TITANIUM: A Breakthrough Metal in Dentistry

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Abstract Titanium is a metallic element which has many attractive characteristics that make it desirable as a material for implants and other biomedical applications. Commercially pure titanium and it's alloys are used for dental implants, surface coatings, and recently for crown, partial and complete dentures, and orthodontic wires. They are used in medical speciality for fabrication of prosthetic joints, surgical splints, stents and fasteners. With continuing evolution, Titanium has promising future in Dental and Medical field.

Key words- Titanium, Implant, Biocompatibility, Alloys

INTRODUCTION

Titanium is the ninth most commonly found and fourth most frequently found metal in earth but it is not found freely in nature. It is found mostly in the igneous rocks, it's sediments and also from the minerals like ilmenite, leucoxene and rutile.

The ASTM (American Society of Testing and Materials) Standard F1295 Specifies titanium in different grades according to its purity, which is evaluated according to the amount of oxygen. Grade 1–4 refers to Commercially pure- Ti, but with different purity grades. Grade 5 refers to the three

combinations of aluminum (Al) and vanadium (V). Titanium-6Aluminium-4Vanadium (Ti-6Al-4V) and Titanium-6Aluminium-4Vanadium ELI (extra low-interstitial) (Ti-6Al-4V) are the two types of titanium alloys used in dentistry.

Titanium is known for it's characteristics such as biocompatibility, excellent corrosion resistance, High rate of osseointegration, good shape memory, flexibility, Highest strength to weight ratio and high mechanical resistance.[1] For more than 25 years, titanium and it's alloys have been used for both endosseous and subperiosteal implants and Wrought alloys of Titanium with Nickel and Titanium with Molybdenum are also used for orthodontic wires.

Different Properties of Titanium

Biocompatibility: Titanium highly non-toxic and does not cause any inflammatory or allergic reactions in the human body. This property makes it suitable for use in Dental implants.

Osseointegration: Titanium is one of the best metals that allows for this integration because it is absolutely inert in the human body, immune to attack from body fluids, compatible with the bone growth and strong and flexible.

Strength: Titanium has a tensile strength of between 30,000 and 200,000 lbs. per square inch. Titanium alloy contains roughly six weight percent of aluminium and four weight percent of vanadium, which doubles its tensile strength relative to commercially-pure titanium, but reduces its ductility. The yield strength (170 – 480 MPa) and ultimate strength (240 – 550 MPa) varies depending on the grade of titanium.

Corrosion: The titanium corrosion resistance in the oral cavity is due to the formation of an adherent and highly protective oxide film on its surface which is mainly formed of TiO2.

Shape memory: The shape memory effect of nickel and titanium, which can be considered a breakthrough. This alloy was named as Nitinol (Nickel-Titanium Naval Ordnance Laboratory). It is widely used in the field of Orthodontics and Endodontics.

Flexibility: Titanium clasps are purported to have greater flexibility than cobalt-chromium cast clasps which should enable them to engage deeper undercuts or be used where shorter clasp arms are needed such as on premolar teeth.

Density: The density of Commercially pure Titanium (4.5 g/cm3) which 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.

Titanium Bonding: In the the oxidation effects of the porcelain-titanium interface reaction, the conventional degassing procedure is not suitable for porcelain-titanium restorations and that the firing cycle should be below 5000º to minimize the metallic oxide formation on the Ti surface. [2]

Passivation: Titanium oxidizes on contact with room temperature air and normal tissue fluids. This reactivity is favourable for dental implant devices. This is one important property consideration for the use of titanium in dental implants. [3]

Material	Nominal Surface Analysis (w/o)	Modulus of Elasticity, GN/m^2 (psi $\mu 10^6$)	Ultimate Tensile Strength, MN/m^2 (ksi)	Elongation to Fracture (%)	
Titanium oxide	99+Ti	97 (14)	240–550 (25–70)	15	Ti
Titanium oxide aluminum–vanadium	90Ti-6Al-4V	117 (17)	869–896	>12	Ti
Cobalt–oxide chromium–molybdenum (casting)	66Co-27Cr-7Mo	235 (34)	655 (95)	>8	Cr
Stainless oxide steel (316L)	70Fe-18Cr-12Ni	193 (28)	480–1000	>30	Cr
Zirconium oxide		97 (14)	552 (80)	20	Zr
Tantalum oxide		—	690 (100)	11	Ta
Gold	99+Au	97 (14)	207–310 (30–45)	>30	Au
Platinum	99+Pt	166 (24)	131 (19)	40	Pt

Table 1: Various types of properties of different materials used for dental implants

APPLICATIONS OF TITANIUM IN DIFFERENT SPECIALITIES OF DENTISTRY

Role In Prosthodontics

There are various applications of commercially pure titanium and it's alloys in different fields of Prosthodontics.[4]

In removable prosthodontics, commercially pure (CP) titanium and titanium alloys (Titanium-6Aluminium-4Vanadium and Ti-6Aluminium-7Neobdinium) have been used for cast partial denture frameworks. It was found in a study that clasps made from Ti alloy are able to maintain more of their retention than Co-Cr clasps and do not show permanent deformation, suggesting that it is a superior material for cast RPD clasps. Titanium has advantage of good retention than clasps made of other metals. Because of flexibility of titanium, it is used in removable prosthodontics. [5]

Titanium is also used in fixed partial denture for the metal ceramic prosthesis. Boening et al used the milling technique which was combined with spark erosion to fabricate titanium copings. The study concluded that Ti-Ceramic bond passed the Duetshe Industrie Norm test but failed the ISO test. The different studies could not draw conclusion for long term serviceability of titanium in this field. This is due to the Titanium Bonding mechanism property.

Titanium is used in the branch of Maxillofacial Prosthesis for fabrication of cranial implants which are used as a mode of retention in eye and ear prosthesis. They are usually manufactured from Grade V pure titanium.

Commercial titanium-based dental implants undergo various surface treatments which are done by applying various methods such as machining, acid etching, anodization, plasma spraying, grit blasting or combination techniques yielding materials with smooth or micro-roughened surfaces. This is done for the Osseointegration of implant with the bone. [6]

• Subtractive treatments	Additive treatments
Machined	Anodization
• Sandblasted	• Fluoride surface treatment
• Acid-etched surface	• plasma spraying Ti Hydroxyapatite (HA).
• Dual acid-etching	Coating sol-gel
• Sandblasted and acid etched surface (SLA)	• Sputter deposition
• Laser treatment	• Electrophoretic deposition
	• Biomimetic precipitation
	• Drugs incorporated

Table 2: Various types of surface treatments

Titanium is used in fabrication of implant abutments. Zygoma implant abutments are similar to multi-unit abutments which are made of commercially pure titanium (Ti6AL4V).[7] Temporary abutments can also fabricated using titanium. They are used during the provisional phase, prior to the final restoration and are made of surgical grade titanium alloy (Ti6Al4V). They can be used in situations when temporization is required for a long period (>30 days). Nobel Biocare was the first company to introduce multi-unit abutments in the year 2001 and is designed for the restorations of partially edentulous, completely edentulous arches.[8]

Titanium has played a key role in field of Nanotechnology. Titanium nanostructures have exhibited great potential for better bone integration and the regeneration properties. Designs of micro/nano-hybrid titanium surfaces have exhibited very superior implant surface properties.[9]

Titanium has been used in implant supported overdenture prosthesis for fabrication of various type of attachments used in it. The example of such is the Locator attachments.[10]

Mini dental implants are a type of dental implants with diameters less than 3.0 mm. They have advantages including reduced bleeding, less postoperative discomfort, shortened healing time, and immediate loading. They use titanium in it's fabrication process. In vitro and in vivo studies have shown that Ultrafine graded-Ti can promote adhesion and proliferation of the osteoblasts and it's excellent mechanical properties and

biocompatibility suggest that it is a promising material for mini dental implants.

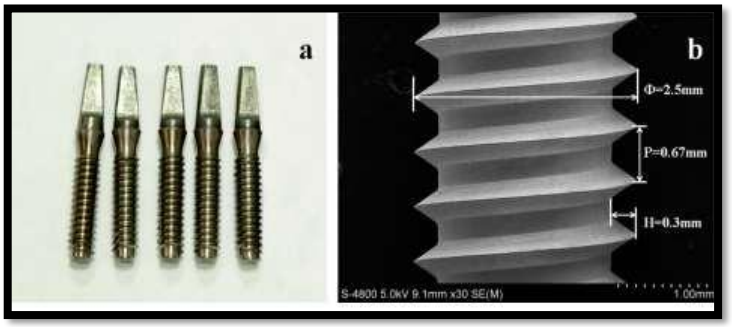

Figure 1: Ultra fine graded-Ti mini implants

Role in Endodontics

Titanium as various applications in the field of Endodontics. Nickel-titanium rotary instruments have become very popular for endodontic treatment because of their lower elastic modulus compared with stainless steel that enables these instruments to negotiate curved root canals with considerably lower likelihood for failure. This is because of shape memory effect of titanium. They have significantly improved resistance to clinical failure and manufactured by some process that minimizes the production of surface cracks, or nickel-titanium alloys with improved fracture toughness must be used.[11]

Titanium is also used for fabrication of metallic posts that have density similar to gutta-percha.[12]

Role in Orthodontics

The introduction of the beta-titanium alloy in the 1970s provided a wire that had the formability similar to the austenitic stainless steel while delivering much lower biomechanical forces. Beta-titanium wires can also be welded, but they have a tendency to fracture and possess a high coefficient of friction.

Nickel-titanium (NiTi) orthodontic wires are especially well suited for clinical situations that require flexibility and exceptional elastic memory. They have a low stiffness, large working range, and produce very low forces and have limited formability, produce higher frictional forces, and cannot be soldered. The NiTi superelastic wire provides considerable deflection in reduced and relatively constant amounts of force.[13]

Mini implants are widely used in orthodontics nowadays that uses titanium for it's fabrication.[14]

Titanium brackets have been introduced to overcome the deficiencies and disadvantages of the stainless steel brackets. It consists of pure titanium or a titanium alloy (Titanium-6Aluminium-4Vanadium) and has good biocompatibility and experiences less friction , which would aid in effectiveness of arch- guided tooth movement. The combined use of titanium brackets in combination with the use of acidic fluoride dentrifrice and fluoridated foods is completely harmless for the bracket and does not cause corrosion.[15]

Role In Oral Surgery

Titanium has the desired mechanical properties to serve as an internal rigid fixation material due to a high degree of biocompatibility The titanium plates and screws contribute to the internal fixation in maxillofacial osteotomies and fractures. The important properties a material needs to possess in order to fulfil its functions are tensile strength and hardness. Osteosynthesis treatment was improved once the titanium alloys were introduced in the maxillofacial fractures. Ti-6Al-4V (TAV), Ti-GAl-7Nb (TAN) and Ti-6Al-4V ELI (TAV ELI) are the most frequently used titanium alloys in the fabrication of miniplates and the orthopedic devices.[16]

Role In Periodontics

A barrier membrane is used primarily in implant, oral and periodontal surgery to prevent the epithelium from growing into an area where bone growth is desire and this method of preventing epithelial migration into a specific area is known as guided tissue regeneration (GTR).

Titanium-reinforced PTFE33 - Titanium reinforcement of PTFE allows shaping of these

membranes and can be used for the socket preservation procedures.

Titanium mesh - Titanium meshes were introduced in 1969 by Boyne and were mainly used to treat continuity defects in the maxilla and mandible. - The rigidity of titanium aids in space maintenance and prevents collapse of the contour. It also prevents graft displacement, permit bending, contouring, and adaptation to any bony defect and limit bacterial contamination due to its smooth surface. Some of the drawbacks of using titanium are: Increased stiffness of titanium sometimes leads to mucosal irritation Adapting a titanium mesh to a defect may require trimming, which may cause exposure of the membrane.

Applications in Medicine

Soft commercially pure titanium is used for cranial surgery where formability is very essential. The hard grades are available for bone plates and screws while the medium strength alloys such as IMI 31 (Ti-6A1-4V) are now the principal titanium materials for total joints such as the knee and the hip. Other areas of medicine where the high strength to weight characteristics of titanium are beneficial are in the manufacture of artificial limbs, in external fixation devices, and in wheel chair production.[17]

DISCUSSION

Research is being conducted to improve the properties of the Stainless Steel implants by coating with materials like Titanium Nitride (TiN) and Tungsten Carbide (WC). These methods have demonstrated improved values of wear resistance and hardness, thus improving the properties of the base (Stainless Steel 316L) metal.

The future of surface modification techniques would be to develop the nanoparticle and multifunctional coatings that would combine the advantages of different coatings and provide more favourable method of surface modification.

It has been proved that surface modification has potential to improve the performance of the Titanium implant, thus further research is necessary to develop the novel surface modification techniques which will produce an implant which will have superior biocompatibility, antibacterial property, corrosion and wear resistance.[18]

A novel method to rapidly deposit bone apatite-like coatings on titanium implants in simulated body fluid (SBF) has been proposed by Han et al. The processing was composed of two steps: micro-arc oxidation of titanium to form titania (TiO2) films, and UV-light illumination of the titania-coated titanium in simulated body fluid.[19]

CONCLUSION

Due to the several possibilities of using titanium, it seems to be a promising material in modern Dentistry. Because of its physiological inertia, biocompatibility, corrosion resistance, and combination of strength and lightness; it can be considered a versatile and utile biomaterial which will probably increase its importance in dentistry.

A wide use of titanium in dental prosthesis will depend on the technological advancements and more laboratorial and clinical investigations in order to develop more profitable techniques proving its efficiency.

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