Titanium and Its Alloys

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Contributor: Rayane Silva , Almerinda Agrelli , Audrey de Andrade , , Luzia Rejane Santos , Giovanna Machado

Metallic materials are widely used in the medical field, in this context, this entry focuses on the relevance of titanium and its alloys for the development of dental implants.

titanium alloys biomaterials dental implants

1. Titanium

Titanium is the ninth most abundant metal and it was discovered by William Gregory in 1791. It presents itself in its pure form as a silver metal with unique physical-chemical characteristics, such as low density (4506 g/cm^3) and high strength (590 MPa) [1]. Titanium can quickly react with oxygen and this provides resistance to corrosion on the metal's surface because of the formation of an oxide layer on the metal's surface. Studies with this metal are developed for the most diverse themes, such as applications in sports, pigments, jewelry, marine equipment, aerospace, and medical industries [2]. Concerning the dental industry, titanium and its alloys are known to be non-toxic and even more biocompatible than chromium-cobalt and stainless steel [3]. In addition, they are compatible with computed tomography (CT) and magnetic resonance imaging (MRI). These titanium biomaterials are the basis for the manufacture of prostheses and dental implants.

Due to the different properties observed in titanium forms, it has been verified that titanium oxide (TiO_2) is the most reported in studies related to dental implants. TiO_2 is formed by the high capacity of titanium metal to react with air forming hydroxyl and hydroxide groups, which gives it a high capacity for resisting corrosion. This oxide layer confers titanium, and its biocompatibility. TiO_2 can be found in three different crystalline forms in ambient conditions: anatase, brookite, and rutile. The phase transitions are possible by performing heat treatment at the end of the synthesis. While brookite (that is arranged in orthorhombic geometry) is the most difficult to obtain, rutile and anatase (both presenting octahedral geometry) are easily formed [4]. The difference found between the rutile and anatase phases is due to distortions between the octahedral formed by TiO_6. To obtain these structures, several methods can be used, from hydrothermal to electrochemical. Therefore, changes in the physicochemical parameters within the synthesis will lead to the preferential formation of one of the intended phases [5]. Thus, the phase directly affects the success of its use for applications in dentistry. Anatase is often associated with applications requiring osseointegration and, therefore, is the most used in dental implants.

Although other materials are found in the manufacture of dental implants according to their chemical composition, such as ceramics or polymers, at present, titanium is the material most commonly used [6]. Currently, six different types of titanium are available as implant biomaterials. Of these, four are grades of commercially pure titanium

(CPTi) (Grade I, Grade II, Grade III, and Grade IV), which is 98–99.6% pure titanium, and two are titanium alloys (Ti-6Al-4V and Ti-6Al-4V—Extra Low Interstitial alloys). These grades differ in resistance to corrosion, strength, and ductility [7].

An ideal material for the fabrication of dental implants should be biocompatible and have adequate strength, toughness, and corrosion and fracture resistance. These properties are usually related to the oxygen residuals in the metal. Grade IV CpTi presents the highest oxygen content (0.4%) and consequently, excellent mechanical strength, which is why it is the most widely used type of titanium for dental implants [1].

2. Titanium's Alloys

Titanium alloys emerged with the interest of reducing device manufacturing costs and were considered a potential metallic material in the biomedical industry. The alloying elements added to titanium are largely divided into alphas (α) stabilizers, such as aluminum, oxygen, nitrogen, and carbon, and betas (β) stabilizers, such as vanadium, iron, nickel, and cobalt. Therefore, dental titanium alloys exist in three structural forms: α, β, or a combination of the two (α-β) [8]. The α-β combination alloy (Ti-6Al-4V) is the most used in dental applications [1]. It consists of 6% aluminum and 4% vanadium, and is highly strong and resistant to corrosion. Aluminum is an α-phase stabilizer. It increases the strength of the alloy and decreases its density. On the other hand, vanadium is a β-phase stabilizer [9]. Beta stabilizing elements are expensive when compared to α stabilizers [10]. Thus, replacing the common β stabilizers for cheaper substitutes is the current industry demand. On this matter, Fe is the most common element used to replace the β-stabilizing element because of its low cost and strongness. However, it has been reported that high temperatures promote the formation of intermetallic compounds, such as TiFe or Ti_2Fe, which have a negative influence on the ductility and mechanical properties of alloys [11][12].

The surface of titanium implants is important because of their influence on interaction with the bone. The surface of the main materials used as dental implants (CpTi and Ti-6Al-4V) is composed of the oxide TiO_2, which allows high resistance to corrosion with a clinical success rate of up to 99% [13][14]. Although aluminum remains the most important and commonly used α stabilizer, it was reported that it makes working and machining titanium alloys difficult [15]. The use of Ti-6Al-4V has been reported to have good biological acceptance [16][17]. However, small quantities of aluminum and vanadium are eventually released, which may induce an inflammatory process. Aluminum inhibits bone mineralization, leading to bone malformation and vanadium is cytotoxic and may induce allergic reactions [18][19]. This is why dental implants are more often made from CPTi. To prevent these biological problems, vanadium-free alloys, such as Ti-6Al-7Nb and Ti-5Al-2.5Fe, have been developed [7]. Furthermore, alloys composed of non-toxic elements, such as Nb, Ta, Zr, and Pd, are under development.

Recently, a new dentistry alloy based on the binary formulation of 83–87% titanium and 13–17% zirconium (Roxolid®, Straumann, Basel, Switzerland) has been developed. It has been related that it exhibits better tensile and fatigue strength characteristics compared to CpTi and Ti-6Al-4V. In vivo studies in animal models have shown bone integration of threaded zirconia implants comparable to that of titanium after insertion in different animal models [20][21][22].

As titanium is unaesthetic in the frontal area, ceramic implants have been constructed as dental implants [23]. Ceramics are known to present an inert behavior and good physical properties [6]. Firstly, it was used as a coating material for metal implants aiming to improve osseointegration. Over recent years, various forms of ceramic coatings have been used on dental implants. Bioactive ceramics, such as calcium phosphates and bioglasses, and inert ceramics, such as aluminum oxide and zirconium oxide are widely used in many medical, orthopedic, and dental applications [24].

Polymers have also been used as dental implant materials. Polymethylmethacrylate, polytetrafluoroethylene, polyethylene, polysulfone, and polyurethane are the most reported to be utilized in this matter [25]. Acting as a coating layer, polymeric materials are more easily manipulated and do not generate an electrolytic current as metals do. Although they are aesthetically pleasing, a lack of adhesion and immunologic reactions have been reported [6][26][27][28].

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