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Application of Nanotechnology In Dental Implants

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***Abstract**: nanotechnology is an upcoming tool in the field of implant dentistry. The aim of this review is to consider the role of nanotechnology for the purpose of improving osseointegration, also the various methods and techniques by which nano features can be imparted to implant surface. With the application of nanotechnology, the composition of dental implants, surface energy and roughness and topography can be improved for better osseointegration and it can also influence the events occurring at the bone-implant interface.The cellular activities and tissue responses occurring at the bone-implant interface can be altered by nanoscale modifications and can result in better treatment outcomes.*

***Keywords**: nanotechnology, dentistry, dental implants, surface topography, osseointegration, nanotubular structures*

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I. Introduction

Nanotechnology or molecular nanotechnology is also known as molecular engineering. It is the control of matter at the nanoscale at dimensions between 1 to 100 nm [1]. With the application of nanotechnology in dentistry a new stream of nanodentistry is rising. With the advent of nanodentistry many dental materials and procedures can be taken to a new level including dental implants. The introduction of modern implants started with the work of Branemark [2]. After decades of research, better designs and materials have evolved, with increase in survival rate and low failure rate. Most frequent cause for failure is insufficient bone formation around the implant surface [3]. In this the implant surface and tissue interface plays a critical role [4]. The arrival of nanotechnology has opened new opportunities for the manipulation of implant surfaces. It is believed that implant surfaces could be improved by mimicking the surface topography formed by the extracellular matrix (ECM) components of natural tissue. These ECM components are of nanometer scale with typical dimensions of 10–100 nm[5].

Implant surface composition, surface energy, surface roughness and topography are the four material related factors which can influence events at the bone – implant interface. Three type of surface structure are there – macro, micro, and nano. Current surface structures are controlled, at best, at the micron level, but tissue response is mainly dictated by processes controlled at the nanoscale. Surface profiles in the nanometer range play an important role in the adsorption of proteins, adhesion of osteoblastic cells and thus the rate of osseointegration. Titanium implants modified by the application of nanostructures promote osteogenic differentiation, and may improve the biointegration of these implants into the alveolar bone[6].Hence, we need strategies to improve the current metallic dental implants, through surface modifications of the implant either by applying novel ceramic coatings or by patterning the implant's surfaces.

II. Surface Modifications

Interaction of implant surface with blood is dependent on the surface properties of materials. It occurs through a complex series of protein adsorption and displacement steps. This is known as the Vroman effect[7].A hydrophilic surface is better for blood coagulation than a hydrophobic surface. So, dental implants manufacturers have developed high hydrophilic and rough implant surfaces with better osseointegration than conventional ones[8]. Osseointegration is described as a direct structural and functional bone to implant contact under load[9]. The biological events occurring at the tissue-implant interface are influenced by the chemistry, topography, and wettability of dental implant surfaces. The challenge is to develop new implant surfaces which result in increasing the clinical success rate as well as decreasing the tissue healing time for immediate loading of implants, particularly in aesthetic situations[10]. Alumina and Zirconia nanocomposites and nanocomposite ceramics can be used to develop new implant materials. However, the unique mechanical properties of dental tissues cannot be exhibited by these materials. A new hybrid of inorganic and organic materials can be developed to closely match the properties of dental tissues.So the use of synthetic composite materials as permanent replacements for bone, which generated much excitement 30–40 years ago[11], remains largely unmet due to significant challenges related to fabrication, performance, and cost. Current hybrid organic/inorganic composites have significant problems related mostly to their mechanical performance and their degradation in vivo[12]. As a result, the use of synthetic composite materials as permanent replacements for bone is nearly nonexistent[13].

New coating technologies have also been developed for applying hydroxyapatite and related calcium phosphates(CaP), the mineral of bone, onto the surface of implants[14]. However, there are some controversial and contradictory reports as well, claiming HA coatings as not very beneficial[15]. Since the discovery of original Bioglass composition by Hench[16], there is increasing interest to use it in the fabrication of coatings. But attempts to coat bioactive glass on metallic surfaces failed due to large thermal expansion stresses and high reactivity between metal and glass[17]. It is difficult to fabricate an ideal coating with a single technique or material. A combination of techniques and materials are required to fabricate layers that properly blend organic and inorganic phases and achieve a thickness in nanometers.

III. Methods for creating nano features on CP Titanium implants

1. Ceramic coating
2. Self-assembly of monolayer
3. Physical approaches

I. Plasma spraying
II. Sputtering
III. Ion deposition

3. Chemical methods

I. Anodic oxidation (Anodization)
II. Acid Treatment
III. Alkali Treatment
IV. Combination of Anodization and Chemical etching
V. Hydrogen peroxide treatment
VI. Sol-gel treatment
VII. Chemical vapor deposition
VIII. Combination of Chemical vapor deposition and Sol-Gel method.

4. Nanoparticle deposition

I. Sol-gel (colloidal particle adsorption)
II. Discrete crystalline deposition
III. Lithography and contact printing technique

IV. Ceramic coating

A thin layer of bioactive ceramics such as hydroxyapatite (HA), tricalcium phosphate (TCP) and bioactive glasses can be applied on the implant surface. They can bond to the implant surface and the surrounding tissue and promote deposition of bone. They form a carbonated apatite (HCA) layer on the surface of implant through dissolution and precipitation. Histological studies have shown that coated implants yield a more reliable interface with bone than mechanical osseointegration of Ti[18].

Advantages of coating implant alloys with CPs:

-Faster healing time
-Enhanced bone formation
-Firmer implant bone attachment
-Reduction of metallic ion release

V. Self Assembly Of Monolayer

Self assembled monolayers or structures are ordered organic films in supramolecular chemistry[19]. These structures are formed by the adsorption (chemisorption) of an active organic coating on a solid surface. The use of SAMs is strongly related to the chemical and physical stability of the thin film, which depend on several factors as:

1) Surface morphology and chemical composition;
2) Affinity of head group toward metal oxide;
3) Coating methodology.

SAMs formation can provides a potential and economic method for obtaining designable physicochemical features of the titanium surface in order to promote the osseointegration[20].

VI. Plasma Spraying

Surface contamination is removed with the help of vacuum and charged metallic ions or plasma is deposited on the surface. Deposition on the implant surface occurs by kinetic energy. This process is widely used for deposition of calcium phosphate coatings (HA) onto dental implant surfaces to modify its bioactivity. Osteoblast density increases on the implant nano scale surface. There is higher percentage of bone implant contact in hydroxyapatite coated implants[21].However, there are disadvantages as well. The long term stability of dental implants could be affected by the variations in the composition of coatings and non uniform thickness of the material. Also lack of adherence of the coating in the long term can lead to health hazards[22].

VII. Sputtering

Thin films of bio ceramic is deposited by bombardment of high-energy ions. Improved healing response and initial fixation were found with sputtered CaP coatings[23]. The main drawback of this technique is that this process is very slow as well as deposition rate is also very low. The slow deposition rate can be improved by radio frequency and magnetron sputtering[24].

VIII. Ion Implantation

This approach offers possible insertion of biologically effective ions such as calcium ion (Ca^{2+}), fluoride ion (F^-), sodium ion (Na^+). It includes atomic rearrangements. This method enables to inject any element on the near-surface region of any substrate. It uses a beam of high energy (10 KeV) ions to fall on metal surface under vacuum. Due to the collision between incident ions and substrate ions, incident ions lose energy and come to rest on near-surface region of metal. Synthesis of high purity layers is possible with controlled depth and concentration of impurities. The properties of the implant material is not affected because this process takes place at low substrate level[25].

IX. Anodic Oxidation

With the help of this technique the smooth surface of titanium implants can be transformed into nano tubular structures of less than 100nm diameter[26]. By modifying parameters like voltage, current density and chemistry of electrolyte one can control physicochemical properties of surfaces[27], spacing and diameter of nanotubes. On titanium surfaces, anodization also forms pillar like nanostructures with tunable size as well as deposition of long nano tube arrays (10 μm)[28].

X. Acid Treatment

By combining strong acids or bases and oxidants nano pits networks (pit diameter 20-100 nm) can effectively be generated on Titanium, Ti6Al4V, CrCoMoalloys and Tantalum[29]. In a study it was concluded that treatment with HCl yields better results as compared to H_2SO_4 and $Na_2S_2O_8$ [30].Combination of acid etching with other techniques can be used for example with grit blasting to eliminate the contamination by blasting residues on implant surfaces. This grit blasting residue may interfere with the osseointegrationof the titanium dental implants [31]. But, an increased surface area by up to 40 % and a greater strength of osseointegration for the nanostructured Ti surface prepared by physical vapour deposition was found compared to an acid-etched surface [32].

XI. Alkali Treatment

In this method the titanium implant is immersed in either sodium or potassium hydroxide followed by heat treatment at 800ºC for 20 minutes that is followed by rinsing in distilled water. It results in the growth of a nano structured and bioactive sodium titanate layer on dental implant surface.

XII. Combination Of Anodization And Chemical Etching

These two methods are combined to create metal or polymer composites with improved biological properties. A combination of hydrothermal treatments (tuning concentration, temperature, reaction medium composition and time duration) and sodium hydroxide has been employed to titanium to create wide variety of unique nanostructures such as octahedral bipyramids, nano flowers, nano needles, nano rods and mesoporousnanoscaffolds [33].

XIII. Hydrogen Peroxide Treatment

H_2O_2 leads to oxidation and chemical dissolution of the titanium surface. Reaction between hydrogen peroxide and titanium dental surfaces leads to formation of Titanium peroxy gels. The thickness of titania layer is controlled by time. Immersion of treated dental implants in simulated body fluid leads to development of thicker layers of titania gel which is beneficial for deposition of apatite crystals [34].

XIV. Sol-Gel Method

It is one of the widely used methods for the deposition ofCaP, TiO2, TiO2-CaP composite and silicabased coatings on the surface of implant. This method leads to the formation of a uniform suspension of submicroscopic oxide particles in liquid (sol) by the procedure of controlled hydrolysis and condensation. When substrate is immersed in simulated body fluid for 1 to 15 days results in faster growth of apatite crystals in gel containing titania [35]. Deposition of discrete 20-40 nm nanoparticles on a dual acid-etched implant surface leads to early bone healing and enhanced mechanical interlocking with bone [36].Sol-gel coating process improves dental implant surfaces by nanoscale surface modifications..

XV. Chemical Vapor Deposition

Nonvolatile compounds are deposited on the implant surface by chemical reaction between implant surface and chemicals present in the gas. By the process of chemical vapor deposition, metallic surface properties can be modified at the nanoscale level [37].

XVI. Combination Of Chemical Vapor Deposition And Sol-Gel Method

Metallic surface properties can also be improved by combination ofthese methods. With the help of these techniques Niobium oxide and diamond like carbon nano topographies has been deposited on titanium and other substrates which improve the bioactivity of implantable metals [37].
Some other recent methods for nano structured dental implant surface are: laser technology[38] and coating of Picometer to Nanometer thin TiO2 by ultraviolet (UV) photo functionalization[39].

XVII. Conclusion

Nanotechnology is still advancing and need much more testing before appreciating its maximum potential in implant dentistry. Several nano surface modification methods are widely being developed to enhance surface properties of titanium dental implant that result in rapid osseointegration and faster bone healing. Many in vitro and animal studies have shown that nanometer-controlled surfaces have a great effect on healing after implant placement. It affects the adsorption of proteins, blood clot formation, and cell behaviours occurring upon implantation. The techniques and methods developed should be applicable to clinical practice. Nanotechnology opens a new spectrum of possibilities for advancement in implant dentistry.

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