Titanium- A Boon in Prosthodontics

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Abstract:

Aim: The objective of this study was to describethe different uses of titanium in Dentistry, reviewing its historical development and discoursing about its state of art and future perspective of its utilization.[1]

Introduction: Titanium is a metallic element known by several attractive characteristics, such as biocompatibility, excellent corrosion resistance and high mechanical resistance. It is widely used in Dentistry, with high success rates, providing a favorable biological response when in contact with livetissues.[1]

Material and Methods: A search in the MEDLINE/PubMed database was performed using the terms 'titanium', 'Prosthodontics', 'implants', osseointegration'. The title and abstract of articles were read, and screening of articles was done and their full-texts were downloaded. Additional text books and manual search of reference lists within selected articles were included.

Results: Although there are wide applications of Titanium in Prosthodontics, its use for prostheses frameworks still needs technological improvements in order to surpass its limitations.

Conclusion: This article will highlight the following aspects of titanium like extraction from its ores, properties, uses in Prosthodontics including complete dentures, RPD's, FPD's and especially in Implantology.

Introduction: Titanium is the fourth most abundant metallic element in the earth's crust. It occurs chiefly as an oxide ore. The commercially important forms are rutile (titanium dioxide) and ilmeite(titanium-iron oxide), the former being richest in titanium content. Titanium was first discovered by William Gregor in 1791 who called it menachite. It was rediscovered by a German chemist M.G. Klaproth in 1795 who named it titanium, after the powerful mythological first sons of the earth – the titans.

The use of titanium and titanium alloys for medical and dental applications has increased dramatically in recent years. Over the past three decades, the development of new processing methods-such as lost-wax casting, computer-aided machining and electric discharge machining has expanded titanium's useful range of applications in biomedical devices. Today, titanium and titanium alloys are used for the fabrication of prosthetic joints, surgical splints, stents and fasteners, dental implants, dental crowns and partial denture frameworks.

History: Towards the end of 19th century in 1887, H. Moissan, Nilson and Petterson succeeded in producing 95% pure titanium. Hunter et al in 1910 in the USA produced the first moderately pure sample of titanium. In 1938 Wilhelm Kroll produced titanium, which involved the reduction of chloride. In the year 1940, he published the first acceptable process of producing titanium and named it Dr. Kroll's process. Dr. Kroll is considered as the father of titanium industry.

It was in the year 1950, Swedish scientist Peringvar Branemark observed that titanium could bond with bone and termed this as osseo-integration. In

1970's and 1980's American Dental Association accepted the commercially pure titanium implants. In 1980 Screw type Titanium-implants with external hexagonal heads were introduced.

Properties: Titanium is a unique material, as strong as steel with less than 60% of its density. In its unalloyed condition, titanium is as strong as steel, but 45% light in weight. The most noted chemical property of titanium is its excellent resistance to corrosion.

ASTM International (the American Society for Testing and Materials) recognizes four grades of commercially pure titanium, or Ti, and three titanium alloys (Ti-6Al-4V, Ti-6Al-4V Extra Low Interstitial [low components] and Ti-AlNb).[2]

Titanium is a highly reactive metal that readily passivates to form a protective oxide layer, which accounts for its high corrosion resistance. The low density of titanium provides for high-strength, lightweight prostheses. Additionally, dental porcelain can be fused and bonded to titanium to produce an aesthetic, life like restoration.

Titanium must be melted in a vacuum or under inert gas to prevent oxidation and the incorporation of oxygen that can lead to embrittlement of the cast metal.[6] Contamination with even low concentrations of atmospheric oxygen can lead to significant loss of ductility. The molten alloy also can react readily with refractory investment materials, requiring careful selection of compatible materials, removal of the surface-reacted layer of metal or both. 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 nanometres thick.[3,4]

The presence of Tio_2 on the implant surface which is responsible for Osseo-integration with the bone has made it comparatively popular than other implant materials. 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, adhesive polymers or in the case of endosseous implants, plasma-sprayed or surface-nucleated apatite coatings.

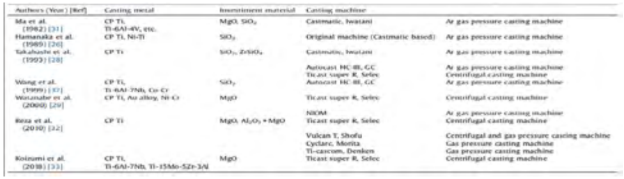
Reports on the allergy to nickel, has helped Titanium to enter into the field of removable partial dentures.

Discussion:

Titanium in complete denture- Ti and its alloy have been verified in complete denture construction and are used to make denture bases after superplastic forming of Ti. Superplastically formed material would only need to be heated to 0.6Tm (K), so that problems associated with thermal mismatch of the investment material, casting shrinkage and porosity would be avoided. The slow strain rates of between 5 x 10 -4 s-1 and 1 x 10-4s-1 used for forming the components would reduce the likelihood of internal stresses leading to dimensional changes on cooling.[7] The process typically conducted at high temperature and under controlled strain rate, giving ten-fold increase in elongation compared to conventional room temperature processes. The evolution of pressure must be closely controlled during the process since the alloys of interest only exhibit superplastic behavior for certain temperature dependent range of strain rate. Specific alloys of titanium, stainless steel and aluminium are commercially available with fine-grained microstructure and strain rate sensitivity of flow stress that are necessary for superelastic deformation. SPF can produce parts that are impossible to form using conventional techniques. During the SPF process, it is heated to the SPF temperature within a sealed die. Inert gas pressure is then applied, at a controlled rate forcing the material to take the shape of the die pattern. The flow stress of the material during deformation increases rapidly with increasing strain rate. Superplastic alloys can be stretched at higher temperatures by several times of their initial length without breaking. The superplastic forming of Ti-6Al-4V was made to apply to fabrication of partial denture major connector and denture base.

Titanium in removable partial denture prosthosis- Successful use of titanium in implants confirmed its biocompatibility beyond doubt. Its favorable mechanical properties such as low density, strength and outstanding corrosion resistance encouraged researchers to employ it in removable partial denture prosthesis. Although conventional base metal partial denture alloys were serving the purpose hypersensitivity reactions had been reported to them[38]. Hence Ti was considered as an alternative to these alloys. While evaluating of Ti and its alloys for rpd[8] it showed several advantages over conventional alloys such as titanium has increased resiliency and makes it more like gold alloys. This property would allow for the retentive clasp arm of RPD to be placed in deeper undercuts on abutment. The hardness value of commercially pure Ti is almost identical to gold alloys and significantly lower than base metal alloys. Although the hardness value is not the sole determinant of abrasiveness, Ti is expected to be more compatible to opposing enamel surfaces. Lower density of Ti approximately one quarter that of gold alloys and half that of Cr-Co alloys is an advantage especially when removable partial denture is constructed of all metal components, reducing markedly the overall bulk of the prosthesis. Retentive forces of TÍ-6A1-4V and Co-Cr RPD clasps were measured on a standard model initially and after 500 reseatings.[9] It was found that clasps made from Ti alloy are able to maintain more of their retention than are Co-Cr clasps.

Titanium in fixed partial denture prosthesis- High noble and noble alloys were first to be used in this field. They have the longest record of successful clinical use demonstrating excellent castability and fit as well. However the allergic and carcinogenic potentials of nickel and beryllium were reported in patients. Possibility of adverse health reactions. Titanium with its excellent corrosion resistance, bio-inertness, and favorable mechanical properties such as low density, high elastic modulus, and adequate strength fulfill most of the criteria. The casting of titanium crowns was noted in early 1970's with works of Waterstratt of US National institute of standards and technology. Alternatives to casting were investigated in the form of machine duplication and spark erosion was introduced by Andersson et al and it is being used clinically with success[4]. An early two-year clinical study reported on restoration with dental cast crowns made of titanium[10]. Titanium was cast using a two-chamber vacuum pressure type casting machine and MgO type investment material. Since the expansion of the mold material was not sufficient, a spacer was used on the stone model. Based on the evaluation of 111 crowns for each metal, the fitness of titanium crowns was superior in 19%, equal in 43%, and inferior in 38% crowns compared to those made of the Ag–Pd–Au alloy. Compared to nickel–chromium alloy, the fitness was superior in 56%, equal in 33%, and inferior in 7%. Problems in occlusal adjustment occurred in 12% of titanium crowns, which was similar to those for the other two alloys. In a follow-up of two years after setting, 62 titanium crowns were examined. Discoloration and wear were found in one case for each, and the degree of plaque adhesion to the crowns was not different among the alloys[10].



Authors (Year) [Ref]	Casting metal	Investment material	Casting machine	
Ma et al. (1982) [31]	CP Ti, Ti-6Al-4V, etc.	MgO, SiO_2	Castmatic, Iwatani	Ar gas pressure casting machine
Hamanaka et al. (1989) [26]	CP Ti, Ni-Ti	SiO_2	Original machine (Castmatic based)	Ar gas pressure casting machine
Takahashi et al. (1993) [28]	CP Ti	SiO_2, $ZrSiO_4$	Castmatic, Iwatani	Ar gas pressure casting machine
			Autocast HC-III, GC Ticast super R, Selec	Ar gas pressure casting machine Centrifugal casting machine
Wang et al. (1999) [37]	CP Ti, Ti-6Al-7Nb, Co-Cr	SiO_2	Autocast HC-III, GC	Ar gas pressure casting machine
Watanabe et al. (2000) [29]	CP Ti, Au alloy, Ni-Cr	MgO	Ticast super R, Selec	Centrifugal casting machine
			NIOM	Ar gas pressure casting machine
Reza et al. (2010) [32]	CP Ti	MgO, Al_2O_3 + MgO	Ticast super R, Selec	Centrifugal casting machine
			Vulcan T, Shofu Cyclarc, Morita Ti-cascom, Denken	Centrifugal and gas pressure casting machine Gas pressure casting machine Gas pressure casting machine
Koizumi et al. (2018) [33]	CP Ti, Ti-6Al-7Nb, Ti-15Mo-5Zr-3Al	MgO	Ticast super R, Selec	Centrifugal casting machine

Table no .1 research on titanium castability

Koizumi H, Ishii T, Okazaki T, Kaketani M, Matsumura H, Yoneyama T. Castability and mechanical properties of Ti-15Mo-5Zr-3Al alloy in dental casting. J Oral Sci2018;60:285–92

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Titanium in implantology: Titanium is a material of choice largely because of its biocompatibility, it may be also that it's low modulus of elasticity, its machinability into strong hollow tubes and its potential to be plasma sprayed of heat sintered in powder form to create porous implant surface makes it a preferred metal.

In Implantology Titanium plays a major role as:

1. Titanium as an implant material: It is clear that the proven high biocompatibility of titanium as an implant material is connected with the properties of its surface oxide. TiO2 is very resistant against chemical attack, which makes titanium one of the most corrosion resistant metals, particularly

in the chemical environment with which we are concerned.

2. Concept of Osseointegration: Osseointegration is characterized by a number of clinical as well as ultra structural observations. It may broadly be defined as the dynamic interaction of living bone with that of a biocompatible implant in the absence of an interposing soft tissue layer Branemark et al. Several studies have analyzed this bone to titanium interface histologically and ultrastructurally, with often-inconsistent findings. The difficulty arises primarily with the need to prepare and section the specimens, without changing or damaging the interface.
3. Structural aspect of interface between tissue and titanium implants: Epithelial cells attach to titanium surfaces in much same manner as they attach to natural tooth surfaces. The literature published by Branemark's group was reviewed and it was proposed that deep within the gingival crevice, collagen fibers could be expected to form a light cuff around the implant abutment. Fibroblasts produced glycosaminoglycans during healing which may coat the implant surface additionally, fibroblasts and endothelial cells, present in the healing wound extracellular matrix, produce 'Fibronectin' a GP found in lamina densa, which binds to collagen and glycosaminoglycans representing the 'glue' between implant and type IV collagen of lamina densa. In contrast to the natural tooth, macroscopic evaluations suggest that implants display no periodontal ligament or gingival sulcus. The epithelium has been observed to have a tight adaptation to the collar of the implant with little inflammation, presumably in the absence of dental plaque. At a cellular level, the relationship of an implant with the surrounding tissue is highly dependent on the interaction between a passive titanium oxide (TiO2), which is formed on the surface of a titanium implant, and biological elements such as collagen, osteoblasts, fibroblasts and blood constituents.
4. Titanium implant surface treatments: Surface modification is one of the most common approaches as the surface properties can be selectively modified while retaining the desirable bulk attributes of the materials. The osseointegration process is influenced by a wide range of factors: anatomical location, implant size and design, surgical procedure, loading effects, biological fluids, age and sex, and, in particular, surface characteristics. For this reason, several attempts have been aimed at modifying implant surface composition and morphology to optimize implant-to-bone contact and improve integration. Preliminary interactions between implanted materials and biological environment are deemed to be governed by the surface properties; they control the amount and quality of cell adhesion on the surface and, consequently, cell/tissue growth. Surface modification can be done by- a) Mechanical methods- Sand blasting By Al_2O_3,By ZrO_2 b) Chemical methods- Acid etching c) Combination of mechanical and chemical d) Electrochemical e) Ion implantation.

Summery and conclusion: The main reason for employing titanium in dentistry was its excellent biocompatibility. Its successful osseointegration was a major achievement in the field of dental and cranio-facial Implantology. Improvements in design, surface characteristics and clinical implantation techniques have resulted in increased success rates over the years. Research regarding feasibility of use of titanium in fixed and removable prosthesis began subsequently at various institutions and laboratories across the world. Titanium had many enticing characteristics such as bio-inertness and favorable mechanical properties viz., low density, adequate strength, flexibility etc. However it had some technical problems due to its high reactivity and high melting point making it difficult to cast with conventional methods and further research needs to be made on the same.

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