Surface matters than the implant itself – A review

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ABSTRACT

Nowadays, dental implants are a predictable and popular treatment option for tooth replacement in completely or partially edentulous patients. Implants are preferred over conventional treatment due to certain advantages, it offers like preservation of bone as well as the adjacent teeth, durability, better mastication, speech, etc. The implant comes in direct contact with bone and anchors through osseointegration. Successful osseointegration revolves around many factors such as biocompatibility of the implant material, quality and quantity of the available bone, surface treatment of the implant, loading and surgical protocol, and various other systemic and local factors. The predictability of clinical success of dental implants can be enhanced using newer materials or alterations in designs, and surgical or loading protocols based on available literature. Various studies have suggested that a rough implant surface enhances its integration with bone more than a smooth implant surface. Several approaches are used to attain a rough surface and to improve the process of osseointegration of titanium dental implants. The present paper reviews different methods of treating implant surfaces to enhance bone-implant interaction starting from the basic material used in dental implant manufacture.

Key words: *Biomimetic, Implant Surface Treatment, Osseointegration, Titanium*

Earlier the implant material was porcelain, gold, aluminum, platinum, and silver which were initially used to replace teeth but the occurrence of inflammatory reactions amidst fibrous tissue formation led to the cessation of the use of these materials. Economically pure titanium is the elite choice as a dental implant material although due to unclear reasons, the survival rate may fluctuate. Titanium has been a material of choice in various prosthetic applications in the medical field due to biocompatibility. The utmost persuasive affirmation of the biocompatibility of titanium is its perpetual use in dental implants. Apart from biocompatibility, other characteristics such as inert behavior, cost, corrosion resistance, non-allergenic property, easy adsorption of proteins, favorable cell growth, and differentiation make titanium a desirable element for biomedical implementation. Oxygen and titanium combine to form an alloy known as commercially pure titanium. Oxygen quantity in surgical implants should be <0.5% to meet the guideline of British standard specification [1]. At 883°C, transformation in the molecular structure of titanium occurs from the alpha phase (hexagonal close packed) to the beta phase (body-centered cubic). Elements such as oxygen, carbon, and nitrogen stabilize the alpha phase whereas molybdenum, niobium, and vanadium stabilize the beta phase.

Quest for a tooth-colored biomaterial to enhance esthetics lead to the introduction of ceramics as implant biomaterial. Ceramics is biocompatible, has high compressive strength, and feasible for surface treatment to enhance bonding with bone. Disadvantages of ceramic are brittleness and the tolerance level of ceramic is less for tensile stress due to occlusal forces. Aluminum oxide (Al_2O_3), as well as zirconium oxide (ZrO_2), exhibits high biostability and can be used as implant material. However, alumina possesses higher surface wettability whereas zirconium offers the advantage of less plaque accumulation [2].

A bioactive ceramic biomaterial is bioglass (SiO_2-CaO-Na_2O-P_2O_5-MgO) because it stimulates bone formation. Al_2O_3 dental implants have been withdrawn from the market due to their poor survival rate, whereas zirconium is a distinctive material of choice, even under high occlusal forces. Scientists at NRC Industrial Materials Institute, Canada, formulated a newer material known as titanium foam by adding foaming agents to a mixture of titanium powder and certain polymers. It offers the advantage of the increased surface area of the implant surface due to its porous nature and makes the implant less invasive. "Roxolid" is a brand name for a material consisting of titanium and zirconium, which offers enhanced mechanical stability.

At present, many propositions related to alteration in surface topography and chemistry of implant surface is available in the literature. Morphometric studies clearly show that rough implant surfaces have more bone-implant contact as compared to smooth surfaces. Therefore, several attempts have been made to modify the implant surface through various processes such as amending surface chemistry or topography, oxide thickness, sandblasting, and anodic oxidation. Grossly, the techniques of transforming implant surface can be either additive, that is, sum up particles on the implant surface and form mounds, for example, titanium plasma spray, hydroxyapatite, calcium phosphate coatings, ion deposition, or subtractive method, that is, removing a portion of material from the surface and form depressions, for example, Al_2O_3-blasted surfaces, acid-etched surfaces, machined and acid-etched surfaces, and electro-polishing [3].

METHODS OF IMPLANT SURFACE TREATMENT

Surface modifications of implants can be broadly classified into three types:

Mechanical

It involves physical treatment that generally results in rough or smooth surfaces which can enhance the adhesion, proliferation, and differentiation of cells, for example, grinding, blasting, machining, and polishing [3].

Chemical

A chemical reaction takes place at the interface between titanium and a solution to alter surface roughness, and enhances surface energy. This includes chemical treatment with acids, alkali, hydrogen peroxide treatment, sol-gel, chemical vapor deposition, and anodization [3].

Physical

It is broadly classified into additive and subtractive methods. The additive methods employed the treatment in which other materials are added to the surface, either superficial or integrated. Subtractive methods involve the removal of surface material by shaping, grinding, machining, or blasting to create roughness in the implant surface [3].

BASED ON SURFACE TEXTURE [3]

(a) Concave texture – predominantly by the additive method Hydroxyapatite coating and titanium plasma spraying.
(b) Convex texture – predominantly by subtractive treatment Etching and blasting.

TITANIUM PLASMA SPRAY

Roughening of titanium implants with titanium plasma spray was primarily described by Hahn and policy as a microporous nature of the surface of orthopedic implants, which was later attempted in dental implants by Schroeder *et al.* Coating of titanium plasma can be obtained by heating titanium to a plasma form and by spraying this plasma on to the implant surface which can increase the apertures on implant surfaces by 6 times (30–50 µm deep), thus enhancing microretention. The surface area of an implant after plasma spray is around 3 times that of a machined surface. Klaus Gotfredsen and UlfKarlsson studied the difference between machined and titanium dioxide (TiO_2)-blasted implant's survival rate and marginal bone loss during a 5-year observation period, there were no significant differences in failure rate and marginal bone loss around implants with a machined and TiO_2-blasted surface.

In a longitudinal multicenter trial by William Becker, significant bone loss from loading to the 2- to 3-year follow-up evaluations was seen in plasma-sprayed implants [3]. The long-term effect of this bone loss on implant loss is unknown. Hydroxyapatite coating is an industrial method to enhance implant surfaces. Hydroxyapatite plasma spraying is done by the heating of hydroxyapatite with a plasma flame at a temperature of around 15,000–20,000 K, and then, hydroxyapatite is forced on the implant surface in an inert environment. The thickness of the coating is approximately 50–200 µm and the roughness is 7–24 µm. A hydroxyapatite bond well with bone and accelerates new bone formation in the initial healing period with the formation of an osteophilic surface, to increase bone formation in initial stages in cases such as immediate implant placement and poor bone quality. Hydroxyapatite surface is a good choice. *In vitro* studies have proved that a larger quantity of human osteoblasts cements to hydroxyapatite surfaces than to titanium.

Klaus Gotfredsen did a study on the rabbit to evaluate the histometric and biomechanical anchorage of TiO_2-blasted implants and $Ti0_2$-blasted implants coated with hydroxyapatite. He concluded that the hydroxyapatite surface had more bone contact and more lamellar bone as compared to the titanium surface in rabbit cortical bone, 13 weeks after implant placement [4].

GRIT BLASTING

It works on the concept of bombarding the surface with high-velocity hard particles of various sizes, with the help of compressed air. According to the size of the bombarding particles, different degree of surface roughness is produced on the implant surface. Alumina particles of the size range of 25–75 µm result in mean surface roughness in the range of 0.5–1.5 µm, while roughness in the range of 2–6 µm is reported for surfaces blasted with particle sizes of 200–600 µm [5]. Factors such as blasting time, pressure, and distance from the blasting nozzle also affect the size of irregularities. The blasting material should be chemically stable and biocompatible and should not restrict the osseointegration of the titanium implants. Different ceramic particles have been used, such as glass, silica, alumina, and titanium oxide particles. The residue of the blasting media may get buried on the implant surface and further survives the cleaning process which ultimately ends up hampering osseointegration. To minimize this, proper post-blasting cleaning such as chemical etching is done, which can decrease the roughening produced by blasting. Therefore, blasting with biocompatible material is advised. There is a lack of detailed studies on the composition and thickness of oxide layers on blasted titanium surfaces. In a study by Rasmussen, TiO_2-blasted implants were suggested as certain long-term support for fixed prostheses in both the maxilla and the mandible [6].

ACID ETCHING

Etching the implant surface with strong acids aids in cleaning the surface and attaining homogenous roughening. The most commonly used solutions for acid pickling of titanium and titanium alloy are 10–30 volume-% of nitric acid (69 mass-%) and 1–3 volume-% of hydrofluoric acid in distilled water, a mixture of 100 ml hydrochloric acid (18 mass-%) and 100 ml sulfuric acid (48 mass-%). Acid etching generally leads to a thin < 10 nm surface oxide layer. These oxide layers have been shown to grow slowly in the air, from 3 nm to 6 nm over 400 days. Immersion of titanium implants in a mixture of concentrated hydrochloric acid and sulfuric acid heated above 100°C for several minutes is dual acid etching. It produces a micro rough surface for rapid osseointegration while maintaining long-term success over 3 years.

Dual acid-etched surfaces accelerate the osteoconductive process by the attachment of fibrin and osteogenic cells, leading to bone formation straight on the implant. Another approach is fluoride treatment of the implant surface, which leads to the formation of titanium fluoride. This approach results in a fluoride embedded surface and also its roughness enhances the osseointegration [7].

ALKALINE ETCHING

Alkaline etching is a simple technique to modify titanium surfaces. Treatment of titanium in 4–5 M sodium hydroxide at 600°C for 24 h has been shown to produce sodium titanate gel 1 μm thick, with irregular topography and ample open porosity. This layer primarily consists of TiO_2. Additional heat treatment can help to modify the configuration and composition of this layer. If alkali treatment is done after acid etching, the resulting surface has increased porosity [2].

ANODIZATION

Anodization of the titanium surface is done at high voltage in strong acids (phosphoric acid, nitric acid, sulfuric acid, and hydrofluoric acid) resulting in crystallization of the surface. It leads to the thickening of the oxide layer to more than 1000 nm on titanium. This process is affected by acid concentration, composition, and the kind of electricity used. Anodization produces modifications in the microstructure and the crystallinity of the titanium oxide layer [3].

Anodized surfaces lead to firm reinforcement of the bone response with greater values for biomechanical and histomorphometric tests as compared to machined surfaces. Anodized titanium implants are more successful clinically than turned titanium surfaces of similar shapes. Rough and microporous surfaces can also be obtained in spark anodizing in sulfuric acid, phosphoric acid, or mixtures of these at above 100 V or spark anodization in calcium- and phosphorus-based electrolytes [2].

LASER TREATMENTS

Lasers can be used as an alternative to previously discussed techniques to avoid contamination. It is rapid, extremely clean, suitable for the selective modification of surfaces. and allows the generation of complex microstructures/features with high resolution. These advantages make the technique interesting for geometrically complex biomedical implants. The average surface roughness produced by the laser-treated acid-etched implant is around 2.28 μm. Studies have shown an increase in bone formation around such implant surfaces which lead to the formation of titanium nitride on the surface [8].

SPUTTER DEPOSITION

The sputtering process is a technique used for the deposition of thin bioceramic films (based on calcium phosphate 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. Scanning electron microscopy showed that the deposited films had uniform and dense structure [9]. The disadvantages of sputter coating are that they are time consuming, produce amorphous coatings and the calcium phosphate ratio of the coating is higher than that of synthetic hydroxyapatite. The thickness of hydroxyapatite coatings produced by the sputtering process varies from 0.5 to 3.0 μm. With sputter processing, the surface roughness of the coating depends on the roughness of the substrate (Hayakawa *et al.*) [10].

The arithmetic average roughness for hydroxyapatite-coated implants by the sputtering process is 3.0 ± 1.2 μm. In a study using TiO_2 grit-blasted and sputtered calcium phosphate implants, the sputtered calcium phosphate coatings showed improved initial fixation and healing response when implanted into the trabecular bone of the goat [11].

CALCIUM PHOSPHATE COATING

It is a class of bio-inorganic materials used to modify titanium surfaces for bone-related biomedical applications. The influence of the physicochemical properties of calcium phosphate and its degradation kinetics on the rate of new bone formation and the long-term stability of the bone biomaterial interface is still the subject of investigations and partly of controversial opinions [12].

Calcium phosphates are released from the implant surface after implant placement, which saturates body fluid and a biological apatite layer is precipitated on the implant surface [13]. This layer promotes osteogenic cell attachment, growth, and bone healing. Studies have shown that fixation of bone to implant is higher in implants with calcium phosphate coating and better long-term clinical success rates have been reported. Due to the problems observed with hydroxyapatite coatings acquired by the plasma spraying process, other processes such as sputter deposition, sol-gel coating, thermal spraying, hot isostatic pressing, pulsed laser ablation, electrophoretic deposition, and biomimetic coating are developed [14].

NANOSILVER

The oral cavity hosts a wide range of microbes that are capable of causing peri-implantitis; thus, these microorganisms always remain a risk factor for dental implant survivability. Therefore, dental implants with antimicrobial surface treatment were introduced [15].

Recently, silver nanoparticles (SNPs) have gained much attention due to their antimicrobial property. SNPs act in the following ways against Gram-negative bacteria: Nanoparticles of size 1–10 nm adhere to the cell membrane of bacteria and affect permeability and respiration; SNPs enter bacteria and interact with sulfur- and phosphorus-containing compounds like DNA; and SNPs emit silver ions, which will have an additional contribution to the bactericidal effect. SNPs are doped over the implant surface in the concentration of 0.05 ppm by Tollens' reaction [16].

In a study by Zhao *et al.*, SNP was inserted into titanium oxide nanotubes (TiO_2-NTs) on the surface of titanium implants by a technique that also involves silver nitrate immersion and ultraviolet radiation. The study showed that during the initial day, planktonic bacteria were inhibited and bacteria adhesion was prevented for 30 days due to SNP coating. Lu *et al.* compared implants treated with different concentrations of SNP and he suggested that a lower concentration of silver in SNP is more favorable to enhance osteoblastic growth [17].

BIOMIMETIC SURFACE TREATMENT

Biomimetic surface treatment is still a developing topic of research in implantology. Desirable properties of biomimetic agents are as follows:

1. It should be able to bring about the differentiation of cells for bone formation
2. It should not delaminate
3. Easy to manufacture
4. Affordable
5. Chemically stable
6. Non-immunogenic.

Bone morphogenetic proteins (BMPs) are a family of proteins responsible for the initiation of bone formation. Recombinant human bone morphogenetic protein-2 (rhBMP-2) is reported to act as a bone-modulating agent for uses in dentistry over the past few years. Study indicates that rhBMP-2 gives very good results as far as their capability of initiating bone formation around dental implants is concerned and also the newly formed bone offers long-term stability. Although these proteins are of a very high cost, it offers certain advantages as they can adhere to a wide range of implant material under physiologic conditions [18].

Roessler *et al.* suggested that arginylglycylaspartic acid (RGD) peptides boost the bonding of animal osteoblasts to RGD peptides treated titanium surfaces and also RGD peptides positively influence the properties of other coatings for biomaterials. Cytokines, platelet-rich plasma, and collagen type I are also capable of inducing osteoblastic activity when treated on the implant surface. Bisphosphonate assimilated on the surface of titanium implants has shown increased bone density around the implant, that is, in the peri-implant area, but the controlled release of the drug is still a challenge [19]. Herr *et al.* suggested that treating the implant surfaces with tetracycline not only kills bacteria but also removes the smear layer and decreases collagenase activity; ultimately increasing bone formation [20].

PHOTO-FUNCTIONALIZATION

This recent technique involves the treatment of implant surfaces using UV light to improve physical and mechanical properties and enhance osseointegration. Photo-functionalization improves the biological effect of titanium implants by converting the implant surface from hydrophobic to hydrophilic and electronegative to electropositive [21].

It involves the removal of the hydrocarbon layer from the surface that was formed during the aging of implants. As a result, the attachment, retention, proliferation, and expression of fundamental phenotypes of osteoblasts are remarkably increased, leading to better bone to implant contact interfaces [22].

FUTURE PROSPECTIVES IN DENTAL IMPLANT SURFACES

Future development of the next, third generation of dental implants should be based on increased knowledge about interface biology on cellular and molecular levels. The development of future generations of oral implants for compromised tissue conditions will, most probably, entail tailored modifications of material surfaces [23].

Implant surfaces, selectively designed for drug and/or cell releases, represent promising candidate strategies. Other surface modifications, such as selective ion substitutions of biomimetic surfaces, may further improve the biological response to those surfaces [24]. Further, as bacterial infection is a major challenge that may jeopardize the success of osseointegrated implants, implant modifications resulting in antibacterial activity might be of importance to reduce such complications [24].

CONCLUSION

There are numerous surface treatment methods to enhance bone healing and shorten the period of edentulousness of the patient. Surface topography plays an important role in the long-term success of the implant therapy,especially in patients with poor bone quality sites [25]. Further research should aim at generating surfaces with standardized topography to understand various tissue reactions with the surface of implants [26]. Surface topography plays an important role in the long-term success of the implant. Further research should aim at generating surfaces with standardized topography to understand various tissue reactions with the surface of implants.

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REFERENCES

1. Wirth J, Tahriri M, Khoshroo K, *et al*. Surface modification of dental implants. In: Biomaterials for Oral and Dental Tissue Engineering. United Kingdom: Woodhead Publishing; 2017. p. 85-96.
2. Andrade CX, Quirynen M, Rosenberg DR, *et al*. Interaction between different implant surfaces and liquid fibrinogen: A pilot *in vitro* experiment. Bio Med Res Int 2021;2021:9996071.
3. Sreeharsha TV. Implant surface modifications: A review. Int J Appl Dent Sci 2020;6:334-8.
4. Singh G. Surface treatment of dental implants: A review. J Dent Med Sci 2018;17:49-53.
5. Cervino G, Fiorillo L, Iannello G, *et al*. Sandblasted and acid etched titanium dental implant surfaces systematic review and confocal microscopy evaluation. Materials (Basel) 2019;12:1763.
6. Kumar A. Recent advances in dental implantology. J Med Dent Sci 2012;3:28-30.
7. Nampoothiri DP, Subhash AK, Aboobacker F, *et al*. Biomimetic materials in implantology. Int J Oral Care Res 2018;6:93-6.
8. Cho YD, Seol YJ, Lee YM, *et al*. An overview of biomaterials in periodontology and implant dentistry. Adv Mater Sci Eng 2017;9:1-7.
9. Padhye NM, Bhange PD, Khimani S, *et al*. Implant surface characteristics and effects on osseointegration-a review. J Adv Sci Res 2018;1:1-2.
10. Adarsh K, Sharma S, Malik P, *et al*. Future trends and recent advances in osseointegration. World J Pharm Sci 2017;6:1871-84.
11. Stanford CM. Surface modifications of dental implants. Aust Dent J 2008;53:26-33.
12. Albertini M, Fernandez-Yague M, Lázaro P, *et al*. Advances in surfaces and osseointegration in implantology. Biomimetic surfaces. Med Oral Pathol Oral Cir 2015;20:e316.
13. Pattanaik B, Pawar S, Pattanaik S. Biocompatible implant surface treatments. Indian J Dent Res 2012;23:398.
14. Cooper LF. A role for surface topography in creating and maintaining bone at titanium endosseous implants. J Prosthet Dent 2000;84:522-34.
15. Deng Z, Yin B, Li W, *et al*. Surface characteristics of and *in vitro* behavior of osteoblast-like cells on titanium with nanotopography prepared by high-energy shot peening. Int J Nanomed 2014;9:5565-73.
16. Jindal S, Bansal R, Singh BP, *et al*. Enhanced osteoblast proliferation and corrosion resistance of commercially pure titanium through surface nanostructuring by ultrasonic shot peening and stress relieving. J Oral Implantol 2014;40:347-55.
17. Kumar PS, Kumar S, Grandhi VV, *et al*. The effects of titanium implant surface topography on osseointegration: literature review. Int J Med Eng Inform 2019;4:e13237.
18. Smeets R, Stadlinger B, Schwarz F, *et al*. Impact of dental implant surface modifications on osseointegration. Bio Med Res Int 2016;2016:6285620.
19. Buxadera-Palomero J, Godoy-Gallardo M, Molmeneu M, *et al*. Antibacterial properties of triethoxysilylpropyl succinic anhydride silane (TESPSA) on titanium dental implants. Polymers 2020;12:773.
20. Ma T, Ge X, Zhang Y, *et al*. Effect of titanium surface modifications of dental implants on rapid osseointegration. *Int J Oral Health Sci* 2016;247-56.
21. Garg H, Bedi G, Garg A, *et al*. Implant surface modifications: A review. J Clin Diagn Res 2012;6:319-24.
22. Bigerelle M, Anselme K, Noel B, *et al*. Improvement in the morphology of Ti-based surfaces: A new process to increase *in vitro* human osteoblast response. J Biomater 2002;23:1563-77.
23. De Groot K, Wolke JG, Jansen JA. Calcium phosphate coatings for medical implants. Proc Inst Mech Eng H 1998;212:137-47.
24. Davies JE. Understanding peri-implant endosseous healing. J Dent Educ 2003;67:932-49.
25. Yang CY, Lee TM, Lu YZ, *et al*. The influence of plasma-spraying parameters on the characteristics of fluorapatite coatings. *J Med Bio Eng* 2010;30:91-8.
26. Nasatzky E, Gultchin J, Schwartz Z. The role of surface roughness in promoting osteointegration. Refuat Hapeh Vehashinayim (1993) 2003;20:8-19, 98.

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