Abstracted references about Titanium Release from Implants and their health effects

How Good Are Those Implants?

Although titanium is used widely as an implant material in medicine, its use in dentistry has become exceptional. It is considered an inert metal but the reality is that it does corrode and release ions which are transported throughout the body. This is even supported by literature published in the Australian Dental Journal [1] and many others. [2,3,4,5,6,7]

A summary of the research which follows shows that many effects are possible from exposure to titanium;

• Damage to human bronchial cells[8]
• Stimulate bone resorption[9]
• Antibody Mediated immune responses[10]
• Excessive corrosion of Titanium is caused by exposure to fluoride[11,12,13]
• Generalized allergic reactions[14,15]
• Amalgam and Titanium in the same mouth increases corrosion of the amalgam and thus the increased release of mercury[16]
• Titanium and amalgam produce dramatic ph changes and a change in taste sensation[17]
• Some are carcinogenic[18] (it is possible that NiTiSMA particles are directly carcinogenic)
• High electrical currents are generated between titanium implants and other metals in the mouth[19,20]

Melisa.org Immune reactivity to Titanium is barely recognized in mainstream medicine - yet laboratories using the MELISA® technology have reported that as many as one in ten people can be affected by it. For those affected with titanium allergy, the symptoms can be multiple and bewildering. These can range from simple skin rashes to muscle pain and fatigue. From foodstuff to medicine, titanium is now an everyday metal. Several brands of candy, such as Skittles and M&M, have titanium dioxide in the coating - often described by its E-number: E171. Some brands of toothpaste contain titanium particles. Hospitals use titanium implants to rebuild bones after accidents. More than just a rash: the effects of titanium allergy Like all metals, titanium releases particles through normal corrosion. These metals become ions in the body and then bind to body proteins. For those who react, the body will try to attack this structure. This starts a chain reaction which can lead to many symptoms including chronic fatigue syndrome (CFS) or, in the most severe cases, Multiple Sclerosis (MS). The MELISA® test is the only scientifically-proven test which can diagnose titanium allergy and measure its severity. Those who test positive should avoid exposure or remove the titanium from their body to stop the internal reaction. This can be simple, like changing brand of toothpaste. Or it can be more complex, such as replacing titanium implants.

Ultrafine titanium dioxide particles in the absence of photoactivation can induce oxidative damage to human bronchial epithelial cells. **Bi Y**, JR, Wang AS, Chen CH, Jan KY. Toxicology. 2005 Sep 15;213(1-2):66-73.

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Ultrafine titanium dioxide (TiO(2)) particles have been shown to exhibit strong cytotoxicity when exposed to UVA radiation, but are regarded as a biocompatible material in the absence of photoactivation. In contrast to this concept, the present results indicate that anatase-sized (10 and 20 nm) TiO(2) particles in the absence of photoactivation induced oxidative DNA damage, lipid peroxidation, and micronuclei formation, and increased hydrogen peroxide and nitric oxide production in BEAS-2B cells, a human bronchial epithelial cell line. However, the treatment with anatase-sized (200 and >200 nm) particles did not induce oxidative stress in the absence of light irradiation; it seems that the smaller the particle, the easier it is for the particle to induce oxidative damage. The photocatalytic activity of the anatase form of TiO(2) was reported to be higher than that of the rutile form. In contrast to this notion, the present results indicate that rutile-sized 200 nm particles induced hydrogen peroxide and oxidative DNA damage in the absence of light but the anatase-sized 200nm particles did not. In total darkness, a slightly higher level of oxidative DNA damage was also detected with treatment using an anatase-rutile mixture than with treatment using either the anatase or rutile forms alone. These results suggest that intratracheal instillation of ultrafine TiO(2) particles may cause an inflammatory response.

Titanium particles stimulate bone resorption by inducing differentiation of murine osteoclasts. Bi Y, Van De Motter RR, Ragab AA, Goldberg VM, Anderson JM, Greenfield EM. J Bone Joint Surg Am. 2001 Apr;83-A(4):501-8.

CONCLUSIONS: The present study showed that titanium particles stimulate in vitro bone resorption primarily by inducing or survival.

Immunohistochemical study of the soft tissue around long-term skin-penetrating titanium implants. Holgers KM, Thomsen P, Tjellstrom A, Bjursten LM. Biomaterials. 1995 May;16(8):611-6. Department of Anatomy and Cell Biology, University of Goteborg, Sweden.

"The data suggest that there is an immunological compensation for the mechanical loss in barrier function at these implants and that an antibody-mediated response is present at clinical signs of irritation."

In vitro corrosion of titanium. Strietzel R, Hosch A, Kalbfleisch H, Buch D. Biomaterials. 1998 Aug;19(16):1495-9. BEGO, Bremer Goldschlagerei, Bremen, Germany.

Titanium is used in dentistry for implants and frame work because of its sufficient chemical, physical and biological properties. The corrosion behaviour is from high interest to value biocompatibility. A static immersion test was undertaken with a titanium test specimen (30 mm x 10 mm x 1 mm, immersion time = 4 x 1 w, n = 3 for each series). The following parameters were investigated: specimen preparation, grinding, pH-value, different casting systems, comparison with CAD/CAM, influence of: chloride, thiocyanate, fluoride, lactate, citrate, oxalate, acetate. Atomic absorption spectroscopy was used to analyse the solutions weekly. The course of corrosion was investigated photometrically. Titanium reveals ion releases [(0.01-0.1) microg/(cm2 x d)] in the magnitude of gold alloys. There is little influence of grinding and casting systems in comparison with organic acids or pH value. The ion release increases extreme (up to 500 microg/(cm2 x d)) in the presence of fluoride. Low pH values accelerate this effect even more. Clinically, no corrosion effects were observed. Nevertheless it is recommended that it is best to avoid the presence of fluoride or to reduce contact time. In prophylactic fluoridation of teeth, a varnish should be used.

(This is another good reason to avoid fluoride toothpastes)

Sensitivity to titanium. A cause of implant failure? Lalor PA, Revell PA, Gray AB, Wright S, Railton GT, Freeman MA. London Hospital Medical College, England J Bone Joint Surg Br. 1991 Jan;73(1):25-8

Abstract:
Tissues from five patients who underwent revision operations for failed total hip replacements were found to contain large quantities of particulate titanium. In four cases this metal must have come from titanium alloy screws used to fix the acetabular component; in the fifth case it may also have originated from a titanium alloy femoral head. Monoclonal antibody labelling showed abundant macrophages and T-lymphocytes, in the absence of B-lymphocytes, suggesting sensitisation to titanium. Skin patch testing with dilute solutions of titanium salts gave negative results in all five patients. However, two of them had a positive skin test to a titanium-containing ointment.

A case of allergic reaction to surgical metal clips inserted for postoperative boost irradiation in a patient undergoing breast-conserving therapy Tamai K, Mitsumori M, Fujishiro S, Kokubo M, Ooya N, Nagata Y, Sasai K, Hiraoka M, Inamoto T. Breast Cancer. 2001;8(1):90-2

Abstract:
We report a case of a 28-year-old woman with right-sided breast cancer. The patient had been treated for atopic dermatitis since her infancy. She underwent breast-conserving surgery (BCS) in July 1998, and three titanium clips were placed at the margin of the excision cavity at the time of surgery. Two months after surgery, the patient exhibited a rapid exacerbation of atopic dermatitis. Various drugs were suspected to be the cause of the allergic reaction, but the results of a bi-digital O-ring test (BDORT) suggested an allergic reaction to titanium clips. In August 1999, the patient underwent a second operation to remove the titanium clips under local anesthesia. Allergy to surgical titanium clips is a rare complication, but in patients with a history of severe allergic diseases, a preoperative immunologic examination should be performed and the patient's history of metal allergy should be investigated.

Biocompatibility of dental casting alloys Geurtsen W Department of Conservative Dentistry and Periodontology, Medical University Hannover, D-30623 Hannover, Germany. Crit Rev Oral Biol Med. 2002;13(1):71-84.

Introduction:
Most cast dental restorations are made from alloys or commercially pure titanium

(cpTi). Many orthodontic appliances are also fabricated from metallic materials. It has been documented in vitro and in vivo that metallic dental devices release metal ions, mainly due to corrosion. Those metallic components may be locally and systemically distributed and could play a role in the etiology of oral and systemic pathological conditions. The quality and quantity of the released cations depend upon the type of alloy and various corrosion parameters. No general correlation has been observed between alloy nobility and corrosion. However, it has been documented that some Ni-based alloys, such as beryllium-containing Ni alloys, exhibit increased corrosion, specifically at low pH. Further, microparticles are abraded from metallic restorations due to wear. In sufficient quantities, released metal ions-particularly Cu, Ni, Be, and abraded microparticles-can also induce inflammation of the adjacent periodontal tissues and the oral mucosa. While there is also some in vitro evidence that the immune response can be altered by various metal ions, the role of these ions in oral inflammatory diseases such as gingivitis and periodontitis is unknown. Allergic reactions due to metallic dental restorations have been documented. Ni has especially been identified as being highly allergenic. Interestingly, from 34% to 65.5% of the patients who are allergic to Ni are also allergic to Pd. Further, Pd allergy always occurrs with Ni sensitivity. In contrast, no study has been published which supports the hypothesis that dental metallic materials are mutagenic/genotoxic or might be a carcinogenic hazard to man. Taken together, very contradictory data have been documented regarding the local and systemic effects of dental casting alloys and metallic ions released from them. Therefore, it is of critical importance to elucidate the release of cations from metallic dental restorations in the oral environment and to determine the biological interactions of released metal components with oral and systemic tissues.

Corrosion of titanium and amalgam couples: effect of fluoride, area size, surface preparation and fabrication procedures. Johansson BI Bergman B Dent Mater (1995 Jan) 11(1):41-6

OBJECTIVES. The aim of this investigation was to study the effect of surface treatments and electrode area size on the corrosion of cast and machined titanium in contact with conventional and high-copper amalgams in saline solutions with and without added fluoride ions. METHODS. The potentials and the charges transferred between amalgam and titanium couples were registered using standard electrochemical methods. RESULTS. Conventional amalgam corroded more than high-copper amalgams in contact with titanium in saline solutions. Adding fluoride to the solution made the titanium potential more active and enhanced the corrosion of titanium in combination with high-copper amalgams. The amalgam corrosion increased with a five-fold enlargement of the titanium area. The increase was significant for one titanium-amalgam combination. Surface preparations affected the electrochemical behavior, and surface alterations were occasionally observed on wet-ground titanium specimens. No significant differences were found in comparisons of cast and lathe- cut titanium. SIGNIFICANCE. Surface preparations and fluoride affect the electrochemical activity of titanium.

Galvanic corrosion and cytotoxic effects of amalgam and gallium alloys coupled to titanium. Bumgardner JD Johansson BI Eur J Oral Sci (1996 Jun) 104(3):300-8

Results of this study indicated that before connecting the high-copper amalgams to titanium, the amalgams exhibited more positive potentials which resulted in initial negative charge transfers, i.e. corrosion of titanium. However, this initial corrosion appeared to cause titanium to passivate, and a shift in galvanic currents to positive charge transfers, i.e. corrosion of the amalgam samples. ... significant cytotoxic effects were observed when the dispersed-type high-copper amalgam and the gallium alloy were coupled to titanium. Even though the corrosion currents measured for these couples were less than gold alloys coupled to amalgam, these results suggest there is the potential for released galvanic corrosion products to become cytotoxic. .

Corrosion current and pH rise around titanium coupled to dental alloys. Ravnholt G Scand J Dent Res (1988 Oct) 96(5):466-72

Corrosion reactions around titanium, usually considered biologically inert, might be provoked by coupling it galvanically with more corrodible dental alloys. Experiments in vitro simulating the conditions of a titanium dental implant or root canal post coupled to an amalgam filling, demonstrated corrosion current densities up to 31 microA/cm2, anodic pH values around the amalgam down to 2, and cathodic pH values around the titanium up to 10. The amounts of tin released by the enhanced corrosion of amalgam might contribute measurably to the daily intake of this element; the corrosion current generated reached values known to cause taste sensations. If the buffer systems of adjacent tissues in vivo are not able to cope with the high pH generated around the titanium, local tissue damage may ensue; this relationship is liable to be overlooked, as it leaves no evidence in the form of corrosion products.

Morphological transformation of BHK-21 cells by nickel titanium shape memory alloy particles encapsulated by titanium oxide Qin R Peng S Jiang X Chung Hua I Hsueh Tsa Chih (1995 Nov) 75(11):663-5, 708-9

Therefore, it is possible that NiTiSMA particles are directly carcinogenic and that NiTiSMA particles encapsulated by titanium oxide are not potentially carcinogenic.

Evaluation of restorative and implant alloys galvanically coupled to titanium. Venugopalan R Lucas LC Dent Mater (1998 Jun) 14(3):165-72

RESULTS: Noble restorative (Au-, Ag-, and Pd-based) alloys coupled to titanium were found to be least susceptible to galvanic corrosion. Co-Cr-Mo, Ni-Cr and Fe-based alloys coupled to tatanium were found to be moderately susceptible to galvanic corrosion due to mechanical-electrochemical interaction. Ni- Cr-Be alloy coupled to titanium was found to be highly susceptible to galvanic corrosion. The in vitro test results for the titanium/Disperalloy combination does not concur with the published clinical performance of this combination, and thus warrants further investigation.

Corrosion of coupled metals in a dental magnetic attachment system. Iimuro FT Yoneyama T Okuno O Dent Mater J (1993 Dec) 12(2):136-44

Corrosion of titanium and ferromagnetic stainless steel seemed to be accelerated by coupling with gold alloys or gold-silver-palladium alloys.

Polymetallism and osseointegration in oral implantology: pilot study on primate. Foti B Tavitian P Tosello A Bonfil JJ Franquin JC J Oral Rehabil (1999 Jun) 26(6):495-502

After 2 months, the presence of a precious alloy superstructure lead to titanium migration towards the area around the cervical region of the implant (10-50 microm). This phenomenon did not occur with a titanium implant. It can therefore be presumed that polymetallism leads to detectable corrosion after 2 months but without apparent modification of osseointegration.

On electric current creation in patients treated with osseointegrated dental bridges. Nilner K Lekholm U Swed Dent J Suppl (1985) 28:85-92

Electric currents are created when metals or metal alloys are immersed and make contact with each other in an electrolyte. ...The mean potential difference between the two metallic systems was found to be 73 mV and the mean generated maximum electric currents was in the magnitude of 26 microA at oral contacts between titanium and dental gold alloy.

In vivo corrosion behavior of gold-plated versus titanium dental retention pins. Palaghias G Eliades G Vougiouklakis G J Prosthet Dent (1992 Feb) 67(2):194-8

Two types of titanium dental retention pins and a gold-plated stainless steel pin were tested for their in vivo corrosion behavior. ... Traces of Hg, Sn, Cu, S, Zn, Ca, K, Cl, P, and S were detected at the gold-plated pin/amalgam interface, while Cl and P were found at the gold-plated pin/composite resin interface.

Influence of fluoride on titanium in an acidic environment measured by polarization resistance technique. Boere, G. J Appl Biomater, 6(4):283-8, 1995.

Abstract: The effect of sodium fluoride on the polarization resistance of titanium was investigated. ... The results showed a large decrease in polarization resistance with increasing fluoride concentration at pH 4. The polarization resistance at pH 7 remained constant after a slight decrease at a very high value, even with a high fluoride concentration. The results clearly confirm that titanium is attacked by fluoride in an acidic environment. The clinical implications are that fluoride rinses or fluoride gels must have a neutral pH if there is a titanium containing device in the oral environment despite the less prophylactic effectiveness.

Corrosion in titanium dental implants: literature review

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Abstract

The corrosion of dental biomaterials is a pertinent clinical issue. In spite of the recent innovative metallurgical and technological advances and remarkable progress in the design and development of surgical and dental materials, failures do occur. The present article describes the problem of corrosion in titanium dental implants. The clinical significance of the dental implant corrosion is highlighted and the most common form of corrosion i.e. galvanic corrosion is emphasized both in vitro and in vivo conditions. The article is presented keeping in view of carrying out different studies for indigenous titanium dental implant and indigenous alloys. The Department of Dental Research at Institute of Nuclear Medicine & Allied Sciences has developed indigenous Titanium Dental Implants and Base metal Alloys. The studies carried out have proven their biocompatibility and suitability to be used for oral defects. The aim of the study is to evaluate galvanic corrosion current around indigenously developed Titanium Dental Implant when coupled to a Base metal Alloy

Introduction

The use of dental implants in the treatment of complete and partial edentulism has become an integral treatment modality in restorative dentistry. [1] Dental implants first appeared as early as 1930 but their clinical use is widespread since about 20 years. Different materials are being used for dental implants.

The metallic biomaterials follow the general patterns for metal degradation in environmental situations. Metals undergo chemical reactions with non-metallic elements in the environment to produce chemical compounds. Commonly these products are called as corrosion products. One of the primary requisites of any metal or alloy to be used within the human body is to be bio compatible and hence it should not form or help in forming any such products which may deteriorate the metal itself and be harmful.

The oral cavity is subjected to wide changes in pH and fluctuation in temperature. The disintegration of metal may occur through the action of moisture, atmosphere, acid or alkaline solution & certain chemicals Further it has been reported that water, oxygen, chlorides, sulphur corrode various metals present in dental alloys.

Titanium has long been successfully used as an implant material. [2] Titanium is widely used in odontology because of its excellent characteristics such as chemical inertia, mechanical resistance, low density, absence of toxicity, resistance to corrosion and biocompatibility. [3]

Biocompatibility has been defined as the state of mutual coexistence between the biomaterials and the physiological environment such that neither has an undesirable effect on the other. [4] It is the ability of a material to perform with an appropriate host response in a specific application. [5] This means that the tissues of the patient that comes into contact with the materials does not suffer from any toxic, irritating, inflammatory, allergic, mutagenic or carcinogenic action [6],[7] For dental implant, biocompatibility depends on both mechanical and corrosion/degradation properties of the material.

Corrosion, the gradual degradation of materials by electrochemical attack is a concern particularly when a metallic implant is placed in the hostile electrolytic environment provided by the human body. [8] The term corrosion is defined as the process of interaction between a solid material and its chemical environment, which leads to a loss of substance from the material, a change in its structural characteristics, or loss of structural integrity.

During corrosion, casting alloys release elements into the body over the short-term (days) and long term (months). The corrosion of biomaterials depends on geometric, metallurgical and solution chemistry parameters.

General concepts related to corrosion.

The features that determine how and why implant corrodes are:
1. Thermodynamic driving forces, which cause corrosion (oxidation and reduction) reactions. These forces correspond to the energy required or released during a reaction. (Jacobs, 1998) [9]
2. Kinetic barriers to corrosion, which are related to factors that physically, impede or prevent corrosion from taking place. (Jacobs, 1998). [9] The well-known process of passivation or the formation of a metal -oxide passive film on a metal surface, is an example of kinetic limitation to corrosion.

Clinical significance of corrosion

Resistance to corrosion is critically important for a dental material because corrosion can lead to roughening of the surface, weakening of the restoration, and liberation of elements from the metal or alloy. Liberation of elements can produce discoloration of adjacent soft tissues and allergic reactions in susceptible patients.

Fracture of dental implant

Fracture of dental implant is a rare phenomenon with severe clinical results. Corrosion can severely limit the fatigue life and ultimate strength of the material leading to mechanical failure of the implant. It has been found that metal fatigue can lead to implant fracture. Since titanium, the implant material is highly corrosion resistant; the superstructures are the main cause of release of metal ions. Corrosion sets in and results in the leaking of ions into surrounding tissues. 'Nirit Tagger Green' reported a fracture of a dental implant four years after loading. The metallurgical analysis of implant revealed that the fracture was caused by metal fatigue and that the crown-metal, a Nickel -Cr-Mo alloy exhibited corrosion. [10]

Yokoyama et al [11] studied the delayed fracture of titanium dental implant. It was concluded that titanium in a biological environment absorbs hydrogen and this may be the reason for delayed fracture of a titanium implant.

Bone loss & osteolysis

Corrosion related failures are feasible. 'Olmedo et al reported from his study that presence of macrophages in peri-implant soft tissue induced by a corrosion process play an important role in implant failure. [12] These processes lead to local osteolysis and loss of clinical stability of the implant. Macrophages loaded with titanium particles as revealed by EDX analysis were associated with the process of metal corrosion.

The particles that are released are reportedly phagocytosed by macrophages, stimulating the release of inflammatory mediators such as cytokines. These mediators are released towards bone surface contributing to its resorption by osteoblast activation. The presence of metallic particles that result from the process of corrosion may directly inhibit osteoblast function. In this way both an increase in bone resorption and an inhibition in bone formation may occur eventually resulting in osteolysis.

Local pain/ swelling

The corrosion products have been implicated in causing local pain or swelling in the region of the implant in the absence of infection. [17]

Cytotoxic responses

Hexavalent chromium ions are released from implant materials, and several studies have shown that its cellular uptake is several-fold greater than trivalent chromium. [14],[15],[16],[17],[18] Hexavalent chromium causes several cytotoxic responses including decrease in some enzyme activities, interference with biochemical pathways, carcinogenicity, and mutagenicity. [19],[20],[21],[22],[23]

Types of Corrosion

Overall Corrosion

This refers to the inevitable corrosion to which all metals immersed in electrolytic solutions are condemned.

Pitting corrosion

It is a form of localized, symmetric corrosion in which pits form on the metal surface. It usually occurs on base metals, which are protected by a naturally forming, thin film of an oxide. In the presence of chlorides in the environment the film locally breaks down and rapid dissolution of the underlying metal occurs in the form of pits.

Daniela Ionescu, Belarisa Popescu, Ioana Demetrescu 24 studied the aspects of dental corrosion on titanium system using various electrochemical techniques on titanium and his alloy with iron in dental media. The susceptibility to local pitting corrosion of titanium and its alloys in dentistry were evaluated by the breakdown potential jBr, the protection potential jPr, the difference between them and the corresponding current density from anodic polarization curves. He also determined that the breakdown potential for Ti is higher in saliva without chloride and fluoride ions, and that Ti becomes passivated in physiological solution.

Localised crevice corrosion

Localized crevice corrosion results from the geometry of the assembly. Crevice corrosion occurs between two close surfaces or in constricted places where oxygen exchange is not available. The reduction in pH and increase in the concentration of chlorine ions are two essential factors in the initiation and propagation of the crevice corrosion phenomenon. When the acidity of the milieu increases with time the passive layer of the alloy dissolves and it accelerates local corrosion process. [25]

Galvanic corrosion

It is the dissolution of metals driven by macroscopic differences in electrochemical potentials, usually as a result of dissimilar metals in proximity.

Stress corrosion

Stress corrosion occurs because of fatigue of metal when it is associated with a corrosive environment. Differential surface of a metallic restoration may have small pits / crevices. Consequently stress and pit corrosion occurs.

Fretting corrosion

Fretting corrosion is responsible for most of the metal release into tissue [26],[27] Conjointaction of chemical and mechanical attack results in fretting corrosion.

Galvanic corrosion in titanium dental implants

The most common form of corrosion, which is generally present in dental implants, is galvanic corrosion. Titanium has been chosen as the material of choice for end-osseous implantation. Long term studies and clinical observations establish the fact that titanium does not corrode when used in living tissue however galvanic coupling of titanium to other metallic restorative materials may generate corrosion. Hence there is a great concern regarding the material for superstructures over the implant.

Gold alloys are generally chosen as the superstructures because of their excellent biocompatibility, corrosion resistance and mechanical properties. The increasing cost of precious alloys used in dentistry has led to the development of cost effective metallic materials. [28], [29] These new different alloys such as Ag-Pd, Co-Cr alloys and Ti alloys have good mechanical properties and are cost-effective but their biocompatibility and corrosion resistance are of concern.

Galvanic corrosion occurs when dissimilar alloys are placed in direct contact within the oral cavity or within the tissues. The complexity of the electrochemical process involved in the implant-superstructure joint is linked to the phenomenon of galvanic coupling and pitted corrosion. [30]

ASTM defines galvanic corrosion as the accelerated corrosion of a metal because of an electrical contact with a more noble or nonmetallic conductor in a corrosive environment

When two or more dental prosthetic devices made of dissimilar alloys come into contact while exposed to oral fluids, the difference between the corrosion potentials results in a flow of electric current between them. [31] An in vivo galvanic cell is formed and the galvanic current causes acceleration of corrosion of the less noble metal. The galvanic current passes through metal/metal junction and also through tissues, which cause pain. The current flows through two electrolytes, saliva or other liquids in the mouth and the bone and tissue fluids.

Phenomenon of galvanic corrosion

When 2 dissimilar metals (with different electrode potentials) come in contact, a potential is generated. The net result is a chemical reaction with oxidation occurring at one surface (anode) and reduction at the other (cathode). The exchange of ions takes place through the electrolyte in which the 2 electrodes are dipped. The respective metals decompose and said to have been 'corroded'.

This particular type is said to be 'Electrogalvanic corrosion' since it is a wet type involving electrolyte and -galvanic- because there is a flow of charge.

The Electrochemical cell will have two electrodes-:

(a) Oxidation Anode M ® M n+ + n e-1

(b) Reduction - Cathode M+e ® 1/2H_2 or M ® e ® M

$O_2 + 2H_2O + 4e$ ® 4OH

Thus flow of charge occurs.
The oral cavity can simulate an electrochemical cell under certain circumstances.
If a base metal alloy superstructure is provided over a Ti implant; then too an electrochemical cell is set up.
The less noble metal alloy forms the anode and the more noble titanium forms the cathode.
Electrons are transferred through metallic contact, and the circuit is completed by ion transport through saliva, mucosa and tissue fluid

In vitro studies

The notable changes due to galvanic coupling have been reported in the literature. The galvanic corrosion of titanium in contact with amalgam and cast prosthodontic alloys has been studied in vitro (Ravnholt, 1988 [32] Geis -Gerstorfer et al 1989; Ravnholt and Jensen, 199133; Strid et al 1991 No currents or changes in pH were registered when gold, cobalt chromium, stainless steel, carbon composite or silver palladium alloys were in metallic contact with titanium. [32], [33] The changes occurred when amalgam was in contact with titanium.

Geis -Gerstorfer et al stated that the galvanic corrosion of implant / superstructure systems is important in two aspects: first the possibility of biological effects that may result from the dissolution of alloy components and second the current flow that results from galvanic corrosion may lead to bone destruction. [24]

In another study Reclaru and Meyer [30] examined the corrosion behavior of different dental alloys, which may potentially be used for superstructures in a galvanic coupling with titanium. Reclaru revealed from his investigations that from electrochemical point of view, an alloy that is potentially usable for superstructures in galvanic coupling with titanium must fulfill the following requisites.

1. In coupling the titanium must have weak anodic polarization.

2. The current generated by the galvanic cell must also be weak.

3. The crevice potential must be much higher than the common potential.

The study regarding measurement and evaluation of galvanic corrosion between titanium and dental alloys was also carried out by 'Brigitte Grosgogeal and L Reclaru [34] using electrochemical techniques and auger spectrometry. The results showed that the intensity of the corrosion process is low in case of Ti/dental alloys. Other types of corrosion, e.g.: pitting corrosion and crevice corrosion should also be considered. Therefore the most favorable suprastructute /implant couple is the one which is capable of resisting the most extreme conditions that could possibly be encountered in the mouth.

From current literature and experimental study, R Venugopalan, LC Lucas [35] defined the profile for an acceptable couple combination as

1. The difference in E OC (open circuit potential) of the two materials and the I couple.corr (coupled corrosion current density should be as small as possible.

2. The E couple.corr (coupled corrosion potential) of the couple combination should be significantly lower than the breakdown potential of the anodic component.

3. The repassivation properties of the anodic component of the couple should also be acceptable, absence of a large hysteresis.

B.I Johanson [36] studied the effect of surface treatments and electrode area size on the corrosion of cast and machined titanium in contact with conventional and high copper amalgams in saline solutions with and without fluoride ions. He found that conventional amalgam corroded more than high copper amalgams in contact with titanium in saline solutions and concluded that surface preparations and fluoride affect the electrochemical activity of titanium.

In vivo studies

Despite the high general corrosion resistance of Ti, increasing evidence is found that titanium is released into and accumulated in tissue adjacent to titanium implants. [37], [38], [39] though Ti is generally considered as highly biocompatible, it has been observed that the tissue reaction to released Ti species can vary from a mild response to a more severe one.

Titanium like all other non-noble metallic implant materials is covered by a protective oxide layer. Although this barrier is thermodynamically stable, metal containing species are still released through passive-dissolution mechanisms. Although the chemical form of titanium that is released in vivo has not yet been experimentally determined, a likely candidate is Ti (OH) 440.

Ferguson and Coworkers [41] were the first to document locally elevated titanium levels in the presence of a titanium implant.

At the atomic level, electrothermal atomic absorption spectrophotometer appears to be a sensitive tool to quantitatively detect ultra-trace amounts of metal in human tissue.

Atomic absorption analyses indicated increased release of metal ions from the amalgam and gallium alloy samples coupled to titanium as compared to their uncoupled condition, although the differences were not always significant.

Galvanic corrosion of amalgam-titanium couples in the long term may become significant, and further research is needed. Coupling the gallium alloy to titanium may result in increased galvanic corrosion and cytotoxic responses. [42]

A single metal inclusion was detected by scanning-electron microscopy and energy dispersive X-ray analysis in one patient, whereas, electrothermal atomic absorption spectrophotometry analyses revealed titanium present in three of four specimens in levels ranging from 7.92 to 31.8 micrograms/gm of dry tissue. [43]

Cortada M, et al [44] determined the metallic ion release in oral implants with superstructures of different metals and alloys used in clinical dentistry using inductively coupled plasma mass spectrometry technique.

The corrosion of Ti in the prophylactic fluoride-containing environment can become problematic. Nakagawa M et al 45 revealed from his study a relation between the fluoride concentrations and pH values at which Ti corrosion occurred and provided data on such corrosion in environments where the fluoride concentration and pH value are known.

CJ Kirkpatrick, S Barth et al [46] presented relevant aspects of the related field of inflammation and repair process and presented that the pathomechanism of the impaired wound healing is modulated by specific metal ions released by corrosion activity.

Conclusion

The corrosion of dental biomaterials is a pertinent clinical issue. In spite of the recent innovative metallurgical and technological advances and remarkable progress in the design and development of surgical and dental materials, failures do occur. The Department of Dental Research, INMAS, DRDO has indigenously designed & developed titanium implants and base metal alloys. Studies have proved that the materials are biocompatible and meet the existing requirement to be used for restoration of oral defects. The study is proposed to evaluate the corrosion of indigenous titanium dental implants with indigenous base metal alloys under in vitro and in vivo conditions.

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Titanium release from implants prepared with different surface roughness. An *in vitro* and *in vivo* study Clinical Oral Implants Research 15 (5), 505–512. October 2004

Abstract

Objectives: There may be a risk of greater ion release for surface-enlarged implants than conventionally turned components. The major aim of the present paper was to investigate whether a correlation exists between ion release and a surface roughness relevant for today's commercial implants. Other aims were to compare ion release after two insertion times and concentration in bone tissue as a function of distance from the implant surface.

Material and methods: Lactic acid aqueous solution (pH=2.3) and phosphate-buffered saline were used for the *in vitro* investigation. For the *in vivo* investigation, synchrotron radiation X-ray fluorescence (SRXRF) spectroscopy and secondary ion mass spectroscopy (SIMS) were performed 12 weeks and 1 year after implantation in rabbit tibiae.

Results: The average height deviation (S_a) was 0.7, 1.27, 1.43 and 2.21 µm, respectively, for the four surfaces investigated. No difference in ion release was found *in vitro*. *In vivo*, SRXRF demonstrated slightly higher values for the roughest surface up to a distance of 400 µm from the implant surface; thereafter no difference was found. SIMS demonstrated no difference in ion release for the roughest and smoothest surfaces, but slightly more titanium in bone tissue after 1 year than after 12 weeks. Titanium rapidly decreased with distance from the implant surface.

Conclusion: At a level relevant for commercial oral implants, no correlation was found between increasing roughness and ion release, neither *in vitro* nor *in vivo*.

Titanium release from dental implants : an in vivo study on sheep

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Abstract

Titanium and its alloys release passive metal dissolution products. This raises the issues ofthe amount and fate of these products. In this study, we document titanium levels released from dental implants. We compared commercially pure titanium, titanium alloy (Ti6A14V) and the effect of hydroxyapatite (HA) coating on dental implants. Seventeen screw type implants were inserted into the cortical bone of sheep's tibias. Bone and soft tissues (liver, spleen, kidney, lymph nodes and connective tissues) were harvested.

Samples were analyzed for Ti content by proton induced X-ray emission (PIXE). Results from bone were compared with those obtained by the energy-dispersive X-ray analysis (EDX) on scanning electron microscopy (SEM). The results suggest that bone remodelingmay reduce the **local accumulation of titanium.**

A study of titanium release into body organs following the insertion of single threaded screw implants into the mandibles of sheep

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Australian Dental Journal (Aust. Dent. J.) 2002, vol. 47, n°3, pp. 214-217 [4 page(s) (article)]

Abstract

Background: Titanium is generally considered a safe metal to use in implantation but some studies have suggested that particulate titanium may cause health problems either at the site overlying the implant or in distant organs, particularly after frictional wear of a medical prosthesis. It was the purpose of this investigation to study the levels of dissemination of titanium from threaded screw type implants following placement of single implants in sheep mandibles. Method: Twelve sheep were implanted with a single 10x3.75mm self-tapping implant for time intervals of one, four and eight to 12 weeks. Four unoperated sheep served as controls. Regional lymph nodes, lungs, spleens and livers were dissected, frozen and subsequently analysed by Graphite Furnace Atomic Absorption Spectroscopy. Results: Results associated with successful implants showed no statistically significant different levelsof titanium in any organ compared to controls, although some minor elevations in titanium levels within the lungs and regional lymph nodes were noted. Two implants failed to integrate and these showed higher levels of titanium in the lungs (2.2-3.8 times the mean of the controls) and regional lymph nodes (7-9.4 times the levels in controls). Conclusions: Debris from a single implant insertion is at such a low level that it is unlikely to pose a healthproblem. Even though the number of failed implants was low, multiple failed implants may result in considerably more titanium release which can track through the regional lymph nodes. Results suggest that sheep would be an excellent model for following biological changes associated with successful and failed implants and the effect this may have on titanium release.

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