Titanium and its role in Dentistry

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Abstract- For dental cast restorations like partial dentures ,frameworks etc usually base metal alloys were used.This was mainly because of the high price ofgold. Despite the desirable properties for frameworkfabrication some characteristics, such as corrosionresistance and casting procedures, needed to be improved.Titanium casting technology was thus developed andsubsequently got refined over many years.Removable partial dentures are usually affected by fatigue because of the cyclic mechanismof the masticatory system and frequent insertion and removal. Titanium and its alloys have now beenused in the manufacture of denture frameworks and also in implants. This article shows the characteristic features of titanium which enables it to be used in dentistry.

Index Terms- Dentistry, Frameworks , Implant ,Titanium

I. Introduction

Titanium (Ti) is a pure element listed in the periodic table with an atomic number of 22 and an atomic weight of 47.9. It is the ninth most abundant element and the fourth most abundant structural metallic element in the earth's crust[1], following aluminum, iron, and magnesium.. Of the total amount of titanium mined, majority is titanium dioxide which is used as a pigment for use in paint. Only 5% to 10% is used in its metal form.[2]

With advances in dental porcelain in the 1960s and the significant increase in the price of gold in the 1970s, alternative alloys such as palladium alloys and base metal alloys, were developed. The allergenic and carcinogenic properties of base metal alloys used in dentistry especially nickel and beryllium-based alloys, have fueled controversy. The evolution of titanium (Ti) applications to medical and dental implants has dramatically increased in the past few years because of titanium's excellent biocompatibility corrosion resistance and desirable physical and mechanical properties.Titanium has become a material of great interest in dentistry in recent years. It has been used a biocompatible replacement for alloys used for fixed and removable prostheses, implants, files etc.Titanium can form several oxides– TiO, Ti_2O_3, TiO_2 – of which TiO_2 is the most common . TiO_2 can have three different crystal structures – rutile, anatase, and brookite – but also can be amorphous

II. HISTORY

Titanium was first discovered by Williams Gregor, a British minerologist in 1791 who found the metal in a "black magnetic sand" in Cornwall and named it 'MENACHITE' . Martin.H.Klaproth, a German chemist and minerologist rediscovered it in 1795 to be known as TITANIUM. He recognized that this metal was identical to the material Gregor had discovered3. Dr. Wilhelm Kroll, a refugee from LUXEMBOURG is considered as the "Father of Titanium Industry". He invented useful metallurgical processes for commercial production of titanium metal, the Kroll process. The United States Bureau of Mines used the Kroll process to produce metallic titanium. Annual production has rapidly increased from 3 tons in 1948 to 20,000 plus tons in the early '80s.

III. MANUFACTURING OF TITANIUM

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Titanium is produced by heating titanium ore (rutile, ilmenite) with petroleum-derived coke in a reactor at 1000 °C. The mixture is then treated with chlorine gas, forming titanium tetrachloride $TiCl_4$ and other volatile chlorides, which are subsequently separated by continuous fractional distillation in the presence of carbon and chlorine and then reducing the resultant TiCl, with molten sodium to produce a titanium sponge. This sponge is then fused under vacuum or in an argon atmosphere into titanium ingots.[4] It is often remelted to remove inclusions and ensure uniformity

Titanium alloys used in dentistry exist in three forms: alpha, beta, and alpha-beta. These types originate when pure titanium is heated, mixed with elements such as aluminum and vanadium in certain concentrations, and then cooled. These added elements are said to act as phase-condition stabilizers[5]. Aluminum has been called an alpha-phase condition stabilizer. Aluminum serves to increase the strength and decrease the weight of the alloy. Vanadium has been called a beta-phase stabilizer. As aluminum or vanadium is added to Ti, the transformation occurs from alpha to beta. The alloy form desired is maintained at room temperature by quenching the alloy.Titanium is available as Commercially pure titanium (cpTi) and as Titanium Alloys. Classification of Titanium is given by American Society for Testing and Materials ASTM (Table 1) , Commercially pure titanium (cpTi) is available in four grades [6,8](Table 2) which vary according to the oxygen (0.18-0.40 wt.%), iron (0.20-0.50 wt%) and other impurities. Grade 1 being the most pure.[7,8]

IV. PHYSICAL & CHEMICAL PROPERTIES

Biocompatibility & Corrosion Resistance

Titanium's highly reactive nature provides both advantages and disadvantages for its use. Titanium must be melted in a vacuum or under inert gas to prevent oxidation and incorporation of oxygen can lead to embrittlement of the cast metal.[9] Contamination with even low concentrations of atmospheric oxygen can lead to significant loss of ductility. The molten alloy reacts readily with refractory investment materials, therefore the material should be selected carefully.

This same reactivity is responsible for many of titanium's favorable properties. The metal oxidizes almost instantaneously in air to form a tenacious and stable oxide layer approximately 10 nanometers thick[10]. This oxide layer provides a highly biocompatible surface and a corrosion resistance similar to that of noble metals. In addition, the oxide layer allows for bonding of fused porcelains. However recently contact dermatitis or granulomatous reactions to titanium is seen in its use in pacemakers, hip prostheses, surgical clips etc. It appears that in rare circumstances, for some patients, the titanium used in dental implants also induced an allergic reaction [11].

Strength & Rigidity

The strength and rigidity of titanium are comparable to those of other noble or high noble alloys commonly used in dentistry[12] and titanium's ductility when chemically pure, is similar to that of many dental alloys. Titanium also can be alloyed with other metals, such as aluminum, vanadium or iron, to modify its mechanical properties. The wrought alloy condition is approximately 6 times stronger than compact bone and thereby affords more opportunities for designs with thinner sections (e.g., plateaus, thin interconnecting regions, implant-to-abutment connection screw housing, irregular scaffolds, and porosities However toxicity of V has been pointed out. V-free titanium alloys as implant materials have been developed. Most of them are, â type titanium alloys composed of non-toxic elements like Nb, Ta, Zr, Mo or Sn with lower moduli of elasticity and greater strength have been developed recently [13]
Titanium has a relatively high tensile strength; it takes quite a bit of pressure to pull titanium apart. According to Key to Metals, titanium has a tensile strength of between 30,000 and 200,000 lbs. per square inch. The yield strength (170 – 480 MPa) and ultimate strength (240 – 550 MPa) varies depending on the grade of titanium [14].

Shape memory

The nickel-titanium alloy (Nitinol) wires have large elastic deflections or working range and limited formability, because of their low stiffness and moderately high strength. This alloy exists in various crystallographic forms. At high temperature stable BCC lattice (austenitic phase) exists. On appropriate cooling, or on application of stress, this transforms to a close-packed hexagonal martensitic lattice, associated with volumetric change. These characteristics of the austenite to martensite phase transition results in two features of clinical significance called as shape memory and superelasticity, or pseudoelasticity.[15] The use of NiTi for medical applications was first reported in the 1970s .Nitinol [also known as a shape memory alloy (SMA), smart alloy, memory metal, or muscle wire] is an alloy that “remembers” its shape. NiTi has been used *in* orthopedic and orthodontic implants [16].

Low thermal coefficient of expansion

This property allows titanium to be much more compatible with ceramic or glass materials than most metals, particularly when metal-ceramic or metal-glass seals are involved.

Low modulus of elasticity

The modulus of elasticity of titanium is 5 times greater than that of compact bone, and this property places emphasis on the importance of design in the proper distribution of mechanical stress transfer.The modulus of elasticity of the alloy is slightly greater than that of titanium, being about 5.6 times that of compact bone. The alloy and the primary element (Ti) both have titanium oxide (passivated) surfaces.

Density

The density of CpTi (4.5 g/cm3) is about half of the value of many of other base metals. Titanium is lighter than the stainless steel (approximately 56% as dense) yet has a yield strength twice and ultimate tensile strength almost 25% higher. This gives it a highest strength –to – weight ratio of any metal suited to medical use.

Non-magnetic

Commercially pure titanium and all the titanium alloys are non magnetic. The physical difference between ferromagnetic and nonferromagnetic materials lies in the degree of magnetization. [17] Titanium is not susceptible to outside interference and won't trigger metal detector. [18] Another benefit to titanium for use in medicine is its non-ferromagnetic property, patients with titanium implants can be safely examined with magnetic resonance imaging (convenient for long-term implants)

V. USES

Titanium alloys are largely used in industrial applications such as jet engines, air frames, and the aerospace industry, which require high strength-to-weight ratios and good corrosion resistance. Other applications include chemical processing, nuclear waste containment, heat exchange units, seawater desalinization, marine equipment, deep-well drilling, and food processing situations that require resistance to corrosion by chemicals and cleaning agents.[2]

VI. ROLE IN DENTISTRY

ATitanium has been used in cast dental prostheses since the 1970s.[12] Equipment is available to cast titanium into single-and multiple-unit-crown and- bridge frameworks, implant-supported structures and partial or full denture bases.[19]Cp-Ti presents mechanical properties similar or slightly better than gold alloys type III and IV, nickel–chromium (Ni–Cr) and cobalt–chromium (Co–Cr), normally used in the fabrication of frameworks[20].Although titanium provides some advantages to these prostheses, the high melt temperature of titanium, 1,672 °C, requires special melt procedures, cooling cycles, investments and equipments to avoid its contamination[10]. Due to the gas absorption and high chemical reactivity of casting, titanium is difficult to be processed through the conventional technique of lost-wax. In high temperatures, it reacts with gaseous elements such as nitrogen, oxygen and hydrogen and forms a thick layer of oxides "alpha case"which may reduce the resistance and ductility of the structure obtained. Due to this , use of a vacuum chamber and controlled environment is preferred [21].There are three main types of titanium casting systems: casting under pressure/vacuum with separated chambers of melt and casting; casting under pressure/vacuum with a single chamber of melt and casting; casting under vacuum/centrifugation. Also, dental titanium casting can be accomplished through the methods of centrifugation or pressure/vacuum[22]. The metal is melt with an electric plasma arch or through inductive heating in a chamber full of inert gas or at vacuum. The metal is melt and then is transferred to the refractory mould through the centrifuge or through filling under pressure/vacuum [23] .Several equipments are commercially available for casting titanium but their cost is considerably higher than the conventional casting equipments[24].

Due to these difficulties other techniques were developed to fabricate crowns and frameworks. Such techniques comprise titanium machining from a solid metallic block. The frameworks are all fabricated in titanium grade 2 considering four generations of development. The first generation is based on pre-fabricated titanium cylinders and a bar component, which are joined through laser welding [25]. In the second generation technique, different pieces of titanium components with cylinders are used. After the leveling of the components, a titanium bar is positioned and, then, horizontally laser welded [25]. In the third generation of frameworks, small titanium components are individually cast by a technician for each titanium abutment at the main mould and, then, joined by laser weld. After that, resin teeth are joined or ceramic is cast to the titanium device [25]. In the fourth generation, Procera® titanium frameworks are fabricated in a single piece through machining controlled by a computer. This technique is based on a concept where the technician makes a resin pattern simulating the final shape of the framework, and then this pattern is scanned and its image is generated by a software. Information about the implants positions are also given to the computer. When all data are collected, a framework is machined from a solid block of titanium grade 2, which is only refined and polished by a technician. Following, resin teeth are fixed or a low fusion porcelain is used to fabricate the teeth [25].

Other techniques of frameworks fabrication through titanium machining are also available. Such techniques utilize the CAD-CAM system and comprise a computed system of restoration/reconstruction that uses a scanning technique primarily in combination with machining techniques of titanium and/or porcelain in the prosthetic laboratory. The different systems can use either CAD-CAM or a wax pattern combined with CAM [26]. Some systems known are: Hint-ELs,Procera, DCS President System, Cad. Esthetics, KaVo

Everest System, microDenta, Cerconbrain and Cerec [27]. These techniques are based on a model scanning, which is digitalized for the production of a design by the software. This design would represent the final shape of the desired structure. Therefore, through the data obtained from the representation of the final structure shape, the framework is fabricated by industrial machining equipments using a single block of titanium. From this moment, also through the same system described previously, the crowns on the framework are obtained by machining a ceramic block .Laser welding aims to enhance the poorer marginal adaptation of titanium castings, because, besides the difficulties of casting and machining, titanium presents a great difficulty related to the conventional welding due to its high melting point and chemical reactivity . In laser welding, the intensity and duration of laser pulse is such that a sufficient energy can be provided to a junction in order to join the segmented structures and reach a weld point before a high heat is conducted to other parts of the piece. It means that there is a small generation of heat for the piece, except for the point of laser application [28]. Despite of these advantages, Sjogren et al. attested that the chemical composition of the highly reactive titanium is changed in the weld point during laser welding, and this can influence the mechanical properties in this region.[29]

Role with Dental Implants

Initial utilization of titanium in Dentistry is dated from the 60's and occurred accidentally. In 1965, the Swedish doctor Per-Ingvar Branemark was investigating the blood microcirculation in rabbits tibiae with an observational camera made of titanium, when he noticed that metal and bone were perfectly integrated, without any rejection, and these cameras were very difficult to be removed. Based on this observation, Branemark developed special cylinders to be implanted in rabbits' and dogs' tibiae; which became, later, a secure, modified and optimized base to receive long-term fixed prosthesis in maxilla and mandible for human application [30]. In this same year, a 10-year follow-up study was initiated in Gothenburg, Sweden to evaluate the clinical results from the application of this technique in humans [31].

Titanium implants have been used with success for years in the substitution of lost dental elements. They can be manufactured both from commercially pure titanium (cp-Ti) or titanium alloys. They have been used for both endosseous and subperiosteal implants.[32]Endosseous implants have taken the form of rods, posts and blades made of either pure titanium or titanium alloys. The passivating oxide on the implant surface permits close apposition of physiological fluids, proteins, and hard and soft tissues to the metal surface. This process, whereby living tissue and an implant become structurally and functionally connected, is called osseointegration.[33] Titanium also has been used successfully as a biocompatible implant material, and continual improvements in both device design and clinical implantation techniques have led to well-accepted and predictable procedures. In 1996, the ADA's Council on Scientific Affairs updated its position regarding the use of endosseous implants as a treatment modality for full or partially edentulous patients.[34]

VII. CONCLUSION

The physical and chemical properties of Titanium and titanium alloys make it a versatile material in modern Dentistry. Properties like corrosion resistance in oral environments, strength-to-weight ratio, Lightweight, excellent mechanical properties , Biocompatible, Non-toxic, Long-lasting, Non-ferromagnetic, Cost-efficient and Long range availability makes titanium the best material choice for many critical applications. However, although all its advantages, the technologies related to it casting, machining and processing techniques, such as spark erosion, laser welding and micromachining, and computer aided design – computer aided manufacturing are still expensive and with important limitations. Therefore, a wide use of titanium in dental prosthesis will depend on technological advance and more clinical investigations in order to develop more profitable techniques to prove its efficiency.

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The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments.

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TABLE 1: Standard Specification for Titanium and Titanium Alloys

ASTM grade 1	Unalloyed titanium

ASTM grade 2	Unalloyed titanium
ASTM grade 3	Unalloyed titanium
ASTM grade 4	Unalloyed titanium
ASTM grade 5	Titanium alloy (6 % aluminum, 4 % vanadium),
ASTM grade 6	Titanium alloy (5 % aluminum, 2.5 % tin),
ASTM grade 7	Unalloyed titanium plus 0.12 to 0.25 % palladium
ASTM grade 9	Titanium alloy (3 % aluminum, 2.5 % vanadium),
ASTM grade 11	Unalloyed titanium plus 0.12 to 0.25 % palladium
ASTM grade 12	Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
ASTM grade 13	Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
ASTM grade 14	Titanium alloy (0.5 % nickel, 0.05 % ruthenium)
ASTM grade 15	Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
ASTM grade 16	Unalloyed titanium plus 0.04 to 0.08 % palladium
ASTM grade 17	Unalloyed titanium plus 0.04 to 0.08 % palladium,
ASTM grade 18	Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 to 0.08 % palladium,
ASTM grade 19	Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
ASTM grade 20	Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 to 0.08 % palladium
ASTM grade 21	Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon)
ASTM grade 23	Titanium alloy (6 % aluminum, 4 % vanadium with extra low interstitials, ELI),
ASTM grade 24	Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.4 to 0.8 % palladium
ASTM grade 25	Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.3 to 0.8 % nickel and 0.04 to 0.08 % palladium
ASTM grade 26	Unalloyed titanium plus 0.08 to 0.14 % ruthenium
ASTM grade 27	Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
ASTM grade 28	Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.08 to 0.14 % ruthenium
ASTM grade 29	Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial elements, ELI) plus 0.08 to 0.14 % ruthenium,
ASTM grade 30	Titanium alloy (0.3 % cobalt, 0.05 % palladium)
ASTM grade 31	Titanium alloy (0.3 % cobalt, 0.05 % palladium),
ASTM grade 32	Titanium alloy (5 % aluminum, 1 % tin, 1 % zirconium, 1 % vanadium, 0.8 % molybdenum),
ASTM grade 33	Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
ASTM grade 34	Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
ASTM grade 35	Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),
ASTM grade 36	Titanium alloy (45 % niobium)
ASTM grade 37	Titanium alloy (1.5 % aluminum),
ASTM grade 38	Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron)

TABLE 2 :Grades for Commercially pure titanium (cpTi)

TYPE	MAXIMUM IMPURITY LIMITS(wt%)				
	Nitrogen	Iron	Oxygen	Carbon	Hydrogen
ASTM grade I	0.03	0.2	0.18	0.1	0.015
ASTM grade II	0.03	0.3	0.25	0.1	0.015
ASTM grade III	0.05	0.3	0.35	0.1	0.015

ASTM grade IV	0.05	0.5	0.4	0.1	0.015