REVIEW ARTICLE

SURFACE TREATMENTS IN IMPLANTS : A COMPARISON OF ADDITIVE AND SUBTRACTIVE METHODS - 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.

KEY WORDS

Additive methods, Subtractive methods, Implant surface treatment, Surface topography, Sand blasting.

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INTRODUCTION

Currently, dental implants provide the most advanced treatment modalities over conventional treatment for single tooth replacements, partially edentulous and completely edentulous arches. In this regard, the clinical success of oral implants is crucial which is related to their early osseointegration.[1]

Low osseointegration or peri-implant bone loss may cause micro-mobility to the implant and lead to its consequent loss. A peri-implant bone loss of greater than 1 mm in the first year after implantation and greater than 0.2 mm in the following year is considered a failure of the dental implant.[2]

Albrektsson et al. identified implant design and surface finish as the two fundamental determinants in the manipulation of osseointegration. Among these, the Geometry and surface topography is a critical factor for the short- and long-term success of dental implants.[1] 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.[3]

Broadly, the surface treatments can be classified under Additive procedures and Subtractive procedures which will be discussed in this article.

SURFACE TOPOGRAPHY:

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]

Sykaras N et al. have classified implant surfaces as:
- Minimally rough (0.5–1 µm)
- Intermediately rough (1–2µm)
- Rough (2–3 µm).

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] Nanotechnology has facilitated the implementation of surface modifications, the use of coatings and even the controlled release of antibiotics or proteins.[8]

One method classifies surface treatments on the basis of physical, chemical or mechanical modifications. The methods can also be classified as: Additive and Subtractive.

The additive methods employed the treatment are 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.[9]

Additive methods:

- Sintering
- Plasma Spraying
- Hydroxyapatitecoating
- Anodization
- Sol gel coating
- Electrophoretic deposition
- Biomimetic precipitation
- Drug incorporated

Subtractive Methods :

- Machined Surface
- Grit blasting or Sand Blasting
- Acid Etching
- Dual Acid Etching
- Laser peening
- SLA

Additive techniques

Sintering : Sintering is the process of compacting and forming a solid mass of material by heat or pressure without melting it to the point of liquefaction.[10] Various methods have been used in the past to impose rough surface over the implant but Direct Metal Laser Sintering (DMLS) is an effective method which uses laser based technique for improved precision. DMLS can be used to fabricate implants layer by layer using powdered materials, radiant heaters and computer controlled laser.[11]

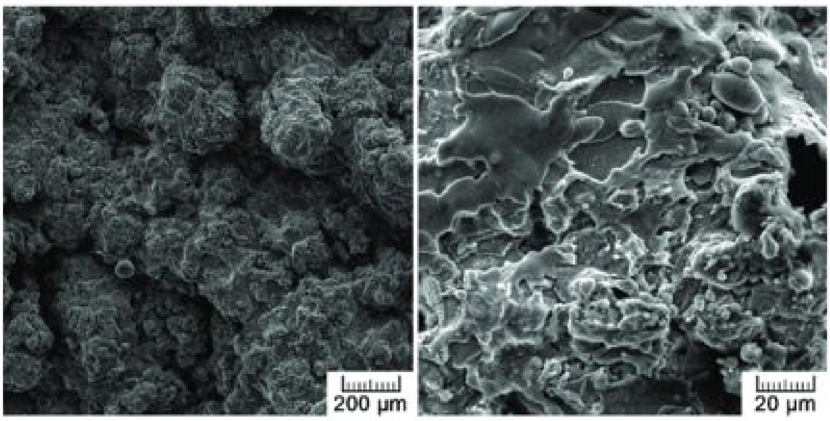
Plasma Spraying : The implant surface can be modified by the projection of titanium particles injected into a plasma torch at high temperatures.[11] At temperatures in the order of 15,000°C, an argon plasma is associated with a nozzle to provide very high-velocity (600 m/ sec) partially molten particles of titanium powder (0.05- to 0.1- mm diameter) projected onto a metal or alloy substrate.[10]

Surface porosities ranging from 150 to 400 mm provide maximum fixation strengths and coincidentally correspond to surface feature dimensions obtained by some plasma-spraying processes. Also, porous surfaces can result in an increase in tensile strength through ingrowth of bony tissues into three-dimensional features. High shear forces determined by the torque-testing methods and improved force transfer into the peri-implant area have also been reported.[10]

Martin et al. showed that plasma spraying an implant surface with titanium dioxide resulted in a rougher surface with average roughness of around 20µm.[12] Due to the high affinity of titanium to oxygen, a thin layer of TiO_2 (5–10 nm) is formed immediately on its surface when exposed to the air and gives it a passive character.[13]

Hydroxyapatite coating:

Hydroxyapatite is mostly used as implant coatings along with nanostructured calcium and calcium phosphate. They are applied to the implant



Pic courtesy-Fousová, Michaela & Vojtech, Dalibor & Jablonska, Eva & Fojt, Jaroslav & Lipov, Jan. (2017). Novel Approach in the Use of Plasma Spray: Preparation of Bulk Titanium for Bone Augmentations. Materials. 10. 987. 10.3390/ma10090987.

surface using hydrothermal deposition or plasma spraying.

Fouda et al. reported that HA coated titanium implant could enhance the healing period compared to the uncoated implants.[14] Xie et al. also discovered that HA coatings promote better cell proliferation.[15]

The inorganic coating also have a beneficial effect over stress distribution and is biomechanically favourable.

Anodization:

This is a process by which oxide films are deposited on titanium implant surface by means of an electro chemical reaction.[11] The electrolyte which is used are phosphoric acid, surphuric acid or nitric acids. This technique results in the formation of micropores and increase the oxide layer of TiO2 in the form of anatase. Anatase and rutile are the two most important phases formed. Studies show improved biocompatibility, blood-clot formation, cell adhesion and osteoblast proliferation.[16] However, mechanical stability may be altered due to anodization process despite biological advantages.[17]

A nano structured surface can be produced by galvanostatic anodization of titanium in strong acids (H2SO4 , H3PO4, HNO3, HF) at high density (200 A/m2) or potential (100v).[11]

Sol gel coating : Sol-gel coating involves the formation of solid materials, mainly inorganic non-metallic materials from solution as a thin homogenous chemical distribution over the implant surface. This can be a solution of monomeric, oligomeric, polymeric or colloidal precursors. This is a low temperature process, thus it does not have implications of structural instability of hydroxyapatite at elevated temperatures. Thickness obtained is of 0.1- 2.0 µm.[18]

Electrophoretic deposition:

This is the process which colloidal particle, such as nano precipitates which are suspended in a liquid medium migrate under the influence of an electric field and is deposited on to a counter charged electrode.[11] It can be processed at room temperature or lower, which avoids problems related to formation of amorphous phases.[19]

Biomimetic precipitation:

Biomimetic precipitation refers to the surface treatment method in which implant surface is coated with a biomimetic agent. A biomimetic agent is an "agent /material able to replicate or imitate a body structure and function. (glossary of implant dentistry).

It has been shown that such biomimetic coatings are more soluble in physiological fluids and resorbable by osteoclastic cells.[11]

BIOMIMETIC AGENTS USED

Bioceramics : Hydroxyapatite (HA), Calcium phosphate phases.

Bioactive proteins: Bonemorphogenic proteins (BMP), Type1collagen, RGD peptide sequence.

Ions : Fluoride.

Polymers : Chitosan

Drug incorporated:

Surface treatment of implant with antibacterial coating serves the possible way to prevent surgical site from infection. Gentamicin can be used along with HA coating. Tetracycline –HCl treatment is also an efficient method for decontamination and detoxification of implant surface.

e coatings of the implant or its bulk structure can allow drugs to be eluted to the environment by diffusion, osmotic pressure, and via matrix degradation for a period of time [171]. In particular, it has been reported that molecules are released from implant.

The desired properties of an implant-coating drug delivery system include a biocompatible material without secondary side effects both locally and systemically, minimizing complications related to the mismanagement of a drug delivery dose but with high bioactivity to promote osseotintegration

A reduced adherence of Staphylococcus aureus to the titanium implant was obtained by the slow release of the agent from a coating formed of vancomycin loaded silica sol–gel film.

Doxycycline has been commonly employed for the formulation of antibiotic-loaded coating since it suppresses bacteria growth and prevents both peri-implant inflammation and bone resorption.

Titanium surfaces have also been functionalized with quercetin, demonstrating that flavonoids promote osteogenic activity. Chlorhexidine showed satisfactory antibacterial results when the drug was loaded into microporous silica coatings by diffusion, which avoided the burst release of the drug.

Subtractive techniques

Machined surface: this was one of the former methods to modify the implant surface. The implant is turned, milled or polished. It creates a minimally rough surface, with a surface area roughness (Sa) value of 0.3-1.0um. The surface morphology is determined by the manufacturing tools used, the implant material, the lubricant, and the speed at which it is machined.[1] Currently most systems used today require further treatment methods for improved outcome.

Grit blasting or Sand Blasting:

Another route for roughening the surface is grit blastingin which pressurized particles are projected through a blasting nozzle using compressed air. Materials such as silica, hydroxyapatite, alumina, or TiO2 particles are usually employed for the purposes.[20]

This procedure is done with aim of increasing the surface irregularity of implant. But often blasting procedure can leave residual particle on surface of implant and this could modify the bone healing process.[11]

the choice of the employed particles (i.e., type, size and shape) is a key point, and abrasives must be harder than implant materials to produce roughness.[21] Moreover, the distance from the projection gun to the surface, the projection pressure, the saturation time and projection diameter represent important parameters that influence the roughness. Sand blasting may increase the risk of microbial contamination.

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

Acid Etching : Acid etching is not only used to remove contaminats and clean the surface but it also produces surface roughness. Strong acids (HF, HNO3, H2SO4) or a combination of strong acids are generally used. There is also a direct co relation between the concentration of acid used and amount of surface roughness generated.

Alla et al. reported that a nanotopography that allows bone ingrowth via acid etching on an implant may improve the osseointegration.[22] Wen., et al. when reported that employing (HCl+H2 SO4) and alkaline solution improves bioactivity of titanium alloy.[1]

Acid etching is frequently utilized in combination with other surface treatment methods to improve the properties of Titanium and titanium alloys.

Dual Acid Etching:

A comparative study between a machined surface and those using HF and HCl /H2SO4 (DAE) has shown the acid treated surface has greater resistance to reverse torque removal and better osseointegration.[23]

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.[1]

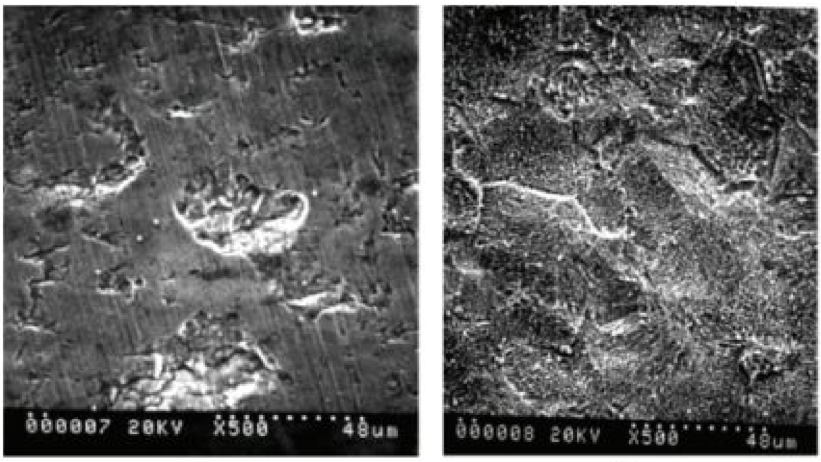
Laser etching:

Process involves the use of high intensity nano second pulses of laser beam (3-5 width) striking a protective layer on the metallic surface, melting the surface layer locally. As this process is contactless the chances of thermal, mechanical deformation of substrate is low.[11]

Thus, the implant surface is not contaminated with blasting media. Laser ablation has also been used to generate antimicrobial surfaces. Thus, for example, Boutinguiza et al. used this technique to deposit silver nanoparticles on top of c.p. titanium implants.[24]

SLA:

One of the most successful surfaces in clinical dentistry is the sandblasted, large-grit, and acid-



(a) (b)

Titanium implant with (a) a machined surface and (b) treated dual acid 48% HF + HCl/H_2SO_4

etched (or SLA) surface. This technique combines the benefit of both to obtain macro roughness and micropits. 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 with strong acids. The average surface roughness (Ra) of the treated material is 1.5 μm.[1]

Kim et al. discovered that human osteoblasts grow splendidly on the SLA surface which provides greater space for cell attachment and proliferation. Surface morphology for SLA typically became rough and irregular after sandblasting, but then after the acid etching treatment the surface is more uniform and small micro pits (1-2 μm in diameter) are created.[25]

Other notable methods:

Electropolishing:

This Technique is also known as electrochemical polishing, anodic polishing or electrolytic polishing. This method removes material from a metallic work piece, which will remove the surface roughness by eliminating peaks and valleys. So this technique is used for polishing and passivation of the metallic surface. Electrolyte used for this purpose is often concentrated acid solution which has high viscosity.

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.Using pulsed magnetron sputtering method, ZrO2- Ag and ZrO2-Cu deposited titanium surface had improved the antibacterial performance relative to pure Ti implant materials

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.[1] Chitosan and carboxymethyl chitosan, which are polysaccharide of natural origin, formed of N-acetylglucosamine and D-glucosamine that vary in composition, sequence, and molecular chain length, have been the most extensive antimicrobial polymers explored among natural cationic polymers. They are considered agents with a broad spectrum of activity due to their killing effect against Grampositive and Gram-negative bacteria.

CONCLUSION

Throughout history and to the modern times, various methods for surface treatment have been discovered and used. In relation to the surface texture, Various factors must be kept in mind which determines the success of the implants like tissue response, BIC achieved, physiochemical properties of the material, economic constraints, etc.

Currently, Most works still favour surface treatment of dental implants via coating and acid etching over other methods in producing good substrate surfaces for osseointegration, with surface roughness ranging from 0.44 to 8.68 μm However, it is necessary to fully understand the principles and effects of such many modification techniques to focus on the practical utilization in different clinical situations.

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