TITANIUM AND ITS ALLOYS: PROPERTIES AND APPLICATIONS FOR USE AS AN ORAL BIOMATERIAL: A REVIEW

ABSTRACT

Titanium and its alloys are being extensively researched and are applied relatively in different fields of dentistry since 1970s. Every property of this metal has proven to be useful in allied branches of dentistry like casting of removable partial denture frameworks, endosseous implants, in surgical reconstruction and orthodontics. Its inherent advantages like high strength, ductility, formability and weldability, low modulus of elasticity, ease of formation of oxidized surface layer, ability to retain mechanical integrity after autoclave and relatively low toxicity has led to extensive application of titanium and its alloys. The success of the treatment modality relies anyways on the knowledge of the properties required to employ them at the right situation. This article provides an insight into the properties of titanium and its alloys employed as a biomaterial for variety of purposes in dentistry with its definitive pros and cons.

BANGERA, Madhu*
D'COSTA, Vivian**

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Department of Dental Materials, Srinivas Institute of Dental Sciences, Mukka, Suratkal, India*
Department of Conservative Dentistry and Endodontics, Srinivas, Institute of Dental Sciences, Mukka, Suratkal, India**
Correspondence: madhu.bangera@gmail.com (BANGERA M) | **Received** 08 Dec 2014 **Received in revised form** 09 Dec 2014 **Accepted** 14 Dec 2014

INTRODUCTION

Titanium has evolved drastically and elicited a great deal of interest from researchers in dental biomaterials and also among the practitioners due to its excellent biocompatibility and acceptable chemical and physical properties. As time elapsed the corrosion effects were also tested in non-aerospace areas and were effectively applied in other industries. The significant progress in casting technology has also helped imbibe this otherwise called- space age metal basically used in aeronautics into dentistry. The rationale of this review is to synopsize the development and the current status of research on titanium in dentistry.

Titanium has been around since 1790 and gets its name from the Greek God "Titan", the God of enormous strength. Not until 1910, 120 years since the discovery of the ore in England, was there a process developed that allowed the metal to be extracted from the ore.

The individual responsible for this process was a researcher by the name of M.A. Hunter. Although the Hunter process was a viable method to extract the metal from the ore, it proved not conducive to large scale manufacturing efforts. A researcher by the name of Dr. Wilhelm Kroll is the man credited with creating a process that reduced titanium effectively on a large scale basis[1]. Currently, the Kroll Process, combined with Vacuum Distillation is the typical method of extracting the metal from the ore.

Applications of titanium for dentistry have been slower to develop. Since past three decades, the advances in new processing methods—such as lost-wax casting, computer-aided machining and electric discharge machining—has improved titanium's useful array of applications in biomedical devices[2]. Currently, titanium and its alloys are used for the fabrication of prosthetic joints, surgical splints, stents and fasteners, dental implants, dental crowns and partial denture frameworks[3], orthodontic arch wires and in various dental armamentariums.

Information from scientific full length papers, reviews and abstracts published from 1975 to date were considered in the review. Published materials were researched in medical, dental and material science literature using general and specialized databases with keywords comprising of titanium; titanium and alloys; titanium in dentistry, medicine and material science; titanium casting and machining; autoclaving of titanium, corrosion in titanium and its alloys, systemic effects of titanium, biocompatibility, titanium in reconstructive surgeries and titanium implants. Data pertaining to coatings of titanium on metals were excluded. Studies on physical, chemical and other miscellaneous properties were also analyzed. American Dental Associations' (ADA) council of scientific affairs and ISO standards reports were also considered. This review revolves around titanium and its alloys range of application based on their specialized associated property which makes it favorable to be applied in a dental scenario.

LITERATURE REVIEW

Most of titanium's chemical, biological and mechanical properties make it desirable as a material for prosthesis. The physical properties like strength and modulus of elasticity of titanium are comparable to those of other noble or high noble alloys frequently used in dentistry[4]. Its mechanical properties can effectively be altered by alloying it with various other metals such as aluminium, vanadium or iron. Apart from high biocompatibility titanium also displays chemical inertia and low density.

Titanium and its alloys readily form a highly protective oxide layer on its surface that imparts them with high corrosion resistance. The metal oxidizes immediately in air to form an insistent and even oxide layer approximately 10 nanometers thick[5]. In addition to providing corrosion resistance this oxide layer helps in bonding of ceramics, polymers and various implant coatings effectually.

Low toxicity has been reported so far by titanium in its ionic and particle form. Titanium ions are subject to renal excretion[6]. High rate of accumulation is reported in lymph nodes, liver, spleen, bone marrow and the brain by Rulite, a titanium corrosion product[7]. Potential toxicity results more often from alloy additives like aluminium and vanadium.

1 TITANIUM IN DENTISTRY

Though titanium was imbibed into dentistry in 1970s it has considerably developed since then and entered various areas of prosthetic dentistry as well as few areas of orthodontics and surgical armamentarium. Furthermore with evolving trends of casting, equipments are readily available for casting of crowns, bridges and partial denture frameworks and implant supported structures.

2 CASTING OF TITANIUM

Casting of titanium in dentistry has practically reached a phase where it can be considered as a contemporary method to compete with dental casting using conventional noble and base-metal alloys. The primary effort of casting dental prosthesis was made in the United States in 1970s using industrial titanium casting equipment.

Dental castings are fabricated through pressure-vacuum or centrifugal casting methods[8]. Vacuum or inert gases are used for melting of the metal alloy to prevent inclusion of oxygen which if not leads to embrittlement of the metal. Numerous commercial machines for casting titanium are available but the high costs make them unemployable often. Casting materials with low or no reactivity are used to counteract surface reaction with the introduced molten metal, and investments with high setting expansion are used to compensate for the high casting shrinkage of titanium.

Titanium is being applied frequently for the production of cast RPD frameworks. Its use is gradually increasing due to no reports on metallic allergy caused by CpTi. The laboratory downsides like tedious burnout procedure, mediocre castability and machinability, surface oxidation in split second, trouble of polishing, and not being cost effective still persists. Problems associated clinically, like surface discoloration, metallic taste, decrease of clasp retention, easy adhesion of plaque due to poor polishability, detachment of the denture base resin, have gradually been resolved[9]. With no apparent reports on catastrophic failure of titanium frameworks and allergies associated it can be conveniently applied for desired RPD castings. One of the reports suggested that frameworks fabricated from titanium and its alloys possess long-term retentive resiliency and hence are suitable to be used for removable partial dentures[10].

2.1 MACHINING OF TITANIUM

Titanium is considered as one of the difficult to machine material due to its complex deformation mechanism which is entirely different from other conventional metals. Commonly used techniques for machining are CAD-CAM and electric discharge machining[3].

2.2 ORAL IMPLANTS

Biological and prosthetic design features crucially influence the success of an implant. The tissue and implant interface is guided by size, shape, material and type of coating on a particular implant. Certain Ti and its alloys are employed in medical and dental implant manufacturing since second half of sixties in the last century.

There are currently four commercially pure (Cp) Ti grades and one titanium alloy specially made for dental implant applications especially endosseous type. These metals are specified according to ASTM as grades 1 to 5. Grades 1 to 4 are unalloyed, while grade 5, with 6% aluminum and 4% vanadium, and are the strongest[11].

The majority of dental implants are made of commercially pure titanium which ~99% titanium and small amounts (0.18-0.40%) of oxygen with trace amounts of iron, carbon, nitrogen, and hydrogen. Recently there is increased use of this titanium alloy containing Ti-6Al-4V (90% Titanium, 6% Aluminum and 4% Vanadium)[12]. Other osteosynthesis systems regularly consists of alloys like Ti-6Al-7Nb (6% aluminium, 7% niobium), as standardized in ISO 5832-3. These materials possess adequate tensile and fatigue strength, as well as excellent osseointegrative properties required as per implant criteria's[13,14].

Titanium is also known to possess exaggerated percentage of direct bone contact when directly implanted without the use of any cements[15]. However, direct bonding to living bone does not occur in case of titanium and its alloys when implanted. The surface properties of the implants are crucial in rendering osseointegration. Hence a variety of surface modifying treatments are proposed to achieve bioactive bone bonding[16].

Recent study has shown that titanium-based implants corrode forming metallic debris resulting in high concentrations of circulating metal-degradation products and their impending chronic systemic health issues, including hepatic injury and renal lesions[17]. The significance of Ti as a cause of allergic reactions in patients with dental implants remains unproven though topographic association of dermal inflammatory conditions, gingival hyperplasia and hyperemia of soft tissues were reported[18]. A thorough investigation of allergy is recommended to prevent associated complications.

2.3 TITANIUM IN ORTHODONTICS

There are few metal alloys which have been traditionally used in dentistry for orthodontic application like the gold-based, stainless steel, chrome-cobalt-nickel, and Nitinol alloys and especially beta titanium. The first clinical application of this alloy in orthodontics occurred in the 1980's and is commercially available as TMA (Titanium Molybdenum alloy). When subjected to heat treatment these alloys undergo changes in the structural rearrangement of their atoms, aka beta phase titanium alloys. The beta titanium wire has a wide range of application due to its distinctive balance of low stiffness, high springback, formability, and weldability[19].

Moreover, it can replace alloys like nickel and chromium which forms part of orthodontic alloys known to be cause for patients to develop hypersensitivity[20].

2.4 SURGICAL ARMAMENTARIUM

The purpose of titanium as a biomaterial in surgical set up is widespread ranging from reconstruction of bony defects resulting from osteotomies, traumas, malformations, tumor resections or functional and aesthetic augmentations. Titanium with its high biocompatibility and corrosion resistance also possess elastic modulus paralleling to that of the bone in comparison to any other metals[21,22] and hence preferred more often in a craniofacial osteosynthetic scenario.

An extensive range of mini- plates, micro plates, meshes, screws and implants are available for reconstruction. These plates can be adjusted intra-operatively without hastles due to their adequate ductility. These systems may be autoclaved and are reused without disruption in mechanical integrity even after many cycles of autoclaving[23]. Though titanium miniplate cranial fixation incurs additional cost in comparison to standard stainless steel miniplates, it provides more precise and unyielding approximation of the bone edges[24]. Individual titanium implants[25] are suitable for secondary reconstruction. Such prefabricated titanium implants are milled from a solid titanium block per Computer Aided Manufacturing (CAM). Thermosensitivity and restricted shaping and remodeling intraoperatively (in contrast to glass ceramics) are the chief drawbacks of metals as bone substitutes[26].

CONCLUSION

Titanium and its alloys are being successfully employed in dentistry from the era of sixties. In dentistry it has established a strong hold in the fields of casting, implant technology, orthodontics and various surgical reconstructive procedures. With the advent of technology it has become less cumbersome to fabricate and machine this otherwise unyielding metal. It can be assumed as a viable alternative to other conventional metals being administered for these aforementioned techniques. With the dawn of better living style accepting an exclusive material becomes convenient where the subjects prefer superior performance of the materials and techniques being employed by the clinicians. Considering its potential to render quality property based applications, it's rather unproven systemic toxicity can be relegated, provided effective measures have been considered to rule out the odds.

Based on the extensive research applied to formulate this review the authors conclude that titanium and its alloys have widespread applications as an oral biomaterial due to its favorable biological, physio-chemical and mechanical properties. The success of these property based applications is subject to thorough knowledge of pros and cons of the metal and its alloy.

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