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RESEARCH ARTICLE

METHODS TO ALTER SURFACE TOPOGRAPHY OF DENTAL IMPLANTS.

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Abstract

A surging significance in implant dentistry has demanded and hence promoted research within the field to bring about the current trends in dental implantology. Surface topography and the modifications brought about to improve the surface characteristics are promising for the betterment of osseointegration resulted. This article reviews different surface modifications, methods to improve the surface characteristics of dental implants and the future of dental implant surfaces.

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Introduction:-

Research within the field of implantology believes in surface modifications altering the surface topography at micro- and nano-meter levels of resolution. Improving the implant surface topography is important for long term clinical results especially in patients with compromised bone. A favourable surface topography provides faster bone-implant integration thus shortening the treatment time.[1]

Dental implant quality depends on the chemical, physical, mechanical and topographic characteristics of the surface.[2] A major factor that determines the success of dental implants is osseointegration, which is the stable anchorage of an implant in living bone achieved by direct bone-to-implant contacts (BIC).[3]

The main objective for the development of implant surface modifications is to promote osseointegration, to confer better stability during the healing process. Surface roughness also has a positive influence on cell migration and proliferation, which in turn leads to better BIC results, suggesting that the microstructure of the implant influences biomaterial-tissue interaction.[4]

Implant surface topography refers to macroscopic and microscopic features of the implant. Ti implants with optimal surface roughness enhances the primary stability of implants, gives higher ratios of BIC and may increase removal torque force.[5]

Ti is the most widely used metallic material for dental subgingival implants, due to its availability, high biocompatibility, high strength and stiffness and relatively low density. More importantly, Ti implants are known to osseointegrate with living bone tissues.[6]

Goal of various surface textures and techniques is to enhance bone growth toward the implant surface.

A number of in vivo studies have demonstrated that increased surface area on the implant improves BIC after the implant placement.[7] The primary aim of the surface texturing or treating the implant surface is to enhance cellular activity and improve bone apposition. Surface topography of an implant can be designed by making porous and/or

by coating the implant surface with other suitable materials to increase bone-implant contact since the anatomic surface of bone cannot be controlled.[8]

Roughness can be produced on the implant surfaces through the addition or subtraction procedures. Implant surface roughness is divided, depending on the dimension of the measured surface features into macro-,micro- and nano-roughness .

Macro-roughness comprises features in the range of millimeters to tens of microns. This scale directly relates to implant geometry, with threaded screw and macro porous surface treatments. The primary implant fixation and long-term mechanical stability can be improved by an appropriate macro-roughness.[9] Micro-roughness is defined as being in the range of 1-10 micrometres. 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.Nanometer roughness plays an important role in the adsorption of proteins, adhesion of osteoblastic cells and thus the rate of osseointegration.[10]

Methods for Surface Modifications Of Implants

The methods employed for surface modifications of implants can be broadly classified into following types-mechanical, physical,chemical and biological [11,12,13].The main objective of these techniques is to improve the bio-mechanical properties of the implant such as stimulation of bone formation to enhance osseointegration[14], removal of surface contaminants and improvement of wear and corrosion resistance.

Mechanical treatment

Mechanical treatments involve either removal of surface material by cutting or abrasive action, or the surface of the implant is deformed (and/or partially removed) by particle blasting. The most commonly employed mechanical techniques are machining, polishing and blasting.

Chemical methods

The chemical methods of implant surface modifications include chemical treatment with acids or alkali, hydrogen peroxide treatment, sol-gel, chemical vapor deposition and anodization. Chemical surface modification of Ti has been widely applied to alter surface roughness and composition and enhance wettability/surface energy.

The process of acid treatment serves to remove the surface oxide and contamination which leads to a clean and homogenous surface. The acids commonly used include hydrochloric acid, sulfuric acid, hydrofluoric acid and nitric acid.

Physical methods

IMPLANT SURFACE MODIFICATION TECHNIQUES[11,13]		
MECHANICAL/PHYSICAL /CHEMICAL		BIOLOGICAL
<i>ADDITIVE METHODS</i>	<i>SUBTRACTIVE METHODS</i>	<ul style="list-style-type: none"> • Growth factors • Peptides • Calcium phosphate
<ul style="list-style-type: none"> • Plasma spraying • HA, Calcium phosphate coating • Oxidation • Ion deposition 	<ul style="list-style-type: none"> • Grit blasting • Acid etching • Electroplating • Mechanical polishing • Laser microfeaturing 	

Methods to alter microtopography:

Turning:–

The first generation of dental implants originally described by Brannemark, were turned surface implants[14] . Although the surface appears to be relatively smooth, scanning electron microscopy analysis revealed grooves and ridges created during the manufacturing process. However, these surface defects provide resistance to bone

interlocking, thus delaying the process of osseointegration as a result of osteoblastic growth along the existing surface grooves. The techniques described by Branemark, burying followed by a six month healing period before loading, improve the clinical outcomes from this type of implant[14]. Clinical studies and systematic reviews have indicated a positive correlation between surface roughness and bone-implant contact.

Grit-blasting:

With various hard ceramic particles such as alumina (AlO_3), titanium oxide (TiO_2), silica or calcium phosphate is one way of roughening the implant surface[11,15]. The size of the blasting particles determines the roughness created and the blasting particles should be chemically stable and biocompatible.

Several in vivo studies have shown significantly improved BIC for TiO_2 blasted implants when compared to machined ones [16,17].

Blasting material	Particle size (in micrometre)[12,13]
1.Alumina	300
2.TiO ₂	0.25-0.50
3.Calcium phosphate	75-85

The large grit sandblasting particles are corundum 0.25-0.5mm and the medium grit particles are 250-500 μm in size.

Acid-etching of a surface with strong acids such as HCl, H_2SO_4 , HNO_3 and HF creates an isotropic surface that may enhance osseointegration in vivo.[18,19]. The most commonly used solutions for acid etching of Ti includes either a mixture of HNO_3 and HF or a mixture of HCl and H_2SO_4 .

Treating surfaces with acids provides the following advantages[15]:

1. Homogeneous irregularities
2. Increased surface area
3. Enhanced bioadhesion
4. Lower surface energy
5. Lesser chances for contamination as no particles are encrusted in the surface

It facilitates osteoblastic retention and allows them to migrate toward the implant surface. Rapid osseointegration with long-term success has been reported when titanium surface was roughened by acids.

Dual acid-etched technique –

Dual acid-etching is a technique used to roughen the surface of implant by immersing the titanium implants for several minutes in a mixture of concentrated HCl and H_2SO_4 heated above 100 °C[12,13]. This method enhances direct bone formation due to an improved osteoconductive process causing attachment of osteogenic cells and fibrin. It has been hypothesised that a specific topography is achieved by dual acid etching of implants, which enables them to attach to the fibrin scaffold, to promote the adhesion of osteogenic cells hence promoting bone apposition. This fibrin adhesion guides osteoblastic migration along the surface. A higher bone-implant contact and less bone resorption with dual acid etched surfaces were reported by Cochran et al.

Anodization[12,13,] –

produces a micro- and or nano-porous oxide layer on the Ti surface. The surface oxides grow from the native state of 5nm to approximately 10,000nm. Anodic oxidation results in the growth of a native titanium oxide layer and a porous topography, with the bone formation occurring directly on the moderately rough oxidized surface. The appearance of the layer from the anodization process depends on current density, concentration and composition of the acids used in the electrolyte solution and the temperature. In vivo studies have demonstrated increased bone response with higher biomechanical and histological values for anodized surfaces compared with machined ones.

Plasma spraying:

[11,13,15]- is a method first developed by Hanh and Palich(1970) where partially molten Ti powder are projected at a very high velocity of 600m/sec onto a metal or alloy substrate through a plasma torch at very high

temperature(15,000 degrees). The particles condense and fuse together on the surface thereby creating a 0.04-0.05mm thick coating. Ti plasma spraying has displayed better bone integration in vivo as compared to smoother implants. Hydroxyapatite coating achieved by plasma spraying was introduced by Groot K in 1983. Plasma spraying with HA particles creates a 50-200 m thick coat but with poor adhesion to the bulk material and this is believed to be the reason for the long term negative clinical results of such implants.

The advantage of plasma coating is that these coatings give implants a porous surface that bone can penetrate more readily. Osseointegration was shown to be fastest and most effective for rough surfaces with open structure that varied between 50-400 mm.

In a study conducted by Schroeder et al utilizing a monkey model, dental implants with TPS surfaces were found to be ankylosed to the surrounding bone and remained stable even after loading conditions of up to 2 years.[11]

Fluoride treatment

Ti is very reactive to fluoride ions, forming soluble TiF_4 by treating Ti dental implants in fluoride solutions[12,13]. This chemical treatment of Ti is found to enhance the osseointegration of dental implants. Based on an animal study, Ellingsen reported that surface modification with fluoride significantly increased the retention of titanium implants after four and eight-week healing periods. He stated that titanium is very reactive to fluoride, forming TiF_4 , providing more firm bone to implant contact when compared to grit-blasted implants with a shorter healing time and also resisted a greater removal torque than grit-blasted implants.

Surface modification using laser ablation

Laser ablation brings about microstructures [12,15] with increased hardness, corrosion resistance, and a high degree of purity with standard roughness and a thicker oxide layer to enhance the titanium implant surfaces. In a two-year retrospective clinical study, 95.6% survival rate for immediately loaded laser microtextured implants placed into fresh extraction sockets in the anterior maxilla was reported by Guarnieri and co-workers.

Sputter deposition

Sputtering is a vacuum process [12] whereby molecules of a material are ejected by bombardment of high-energy ions, 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. Radio frequency sputtering and Magnetron sputtering[13] are methods used to deposit hydroxyapatite on implant surfaces. Animal studies by Vercaigne et al. demonstrated higher bone implant contact rates with sputter coated implants. The disadvantages with sputter coating is extensive time required for the procedure as well as the amorphous coatings produced (Ca phosphate) ratio of the coating is higher than of synthetic HA).

Radio frequency (RF) sputtering

RF magnetron sputtering is largely used to deposit thin films of Ca phosphate coatings on Ti implants. The advantage of this technique is that the coating shows strong adhesion to the Ti and the Ca/P ratio and crystallinity of the deposited coating can be varied easily.

Magnetron sputtering

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.

Some methods to alter nanotopography

Sol-gel coatings

During the sol-gel process, a liquid with a specific composition (ie. the sol) is converted into a solid-gel phase. Thin coatings can be deposited onto a surface by dip-or spin coating techniques. The procedure makes it possible to produce coatings of Ti, HA or combination of both. This is a low cost method capable of enhancing chemical homogeneity in the production of HA coating to a higher level. In a short term laboratory study by Gan et al, better osseointegration with no adverse effect was evaluated after analyzing the bone tissue around the implant surface using sol-gel method[12,13].

Nanocrystalline HA coatings:

Nanoparticles of HA[11] is prepared by mixing H_3PO_3 and $Ca(NO_3)$ to a Ca-Phosphate ratio of 1.67 in the presence of a liquidcrystalline phase. The crystalline phase limits particle growth to ~5 nm. When HA particles have formed, the liquid crystalline phase is dissolved and the particles can be deposited onto a surface using dicyandiamide.

Biologically active drugs incorporated dental implants:

Some osteogenic drugs have been applied to implant surfaces. In clinical cases lacking bone support, incorporation of bone antiresorptive drugs, such as bisphosphonate might prove worthy[11,12,13].

Bisphosphonates;

Bisphosphonate incorporated on to Ti implants increased bone density locally in the peri-implant region.[13] with the effect of the antiresorptive drug limited to the vicinity of the implant. Other experimental studies using PSHA-coated dental implants immersed in pamidronate or zoledronate demonstrated a significant increase in bone contact area.

The main problem lies in the grafting and sustained release of antiresorptive drugs on the Ti implant surface. Increase in peri-implant bone density is bisphosphonate concentration-dependent.

Simvastatin:

Simvastatin, known to induce the expression of bone morphogenetic protein (BMP) 2 messenger ribonucleic acid might promote bone formation. In an in vitro study Yang et al. (2010) showed that simvastatin-loaded porous implant surfaces promote accelerated osteogenic differentiation of preosteoblasts, which have the potential to improve the nature of osseointegration.[12,13]

Antibiotic coating:

Gentamycin along with the layer of HA can be coated onto the implant surface, which may act as a local prophylactic agent along with the systemic antibiotics in dental implant surgery.[13]

Tetracycline-HCl functions as :

1. An antimicrobial agent
2. Effectively removes the smear layer
3. Removes endotoxins from the implant surface
4. Inhibits collagenase activity
5. Increases cell proliferation as well as attachment and bone healing (Herr et al., 2008).
6. Enhances blood clot attachment and retention on the implant surface during the initial phase of the healing process and thus promotes osseointegration.

Future directions in implant surface modifications:

The adhesion of plasma proteins on the surface of Ti implants has been reported to play an essential role in the process of osseointegration.[13] Polypeptide growth and differentiation factors and cytokines have been suggested as potential candidates in this regard to stimulate a deposition of cells with the capacity of regenerating the desired tissue.

Growth factors released during the inflammatory phase have the potential of attracting undifferentiated mesenchymal stem cells to the injured site.

These growth factors include :

1. Platelet-derived growth factor (PDGF)
2. Epidermal growth factor
3. Vascular endothelial growth factor
4. Transforming growth factor (TGF)
5. BMP-2
6. BMP-4.

Future Of Dental Implant Surfaces:

Ceramic implants:

Inferior mechanical properties and low survival rates hampered an anticipated popularity of ceramic implants, though these were introduced 30-40 years ago [12]. Introduction of zirconia implants which exhibit good mechanical and physical properties has raised the interest in the recent years.

Lately, the outcome of ceramic implants has been assessed based on the available clinical data from retrospective and prospective studies and high survival rates of up to 98% after an observation period of 12–56 months. However, a scarcity of clinical data propose less support for the use of zirconia implants. Zirconia may have the potential to become the material of choice in implant dentistry, however adequate clinical research must be required for the same [12].

PEEK implants:

Polyetheretherketone (PEEK) is a semi-crystalline linear polycyclic thermoplastic that has been proposed as a substitute for metals in biomaterials. PEEK can be applied to dental implant materials as a superstructure, implant abutment, or implant body.

PEEK has some clinical advantages as a dental implant material compared to Ti. First, it causes fewer hypersensitive and allergic reactions. Certain studies have shown that titanium is an allergen. Second, it is radiolucent and causes fewer artifacts on magnetic resonance imaging. Third, it does not have a metallic color; it is beige with a touch of gray, and has a more aesthetic appearance than Ti. Fourth, PEEK is a versatile foundation material that can be tailored to a particular purpose by changing its bulk or surface properties. [20].

Surface modifications of PEEK. [20]

Surface Modifications	Procedures	Material
Coating	Plasma spraying	Hydroxyapatite (HA), titanium (Ti)
	Spin coating	Nanosized HA crystals containing surfactants, organic solvent, an aqueous solution of $\text{Ca}(\text{NO}_3)_2$ and H_3PO_4
	Electron-beam evaporation (EBE)	Ti; Silicate
	Plasma immersion ion implantation (PIII)	Titanium dioxide (TiO_2); calcium (Ca); water (H_2O); Argon (Ar)
Surface topographical modifications	Acid etching	Sulfuric acid
	Sandblasting	TiO_2 , alumina (Al_2O_3)
Chemical modifications	Sulphonation	Sulfonate groups ($-\text{SO}_3^-$)
	Amination	Amine functions
	Nitration	Nitrate functions
Incorporating with bioactive properties	Bioactive inorganic materials	Nano- TiO_2 (n- TiO_2); nano-fluorohydroxyapatite (n-FHA)
Improving hydrophyllicity	UV irradiation	UV-A light, UV-C light
	Plasma gas treatment	Oxygen plasma

As per literature PEEK is basically osseointegrated as biocompatible material in vivo. The design of a 2-piece implant made from PEEK, which allows the submerged healing method, has to be developed. PEEK used for a

dental implant should have a light translucency similar to a natural tooth to achieve favorable esthetic results. Unmodified PEEK is a bioinert material, and shows a water-contact angle (CA) of 80–90 degrees, which is close to being a hydrophobic value [21].

Nanotubes:

Nanotubes are submicron structures, which possibly increase osseointegration. The idea is taken from osteoblastic response to nanofiber alumina.[12]The adsorption of proteins, which mediate osteoblastic adhesion, such as vitronectin and fibronectin, are freed on nanophase substances thus may provide improved osteoblast interaction. Titanium oxide nanotubes range between 15–100 nm and can be tailored through anodisation. A space of 30 nm was found to be an effective diameter for rapid bone deposition and improved cellular activity. Furthermore, nanotubes have been proposed as a drug delivery system for various therapeutic indications, For example, the inner substructures could be filled with drugs, chemicals and biomolecules. Nanotubes seem to be a promising method for the future of implant dentistry due to :

1. Low-cost
2. Flexible manufacturing
3. Possibility of usage as a drug delivery system

Conclusion:-

Alterations made in surface topography of dental implants is an attempt to improve the BIC by increasing the surface area available ,thereby promoting success rates by better osseointegration. The materials, forms, and surface coatings have to be refined and restructured to allow a better bone implant integration, lesser healing time and patient satisfaction

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