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Review Article

Review on use of Titanium and its alloys as Implants in Dental Applications

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Abstract

Proper selection of the implant biomaterial is a prominent factor for the success of implants in dental medicine. The biologic environment does not accept completely any material so to optimize biologic performance, implants should be selected to reduce the negative biologic response while maintaining adequate function. Among all the biocompatible materials (Ti-6Al-4V) have become the choice for dental implants due to their properties such as low specific weight, high strength to weight ratio, low modulus of elasticity, very high corrosion resistance and excellent general biocompatibility. Titanium Alloy (Ti-6Al-4V) is the most widely used titanium alloy. It features good machinability and excellent mechanical properties when compared to the Pure Titanium. These alloys are widely used in the engineering field, namely in the aerospace, automotive and biomedical parts, because of their high specific strength and exceptional corrosion resistance. This paper deals with the present views on material properties, passive oxidation film formation, corrosion, surface activation, cell interactions, biofilm development, allergy, casting and machining properties of Ti-6Al-4V.

Keywords: *Titanium Alloy (Ti-6Al-4V), Dental Implants , biocompatibility*

1. Introduction

According to the American Society for Testing and Materials (ASTM), there are six distinct types of titanium available as implant biomaterials. Amongst these six materials, there are four grades of commercially pure titanium (CpTi) and two titanium (Ti) alloys. The mechanical and physical properties of CpTi are different and are related to the oxygen residuals in the metal. The two alloys are Ti-6Al-4V and Ti-6Al-4V-ELI (extra low interstitial alloys). The commercially pure titanium materials are called pure Grade I, Grade II, Grade III and Grade IV titanium. Commercially pure titanium is also referred to as unalloyed titanium and usually contains some trace elements of carbon, oxygen, nitrogen and iron. Theses trace elements markedly improve the mechanical properties of pure titanium and are found in higher amounts from Grade I to Grade IV.

Titanium and its alloy are considered as important engineering materials for industrial applications because of good strength to weight ratio, superior corrosion resistance and high temperature applicability.

Titanium alloys have been widely used in the aerospace, biomedical and aircraft industry due to their ability to maintain their high strength at elevated temperature and high resistance for corrosion.

They are also being used increasingly in chemical process, automotive and nuclear industry. Titanium grade 5 has outstanding resistance to corrosion in most natural and much industrial process environmental.

The metallurgy of titanium has a large influence on the machining characteristics of Ti alloys. Pure titanium undergoes an allotropic transformation at 882,5°C, and changes from alpha to beta phase, from HCP crystal structure to BCC. The precise temperature at which this transformation occurs can be affected by the presence of other chemical elements, some of which stabilize the alpha form and thus raise the effective transformation temperature, and some which stabilize the beta form and so have the opposite effect. These additions also alter the physical properties of the metal, and so change the machining characteristics.

Titanium alloys can therefore be classified into four distinct groups:

1) ***Unalloyed titanium*** – these possess excellent corrosion resistance but low strength properties. They are used largely in cryogenic applications

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2) ***Alpha structure*** **–** with alpha stabilizer elements present, these alloys possess excellent creep resistance. They are also used largely in cryogenic applications.
3) ***Alpha Beta structure*** – this group contains both alpha and beta stabilizer elements. This is the largest group in the aerospace industry.
4) ***Beta structure*** – with beta stabilizers this group has high hardenability and high strength, but also a higher density.

2. Essential properties of implants

2.1 ***Modulus of elasticity:*** Implant material with modulus of elasticity comparable to bone (18 GPa) must be selected to ensure more uniform distribution of stress at implant and to minimize the relative movement at implant bone interface.

2.2 ***Tensile, compressive and shear strength*****:** An implant material should have high tensile and compressive strength to prevent fractures and improve functional stability. Improved stress transfer from the implant to bone is reported interfacial shear strength is increased, and lower stresses in the implant.

2.3 ***Yield strength, fatigue strength:*** An implant material should have high yield strength and fatigue strength to prevent brittle fracture under cyclic loading.

2.4 ***Hardness and Toughness****:* Increase in hardness decreases the incidence of wear of implant material and increase in toughness prevents fracture of the implants. Surface properties Surface tension and surface energy: It determines the wettability of implant by wetting fluid (blood) and cleanliness of implant surface. Osteoblasts show improved adhesion on implant surface. Surface energy also affects adsorption of proteins.

2.5 ***Surface roughness:*** Alterations in the surface roughness of implants influence the response of cells and tissue by increasing the surface area of the implant adjacent to bone and thereby improving cell attachment to the bone. Implant surfaces have been classified on different criteria, such as roughness, texture and orientation of irregularities.

2.6 ***Biocompatibility:*** This is property of implant material to show favorable response in given biological environment in a particular function. It depends on the corrosion resistance and cytotoxicity of corrosion products.

3. Corrosion and corrosion resistance of implants

It is the loss of metallic ions from metal surface to the surrounding environment.

Following types of corrosion are seen.

3.1 ***Crevice corrosion:*** It occurs in narrow region like implant screw-bone interface. When metallic ions dissolve, they can create a positively charged local environment in the crevice, which may provide opportunities for crevice corrosion.

3.2 ***Pitting corrosion:*** Pitting corrosion occurs in an implant with a small surface pit. In this the metal ions dissolve and combine with chloride ions. Pitting corrosion leads to roughening of the surface by formation of pits.

3.3 ***Galvanic corrosion:*** This occurs because of difference in the electrical gradients. Nickel and chrome ions from artificial prosthesis may pass to peri-implant tissues due to leakage of saliva between implant and superstructure. This may result in bone reabsorption and also affect the stability of the implant and eventually cause failure.

3.4 ***Electrochemical corrosion:*** In this anodic oxidation and cathodic reduction takes place resulting in metal deterioration as well as charge transfer via electrons. This type of corrosion can be prevented by presence of passive oxide layer on metal surface.

3.5 ***Clinical significance of corrosion:*** Implant bio-material should be corrosion resistant. Corrosion can result in roughening of the surface, weakening of the restoration, release of elements from the metal or alloy, toxic reactions. Adjacent tissues may be discolored and allergic reactions in patients may result due to release of elements.

4. Types and size of dental implants

The average width for standard implants ranges from 3.5 to 4.5 mm but several factors can make necessary the use of different width implants. The dentist must evaluate properly the condition of the patient's jaw and the position of the missing tooth in the mouth and in relation to the adjacent teeth.

4.1 Wide form implants (large diameter)

Figure 1 Back teeth have to withstand much more load than the rest of the teeth during chewing. If there is enough healthy jawbone in the area, the dentist may prefer to use wide form implants for better stability and force distribution. Wide platform dental implants range between 4.5 - 6.0 mm in diameter.

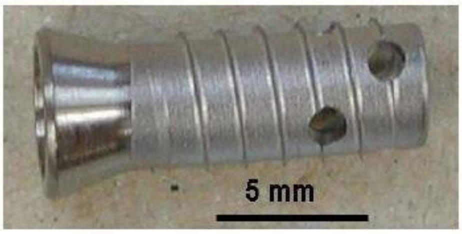

Figure 1 Large Diameter Implants

4.2 Shorter implants

If there is close proximity with a facial nerve, a shorter implant has to be used to avoid the risk of nerve damage.

The use of shorter types of dental implants is also recommended in some special cases for the upper jaw to avoid damage to the sinus.(Figure 2)

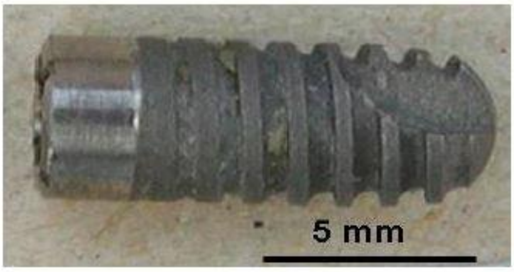

Figure 2 Short Implants

4.3 Narrow form implants (small diameter)

The implant must not disturb the roots of the natural teeth on its sides. If the empty space is not wide enough, the dentist may decide to use narrower implants to allow adequate space from adjacent roots for better Osseo integration of the implant. Narrow implants are also known as mini dental implants and their diameter varies from 1.8 to 3.5 mm. (Figure 3)

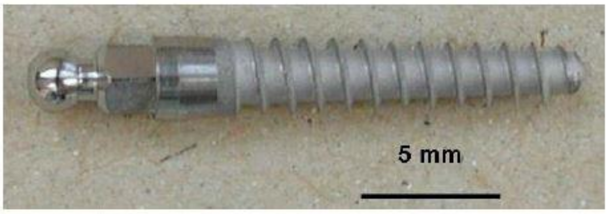

Figure 3 Small Diameter Implants

The use of mini dental implants has increased significantly over the recent years. Many dentists promote the use of small diameter implants because they involve less surgical time making them a simpler and low cost solution.

5. Literature review

Aybar *et al*. performed an immune histochemical study of osteoblast-like cells on four different types of Ti discs: SLA1 (Grade 4, Straumann), SLA2 (Grade 5, Alpha-Bio Tec), acid-etched (Grade 5, Alpha- Bio Tec) and machined (Grade 5, Alpha-Bio Tec).48 Proliferation and DNA synthesis of primary rat calvarial cells were evaluated after one and seven days of incubation. After 24 hours, the highest level of DNA synthesis was observed on SLA1, but after one week, the proliferation of osteoblast-like cells decreased significantly on this surface, while a significant increase of DNA production was observed on the Grade 5 surfaces.

Roccuzzo *et al*. examined 106 implants (53 SLA, 53 control TPS) in 27 patients and found no implant loss after five years' follow-up (100 % success rate).46 no significant differences were seen in the basic periodontal indices (bleeding on probing, probing pocket depth, bone loss) between the two surfaces,46 indicating superior biocompatibility.

Van Velzen *et al*. evaluated the ten-year survival of 374 SLA-modified dental implants in 177 patients with special attention to peri-implantitis. The success rate was 99.7 % at the implant level and 99.4 % at the patient level, with 7 % prevalence of symptoms specific to peri-implantitis.

In a split mouth design, Kohal *et al*. compared osseointegration and peri-implant soft tissue dimensions between loaded titanium and zirconia implants in a primate model and found no statistical difference between the two materials. Several other animal investigations showed that zirconia implants undergo osseointegration similar to or even better than that of titanium implants.

Sennerby *et al* and Rocchietta *et al*. histologically and biomechanically analysed the bone tissue response to Y-TZP with different surface topographies and used oxidized titanium implants as controls. The removal torque values were significantly higher for surface-modified zirconia and titanium implants compared to machined-surface implants, with no significant difference regarding bone-to-implant contact between the two different materials.

Schliephake *et al*. compared the peri-implant bone formation and mechanical stability of surface-modified zirconia implants with sandblasted and acid-etched titanium implants and found similar degrees of bone implant contact and bone volume density for all of the implants, despite the fact that the titanium surface was significantly rougher than the tested zirconia surfaces. However, titanium implants were found to have a higher removal torque resistance, probably due to the difference in the surface roughness.

A cell culture study by Bächle *et al*. found that cell attachment and proliferation of osteoblast-like cells on Y-TZP disks of differently treated surfaces were comparable to those of a sandblasted/acid-etched titanium surface. In contrast, another study showed that modified zirconia surfaces mediate more pronounced adhesion, proliferation and differentiation of osteoblasts compared with titanium.

In a human in vivo study, Scarano *et al*. quantified the percentage of surface coverage of titanium and zirconium oxide discs by bacteria and found a statistically significant difference between the two materials. The zirconium oxide surfaces showed a significant reduction in bacterial adhesion when compared to the titanium specimens. This could positively affect the health of peri-implant soft tissues as suggested by the authors. Another in vivo human study compared vascular endothelial growth factor (VEGF) and nitrous oxide synthase (NOS) expression, inflammatory infiltrate and microvessel density (MVD) in peri-implant soft tissue of titanium and zirconium healing caps. The results revealed higher values of VEGF, NOS, MVD and greater extension of inflammatory infiltrate with a subsequently higher rate of inflammation-associated processes in the titanium specimens compared to that of zirconium oxide specimens

In an in vitro and in vivo study, Rimondini *et al*. compared oral bacterial colonization on the surfaces of disks fabricated from machined Grade 2 Ti and Y-TZP. Y-TZP was found to accumulate fewer bacteria than Ti and was suggested to be a promising material for abutment manufacturing. On the other hand, Lima *et al*. and Al-Ahmad *et al*. found that Ti and ZrO2 surfaces displayed similar biological properties in terms of protein adsorption, biofilm composition and bacterial adherence.

Recently, a new alloy for manufacturing narrow diameter implants (Roxolid®, Straumann, Basel, Switzerland) has been introduced to dentistry. The alloy is based on the binary formulation of 83%–87% titanium and 13%–17% zirconium. It has been claimed that this alloy exhibits better mechanical characteristics compared to CpTi and Ti-6Al-4V with a tensile strength value of 953 MPa and a fatigue strength value of 230 N, according to ISO 14801 internal tests (manufacturer's information). The exact data on the elastic modulus of this material is still missing. An in vivo biomechanical study in an animal model showed that the novel Ti-Zr alloy had significantly higher ($p = 0.02$) removal torque values (230.9 ± 22.4 Ncm) in comparison to Ti (204.7 ± 24 Ncm)

Conclusion

1. Titanium allergic reactions are rare, occurring in about 0.6% of the population. Symptoms for these can vary from mild to severe. These reactions can cause dry patches, swelling and also bone loss.
2. In order to avoid these titanium allergic reactions titanium alloys are formed and tested for their properties and also their biocompatibility.
3. Titanium and its alloys have high corrosive resistance and shows high surface reactivity and less abrasive corrosion.
4. Implants can cause fever, chills, swelling of the implant site due to rejection.
5. Titanium and its alloys have low rejection rates comparatively.
6. Implants have been gaining popularity amongst the patients and frequently are being considered as a first treatment option.

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