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Surface Treatment on Dental Implants–A Review

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Review Article

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Abstract: Over the years implant design by various researchers have been introduced as well as modification to the surface of titanium being used .The field of surface modification is vast and constantly evolving to keep up with technology . The aim of the present review was to elaborate on the surface modifications of biomaterials which are used in implant dentistry and to introduced the contemporary knowledge about the influencing factors affecting the osteointegration process of dental implants, analyze the currently available techniques for implant surface modification and their limitations, and also discuss the future trends in surface bioengineering and nanotechnology for improving the osseointegration and consequently enhance their biological performance.
Keywords: Surface treatment, Grit blasting, Acid etching, Plasma spraying, Hydroxyapatite.

INTRODUCTION

Dental implants represent a reliable treatment option in oral rehabilitation of partially or fully edentulous patients in order to secure various kinds of prostheses. Dental implants have become a standard procedure for single tooth replacement in the esthetic zone, providing many advantages but also challenges in sophisticated patients[1,2].

An implant is a medical device which is made from one or more biomaterials, that is intentionally placed in the body either totally or that is partially buried beneath an epithelial surface[3].

Branemark *et al*. first described the process of osseointegration more than 45 years ago[1]. Osseointegration is the foundation of implant sciences and infinite articles have been published on the various aspects of manufacturing the implants and on the clinical and laboratory phases of implants. The implant machining, surface, designing, surgical techniques and the peri-implant considerations have all progressed from infancy to the state of art and science and continue to evolve with each passing year. The surface characteristics at the micro or nanometre level, hydrophilicity, biochemical bonding and other features are few of the determiners which are responsible for the implant's success[4].

Today, roughly 1300 different implant systems exist varying in shape, dimension, bulk and surface material, thread design, implant-abutment connection, surface topography, surface chemistry, wettability, and surface modification [5]. The common implant shapes are cylindrical or tapered[6]. Surface characteristics like topography, wettability, and coatings contribute to the biological processes during osseointegration by mediating the direct interaction to host osteoblasts in bone formation[7]. 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[8].

Surface characteristics are one of six key factors that determine the long-term success of dental implants[9]. By modifying the characteristics of the Ti surface, biocompatibility can be improved, faster Osseo integration can be provoked, and the edentulous period of a patient can be finally shortened[10]. Some of the objectives for the development of implant surface modifications are to improve the clinical performance in areas with poor quantity or quality of bone, to accelerate the bone healing and thereby allowing immediate or early loading protocols and also stimulating bone growth in order to permit implant placement in sites that lack sufficient residual alveolar ridge. The surface characteristics at the micro or nanometre level, hydrophilicity, biochemical bonding and other features are few of the determiners which are responsible for the implant's success[11-14]. The surface area can be increased remarkably by using proper modification techniques, either by addition or subtraction procedures. A surface treatment can also be classified into mechanical, chemical, and physical methods[15].

Morphological surface modification

By increasing the surface roughness, an increase in the osseointegration rate and the biomechanical fixation of titanium implants have been observed [16-17]. The implant modifications can 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, 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 crystals within 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 (HA) coating, alumina coating, and biomimetic calcium phosphate (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[18]. The removal of surface material by mechanical methods involved shaping/removing, grinding, machining, or grit blasting via physical force. A chemical treatment, either by using acids or using alkali solution of titanium alloys in particular, is normally performed not just to alter the surface roughness but also to modify the composition and to induce the wettability or the surface energy of the surface[19]. As for physical treatment such as plasma spray or thermal spray, it is often carried out on the outer coating surface to improve the aesthetic of the material and its performance. Additionally, ion implantation, laser treatment and sputtering[20-24], alkali/acid etching[25-27], and ion deposition [28] are also utilised.

Different approaches are being used in an effort 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, bone quality. As described by Ito *et al.* [29] the approaches can be classified as physicochemical, morphologic, or biochemical.

Physicochemical Method[30-32].This method 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 glow discharge method which increases the cell adhesion properties. The role of electrostatic interaction in biological events mainly proposed to be as conducive to tissue integration. But on the contra lateral side it has been found that it does not help in adhering selective cells/tissues and it has not been shown to increase bone implant interfacial strength.

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 in growth into macro rough surfaces enhances the interfacial and shear strength. In addition to that, surfaces with specially contoured grooves can induce contact guidance whereby direction of cell movement is affected by morphology of substrate. This has got added advantage as it prevents the epithelial down growth on dental implants [33].

Biochemical methods of the surface modifications

The biochemical methods of the surface modifications offer an adjunct to the physiochemical and the morphological methods. Their goal is to immobilize proteins, enzymes or peptides on biomaterials for the purpose of inducing specific cell and tissue responses, or in other words, to control the tissue-implant interface with molecules which are delivered directly to the interface. One approach uses cell-adhesion molecules like fibronectin, vitronectin, TypeI collagen, osteogenin and bone sialoprotein. The second approach uses biomolecules with osteotropic effects which range from mitogenicity (interleukin growth factor-I, FGF-2, platelet derived growth factor – BB) to the increasing activity of the bone cells, which enhances the collagen synthesis for osteoinduction [8].

The application of various biotolerant agents, for example, rhBMP-2, within the confined boundaries of the hollow chambered implant, have been tried to modify the surface topography or the chemistry of the implants. Reports have shown a limited effect on the osseointegration level along its outer surface, perhaps, because of the physically restricted diffusion [34].

Ablative /subtractive procedures

Grit blasting

Grit-blasting, consists in the propulsion towards the metallic substrate of hard ceramic particles that are projected through a nozzle at high velocity by means of compressed air and leading to different surface roughness, depending on the size of the ceramic particles. The blasting material should be chemically stable, biocompatible and should not hamper Osseo integration. The grit blasting technique usually is performed with particles of silica (sand), alumina, titanium dioxide or resorb able bio ceramics such as calcium phosphate. Alumina (Al_2O_3) is frequently used as a blasting material, however, it is often embedded into the implant surface and residue remains even after ultrasonic cleaning, acid passivation and sterilization. It has been documented that these particles have been released into the surrounding tissues and interfered with the osteointegration of the implants[35]. Moreover, this chemical heterogeneity of the implant surface may decrease the excellent corrosion resistance of titanium in a physiological environment. Titanium oxide (TiO2) particles with an average size of 25 µm can produce moderately rough surfaces in the 1–2 µm range on dental implants.

Acid etching

The immersion of a titanium dental implant in strong acids such as hydrochloric acid, sulfuric acid, nitric acid and hydrogen fluoride is another method of surface modification which produces micro pits on titanium surfaces with sizes ranging from 0.5 to 2 µm in diameter. Acid etching greatly enhances the potential for Osseo integration especially in the early stage peri implant bone healing. Acid treatment produces a clean detailed surface texture and lacks entrapped surface materials and impurities. This is reported to have a positive response in terms of bone apposition, higher percentage of bone to implant contact and strong implant anchorage. In addition, it is important that the etching procedures following grit-blasting removes any particle remaining, because chemical analyses of failed implants have shown evidence that the presence of such particles interferes with titanium osteoconductivity regardless of the established biocompatibility profiles of the biomaterial[36].

Anodized Surface Implants

Anodized surface implants [4] 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. In order to alter the topography and composition of the surface oxide layer of the implants ,micro- or nano-porous surfaces may also be produced by potentiostatic or Galvano static anodization of titanium in strong acids, such as sulfuric acid, phosphoric acid, nitric acid and hydrogen fluoride at high current density or potential. When strong acids are used in an electrolyte solution, the oxide layer will be dissolved along current convection lines and thickened in other regions which create micro-or nano-pores on the titanium surface. This electrochemical process results in an increased thickness and modified crystalline structure of the titanium oxide layer. However, it is a complex procedure and depends on various parameters such as current density, concentration of acids, composition and electrolyte temperature.

Shot peening/laser peening

Shot peening [37] is similar to sand blasting where the surface is bombarded with spherical particles, each particle that comes in contact with the surface form a small indentation or dimples. Laser peening involves high intensity 5-15 GW/cm^2 nanosecond pulses of laser beam striking the protective layer of paint on metallic surface. Laser treatment improved the bone response and ideal pores with a specific diameter, depth and intervals can be controlled. Itala *et al.* observed that the optimal pore size which was needed to encourage the mineralized bone was 100-400µm. Laser treatment leads to contamination with carbon and oxygen, with 1.44% carbon on the surface. Deppe *et al.* [38] determined that carbon dioxide from the air may have provided the carbon and that laser was considered to be least contaminating surface treatment in comparison to the acid etching, sand blasting or the plasma spraying technique.

ADDITIVE METHOD

Plasma spraying

Plasma spraying (PS) is a process of thermal spray technology that uses a device to melt and deposit a coating material at a high velocity onto a substrate. Adhesion of Hydroxyapatite (HA) is purely mechanical and adhesion can be enhanced by roughening substrate surface. The PS processing may increase the surface area of dental implants up to approximately six times the initial surface area[39] and is dependent on implant geometry and processing variables, such as initial powder size, plasma temperature, and distance between the nozzle output and target[40]. The advantage of PS includes simplicity, rapid deposition rate, low substrate temperature, low cost. 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.

Electrophoretic deposition

EPD is a process in which colloidal particles such as HA Nano precipitates which are suspended in liquid medium migrate under the influence of electric field and are deposited onto a counter charged electode. The coating is simply formed by pressure exerted by the potential difference between the electrodes. EPD can produce HA coatings ranging from <1 to 500>micron thick The advantage of EPD includes low cost ,simple methodology capable of producing coating of variable thickness , high deposition rate and ability to uniformly coat irregularly shaped or porous objects such as threaded implants due to its high throwing power. The major disadvantage includes the need for postdeposition heat treatment to densify the coating[41-42].

Sol-gel coating

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.

Sputter deposition

These techniques involve the bombardment of a target in a vacuum chamber, resulting in sputtered or ablated atoms being coated on the positioned substrate. 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 [41] and pulsed laser deposition. However an inherent disadvantage is deposition rate is very slow. The key advantages are: high deposition rates, ease of sputtering of the most of the materials, high purity films, extremely high adhesion of the films, excellent coverage of highly difficult surface geometry, ability to coat heat sensitive substrates, ease of automation and excellent uniform layers.

Ratio frequency sputtering (RF) Technique: This technique involves the deposition of HA in thin films. Studies have shown that these coating are more retentive and chemical structure is precisely controlled. The other major advantage of this technique is that the design of implant particularly threaded implant is maintained.

Magnetron sputtering [42, 43]: This technique shows strong HA titanium bonding associated with outward diffusion of Ti in to HA layer forming TiO2 at an interface.

Pulsed laser deposition

The Pulsed laser deposition [44-48] results in titanium surface microstructures with greatly increased hardness, corrosion resistance, and high degree of purity with standard roughness and thicker oxide layer. HA is deposited on to pure Ti substrates at 400^{o} C in water vapour and oxygen atmosphere, the pressure valve in the range of 3.5 .10 1 -10 1 torr.

Biomimetic Calcium Phosphate Coatings

Biomimetic coatings involve the use of microstructures and functional domains of organismal tissue function to deposit calcium phosphate upon medical devices in order to improve their biocompatibility[49]. This bioinspired method consist in the precipitation of calcium phosphate apatite crystals onto the dental implant surface through simulated body fluids under near- physiological or ―biomimetic‖ conditions of temperatutre and PH.

This technique allows for nucleation and growth of bone like crystals on a pretreated substrate by immersing it in a supersaturated solution of calcium phosphate under physiological condition (37^{0} C and ph-7.5).

PVD coating (TiN, ZrN)

PVD (Physical Vapour Deposition) coatings, such as Titanium Nitride or Zirconium Nitride are applied for cosmetic reasons on dental implant collars and abutments or for reasons of wear protection on rotating dental instruments. TiN ceramic hard coatings with a thickness of ~2 μm enhance the product life span of instruments and can avoid potential contaminations due to their proven biocompatibility.

Nanotechnology

Nanotechnologies can create surfaces with controlled topography, and chemistry which would help understanding biological interactions and developing novel implant surfaces with predictable tissue-integrative properties [49]. The application of nanotechnology to biomedical surfaces is explained by the ability of cells to interact with nanometres features, which is mainly mediated by integrins, binding to the arginine-glycine-aspartate sequences of peptides. Cell adhesion to the extra-cellular matrix (ECM) leads to clustering of integrins into focal adhesion complexes (FA), and activates intracellular signaling cascades [50]. Nanofeatures are crucial to modulate stem cells behaviour[51]. Osteoblasts are able to encode‖ the 3-dimensional characteristics of the surface like lines, pores or dots and modulate their growth according to the suggested structural features. Hence, the surface pattern in particular has been demonstrated to play a key role.

There is still little evidence of the long-term benefits of nano features, as the promising results achieved in vitro and in animals have still to be confirmed in humans. Additionally, there is a lack of data about the release of metal ions in the surrounding tissues and the possible systemic effects. Moreover, a complicating feature of nanoscale manipulation is that there are many chemical changes on the bulk material surface and it can be very difficult to investigate positive or negative effects induced[52]. However, the increasing interest in nanotechnology is undoubted and more researches are going to be published in the next years. Ongoing developments suggest that dental implant manufacturers will invest increasing resources to give patients the most durable and most biocompatible material to replace their teeth.

CONCLUSION

Dental implants are valuable devices for restoring lost teeth. Implants are available in many shapes, sizes and length using a variety of materials with different surface properties. Several techniques have been widely studied and developed to modify dental implant surfaces to promote rapid Osseo integration and faster bone healing. Several in vivo and in vitro studies demonstrated various novel dental implant surfaces mostly consisting in modifications of commercial available ones. Some studies [53] support the hypothesis that in case of a favourable bone quality implant, the surface roughness plays a minor role. A positive influence of the moderate rough surfaces on the early loading concepts has been suggested by many groups. A positive effect of the surface roughness has been observed in poor quality bone, but the pivotal proof of this effect is still lacking, according to some studies. Some indications which support the selection of HA coated implants over metallic implants include, the need for a greater bone implant interface contact and the ability to be placed in type IV bone, fresh extraction sites and newly grafted sites[54]. The main shortcoming in dental implant surfaces is empirical nature of manufacturing process as it lacks generalized consensus to make one standard for obtaining controlled topographies. In order to overcome this matter, several in vitro and in vivo studies are still required. Dental implantology is a limitless field with countless possibilities and innumerable benefits and is definitely here to stay.

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