CORROSION OF TITANIUM DENTAL IMPLANTS : TRUTH OR FALLACY -A SYSTEMATIC REVIEW

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Abstract

Background: Dental implants are commonly used for replacement of teeth owing to their high success rate. Though medical grade titanium/ titanium alloy-based dental implants are considered as biocompatible, long term effects of these materials in/on host tissues need be addressed. Research quoting titanium toxicity has been increasingly reported in recent times.
Aim: The aim of this systematic review is to find the plausible answer for the research questions "Do dental implants corrode? If so, "What are the effects of their by-products."
Methodology: Literature search was done using key words such as ("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) AND ("titanium"[MeSH Terms] OR "titanium"[All Fields]) AND ("corrosion"[MeSH Terms] OR "corrosion"[All Fields]), "titanium implant toxicity," "titanium implant corrosion," from data bases i.e., MEDLINE (PubMed), Cochrane Library, Embase and Google Scholar from time line year 1990 to 2019. Data was filtered using inclusion and exclusion criteria. The literature reports were collectively analysed and findings are reported using PRISMA guidelines.
Results: 36 Literature reports were analysed. Invitro studies demonstrated release of Ti, V, Al ions from titanium implants/ analogues while subjected to various environments mimicking oral cavity. Animal studies showed, presence of ions in the adjoining tissues and also in distant organs. The effects of the released ions initiated proinflammatory response in invitro and animal studies. Limited human studies are available for drawing conclusions.
Conclusions: Literature evidence indicates that titanium /alloy dental implants do corrode under specific circumstances. However, longitudinal studies in larger human population are required for establishing hypothesis.

Keywords*:* Corrosion, Dental Implant, Titanium, Metal, Ions

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1. Introduction

Titanium and its alloys are known for their use in medical/dental reconstructive applications since many years owing to their biocompatibility, mechanical properties like low thermal conductivity, low density, high hardness and corrosion resistance. Titanium has various applications in the field of dentistry, industries, drugs, paints, orthopaedic prosthesis and cosmetics. Titanium/ Titanium alloys are the choice of materials as dental implants and had shown to be successful in restoring functions of missing teeth(1) . However, long term influence of these metal /alloys need to be studied as there were conflicting literature reported in recent past, regarding the dental implant corrosion, allergy and hyper sensitivity.

Protocol development

This systematic review and meta-analysis were written and conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement (Liberati et al., 2009). The following focused question in the Patient, Intervention, Comparison and Outcome (PICO) format was posed (Stone, 2002): Do dental implants corrode? If so, "What are the effects of these by-products."

Systematic search strategy and study selection

An extensive search was performed in the electronic databases of the PubMed/ MEDLINE and the Cochrane Library, Embase and Google Scholar for articles published between 1990 and July 2019. The following key words were used for data search: ("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields] OR ("dental"[All Fields] AND "implant"[All Fields]) OR "dental implant"[All Fields]) AND ("titanium"[MeSH Terms] OR "titanium"[All Fields]) AND ("corrosion"[MeSH Terms] OR "corrosion"[All Fields]), "titanium implant toxicity," "titanium implant corrosion".

The reference lists of related review articles and publications were systematically screened and inclusion criteria consisted of manuscripts stating titanium /titanium alloys /surfaces employed for dental implantation examined/studied for corrosion in invitro/ invivo conditions/ clinical case reports/reviews. Corrosion related to medical devices consisting titanium alloys, Non-English publications were excluded. Further, literature reports with complete manuscript were considered for review and analysis.

Data extraction and management

The data were independently extracted by the three review authors. Data was procured in accordance with the guidelines provided Higgins 2011.For clarification or requirement of additional details, the authors of the studies were contacted through email. The reviewers evaluated each of the article obtained from the electronic search engines to assess the eligibility. A Fourth reviewer was included in case of disagreement in the eligibility of a study by the three reviewers. Full text copies of all the eligible as well as potentially eligible studies were further evaluated next by all the reviewers. From this, the studies which did not meet the inclusion criteria were excluded. Any disagreement was resolved by discussion among all the authors.

2. Results

188 articles were identified in initial search and in accordance with the PRISMA guidelines which included a series of systematic screening of the articles [identification, screening, eligibility and inclusion] a final sample size of 41 articles were selected and considered for review. (Fig-1)

3. Discussion

Wide-ranging data was searched and according to data analysis the number of papers from 1990 to 2019, with highest reports published after year 2000 indicating the inclination of hasty increase in recent years. But there was only limited human studies reported the study of corrosion of dental implant.

Corrosion is said to be the continuing degradation of materials by electrochemical attack which is a of more apprehension chiefly when a metal implant is positioned in a unfriendly electrolytic environment in the human body(2). Alloys release elements into the human body over days to months. This corrosion of materials depends on the metallurgy chemistry and geometric parameters. According to Jacobs, corrosion could be a result of thermodynamic driving forces, which corresponds to the energy released or required during the reaction. The author also stated that kinetic barriers to corrosion were related to certain factors which could physically hamper the happening of corrosion(3). For example, the process of metal oxide layer on the surface of the metal which could limit the corrosion. So the corrosion can reduce the fatigue property and strength of the material and leads to mechanical failure of the implant which could ultimately lead to implant fracture. The literature talks about various corrosion of implants like the localized crevice corrosion, stress corrosion, galvanic corrosion and fretting corrosion. Localized crevice corrosion resulted from inadequate oxygen exchange which lead to reduced pH and in turn the chlorine ions concentration is increased, which make the passive layer of alloy to dissolve and promotes corrosion in acidic environment. Stress corrosion can occur due to fatigue of metal when it is placed in corrosive environment due to the presence of small pits on the metal surfaces. Fretting corrosion occurs by the combined effect of chemical and mechanical attack. In this the most common implant corrosion is galvanic corrosion.

ASTM defines “ corrosion as the accelerated corrosion of a metal because of an electrical contact with a more noble or non metallic conductor in a corrosive environment”. The electrons are transferred through the metallic contact and the circuit is completed by the transportation of ion through saliva, tissue fluid and mucosa. Venugopal et al stated the difference in the open circuit potential of two metals and the coupled corrosion current density which should be small as possible. The coupled corrosion potential of the metals should be considerably less than the breakdown potential of the anodic constituent. The author also stated that the repassivation property of the anodic component should be more acceptable and should be devoid of huge hysteresis(4).

Titanium and its alloys have improved properties like excellent corrosion resistance in acidic and saline environment due to the stability of TiO_2 oxide layer. But, when the titanium oxide is removed it is not possible to reconstitute by itself. It tends to release corrosion products and metallic ions to the hard and soft tissues of the peri implant region. Later the implant surface undergo oxidation, corrosion and it tend to release ions(5) . This release of ions will kindle the attraction of T- lymphocytes and macrophages from the immune system. This free ions can cause loss of biological stability and osteolytic effect in the region of the implant. This in turn can affect the gene expression in the microbiota DNA and increase the risk of inflammation(5).

It is said that corrosion products which were released from the implant surface could be absorbed into the circulation and the absorbed titanium ions can accumulate in other organs in the body and it was shown in some animal and cell culture experiments(6). Further, the simultaneous actions of wear and corrosion are known as ‘tribocorrosion’ ‘a degradation phenomenon due to the combined action of tribological (wear and fretting) and corrosive (chemical and/or electrochemical) events influenced by the variation in the contact conditions (relative load) and in nature of the environment (pH, humidity and biochemistry)’ that may influence the overall performance of dental implants. This can endanger the mechanical stability of the implant and also disturb the integrity of the surrounding tissue. It was also proved that the corrosion products can disturb the DNA synthesis, mineralization and mRNA expression of alkaline phosphatase and in turn it would disturb the homeostasis (Fig:2). It has been shown that the corrosion can generate electric currents which were amplified by cyclic loads like chewing and biting(7). Dental titanium implants have been used in dental profession for more than 40 years. Though they have various advantages, however over time it generates debris and sub products during the life time of the implant. The implant surfaces are exposed to oral environment, saliva, bacteria and chemicals which in turn can continuously attack and dissolve the titanium oxide layer. This facilitate the degradation and dissolution of exposed titanium and initiates the corrosion cycles. The other variables like density of the bone, mechanical overloading, use of fluorides which also can influence the metal oxide layer of the implant(8). So the long term systemic and local effects of titanium particles and its products needs to be studied.

The long-term local and systemic effects of titanium particles and ions released into the oral environment and their potential effects on cells, tissues and organs remain unknown due to the

rapid evolution and variability of new implant surfaces, new implant-abutment connections and new restorative materials.

Existent data comprised of heterogenicity of reports, in terms of method of evaluation of titanium & different implant surfaces being studied in invitro (table 1)[9-19]. With minimal clinical reports being reported we conclude that longitudinal studies understanding the effects of corrosion products need to be conducted and the effect of environmental factors, inflammatory/ immune response and microflora – simultaneous evaluation needs to be investigated(20,21).

4. Conclusion

Preservation of Tio2 layer and improvement in structural design aiming at minimum degradation, corrosion, dissolution, deformation and fracture and also search for alternative metals / non alloy form of dental implants are the need of the hour.

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Figure -1: Flowchart Representing Data Collection Methodology

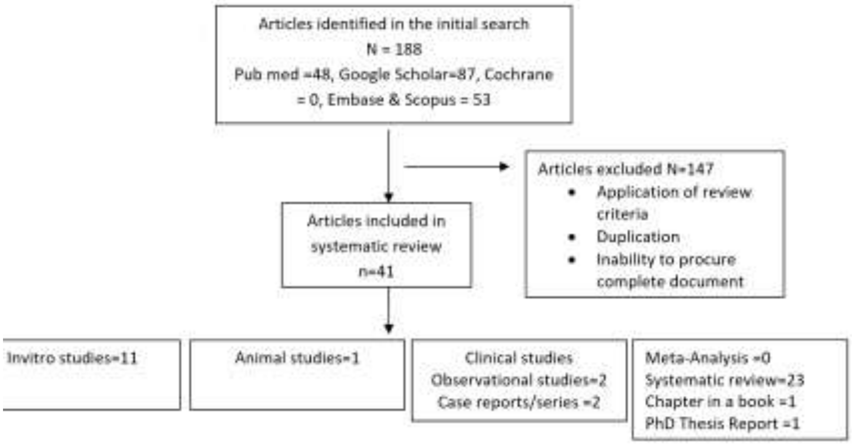

Figure - 2: Table Representing Plausible Effects On Titanium Implants Corrosion Products

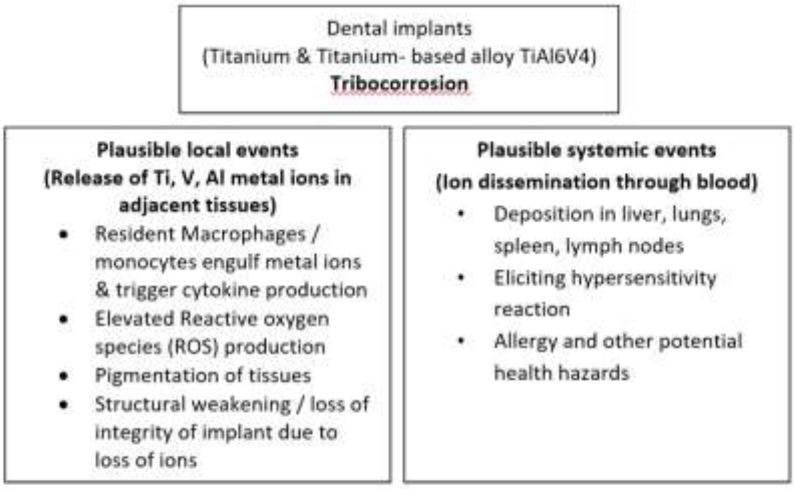

Table 1: Literature evidence regarding titanium corrosion

Author	Type of investigation	Objective	Methodology	Inference
L. Reclaru 1999 [9]	Invitro	Fifteen galvanic couples (Ti/gold-based alloys, Ti/ palladium-based alloy and Ti/non-precious alloys) were analysed for galvanic current	Various electrochemical parameters (EC,,, Ecommon.E coup~eC OmE. crevice.L ,,,. icouple com and Tafel slopes) were analysed.	Authors concluded that: in a coupling, titanium must have a weak anodic polarization; the current generated by the galvanic cell must also be weak: the crevice potential must be markedly higher than the common potential.
J.E.G. Gonzalez 1999 [10]	Invitro	The influence of alloying elements and the potential on the corrosion resistance of Ti and other Ti-based biomedical implant alloys under simulated physiological conditions was studied.	Electrochemical impedance spectroscopy was used and potentio static & potentio dynamic technique out puts were compared.	Mo, V and Fe improved passivity and limited the active corrosion of the b-phase of Ti while Al enrichment of the a-phase was found to be detrimental to the passivity and corrosion resistance of Ti
Satendra Kumar, 2008 [11]	Invitro	The corrosion behaviour of Ti–15Mo alloy at varying concentrations of fluoride ions was evaluated	Potentio dynamic polarization, electrochemical impedance spectroscopy (EIS) and chronoamperometric/ current–time transient (CTT) studies were employed.	In spite of the active dissolution, the Ti–15Mo alloy exhibited passivity at anodic potentials at all concentrations of the fluoride ions studied. Results of the study indicated that Ti–15Mo alloy may be a suitable alternative for dental implant applications.
Regina L. W. Messer, 2008[12]	Invitro	To assess implant corrosion in a simulated environment like diabetes and other inflammatory conditions.	Machined titanium implants were studied in blood, cultures of monocytic cells, and solutions containing elevated dextrose concentrations. Implant corrosion was estimated by open circuit potentials, linear polarization resistance, and electrical impedance spectroscopy (EIS). IL-1b secretion was measured from activated THP1 monocytic cells to assess the effect of the implants on monocyte activation.	The results suggested that inflammatory stress and hyperglycemia may increase the corrosion of dental endosseous titanium-based implants. However, IL-1b secretion was not altered under conditions of corrosion or implant exposure.
Rahul Bhola 2013 [13]	Invitro	Corrosion behaviour of titanium alloys	Interfacial electrochemical changes	Listerine acts as a corrosion inhibitor for

		Ti6Al4V (two-phase structure, i.e., α and β) and a newer Ti15Mo (single β phase) in a antibacterial mouth rinse, Listerine were studied	occurring at the oxide-solution interface have been analysed using EIS circuit modeling.	Ti15Mo alloy and a corrosion promoter for Ti6Al4V alloy.
Rui Zhang 2016 (14)	Invitro	Novel titanium surface developed in oxygen-rich environment was studied for corrosion and cell adhesion.	The corrosion resistance was determined using electrochemical testing. Biological activity on the samples was also analyzed, using a vitro cell culture system	oxygen-rich atmosphere (increased by 4.6 and 7.3 times) improved the corrosion resistance of the implants in a simulated body fluid. Further, cells exhibited the best adhesion characteristics.
D. G. OlmedoM. L. Paparella 2010 (15)	Invivo case report	Reported 2 clinical cases of reactive lesions of the peri-implant mucosa associated with titanium dental implants where metal like particles were observed histologically. The presence of metal-like particles in the tissues suggests that the etiology of the lesions might be related to the corrosion process of the metal structure.		
M. BARBIERI, 2017 (16)	Invitro	Compared levels of metallic ions and particles dissolution collected from two different dental implants surfaces immersed into human saliva	Inductively coupled plasma mass spectrometry (ICP-MS) was performed to detect metallic ions released from dental implants at various time intervals	Reported significant release of Ti, Ni and V ions by micro-sanded and acid-etched dental implants immersed in human saliva
Larissa O. Berbel, 2019 (17)	Invitro	Effect of simulated peri-implant inflammatory conditions on corrosion susceptibility of Ti-6Al-4V dental implants	The effects of hydrogen peroxide, albumin, deaeration, acidic environment (pH 3) were investigated. Corrosion resistance of Ti-6Al-4V acid etched surfaces was investigated by lectrochemical techniques: Open Circuit Potential; Electrochemical Impedance Spectroscopy; and Anodic Polarization	Results showed that Ti-6Al-4V implant's corrosion resistance can be reduced by, i.e. hydrogen peroxide, in the presence of protein and deaeration of the physiological medium
Danieli C. Rodrigues, 2013 (18)	Exvivo study	Investigate the mechanisms for implant degradation by evaluating the surface of five titanium dental implants retrieved due to peri-implantitis	SEM & EDS analysis	The results demonstrated that all the implants were subjected to very acidic environments, which, in combination with normal implant loading, led to cases of severe implant discoloration, pitting attack, cracking and fretting-crevice corrosion. The results suggested that acidic environments induced

				by bacterial biofilms and/or inflammatory processes may trigger oxidation of the surface of titanium dental implants. The corrosive process can lead to permanent breakdown of the oxide film, which, besides releasing metal ions and debris *in vivo*, may also hinder re-integration of the implant surface with surrounding bone.
Safioti LM, 2017 [19]	Invivo cross sectional study	Compared levels of dissolved titanium in submucosal plaque collected from healthy implants and implants with peri-implantitis	Levels of titanium were quantified using inductively coupled plasma mass spectrometry	Reported significantly higher mean levels of titanium ions associated with implants affected by peri-implantitis.