure of the outer surface layer [32].

Peptide Coating

This involves the coating of titanium implant surface with synthetic arginylglycylaspartic acid (RGD) peptides that contain binding sites for integrin receptors [33].

Antibiotic Coating

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 [34].

Growth Factor Coating

The implant surface can be coated with osteogenesis-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 [35].

Bone Modulating Agent Coating

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 [36].

Sla Treated

The traditional approach to the surface modification of a Ti implant has been roughening at the micro-level. One of the most successful surfaces in clinical dentistry is the sandblasted, large-grit, and acid-etched (or SLA) surface. An SLA Ti surface is made by sandblasting the turned Ti surface with large-grit particles, the sizes of which range from 250 μm to 500 μm in general, and by acid-etching the blasted surface. The acids for etching are usually strong acids including hydrochloric, sulfuric, and nitric acids [37]. The average surface roughness (Ra) of the treated material is 1.5 μm [38].

Chitosan Coating

The chitosan coating allowed the adhesion and proliferation of human gingival fibroblast
cells and it showed a high level of cytocompatibility while preventing the growth of the P. gingivalis bacteria [39].

White Surface Coating

Obtained the white coated Ti topographies by anodic plasma-electrochemical oxidation. Has a positive influence on osteoblast cells, high rate of proliferation, and upregulates the expression of osteocalcin, bone sialoprotein and are promising from aesthetic point of view [40].

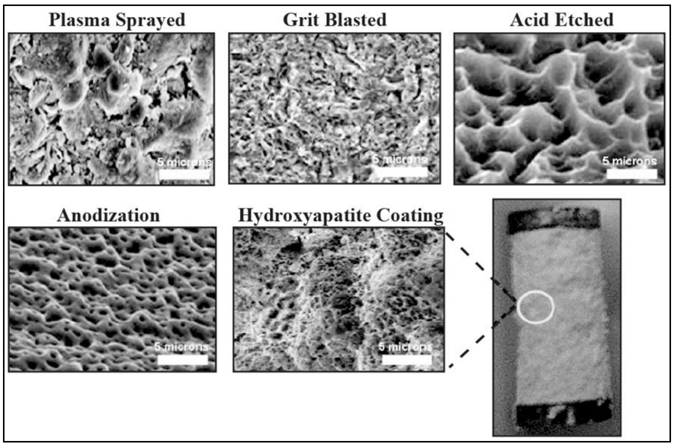

Fig 1: Various surface treatment methods

Table 1: Surface treatments and various implant systems available commercially

Surface treatment	Implant surface/surface
Blasted and acid washed/etched	Hahn Tapered Implants, Denstsply Implants FRIALIT and Friadent plus, Straumann SLA
Anodized	Nobel Biocare TiUnite
Acid etched	BIOMET 3i OSSEOTITE and NanoTite
Blasted	DENSTPLY Implants ASTRA Tech TiOblast,Zimmer Dental MTX
HA Coated	Implant Direct,Zimmer Dental MP-1
Laser ablation	BioHorizons Laser-Lok
Titanium plasma sprayed	Straumann ITI titanium plasma sprayed

Recent Advances

Human dental pulp stem cells in combination with autologous plasma components stimulated by PRGF and PRF, cultured on titanium surface, suggested a icreases osteoblastic differentiation out of mesenchymal stem cells, generation of calcified bone matrix and therefore increases bone deposition around implant surface thereby increasing anchorage [41].

Nanotextured implants fabricated by double acid-etching followed by anodization to grow TiO2 nanotubes. For TiO2 nanotube formation, the anodic oxidation at room temperature was carried out with a constant potential of 30 V for 3 h in an electrolyte containing ethylene glycol, ammonium fluoride and water. This novel nanotextured surface exhibited superior wettability, improved peri-implant bone formation, and expedited osseointegration [42].

TESPSA (ftriethoxysilylpropyl succinic anhydride) surface treatment showed a significant inhibition of bacterial adhesion and biofilm formation in both bacterial single-species (S. sanguinis and L. salivarius) [43].

Conclusion

Various surface modification techniques commonly used for bone-related implants are reviewed in this article. In practical terms, one approach would be chosen for surface modification according to the target effect and physiochemical properties of the substrate, also cost as an important factor. As comprehensive utilization of multiple methods is often required to fulfil the needs, it is necessary to fully understand the principles and effects of such many modification techniques, and their latest advances prior to the processing.

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