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Review Article

Corrosion in titanium dental implants: literature review

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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.

Key words: dental implant, galvanic corrosion, indigenous titanium dental implant

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.

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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.[14-18] Hexavalent chromium causes several cytotoxic responses including decrease in some enzyme activities, interference with biochemical pathways, carcinogenicity, and mutagenicity.[19-23]

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

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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] Conjoint action 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 $M \rightarrow M\ n+ + n\ e\text{-}1$

(b) Reduction – Cathode $M+e \rightarrow 1/2H_2$ or $M \rightarrow e \rightarrow M$

$O_2 + 2H_2O + 4e \rightarrow 4OH$

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

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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. Inspite of the recent innovative metal-

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lurgical 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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