

APPLICATION OF Ti AND Ti ALLOYS IN DENTAL IMPLANTOLOGY

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Abstract: The aim of the present communication is to evaluate the existing scientific evidence on the rising application of titanium and titanium alloys for the preparation of implants in dental surgery. The choice of suprastructure alloy combined with titanium for the oral cavity is still controversial and needs investigations of the electrochemical interaction of the suprastructure/implant couples. Nowadays multiform coated titanium implants are widely used in this field. There exist numerous biomaterials currently used in restorative implant dentistry. Their properties can be assessed by a variety of methods such as histology, histomorphometry, scanning electron microscopy, mechanical testing, computer-quantified tissue morphology, computer-aided design and computer-assisted manufacturing, radiography, three-dimensional finite element analysis, resonance frequency of Astra Tech TiO₂ blasted implants at second surgery, etc. Implant stability is considered as a factor influencing on the achievement of osseointegration. The stability of titanium dioxide grit-blasted dental implants is improved with fluoride treatment during the first six months following implant placement. A special attention should be paid to antibacterial/bacteriostatic titanium, titanium nanocoating and nanopatterning as well as to antimicrobial drug/titanium implant. Both early and immediately loaded implants present with a high clinical level of osseointegration as shown by the bone-titanium interface of immediately loaded and submerged titanium implants. A superior biocompatibility and osteogenic efficacy of micro-arc oxidation-treated titanium implants is experimentally proved. The analysis of effects of titanium ions on the cell viability and differentiation demonstrates that they exert the biological effects, both on the viabilities of osteoblast and osteoclast and on the differentiation of either the osteoblastic or osteoclastic cells, which may influence on the prognosis of dental implants. Further studies would try to elucidate the benefits of titanium and its alloys in dental implant surgery.

KEYWORDS: TITANIUM, TITANIUM ALLOY, PHYSICAL PROPERTIES, DENTAL IMPLANTS

1. Introduction

More than 25 years ago, initial steps in the application of titanium and its alloys as dental material were done [1]. Titanium and its alpha-beta alloys possess mechanical properties that make them ideal implant materials. They oxidize readily in air. This surface oxide is extremely stable in the physiologic environment of the body. Its stability and inertness acts to protect titanium from corrosive breakdown when used in the body. The elimination of surface irregularities and contaminants is important when preparing a metal for implantation. Titanium can be coupled with equally passive metals in the body without causing galvanic corrosion. Because of light weight, high strength to weight ratio, low modulus of elasticity, and excellent corrosion resistance, titanium and some of its alloys have been important materials for several industries [2]. With the additional advantages of excellent biocompatibility, good local spot weldability, and easy shaping and finishing by a number of mechanical and electrochemical processes, these materials are widely used in dental implantology and restorative dentistry.

Nowadays titanium is used for orthodontic wires, endodontic files, dental implants, and cast restorations. Its popularity is primarily due to its good mechanical properties, high corrosion resistance, and excellent biocompatibility [3]. According to the ADA Council on Scientific Affairs [4], titanium and its alloys are especially suitable for dental implants and prostheses and thus considered the materials of choice, e. g. for endosseous implant

devices. They are viable options to more traditional noble and base metal alloys for crown and bridge prostheses. However, titanium can also cause chemical-biological interactions, such as tissue discoloration and allergic reactions.

The aim of the present communication is to evaluate the existing scientific evidence on the rising application of titanium and titanium alloys for the preparation of implants in dental surgery.

2. Retrospective search

Our own problem-oriented retrospective search in *Web of Science* of Thomson Reuters (Philadelphia, PA, USA) for 1985 - May 2012 demonstrates a dramatic growth of the world publication output in the very narrow field of 'titanium dental implants'. There are 2818 publications in 12 languages by authors from 69 countries in 461 journals and 220 conferences. In 1985-1990 there are only 14 papers while in 2004-2009 they amount to 1564. Original articles prevail (2336) followed by conference papers (327), review articles (115), meeting abstracts (19), etc. (Fig.1). The journal '*Clinical Oral Implants Research*' comes first with 408 papers (14,48% of all the papers) followed by the '*International Journal of Oral & Maxillofacial Implants*' with 371 papers (13,17% of all the papers) (Fig.2). The sum of the times cited is 41,175, of which 12,967 are not self-citations. The average citations per item are 14,61, those per year - 1583,65. The h-index is relatively high - 78.

K. Subramani et al. [5] conduct an electronic MEDLINE

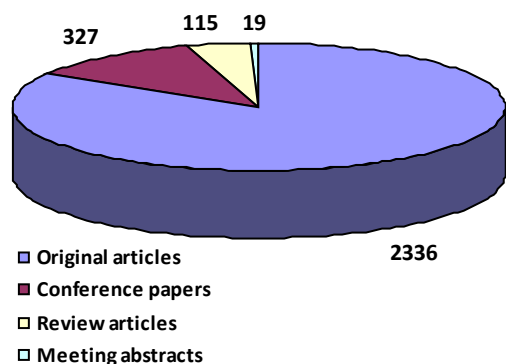


Fig.1. Publication output in the field of 'titanium dental implants' for 1985 - May 2012.

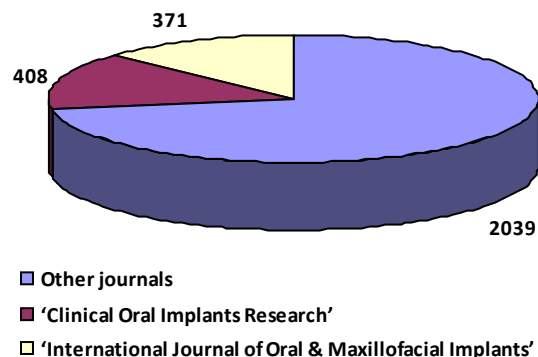


Fig.2. Distribution of publications in different journals.

literature search of studies of biofilm formation on dental implants published between 1966 and June 2007. They pay attention to the influence of surface characteristics of implant biomaterials, especially titanium, and design features of implant and abutment components on biofilm formation. Basic research articles on surface modification of titanium are analyzed to reveal the role of fabrication of implant surfaces that could possibly decrease early bacterial colonization and biofilm formation.

3. Biocompatibility of Ti implants

Biocompatibility is the ability of a material to perform with an appropriate host response in a specific application. It can be achieved in several ways. Either an implant can be made from a biocompatible material and then implanted directly. Otherwise, biocompatibility can be achieved by coating the implant with a biocompatible material, or modifying the surface in another way.

G. L. Yang et al. [6] evaluate comparatively the effects of biomimetically and electrochemically deposited nano-hydroxyapatite (HA) coatings on the osseointegration of porous titanium implants after 6 and 12 weeks of insertion. These implants belong to three groups: roughened, biomimetically deposited CaP (BDCaP) and electrochemically deposited HA (EDHA). The authors prove that the EDHA coating has a better bone integration potential than BDCaP one. G. L. Yang et al. [7] examine these effects on the fixation of a titanium implant with bone tissue. The authors establish that the electrochemical HA coating contributes better to the fixation between bone and implant than the roughened surface, whereas the biomimetic calcium-phosphorus coating has little effect on the fixation.

The efficacy of a bioactive glass-ceramic (Biosilicate) and of a glass (Biogran) placed in dental sockets in the maintenance of alveolar ridge and in the osseointegration of titanium implants has been evaluated and the percentages of bone-implant contact, of mineralized bone area between threads, and of mineralized bone area within the mirror area has been determined [8]. The filling with Biosilicate or Biogran particles preserves alveolar ridge height without affecting its width and allows titanium implant osseointegration. A. Scarano et al. [9] establish a statistically significant correlation ($p=0,016$) between the bone-implant contact percentage of retrieved human titanium implants and resonance frequency analysis (RFA) values. The relationship between RFA values and their association with implant osseointegration, success, or failure is important from a clinical point of view.

R. J. Miron et al. [10] assess the effect of Emdogain, an enamel matrix derivative (EMD) on the attachment, proliferation and differentiation of osteoblasts on titanium surfaces *in vitro*. EMD significantly increases cell spreading and proliferation at time between 3 and 7 days. Alkaline phosphatase activity is significantly increased on EMD-coated titanium compared with titanium alone.

4. Corrosion resistance of Ti implants

One of the principal requirements of all medical implants is corrosion resistance. The consequences of corrosion are the disintegration of the implant material, which weakens the implant, and the harmful effect of corrosion on the surrounding tissues and organs is produced.

According to B. Bozzini et al. [11], in dental applications, the contact between the metal implant and the receiving living tissue is made through the oxide layer on the implant surface allowing the osseointegration process. The passive film formed on titanium is more stable and protective than that formed on the titanium alloys used in other medical applications. Their corrosion in the mouth can result from the presence of a number of corrosive species, such as the hydrogen ion, sulfide compounds, dissolved oxygen and chlorine and cause the release of titanium ions that reduce alkaline phosphatase activity of osteoblastic cells. Surface Raman spectroscopic measurements demonstrate that the corrosion resistance of the oxide films formed on titanium is strongly affected

by the presence of biomolecules in the chloride- and phosphate-based aqueous solution.

Because of the increasing use of implants in restorative dentistry a special attention should be devoted to the galvanic combination of restorative materials with titanium. R. Venugopalan and L.C. Lucas [12] study galvanic corrosion properties of restorative and implant materials coupled with titanium (ASTM F67-Grade II). Noble restorative (Au-, Ag-, and Pd-based) alloys coupled to titanium are least susceptible to galvanic corrosion. Co-Cr-Mo, Ni-Cr and Fe-based alloys coupled to titanium are moderately susceptible to it due to mechanical-electrochemical interaction while Ni-Cr-Be alloy coupled to titanium is highly susceptible to it. According to K.T. Oh and K.N. Kim [13], suprastructures and implants of different compositions (Co-Cr/Ti, Ni-Cr, Co-Cr, Ag/Ti and Ni-Cr/Ti couples) in electrical contact may develop galvanic or coupled corrosion problems. Crevice and pitting corrosion may occur in the marginal gap between dental implant assemblies. However, both potentiodynamic and potentiostatic testings performed in artificial saliva at 37°C with Co-Cr/Ti implant couples show a possibility of galvanic corrosion of insignificant degree only.

Y. Tamura et al. [14] examine corrosion, other related properties and biocompatibility of surface nitride titanium to reveal its possible use as an abrasion resistant implant material. They establish that the wettability, corrosion resistance, and biocompatibility of nitride titanium are nearly equivalent to those of titanium itself as an implant material for an abutment part of a dental implant requiring high abrasion resistance. The long-term behaviour of titanium and Ti-5Al-4V alloy-Carter-Brugirard saliva interface and the short-term resistance of titanium and Ti-5Al-4V alloy-Tani&Zucchi saliva interface is studied by means of a potentiodynamic polarization method [15]. In Carter-Brugirard saliva both titanium and Ti-5Al-4V alloy present very stable passive films, long-term stability, very good resistance and low values of the open circuit potential gradients which cannot generate local corrosion.

M. Takahashi et al. [16] characterize the relationship between the corrosion behaviour and the microstructures of cast titanium-silver (Ti-Ag - 5-40% Ag) alloys. The microstructures of the corroded alloy surfaces indicate the deterioration of precipitated intermetallic compounds along the grain boundaries. The Ti-Ag alloys up to 17,5% Ag have excellent corrosion resistance similar to that of pure titanium. M. E. Souza et al. [17] examine the corrosion properties by using potentiodynamic anodic polarization, cyclic polarization and electrochemical impedance spectroscopy (EIS) to evaluate the electrochemical behaviour of two commercial titanium alloys - Ti-6Al-4 V (ASTM F136) and Ti-13Nb-13Zr (ASTM F1713) in Ringer physiological solution at pH of 5,5 and 7,0. The corrosion of commercially available, machined titanium implants is estimated by open circuit potentials, linear polarization resistance and EIS [18]. It is suggested that inflammatory stress and hyperglycemia may increase the corrosion of dental endosseous titanium-based implants. S. Kumar and T. S. Narayanan [19] evaluate the corrosion behaviour of Ti-15Mo alloy in 0,15M NaCl solution containing varying concentrations of fluoride ions. They prove that this alloy is a suitable alternative for dental implant applications.

5. Clinical investigation

M. Degidi et al. [20] perform a clinical follow-up study of 142 TiUnite (Nobel Biocare, Göteborg, Sweden) immediately loaded titanium implants with a porous anodized surface in fixed restorations in 50 completely edentulous mandibles and 50 completely edentulous maxillae for at least 3 years. They have been subjected to immediate functional loading (IFL) (immediate restoration with full occlusal contact) while 23 implants have undergone immediate nonfunctional loading (INFL) (immediate restoration without occlusal contact) in different anatomical configurations (single tooth, small bridges in the anterior mandible, anterior maxilla, and posterior maxilla). All implants are

osseointegrated from a clinical and radiographic point of view. There are no failures in the IFL and INFL groups. The mean marginal bone loss is 0,8 mm and 1,0 mm at 12 and 36 months, respectively. M. Degidi et al. [21] examine 20 patients with edentulous maxillae who have received a fixed restoration supported by an intraoral welded titanium bar. Final abutments are connected to the implants and welded to a titanium bar using an intraoral welding unit. Mean marginal bone loss and radiographically detectable alteration of the welded framework have been assessed by using periapical radiographs immediately after surgery and at 6- and 12-month follow-up examinations. Between 0 and 6 months, mean marginal bone loss is 0,43 mm, between 6 and 12 months it is 0,14 mm, and accumulated mean marginal bone loss is 0,57 mm. In 2009, an analysis has been done of the histologic and histomorphometric patterns of the bone-titanium interface in immediately restored implants with and without occlusal contact, retrieved after a healing period of 5 weeks [22]. Two freestanding implants have been inserted in the posterior mandible. There are no differences in the histologic response around immediately restored implants with and without occlusal contact. Human biopsy of immediately loaded implants is the most definitive means to determine the occurrence of osseointegration. The prospective evaluation of the suitability of intraoral welding of titanium implant frameworks to allow placement of the definitive restoration of the edentulous mandible on the same day of surgery shows that all implants have osseointegrated [23]. There are no fractures or radiographically detectable alterations of the welded frameworks. All implants are clinically stable at the 24-month follow-up.

T. Traini et al.[24] analyze the bone mineral density of peri-implant bone under different techniques of 5 unloaded titanium dental implants with a micro-structured surface (3 XiVE plus and 2 Frialit 2, DENTSPLY-Friadent, Mannheim, Germany) from the mandible of 5 patients after a 6-month period. These authors use scanning electron microscopy with back-scattered electron signal (BSE), light microscopy (LM) with a double staining technique, fluorescence microscopy (FMi) and confocal laser microscopy for measuring microscopic mineral content variations in peri-implant bone, histomorphometry and image intensity. FMi analysis shows clearly the difference between old (high mineralized) and new (low mineralized) bone tissue near the implant surface. Confocal laser microscopy indicates the area of bone modeling closest to this surface while conventional LM technique intensely stains the bone area with a low mineral content.

6. Conclusion

The present review of the recent publications dealing with the physical properties of titanium and titanium alloys and their clinical applications in dental implant surgery demonstrates the obvious necessity of further interdisciplinary research which should elucidate the various benefits and certain disadvantages of these materials.

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