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A REVIEW ON SURFACE MODIFICATION OF TI-6AL-4V(TC4), GRADE-5 TI ALLOY USED IN ORTHOPEDIC IMPLANTS

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Abstract

Now-a-days Titanium Alloys are one of the most used biomaterial in orthopedic implants however its use increased dominantly, similarly revision procedures of orthopedic implants are also comparatively increasing. One of the reason is the aseptic loosening of implants due to infection occurred in the vivo environment of the implant due to its degradation, which causes due to removal of coating on the orthopedic implant surface by the action of chemical reaction by the alkaline acids present in the body fluids. Ti and Ti alloys have excellent biomechanical properties, which make them the first choice in orthopedic implant application. The target of the paper is mainly on Ti-6Al-4V (Ti G5) alloy rather than other existing biomaterials. The paper discusses the biomechanical congeniality of many materials and it depicts the allover supremacy of Ti-6AL-4V alloy even though it is expensive. This review inspects the current information on the biomechanical characteristics of Ti-6Al-4V alloy used in orthopedic implants and the most common reasons of its failure after implantation are briefly narrated. Various orthopedic implant materials and their coatings effect on longevity and life on the respective material are briefly summarized.

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1. Introduction

Ti and its alloys are mostly being used in orthopedics priorly in bone implants, specifically Ti-6Al-4V (TC4). As the growth of TC4 was prohibited due to release of Vanadium (V) which is toxic in nature and high wearing of Ti alloys is a new problem. Ti alloys many times shows low wear resistance and large wear loss are the negative factors of TC4 nature. Although it has high resistance to corrosion, the oxide layer which protects the TC4 surface can be damaged by infection by the virtue of body fluid with less biomolecules and oxygen content. The wearing of prosthetic components leads metallic wear and causes adverse cellular responses, toxicity and swelling, ultimately gives birth to osteolysis, loosening of implant or origination of a false-tumor. The health of human has a decisive role of electrochemical behavior of TC4 implants. In vivo environment, the poisonous ions from TC4 i.e. cobalt, chromium, nickel, aluminium and vanadium are encountered in the adjacent tissues and also in vivo organs by virtue of fluids of body via corrosion, favoring danger of immunosuppressive, toxic to DNA and sensitive responses in orthopedic implants. Corrosion of TC4 shows unfavorable effects, shorten implant life and hazardous to human safety. Main requirement for longer implant steadiness is connected to their suitable biological response. Infection caused due to bacteria is the prime reasons for the loosening of Titanium alloys implants in human body. Bacterial infections causes the most implant failures, which tends to implant loosening and eventually revision surgeries, hence its importance plays a major role in enhancing antibacterial abilities of TC4. Surface modifications helps to improve wear resistance of TC4 to a large extent the main target of the presented review is literature survey of surface modification of TC4. In previous literature lots of reviews are on Titanium alloys for biomedical applications via surface modification methods for improved quality. The previous review is not directing exclusively on orthopedic implant application and its surface modification via coating for improved antibacterial properties. The focus of presented review is to perform a reproving review of the literature on surface modification methods to reduce implant loosening to a great extent by improving the bacterial resistant properties which will lead to long life of orthopedic implant in the human body and reduce the cost and time associated with the revision surgeries. Hence it is very much important to improve antibacterial property via surface modification on TC4 orthopedic implants.

2. Need for Orthopedic Implant

There is continuously increased custom of orthopedic implants for substituting and reestablishing of tissues. It has been found that more than 80% of the existing population above the age of 40+ suffers from the bone related diseases. An artificial implant is the only option for fixing of broken bone. Patient suffers breaking of bone through fracture which unbearable. There are different fractures, which may include complex, complete, incomplete and simple types of failures which a cartilage undergoes. Any age people can suffer bone fracture. In children, the most common fracture is a broken forearm boys sustain fractures more than girls.

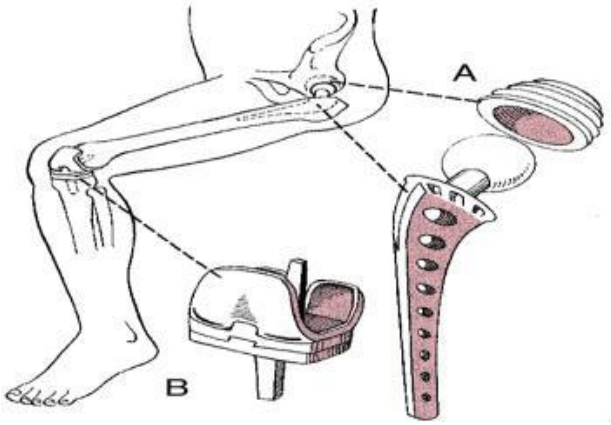

Figure 1. Orthopedic implant fixture for human leg.

The necessity for orthopedic implant products is not limited to early replacement surgeries; it is also, for the repeat of the second procedure due to the failure of implant. There starts pain due to orthopedic implant, because years after implantation the components starts to wear and loosen, moving a little side in the bone. The loosening results in bone loss and damage, and the occurred bone loss needs to be treated during revision surgery. Revision surgery is the only option to stop this distressing complication happening due to implants dislocation on repeated occasions. Implant loosening is one of failure happening due to movement of implant or migration in the bone or cement. The reason for most of the failures is due to loosening. To cure the problem use of orthopedic implant reinforced with modern technology becomes the need of time. (1)

3. Requirement of a Biomaterial

The intended medical application gives the way to select desired biomaterial. New biomaterials development is an extraordinary effort and it is not possible without collaborative efforts between expertise of different fields. Essential properties must be possessed by the implant to be in the service for extended span without any deficiency. The implant material must be highly nontoxic and there shall not be any swelling or sensitive reactions in the vivo environment.

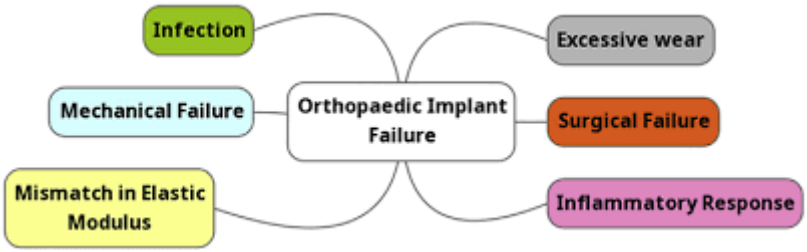

Figure 2. Possible reasons for implant failure.

The measure of biocompatibility of a material is the positive result of biomaterial which depends on the implants human body reaction. The response got by the implant material and its deterioration in the body situation are the influencing factors for the biocompatibility of material. When implants come in contact with fluids and human tissues, various reactions occurs among the host and the implant material and reactions denotes the acceptance of same materials by the system. The less wear and resistance to corrosion of the implants introduced in the body fluid promotes the discharge of harmful metal ions by the implants inside the body. Allergic and toxic reaction occurs due to the release of such ions. Abrasion and wear resistance determines the serving period of the material. For long term serving of the material in the human system, development of implant material with increased wear resistance and corrosion is of utmost importance. The incapacity of the surface of implant to co-inside with the nearest bone and other tissues due to micro-motions, leads to loosening of implants. A fibrous tissue forms within the bone and the implant. Hence, materials with proper appearance are mostly recommended for the implant material to co-inside properly with the nearest cartilage. Hence there is need

of a biomaterial which will fulfill all requirements for implant to last long. The above mentioned is possessed by TC4 hence it is one of the most used and trusted biomaterial for implants. (2)

4. Ti-6Al-4V (TC4) as a Biomaterial

When mineral ore is attained, titanium goes through series of operation before it is acceptable for implementation in biomedical field. The strength of CP-Ti is usually less than the other higher alloyed grades. Grade 5 is the most usual alloyed grade, which is Ti-6Al-4V. Ti-6Al-4V has superior biocompatibility aligned with excellent mechanical properties. Ti-6Al-4V is one of the mostly used titanium alloy in practice. Titanium is widely used for orthopedic insertions because of its superior biomechanical possessions. The long-term cyclic loading success of the implant is determined by the factors like material, shape, strength, loading type. Form these factors, if the metallic strength of material is less than required to care the periodic recurring masses or body impressions, host will have to suffer repeated surgery, reason is rupture of orthopedic bone implants. Biocompatibility shows the strength of implant material to be indulging with a alive organism without having contrary result.

Table 1. Comparison of properties of materials used in biomedical field (6).

Material	Benefit	Drawback	Use
CP Ti	Noble biocompatibility	Less power and wear opposition	Dental implants
Ti-3Al-2.5V	Noble power and corrosion opposition	Poisonous elements (V,AL)	Dental implants
Ti-6Al-4V	Outstanding strength and corrosion opposition	Poisonous elements (V,AL)	Bone fixation and implants
Ti-6Al-7Nb	Noble wear opposition	Poisonous element (Al)	Dental Implants

We must be aware of, when the implant is inserted in vivo environment of the body, within 9-10s, around the surface of the implant water molecule layer is formed, which helps in the adsorption of cells and proteins. Hereafter, within 30s, water molecule layers are covered by proteins. After adsorption of proteins, in the period of few hours to days, adsorption of cells starts to occur on the adsorbed protein layers. The host body fluid is complex in nature, which includes organic compounds, proteins and amino acids. Hence, corrosion takes place when the implant is inserted in the body, contacting the body fluid. The all requirement of a good biomaterial is fulfilled by Ti-6Al-4V hence it is of first choice to be used in Biomedical Orthopedic Application. (3)

5. Degradation of Biomedical Alloys

The medical community is facing the increasing concern of restricted life period of orthopedic implants. Orthopedic researchers are majorly focusing on wear characteristics and improving the fixation of implants. The result of this procedure tends to the insert relaxing of implants and later there feels need of replacement. The success rate of revision surgery is less compared to original implantation and it is expensive too. Again, the remnant of imported elements such as hydroxyapatite, metallic blob and cement particles, as of covering favors the formation of wear remains at the crossing point. Accumulation of Ta, Nb, Zr and Fe is found in post mortem results of patients who had implants in the two base alloys. Finally it can be pointed out that with wear in biomedical alloys cannot be totally eliminated but can be restricted to certain limit which eventually will increase the implant life. (2)

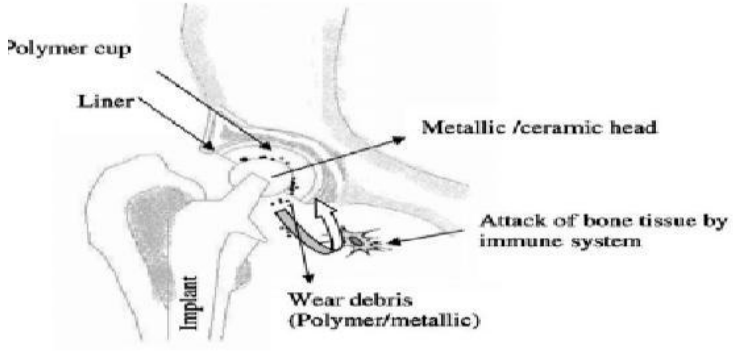

Figure 3. Wear of implant inside the host body.

6. Shortcomings of TC4

In orthopedic applications Ti alloys possess better potential. Moreover, for Ti alloys less wear resistance is always a challenge. Additionally, implant failure and infection causes by corrosion behavior. Although having impressive antibacterial ability, biocompatibility and regeneration of bone are also necessary for bone recovery with Titanium alloys. Various novel Ti alloys are studied and developed by researchers, but systematic optimization is not achieved as required. In brief, Titanium alloys shows considerable prospects in the coming time for biomedical and orthopedic implant applications. (1)

7. Corrosion Behavior of Biomedical Ti Alloys

Oxidation of metallic components to their ionic form occurs and melted oxygen is condensed to HO ions. The environment of human body fluid is a complex due to the presence of organic compounds, amino acids and proteins. Titanium beside its alloys holds immunity to resist together stress and corrosion. The cause why titanium has such outstanding act in deterioration fighting can add to the creation of a chemically steady, continuous protective and very adherent, and nonstop oxide film (TiO2 film) on the titanium surface. The idle TiO2 film is formed instinctively in environment and remains steady, which parts the metal from the outer surrounding. The thickness of the passive film is around 12-22nm would shake the oxide steadiness. Osseo-integration is favored by TiO2. The movement of metallic ions or electrons along the surface is prevented by the passive film. For Now, in the medical field Ti-6AL-4V is widely used. But, the human body has toxic effects of Al and V. Release of Al and V ion will travel into the human fluid as metal ions, triggering severe neuropathy diseases and Alzheimer's. Limiting the ions transportation in the body fluid can be controlled by making the film compact which will possess an atomic structure. The corrosion of Ti is not the main concern in medical application but it is in the industry. A study found that Amongst Ti-6Al-4V, CP Titanium and SMA Ti-Ni the crevice corrosion behavior of TC4 is the best. In load-bearing implants fretting corrosion is very common. At stem-cement interface, bone-cement boundary and on the boundary of linked joining among insert apparatuses fretting may occur. (4)

8. Surface Modification of TC4 for Application in Biomedical Field

The long-term performance of implant devices is decided by surface properties, before implant stabilization different surface modification is needed. There is variety of reasons required to carry out the surface modification of implants before implantations. As recent research evaluate the surface modification of Ti and its alloys for orthopedic application, along with future perspective. The aim is to improve biocompatibility, corrosion resistance and wear confrontation of titanium and its blends. (9)

9. Surface Modification with Coatings

9.1. Coating Techniques. To improve the efficiency of biomedical orthopedic inserts vast study is being carried out with a main target on emerging methods for layer or putting bioactive constituents on metal implant surfaces. Currently, investigators in the respective field are doing study on layering methods to get optimized solution. There is much requirement of study upon finest hold within layer and substrate, improvement of approaches for multilayers coating to get diverse appearances, and practice of original constituents. In orthopedics, metallic implant coating is done with sputtering. Sputtering is done within argon-rich nature in which vaporous argon is converted into positively charged gases. Then there is bombardment of positive charge ion at metal surface, forming responsive metal particles. That collides with metal and form a covering. Physical Vapor Deposition is employed to create great clarity plus great thick bioactive coverings on orthopedic insert with decent union forte. Though, physical vapor deposition is a lengthy plus costly method and forms a little glassy coat that might melt within the bulk liquid. Therefore, additional research is desirable to learn the effect of PVD treating constraints on the stability, absorbency, and crystallinity of bioactive layers. (7)

Table 2. Surface modification and its positive effect.

Surface modification result	Purpose
Mechanical properties	Increase the fatigue time Upsurge the wear opposition

	Increase the attachment
Biological purpose	Promote Osseo integration Passive coating to end toxic ion discharge Clear surface and improve anti-bacterial behavior

9. 2 Coatings for Metal Implants.

Coatings aimed at Titanium

Common Ti alloy for use in biomedical field is Ti-6Al-4V. TC4 is widely used in orthopedic implant applications due to its good resistance to corrosion, great influence, weariness power, less thickness, intrinsic durability, and precision. Moreover, its biological inertness have undesirable response to tissue plus cell performance. So, the newer bone tissues growth is restricted. Therefore, the weak bonding between implants and host tissues leads to weak Osseo-integration. Therefore, Titanium insert is detached from the host tissue in extended tenure inserting. Additional vital reason of insert letdown is an infection, which is triggered by inappropriate operation, or bacteriological movement in biological surroundings. Hence, Osseo-integration must be promoted by all implants smoothly, and minimize prosthetic infections and good bacterial adhesion. Various coating materials are recommended for apparent alterations of TC4 insert material to improve biocompatibility. Calcium phosphate-based biocompatible constituents such as hydroxyapatite (HA), biphasic calcium (BC), bioactive glass (BG) and biphasic calcium phosphate (BCP) are broadly used for the replacement or reparation of diverse inserts owing to their outstanding biocompatibility, osteoconductivity, and Osseo-integration. To improve the biocompatibility of titanium, the implant is deposited with BCP covering on Ti-6Al-4V and calculated the effect of covering depth on mechanical possessions, wettability and bioactivity. The apatite film placed upon surface of covered titanium delivers the essential surface chemistry for cell propagation and adherence. Surface study checks the development of minor elongated and spherical-like constructions of apatite film on the covered titanium surface. Consequently, it can be decided that BCP-covered Titanium models display decent bioactivity owing to the development of apatite precipitation. (8)

10. Conclusion

It is found that as the population is increasing the problem of elderly people related to bone implant or surgeries is also comparatively increasing. The most common reason leading to implant is the obesity which eventually causes pain at the knee joint which is sometimes unbearable for the patients. So patient opts for orthopedic implant. Now a day implant life is reduced far than the life expectancy of elderly people which takes them towards implant revision due to pain and loosening of implant. So to overcome the implant revision with increased implant life by doing surface modification and coating may prevent the patient both from economic burden and frequent health hazards due to revision surgeries. Hence the focus of the review is to improve the life of most commonly used Ti-6Al-4V material for orthopedic implantation by performing surface modification and coatings.

Future scope: with TiN coating the bacterial and mechanical reasons leading to implant loosening and failure can be limited and controlled to a certain limit, which will prevent the revision surgeries of orthopedic bone implants. Conflicts of interests: There are no conflicts of interests amongst the authors.

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