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Review

Biomaterial properties of titanium in dentistry

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ABSTRACT

Background: Among various dental materials and their successful restorative uses, titanium provides an excellent example of integrating science and technology involving multiple disciplines of dentistry including biomaterials, prosthodontics and surgical sciences. Titanium and its alloys have emerged as a material of choice for dental implants fulfilling all requirements biologically, chemically and mechanically. Several excellent reviews have discussed the properties of titanium and its surface characteristics that render it biocompatible. However, in most patients, titanium implants are used alongside several other metals. Presence of different metals in the same oral environment can alter the properties of titanium. Other influencing factors include intra-oral pH, salivary content, and effect of fluorides.
Highlight: This review discusses the effect of the above-mentioned conditions on the properties of titanium and its alloys. An extensive literature search encompassing the properties of titanium in an altered oral environment and its interaction with other restorative materials is presented. Specific conditions that could cause titanium to corrode, specifically due to interaction with other dental materials used in oral rehabilitation, as well as methods that can be employed for passivation of titanium are discussed.
Conclusion: This review presents an overview of the properties of titanium that are vital for its use in implant dentistry. From a restorative perspective, interaction between implant restoration metals, intra-oral fluorides and pH may cause titanium to corrode. Therefore, in order to avoid the resulting deleterious effects, an understanding of these interactions is important for long-term prognosis of implant restorations.

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1. Introduction

Commercially pure titanium (CpTi) and titanium (Ti) alloys have been used successfully in dentistry and orthopedics for many years. These materials have become the material of choice in dental implants due to favorable material characteristics and biocompatibility in the oral environment [1–3]. The biomaterial properties of CpTi include a combination of mechanical strength, chemical stability as well as its successful integration with the surrounding bone (osseointegration) [2,3]. Additional advantages of using CpTi and/or Ti alloys in dentistry include its high strength-to-weight ratio and resistance to corrosion [2,4]. Ti has a neutral taste and is considered to be translucent to x-rays making diagnostic radiographs feasible in the presence of titanium castings [5–7]. Ti is also non-ferromagnetic and therefore, patients with titanium implants can safely undergo magnetic resonance imaging [8]. Additionally, the modulus of elasticity of Ti is similar to that of bone, making the bone-to-implant interface closer matching than many other metals [9]. Due to these properties, CpTi and Ti alloys are now extensively used to fabricate endodontic files, orthodontic wires and brackets and dental implants [10].

Ti was first discovered in England by William Gregor in 1791 [11]. However, its use for dental implants was discovered much later by Brånemark [3]. Since then tremendous amount of research has been done that has dramatically influenced the clinical treatment planning of dental implants. Several generations of titanium implants have emerged over the last few decades owing to the huge advances made in biomaterial science [12–16]. Most of the body of research has been focused in developing or enhancing molecular interactions, cellular response, surface treatment and eventually improving osseointegration [13–16]. Several laboratories have done extensive surface engineering with in vitro and in vivo experiments for the development of implant surface modifications to enhance osseointegration [12–16]. This has led to improved implant stability during the healing process resulting in improved clinical performance especially in challenging cases with reduced bone quantity and quality [17]. These improved characteristics have proved beneficial for faster bone healing and reduced implant-loading timelines.

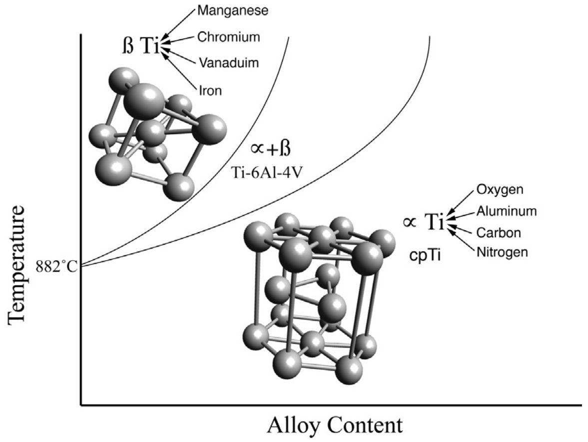

Fig. 1. Crystalline structure of Ti. Below 882 °C Ti exists in hexagonal alpha (α) phase. Elements like Al, C, O and N stabilize the alpha phase. At a temperature above 882 °C Ti exists as centered cubic crystal (β) phase. Elements like Mn, Cr, Fe and Vn stabilize the beta phase. Selective alloying helps create stable alpha+beta phase.

Several reviews have discussed the beneficial properties of titanium in dentistry [1,17–21]. However, a review of the literature from a restorative perspective encompassing the behavior of titanium in an altered oral environment and its interaction with other restorative materials is lacking. Specific conditions can result in altered effect in the material properties of titanium. Use of dissimilar restorative metals leading to galvanic coupling could result in corrosion [22]. Other changes include effect of fluoride, alteration in oral pH and hypersensitivity reaction to titanium [23,24]. Understanding of these various interactions with titanium is crucial from a restorative and prosthodontics aspect. The purpose of this review is to provide an overview of the properties of titanium that are responsible for its beneficial characteristics specifically as related to its use in restorative implant dentistry. Specific conditions that could result in adverse effects due to interaction of titanium with other dental materials used in oral rehabilitation as well as methods that can be employed for passivation of titanium are presented.

2. Structure

Ti is the ninth most abundant element found in the earth's crust and needs to be extracted from mineral ores such as rutile and ilmenite [25]. In 1936 with the introduction of Kroll's process for extracting Ti, industrial use of Ti increased exponentially [26]. Ti is an allotropic element and can exist in 2 crystal orientations (Fig. 1) [26]. At temperatures below 882 °C, pure Ti exists as a hexagonal close-packed crystal also called the alpha phase (Fig. 1). Above 882 °C, it exists as a body centered cubic crystal known as the beta phase (Fig. 1) [5,27]. However, through selective alloying with other elements it is possible to create Ti alloys with stable alpha phase, beta phase or alpha+beta phase at room temperature [28]. Elements like aluminum, carbon, oxygen and nitrogen stabilize the alpha phase of Ti and elements like manganese, chromium, iron, and vanadium stabilize the beta phase [5,29]. The Ti implants used in dentistry are most commonly composed of commercially pure titanium (cpTi) or titanium–6aluminum–4vanadium (Ti–6Al–4V) [29]. The cpTi is a single (alpha) phase crystal at body temperature whereas the Ti–6Al–4V is an alpha+beta phase alloy [5,28].

Ti is highly reactive and belongs to the transition group of elements in the periodic table. The atomic number and atomic mass of Ti is 22 and 47.88 respectively. The electrons in Ti are arranged around its nucleus in 4 energy levels having 2, 8, 10 and 2 electrons respectively (Fig. 2) [30]. Each energy level is further divided into energy sublevels of s, p, d and f. The electronic configuration of Ti is $1s^2\ 2s^2p^6\ 3s^2p^6d^2\ 4s^2$ with lightly held valence electrons in $3d^2\ 4s^2$ energy sublevels (Fig. 2) [26]. These lightly held valence electrons are responsible for making titanium highly reactive [25,29,31].

3. Titanium passivation

Titanium has a standard reduction potential of −1.6 V [29]. This indicates that Ti is a very reactive metal that wants to undergo oxidation (i.e. Ti wants to corrode). However, when exposed to water or air, pure metallic Ti spontaneously reacts to form a thin oxide layer at the surface [29]. Oxygen with a valency of only 2 electrons is relatively electronegative and readily binds with the lightly held valence electrons of titanium to form a tenacious oxide layer (Fig. 3) [25,29].