

Self-Assembled Monolayer- A Nano Surface Modification

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ABSTRACT

BACKGROUND

Dental implants are made from one or more biomaterials, with titanium and alloys being the most commonly used biomaterials as they exhibit good biocompatibility, mechanical properties and machinability. Osseointegration as defined by Branemark and the closure of soft tissue is the foundation for the success of dental implants. Improving the success rate of dental implants, reducing treatment time, helping with rapid loading and reducing the incidence of peri-implantitis and peri-implant mucositis remains an important area of research in the field of oral implantology. Increasing numbers of studies have focused on altering the surface of titanium and titanium alloy in order to increase their biological activity and facilitate osseointegration and soft tissue healing. To achieve these objectives, various conventional methods exist to alter the surface of titanium, but many revolutionary approaches were implemented with the advent in nanotechnology to efficiently modify the surface. However, with the advent of nanotechnology, an innovative technology called Self Assembly is introduced for surface modification. It is done by imprinting the monolayers on the surface of the biomaterials (titanium or its alloys) by a process called self-assembly. Hence, this paper reviews the progress of the application of the self-assembly technique for the surface modification of titanium and its alloys.

KEY WORDS

Dental implants, Self-assembly, Titanium, Osseointegration

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BACKGROUND

Dental implants provide a reliable, effective and a predictable tooth replacement. It also offers function and aesthetics to both edentulous and partially edentulous patients, which they had with natural dentition. The other benefits of dental implants are recovery of normal masticatory function together with speech, smile and deglutition.¹

The history of dental implants has two distinct points; the pre-osseointegration period and the post-osseointegration age. During pre-osseointegration era, cobalt-chromium-molybdenum and different stainless steels were used to develop the blade and plate form implants. However, the success was very limited. Second era or the new paradigm of therapy was opened when the studies on osseointegration of implants were presented to the scientific world by the people like Branemark, Albrektsson T etc. The biological phenomenon involving direct bone-to-titanium surface contact is the basis of Osseointegration.² It was initially described as "a structural and functional interface between an ordered, living bone and an implant surface."^{3,4,5} Later the researchers gave it a more comprehensive clinical definition and technically it is "a mechanism in which alloplastic material is clinically asymptotically accomplished and preserved in the bone during functional charging."^{6,7}

If the dental implant success rate is improved, the treatment time can be shortened considerably, peri-implantitis and peri-implant mucositis can be minimized, thus the osseointegration is an area where researchers are spending some quality time.⁸ From the literature, the main process that defines the success and failure of implant osseointegration occurs largely at the tissue implant interface. Factors like surface- texture, topography, roughness and energy of implant material determine the mechanical stability of the implant tissue interface. It is evident from these observations that the surface of the interface in osseointegration is very critical. Thus, the greatest potential for enhancing the implant dentistry lies on the implant surfaces.⁹

The research to increase the biological activity on the surface of Titanium and Titanium alloy for promoting better osseointegration and soft tissue healing is gaining ground and an umpteen number of researches are being devoted to it.⁸ There are many conventional methods to alter the surface of titanium, but many revolutionary approaches were implemented with the advent in nanotechnology to efficiently modify the surface.

Usually most of the conventional surface modification techniques are a top down process, which required multiple interventions and special guidance during the process. With the advent of nanotechnology, an innovative technology called Self Assembly is introduced for surface modification. It is done by imprinting the monolayers on the surface of the biomaterials (titanium or its alloys) by a process called self-assembly. Self-assembly is a bottom up process which required neither the guidance nor the intervention during the assembly process.

This article reviews the present self-assembly method and its application in the dental implants.

Self-Assembly (SA)

"SA is a type of process in which a disordered system with pre-existing components forms an ordered structure or sequence as a result of specific local interactions among its components without external influence. This mechanism is dependent on weak covalent bonds including hydrogen and ionic bonds or Van der Waals and hydrophobic interactions and can be extended to the manufacture of various complex micro- and nanostructures such as flowers, tubes, micelles, films, mesophase particles and hollow sphere structures."¹⁰

SAM is an interface between materials with different chemical and physical property. This changed the focus of surface science, which was early dominated by metal and metal oxides into organic molecules, which turned the surface study into solvents and their contact with biologically relevant surfaces. In practical applications such as chemical sensing, adhesion and implants, it provided an alternative truly innovative implementation of chemical surface treatments.¹¹⁻²¹

Need for SAM in Dental implant

As discussed earlier, the implant therapy's focus on osseointegration changed the total outcome of the treatment. The treatment's clinical part is multidisciplinary and better outcome can be predicted if the treatment is planned and controlled well. Even though this phase is well managed, many cases reported failure and the studies showed the evidence for the importance of implant design while planning the treatment. The main aspect of the implant design factor is its surface character.²²⁻²⁸ From early investigation, it was clear that surface property of Cp-Titanium is more biocompatible in terms of surface characteristics.^{29,30} This early knowledge led to the modification of Ti first in micro scale level and later in nano scale; after the advent of nanotechnology.

The application of nanotechnology to alter Ti dental implants surface topography led to the discovery of novel physiochemical behaviours or biochemical events such as bone bonding and cell adhesion.²² With self-assembly, the formed monolayer is osteo inductive or a cell adhesive molecule.³¹ To obtain better implants, it was necessary to find a better way to bring changes to the surface topography on the nano scale. Many methods were invented and among them the best is the self-assembly of monolayer on the Ti surface.

Formation of Monolayer by SA

SAM is a hierarchically organized amphiphilic molecular layer at the end a head group and on the other end or tail a functional group. The presence of end functional group improves the hydrophilic and hydrophobic property of the substrate. SAM process includes bulk solution transfer, specimen surface preparation, surface uptake and two-dimensional substrate organization.³² Chemisorption of hydrophilic head groups onto the substrate is accompanied by hydrophobic tail group organization in two dimensions to the substrate. Standing up phase will be reached once the alkyl groups are stacked to a striped phase. Last phase is the rearrangements of in which the monolayer will grow fully on the surface until no area is left on the surface.¹¹

The speed of SAM formation depends on preparation, conditioning of materials and substrate property. Both the stability and packing order of SAM depends on the head group. Chain length of the monolayer is the responsible factor for the monolayer thickness. External considerations, such as surface cleanliness, surfactant concentration, substrate preparation and the purity of the solvent all can affect the monolayer formation on the surface of the substrate³³⁻³⁵. Since it is proved that the implants of Ti with modified surface topography shows the better quality, it is important to discuss the formation of SAM on Ti.

Formation of SAM on Ti

A pre-treatment should be performed to obtain a clean and smooth substrate for the best deposition of the SAM Ti layer. Contaminants are removed from the surface by using a solvent such as acetone, methanol or ethanol¹¹. Mechanical polishing of the surface is done to get a smooth and flat surface. A porous surface is highly undesirable; thus, these chemical pre-treatments should be carefully conducted in order to control the surface modification³⁶. Purity of the absorbent or the surfactant is very important for SA. Minute contamination can lead to disordered, non-ideal monolayer.¹¹ Silane/Siloxane and phosphonic acid/ phosphonates are the organic reagents used in the SA of Ti monolayer.

Sample is placed in vertical position for the chemical pre-treatment. The vertical positioning will remove the microscopically small particles from the surface. The samples were taken out of the chemical solvent before the assembly process and rinsed with high purity water followed by additional washing in the nitrogen stream and UV ozone cleaner. Phosphonic acid was sprayed on the hydroxylated titanium substrate and immediately the cleansed Ti is immersed in tetrahydrofuran solution. Then the deposition of monolayer corresponding to the phosphate begins on the Ti surface and the entire process is completed in 48 hours. The Ti with phosphate SAM is taken out and rinsed in the pure water and then used for the implant production.¹¹

SAM's formation is a potential and economical method for obtaining better osteointegration. SAM is a physiochemical thin film able to modify the chemical characteristics of Ti surface. Nano level surface integration has great influence in healing process.¹¹ On nano level things act very differently and it is the reason for the success of SAM in the implant application.

Nanotechnology of Surface Science

On nano scale the surface property of the material is controlled by quantum physics. The surface quality of implants depends on its mechanical property, topographic property and physiochemical properties. All these three properties are dependent on each other. Thus, a change in any of these properties results in different outcomes, this is because the quantum physics governs the behaviour in nano-world. However; this approach conserves the surface chemistry of different topographies and enhance the cell adhesion on the biomaterials. On nanoscale the natural cellular environment can be emulated. It favours rapid healing of the wounds.

Nanotopography alters the cell interaction when compared to conventional surface topography. When implant comes in contact with body its cell integration and proliferation depend on the protein absorption. Cell binding to bio-nano materials are exceptional. With nano material, the protein interaction at the biological site can be altered. When compared to conventional materials, the nano-scale surface modified implants increase the vitronectin absorption. From the studies it is evident that the fibronectin adhesion on hydrophilic SAM is more than what is anticipated. It is considered as the proof for the osteoblast adhesion.³⁷⁻⁴² Other than these SAM is showing great selective adhesion of cells, proteins and increased osteoblast proliferation.^{43,44} Bacterial adhesion is minimal in SAM.⁴⁵ Thus it is obvious that the nano-scale alteration of surface topography using SAM is revolutionary and improving the quality of implant treatment.

APPLICATION OF NANO-SCALE MODIFIED TI IMPLANTS

TI Implant with Better Biologically Active Surface for Enhanced Osseointegration

The osseointegration of bone with dental materials is improved with bioactive surfaces. The implant's surface roughness affects bone to implant contact and the implant's primary stability.² Way the cells respond to smooth, rough surfaces may change the process of osseointegration. The surface property of the implant therefore plays an important role in the biological interaction between the implant and the host bone. At nano scale, surface energy increases, which in turn increases surface wettability to the blood, cell adhesion to the surface and induces fibrin binding, matrix proteins, growth and differentiation factors. It can also influence the process of cell migration, proliferation and differentiation, thereby enhancing the step of osseointegration by promoting wound healing after implantation.⁴⁶

TI Implant with Antibacterial and Antimicrobial Property

There are possibilities for inflammation on the implant site as the bacteria colonize and grow biofilms on the osseointegrated dental implant transmucosal abutment. In SAM, a lot of work is taking place around the world to coat the implant with a thin film of antimicrobial substances as well as to confine the drugs on the surfaces of the implants for release into the implant bed to prevent bacterial adhesion. In other words, the SAM helps practitioners to combat inflammation by immobilizing biomolecules like antibodies, antibiotics and antimicrobial peptides by binding affinity to the implant surface.² Bisphosphate loaded implants and simvastatin trapped implants are already being tested in the research labs. More advancement is required in the field for more effectiveness of this treatment methodology⁴⁶.

LIMITATION OF THE SAM SURFACE MODIFICATION IMPLANTS

It is not exactly the limitation, but the reproducibility of an ideal surface is still a question for the researchers. With chemical treatment, reproducible surface roughness in the

nanometer is difficult to obtain. Although all modified surfaces that display nano-topography, most of them will not have significant nanostructures that enable cell migration, attachment, proliferation, and differentiation.⁴⁶

CONCLUSIONS

Titanium and its alloys are the first choice as implant materials for most practitioners, owing to their excellent biocompatibility and mechanical properties. Surface energy, surface composition, surface roughness and surface topography may affect the treatment outcome significantly. Thus, the surface modification of the implant is very important for obtaining better treatment outcome. With the help of nanotechnology, it is possible to perform ideal surface modification on the implant surfaces. SAM is one of the best technologies to do a surface modification on the implants at nano-level. These modified surfaces give better results than the implants with micro-scale surface modification, especially in osseointegration. In addition to this, SAM also opens the door for targeted and localized drug delivery to control the post implant inflammation. It also helps to fight the bacterial and microbial infection as SAM gives the provision to design the surface with antimicrobial monolayer coatings.

Though the SAM surface modification technique on dental implants is a promising breakthrough in the implantology, it is not yet commercialized as the reproducibility of the ideal implant surface is not yet achieved. However, it is certain that one day, the laboratory researchers will help the clinicians to achieve the successful implant treatment with SAM that promotes ideal healing process without compromising the cost and quality.

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