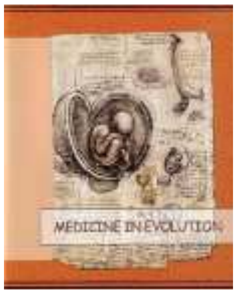
Characteristics of titanium-based materials used in implant dentistry



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Abstract

Titanium and titanium-based alloys are the materials of choice for the dental implants, proving excellent biocompatibility and corrosion resistance. Surface modifications are currently performed, primarily to promote better osseointegration. As a result, many approaches have been carried out to improve the quality of existing dental implants, and to accomplish the biological requirements. The present paper aims to review the main characteristics of titanium-based materials and their advances in implant dentistry.

Keywords: Titanium, Dental Implants, Dental Alloys.

INTRODUCTION

During the Second World War, titanium applications in medicine were aimed for surgical and dental devices. Nowadays, pure titanium and its alloys are widely used to make orthopaedic and dental implants due to physical properties, such as corrosion resistance and high modulus resistance, elasticity in tension and excellent biocompatibility [1]. In dental field, titanium is used as dental implants, as frameworks in prosthodontics, as plates in maxillofacial surgery, as instruments in endodontics and as wires and mini-implants in orthodontics. Dental implants are used as artificial tooth roots since more than five decades, to fix and support prosthetic suprastructures, from single crowns to fixed and removable prostheses. The indication ranges from single tooth gaps up to edentulism. Remarkably, since the pioneering work of Brånemark, Zarb, Albrektsson, Schulte, Schroeder and others in the field of osseointegration [2-7], the material of choice is still titanium or titanium alloys, even though recent alternative materials have gained increasing interest, such as zirconia.

The present paper aims to review the main characteristics of titanium-based materials currently used, and their advances in implant dentistry.

1. PHYSICAL AND CHEMICAL PROPERTIES

Titanium is a metallic element, a transition metal, which is found in the periodic table of elements, represented by the atomic symbol of "Ti", with an atomic number of 22 (22 protons and 22 electrons) and with an atomic weight of 47.87 u. Titanium is characterized by a lustrous metallic white colour, high strength, low density and a melting point of 1672ºC [8]. It exhibits high electrical conductivity and low thermal conductivity. When titanium is exposed to air, it forms a layer of titanium dioxide (TiO2) which protects the surface against dissolution (corrosion processes) [9].

Titanium is used as commercially pure titanium (CP Ti) and in titanium-based alloys. CP Ti can be found in four grades (1 - 4), with main differences in chemical and mechanical behaviour. These four types present different physico-chemical properties, grade 1 being the softest, while 4 is the toughest [10]. CP Ti is used in oral implantology due to the superior properties that it offers, such as osseointegration, lower modulus of elasticity and very good corrosion resistance. Titanium alloys exist in the form of alpha, beta and α-β, depending on the predominant phases within the alloy. Ti-6Al-4V is most used in the field of medical applications and it represents the alloyed form of titanium, and it is preferred when stress tolerance is required. The alloying elements (aluminium, vanadium, zirconium, tantalum etc.) are used to improve the implant's mechanical properties in order to obtain a better behaviour in terms of resistance, strength and formability [10, 11].

Corrosion and resistance to corrosion. Corrosion is defined as a chemical and electrochemical reaction that leads to the progressive destruction of a material in its environment, leading to the loss and release of metallic ions from the surface. Several types of corrosion processes have been described: uniform, crevices, galvanic, intragranular or electrochemical corrosion [12]. The release of different types of metallic ions in the oral cavity can lead to biocompatibility issues due to cytotoxicity and allergic reactions, with local or general manifestations. Corrosion is induced by interactions between the implant material and the chemical compounds with an electrochemical process [13]. The corrosion resistance has to withstand the oral environment which can suffer pH and temperature variations, mechanical loading forces during mastication and food and drugs contact [14]. The passive oxide layer that forms on the biomaterial surface, at the bone-implant interface, is responsible for the electrochemical stability. The corrosion behavior of titanium alloys depends on the oxide film mainly composed of TiO2, so-called 'passive layer' which spontaneously covers the titanium surface and its alloys, storing phosphorus and calcium ions from the bone matrix [15, 16].

2. BIOCOMPATIBILITY

The definition of biocompatibility has changed over time, following the evolution of techniques and methods in the biomaterial industry. In the past, a material had to have the ability to behave specifically, with an appropriate response from the host, while a much more modern approach emphasises that, beside the functions, it performs a suitable cellular or tissue response in that specific situation is needed [17, 18].

In implant dentistry, biocompatibility and surface roughness are considered important for obtaining good tissue interaction and promoting osseointegration [19]. After implant placement, various biological effects occur, being influenced by surface roughness, and allowing osseointegration within different time periods [20].

Blood is often the first body fluid encountered by implants. Blood-material interactions trigger a cascade of events including protein adsorption, platelet adhesion and activation, coagulation, and thrombosis [21]. Therefore, issues concerning biocompatibility first address these events related to interaction with biomaterial surface. Several varieties of tests are currently used to establish that new materials are biologically suitable. These tests are classified as in vitro, in vivo (animal) and usage tests [22]. In vitro tests for biocompatibility are performed by placement of a material or a constituent of a material either in contact with a cell, or different isolated biological components [22]. The contact can be either direct, when the contact material - cell system is without barriers, or indirect, when there is a barrier between the material and the cell system [22]. In vivo testing for biocompatibility involves mammals such as mice, rats, hamsters, guinea pigs, and they are different from usage tests in that the primary aim of material testing is to understand complex systemic interactions and mechanisms, irrespective of material's final use [22]. Thus, the biological responses in animal tests are more exhaustive and often more relevant than in vitro tests [22]. Various tests are currently used to investigate new materials, such as screening for genotoxicity, carcinogenicity, cytotoxicity, irritation, sensitivity, etc [23, 24]. Usage tests can be performed in animals or in humans [22]. They are considered gold standard because the material to be tested is placed in a situation identical to its future planned clinical use [22]. The fidelity of parameters mimicking the clinical use of material impacts the accuracy of biocompatibility assessment [22]. However, these tests are the most expensive, long lasting and involve many ethical issues.

Titanium and its alloys are well known as materials that are not only well tolerated by living tissues, but also able to promote osseointegration, being a key factor for successful dental implantation. Most of the titanium alloys used in medicine are CP Ti and the Ti–6Al–4V alloy [25]. However, the presence of Al and V in the alloys may promote toxicity after long-term implantation [26]. Therefore, development of new alloys without these two elements, and containing nontoxic elements, such as Nb, Ta, Mo, and Zr, is extensively investigated [25, 26].

Another important aspect proved to be of utmost important for research in biomaterials field concerns porous titanium and its alloys. Titanium-based materials with porosity are beneficial not only for adhesion and viability, but also for cell differentiation and growth, and most important for bone formation [27]. Many studies have been conducted on porous coatings and completely porous scaffolds [28-30]. With this respect, high porosity and large pores of scaffolds enhance bone ingrowth and osseointegration of the implant after surgery [30].

3. SURFACE PROPERTIES AND SURFACE MODIFICATIONS

The quality of the dental implant depends on the surface properties [19]. Modifications of the implant surface have been mainly performed to improve osseointegration.

Surface roughness. One of the most important surface features is roughness. Surface morphology plays a crucial role in osseointegration of the implant by stimulating osteoblasts and collagen secretion. Surface roughness plays an important role in implants osseointegration, a rougher surface favouring osteoblasts attachment, whereas epithelial cells and fibroblasts attachment is facilitated by a smoother surface [31].

Surface tension and surface energy. Surface tension usually defines liquid surfaces, while surface energy defines solid surfaces. Surface tension is related to surface topography and chemistry, being an important parameter. Surface energy is determined by the "contact angle" (CA) measurement of a fluid droplet on the solid. The CA is measured from the tangent to the droplet surface at the point of contact, through the droplet to the solid surface [32]. Surface topography, surface charge and chemical composition can influence the surface energy. Surface energy affects the adsorption of proteins [33].

Changes in the surface roughness can raise the implant's surface, enhancing tissue response and cell attachment. Surface modification increases osseosintegration by stimulating cell adhesion, migration, and proliferation processes [31]. From the point of view of the biological response, titanium and titanium alloys are bioinert materials, but surface treatments can make them bioactive [34].

Surface treatments methods can be chemical, physical or physical. Surface modification can be achieved through different methods: subtractive methods (acid etching, grit blasting or combinations), additive methods (plasma spraying, pulsed laser deposition, electrostatic spray deposition, sol-gel deposition) or additive/subtractive methods (anodization) [15].

Several materials have been used as coatings over dental implants made out of a core of titanium, such as: carbon [35], bisphosphonates [36], bioactive glass [37], hydroxyapatite [38, 39], nitrided titanium [40].

CONCLUSIONS

Titanium and titanium-based alloys are extensively used in implant dentistry. Researches and developments in this field have led to improved characteristics of these materials as related to biocompatibility, which is the most important issue to be considered for successful results.

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