Effect of Silver Nanoparticles (Ag NP's) And Hydroxyapatite Coatings on Titanium Dental Implants

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ABSTRACT

Titanium and titanium alloys are widely used as implant materials owing to its superior corrosion resistance and high mechanical strength. The properties that have been observed to be the most crucial for the success of the implants are the rate of osseointegration, the roughness of the titanium implant surface and finally the antibacterial property. Titanium also possesses lower wear and resistance to abrasion, as its hardness value is low. Surface modification of the titanium surface is necessary. For dental implant the material used should be both biocompatible and antibacterial.This can be achieved only by multilayer coating of silver nanoparticle and hydroxyapatite. Silver nanoparticle having a toxic effect with human cells. So we want to avoid the direct contact of silver nanoparticles with the human cells. So first we are applying a base layer of silver nanoparticles by electroplating method. Then we are applying a layer of hydroxyapatite as a secondary layer. Hydroxyapatite having porosity, that means it having spaces between HA particles. Hence the antibacterial activity of silver nano particles can be retained.

Keywords: Osseointegration, Biocompatability.

1 INTRODUCTION

In recent times, the development of biomaterials are increasing day by day. Materials used for biomedical materials having very high importance[1]. because they have properties that enable them to stay in contact with human cells for long periods of time. Dental implants, orthopaedic and cardiovascular implants, drug delivery devices, and other biomedical materials are being made by using these materials[2]. The criterion for such materials is that they are biocompatible, meaning that they do not have any negative effects on the human body. Metals and their alloys are commonly used in biomaterials[3-5].

A dental implant is a surgical component, usually a titanium post, that supports and allows replacement teeth to be mounted. The implant osseointegrates with the human bone and provides a stable support once it is placed in the jaw. Dental implants made of titanium (Ti) are widely used in the medical industry. This increased use can be due to Ti's low elastic modulus, as well as its other mechanical properties, such as its incredible corrosion resistance. Other metalic alloys that are used instead of Ti alloys are Silver,Gold,Palladium etc. But the cost of these materials are comparitively high. This cost reduction is another advantage of using Ti alloys[6-8].

The Grand View Research assessed that the global dental implant market is at around USD 4.6 billion in 2019, with an expected growth rate 9.0% CAGR. The rising popularity of dental implants, the demand for prosthetics, and the the number of dental injuries are all contributing to this projected rise.

Owing to its many advantages, titanium dental implants have the highest market share.

But titanium cannot osseointegrate with the human bone cells. It also having some disadvantages that Titanium also possesses lower wear and resistance to abrasion, as its hardness value is low. Since these qualities can't be infused into the metal during the manufacturing process. As a result, surface modification of titanium is needed when it is used as a biomaterial. Surface modification techniques are thus necessary in order to speed up the bone forming and bonding process on titanium and titanium alloys[9].

This paper is organised to explore how dental implant surface and surface modulation techniques aid in osseointegration rate improvement. Dentists and patients are increasingly accepting titanium dental implants as a form of tooth replacement. Dental implants have many benefits over conventional dentures, including patient comfort, convenience, and longevity[10,11].

2 FAILURE OF THE IMPLANT

Implants can fail sometimes, and although the failure rates are low (around 7%), the possibility of additional surgery is a concern for patients[12]. Mechanical overload on the surrounding tissue, slow wound healing or osseointegration of the implant after surgery, infection around the implant are the causes for implant failure. The most common cause of implant failure are bacterial infection on and around the implant (peri-implantitis) and poor osseointegration[13].

Dental implants are sterilised and the bone cavity can be disinfected with chlorhexidine or equivalent agents after treatment to reduce the chance of bacterial infection[14]. However, such techniques only offer transient infection protection, so researchers are focusing their efforts on coating the implant surface with antibacterial agents to provide longer-term protection. Doping the implant with antibiotics like gentamicin or disinfectants like chlorhexidine has become one of them[15,16]. Traditional antibiotics aim to target specific microbe organisms, raising concerns about antibiotic resistance. The antimicrobial properties of engineered nanomaterials have recently got a lot of coverage[17].

3. RELATIONSHIP BETWEEN OSSEOINTEGRATION AND SURFACE MODIFICATION

Osseointegration is characterised as a direct structural and functional link between organised, living bone and the surface of a load-bearing implant[18]. It is considered a requirement for implant loading and long-term clinical performance of end osseous dental implants. Around the root of the natural tooth and the underlying bone, there are many periodontal ligaments that protect the tooth in the case of a natural tooth. In case of artificial implants there is no any presence of periodontal ligaments.In case of implants ,when it is inserted into the bone,bone will starts to grow[19].Bone growth is a natural process.When the bone grows around the surface of the implant having major role in case of osseointegration. If the surface is more rough then the rate of osseointegration will be high[20]. The implant becomes as flexible and solid as a normal tooth until it has osseointegrated. On the other hand, it can take a long time, ranging from a few weeks to a few months to complete the osseointegration. Surfaces with a higher roughness and waviness were found to improve osseointegration[21]. As the surface properties of the implant are enhanced, it assists in enhancing the bonding between the implant and the bone, as well as the overall efficiency of the implant. As the surface properties of an implant are enhanced, it helps to strengthen the bonding between the bone and the implant, as well as the implant's degradation and wear resistance and biocompatibility.[22]. The surface of a titanium implant must be adjusted in order for it to osseointegrate with human bone. Rough-surfaced dental implants have been shown in studies to have higher bone fixation and Bone-to-Implant Contact (BIC) percentages than commercially available implants[23]. We have already discussed that bacterial infection around the implants is also a major cause of failure of implants.

4 SURFACE COATING METHODS

4.1 Methods using external pressure

The aim of mechanical methods for titanium implant surface alteration is to change the implant's surface morphology. External forces are used to form or roughen the surface in these techniques. Grinding, machining, drilling, and polishing are some of the techniques used for this[24]. These techniques aid in the creation of the necessary surface topography and roughness. It would also aid in the removal of any existing surface contaminants, improving the bond between the implant surface and the bone[25,26]. The selection of an optimal thread profile for the implant is another tool for optimising osseointegration.Thread profile of the implant plays important role in osseointegration.[27,28]. Wennerberg et al. found that modified implants with a rougher surface had greater bone fixation than smoother machined implants[29]. Souza et al. examined and outlined the different approaches used for nano-scale alteration of the titanium implant surface [30].

4.2 Hydroxyapatite Coatings

HA is a biocompatible and osteoconductive composite that is well-known for simulating the mineral properties of natural bone[31,32]. For several years, HA has been used to improve the biocompatibility of bone implants[33]. When it comes to interactions with osteoblasts, the material's surface topography is crucial, and nanoscale HA has received a lot of attention lately[34]. As compared to conventional micron scale HA, nano HA will enhance osteoblast cell adhesion to the implant surface, facilitate bone cell proliferation, and their subsequent calcium deposition to form new bone[35]. The chemical formula for hydroxyapatite (HA), which is essentially pure calcium hydroxide phosphate, is $Ca_{10}(PO_4)_6(OH)_2$. It has good osteoconductive and bioactive properties, making it a good alternative for dental and orthopaedic biomedical applications.[36]. It has a broad adsorption potential for proteins. Because of its excellent biocompatibility and strong bonding with human bones, HA is one of the most commonly used coating technologies in orthopaedic and dental applications. Plasma Spraying, Physical Vapour Deposition (PVD), Sol-gel, Chemical Vapour Deposition (CVD), Electrochemical Deposition, Electrophoretic Deposition, and Pulsed Laser Deposition are some of the coating techniques that have been developed for coating HA on implants (PLD)[37]. From different studies we can see that the HA coating has some porosity, it can be used. Porosity means it having spaces in between the HA particles. Besins et.al in his journal showed that hydroxyapatite can be coated in titanium by sintering technique cost effectively.From his journal it found that the HA coating that done by sintering technique having stability,porosity,surface roughness and many more properties that helps to increase the rate of osseointegration[38].Water contact angle for HA coating is comparitively less.If the water contact angle is less than the chances for protein adhesion will be high,it will increase the osseointegration rate[39]. Ramires et al. investigated the biocompatibility of titanium oxide/hydroxyapatite coatings prepared by the sol–gel process in various ratios (w/w - TiO2/HA 0.5, TiO2/HA 1.0, TiO2/HA 2.0) [40]. The cytotoxicity test indicated that titanium oxide/hydroxyapatite-treated samples had little effect on cell viability or proliferation. TiO2/HA 1.0 was the most beneficial of these tests. The surface hydroxyl (OH) groups facilitated the precipitation of calcium (Ca) and phosphate, improving the associations with osteoblastic cells, leading to the conclusion that the titanium oxide/hydroxyapatite coatings were bioactive.

4.3 Silver (Ag) coatings

Kim et al. investigated the impact of a stabilised Ag nanostructure on a titanium implant's surface[41]. Silver was chosen for its excellent biocompatibility and antibacterial activity because silver ions would enter bacteria without destroying the cell membranes. The nanostructured layer of silver on titanium was created using the Target-ion Induced Plasma Sputtering (TIPS) process. TIPS produced a superior titanium coating with improved mechanical integrity, cell binding, proliferation, and differentiation. The length of the silver coating process on TIPS - titanium was varying, (10.0 s, 30.0 s and 120.0 s) and the findings were compared. TIPS-Ti's touch angle decreased from around 60^0 for the unpolished sample to around 5^0. TIPS - titanium was shown to have superior bioactivity and biocompatibility. With longer silver sputtering times, the touch angle improved. The 10.0 Ag-TIPS-titanium specimens were found to have the best conditions for cytotoxicity and antimicrobial activity. Excessive silver concentrations (120.0 Ag-TIPS-titanium) triggered pro-inflammatory pathways and influenced the rate of proliferation. As a result, it was determined that stabilised silver on a TIPS-titanium surface increased overall healing and offered long-term implant stability. Sieh et al. conducted an experiment in which Ti6Al4V discs were electroplated with Ag NP's**[**42**]** A disc was attached to the end of a silver wire (cathode), while the silver root was a second silver wire (anode). Both wires' ends (including the titanium disc) were crimped together. Immersed in a silver solution (electrolyte) with a concentration of 0.2 M Ag (pH 8.5) 0.4 M succinimide and 0.5 M KOH distilled water rinsed and allowed to air dry. Silver nanoparticles (Ag NP's) are antimicrobial. With potential uses in medical implants. Over the course of seven days, the coating's durability and biocompatibility with primary human osteoblasts is investigated. Ti6Al4V discs were successfully coated with silver, according to the results[43]. In vitro, silver nano coating on titanium dental implants had antibacterial effect and inhibited biofilm formation against Streptococcus sanguinis. Silver, on the other hand, is poisonous to mammalian cells[38]. fibroblasts used in wound repair, where a deadly concentration of $AgNO_3$ is present (50 mg L^{-1})[10]. Ag NPs are also toxic to cells *in vitro* (EC_{50} 26.7 mg L^{-1}),[44]. However,the precise concentrations of Ag NP's are biocompatible

5 DISCUSSIONS

In introduction we have already discussed the needful properties of implant materials.if these properties didn't meet , sometimes implant fails. Patients are concerned about the possibility of further surgery. As a result, it is preferable to achieve implantation effectiveness on the first try.So all are looking for an implant material with desirable properties.

We have discussed that the the properties that have been observed to be the most crucial for the success of the implants are the rate of osseointegration, the roughness of the titanium implant surface and finally the antibacterial property[45].In this paper we discussed some of the most promissing coating methods.Among them first we have discussed the coating of hdroxyapatite(HA).From different studies it concluded that HA coated titanium surface having good surface roughness.Surface roughness is a key attribute for the rate of osseointegration. HA coated titanium sufaces shows high rate of osseointegration,and it also having normal antibacterial properties. So in case of HA coated implants there is a chance for microbial attack. It will effect the success of the implant. Nano HA can improve osteoblast cell adhesion to the implant surface, promote bone cell proliferation, and their eventual calcium deposition to form new bone as compared to traditional micron scale HA. So we can conclude that HA coated surfaces having predominent properties to increase the rate of osseointegration.

For a best impalnt material it should exhibit high osseointegration rate and antimicrobial properties .By using HA it will get the best osseointegration rate by enhancing osteoblast cell adhesion to the implant surface[46].To achieve good antimicrobial property AgNp's can be used.

Silver is known for it's antibacterial activity, since silver ions will move across bacteria's cell membranes without damaging them[47].Against Streptococcus sanguinis, silver nano coating on titanium dental implants have an antibacterial effect [48].AgNp's can be coated on the titanium implant by using electroplating method.Silver is harmful to mammalian cells.Because of this toxic effect,use of silver nano particles in biomedical implants are limited.In order to avoid the deadly concentrations of $AgNo_3$ electroplating can be used. By using electroplating method by adjusting current,voltage ,and electrolyte concentrations precise concentrations of AgNp's can be made [49]. There is also a slightly toxic effect to the cells when AgNp's are in direct contact. The exact concentrations of Ag NP's are biocompatible with osteoblasts.

In orde to get both dominant properties in an implant, single layer coating is not sufficient.So it necessitates multilayer coating. By using multilayer coating of HA and AgNp's both boicompatible and antimicrobial properties can be achieved.There are to ways of doing multilayer coating of HA and AgNp's.First way is to do a Biocompatible (micron scale HA) on the surface of Ti.Then After that, Ag NPs can be applied to this biocompatible layer. The use of silver as the top layer provides a biocidal benefit. Microbes can be directly poisoned by any dissolved silver released from the coating. Both metal dissolution from the particles and direct contact of the particles with bacteria can be poisonous in the case of Ag NPs.However, the osteoblast cells still have limited access to their preferred substrate beneath the silver layer(HA), which is a problem.

Another option is to coat the Ti alloy in silver and then cover it with a layer of biocompatible HA. Electroplating is often used to accomplish the silver coating.After forming an amorphous layer of AgNp's , a final coating of micron- or nano-HA can be applied.HA can be coated by sintering technique.

Previous research has shown that the HA coating has some porosity(spaces in between the HA particles), The antibacterial properties of the silver layer are then maintained, and the microbes are killed within 24 hours[50].Hence by using this second method the implant will get both antibacterial property as well as biocompatibilty. And there is an advantage that the toxic effect of AgNp's are avoided and the biocompatibility is enhanced

6 CONCLUSIONS

The use of titanium dental implants is increasing, necessitating the development of implants with a longer lifespan and higher success rate. Titanium, on the other hand, is also relatively cheap. It is chemically inert since it remains unchanged in the human body. As a result It is necessary to make the titanium implant biocompatible . To improve the rate of healing, it is important to change the implant surface.Because of the toxic nature,the uses of AgNp's are limited.

By using the multilayer coating of Ti dental implant (First layer with AgNp's and second layer with HA),the direct contact of silver surface with mammalian cells can be avoided.Hence the toxicity of silver is also avoided.HA coating has some porosity,hence the antimicrobial effect of AgNp's can be retained through that pores.Because of HA coating as the second layer the biocompatibility is also increased

7.References

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