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ORIGINAL ARTICLE

Tribocorrosion of Dental Implants A Systematic Review

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ABSTRACT

Objective: This systematic review seeks to analyze the impact of the concentration, size, and location of corrosion particles on oral tissues and different surface treatments of implants to increase their durability in the oral cavity.

Methodology: An electronic search was conducted using the database of PubMed. In addition, manual search of the papers cited in relevant studies was also undertaken. Only human studies published in the last decade were included.

Conclusion: This study concluded that apart from established functional and metabolic factors, implants also undergo wear and tribocorrosion when subjected to the oral environment. These tribological factors not only contribute to the eventual failure of implants but also instigate certain biological responses.

Keywords: Corrosion, Allergy, Hypersensitivity, Implant, Dental Implant

INTRODUCTION

Osseointegration is the creation of a clear structural and functional relationship among the organic bone and the synthetic implant. It is controlled by variation in external properties like wettability, irregularity, superficial energy, texture, surface tension and attitude etc. [1] One of the principal constituents that defines osteogenesis is the sorption of various proteins to the alloy surface. The initial mechanism involves the dynamic association of multiple inflammatory mediators and signaling molecules. Over a span of approximately 21 days it contributes to osteoinduction and osteoconduction.[2]

The likelihood of implant failure rises because of many contributing factors such as smoking, disorders and metabolic illnesses. Some other causes that contribute to implanting failure are osteomyelitis, Infection/peri-implantitis and insufficient bone-bonding due to over-load.[3] However, some tribological and electrochemical causes, such as wear and corrosion also speed up the above explanations, contributing to the failure of implants.[4, 5]

Tribocorrosion is referred to as the parallel activity of mechanical and electrochemical contact happening between products subjected to corresponding movement, i.e., corrosion and wear occur simultaneously.

Many anatomical faults in the oxide layer are produced by lattice parameters of certain chemical substances, and the bulk content is thus more vulnerable to electrochemical attack.[6]].

For enhancing the efficiency and durability of Dental implants and minimizing the potential issues in the sector of implant dentistry, this paper accentuates the deterioration process of titanium dental implants in the oral cavity, the biological response generated by it, with the different techniques and surface treatments to prevent it.

METHODOLOGY

The electronic search was conducted using the database of PubMed [MEDLINE] by adding Booleans [AND OR NOT] with the keywords. In-addition, manual search of the papers cited in relevant studies was also done. Only the articles published in the last decade were screened based on set inclusion and exclusion criteria. Screening criteria have been summarized in tabulated form **(Table 1)**. A total of 475 articles were obtained initially without filters. After applying filters, the results showed 25 articles. Three staged screening protocol resulted in 4 articles **(Table 2)**.

Inclusion criteria	Exclusion criteria
1. Studies reporting **2.** Studies from Jan 2010 to Jan 2020 (10 years). 1. Reviews published in the English language only.	**1.** Reviews involving medically compromised patients. **2.** Studies reporting cast measur to assess the dimensional cha 1. Descriptive, narrative reviews animal studies.

Table 1 Selection criteria

Table 2 Search strategy table

	Included studies	Implant Materials	Particle Size	Location	Concentration (Ti)	Biological Response	Follow-up time	Surface Treatment (Ti Alloys)
Study 1 Andrea Mombelli et al. (2018)	Flatebø et al. (2006)	Ti particles in 100% biopsies	NR	Between collagen fibers	NR	-------	NA	-------
	Halperin-Sternfeld et al. (2016)	Ti particles in 75% samples	NR	Connective Tissue	NR	-------	-------	-------
	Olmedo et al. (2010)	Ti	NR	Inside and outside cells	NR	-------	-------	-------
	Olmedo et al. (2012	Ti	NR	Inside and outside cells	NR	-------	-------	-------
	Paknejad et al. (2015	Ti particles 100% samples	NR	Inside and outside cells	PP: 2.02–2.44 ppb; H: 0.41–0.88 ppb; C: 0 ppb	-------	-------	-------
Study 2 M. Noronha Oliveira et al. (2017)	Maloney et al.16	Ti, Ti-Al, Co, Cr	0.1–10 μm (TiO2)	All particles toxic at high concentrations; Co caused cell death	0.1–10 μm (TiO2)	All particles toxic at high concentrations; Co caused cell death	-------	-------
	Kumazawa et al.	Ti, V and Ni (solution and particles	1–3 μm	The systemic distribution of metallic and polyethylene wear particles; one patient with granulomas in the liver, spleen and abdomi-------l lymph nodes	1–3 μm	The systemic distribution of metallic and polyethylene wear particles; one patient with granulomas in liver, spleen and abdomi-------l lymph nodes	8 weeks	-------
	Mabilleau et al.23	Different culture media (F-, H2O2, lactic acid)	Medium with lactic acid: 216±2.2 nm; medium with Na 2TiF: 8.97±0.56 μm	Cytotoxic (dependent on particle size, if smaller than cells	Medium with lactic acid: 216±2.2 nm; medium with Na 2TiF: 8.97±0.56 μm	Cytotoxic (dependent on particle size, if smaller than cells	9 days	-------
	Taira et al.	1 ppm Ti-containing culture medium and control (without Ti)	-------	60% macrophage viability, 170% more TNF-α than control	-------	60% macrophage viability, 170% more TNF-α than control	2 days	-------
	Wang et al.20	UF-TiO 2 medium; untreated control	0, 26, 65, 130 μm/mL	Cytotoxic, genotoxic	0, 26, 65, 130 μm/mL	Cytotoxic, genotoxic	6, 24 and 48 h	-------
Study 3 A Revathi et al. (2017)	Z. Doni et al. (2013)	-------	-------	-------	-------	-------	-------	Ti6Al4V
	M.P Licausi et al. (2013)	-------	-------	-------	-------	-------	-------	Ti6Al4V
	M.T. Mathew et al. (2012)	-------	-------	-------	-------	-------	-------	Cp Ti, Ti6Al4V
	J.C.M. Souza et al. (2012)	-------	-------	-------	-------	-------	-------	Cp Ti
	A.C. Vieira et al. (2006)	-------	-------	-------	-------	-------	-------	Ti G2

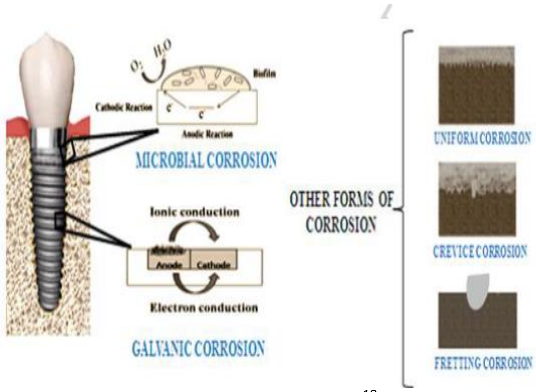

Figure 1 Types of Corrosion in Implants [12]

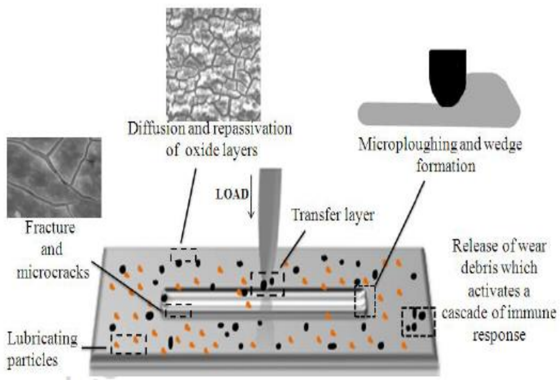

Figure 2: Representation of Tribocorrosion

DISCUSSION

Many contributing components like smoking, problems relating to metabolism such as Diabetes Mellitus , heart diseases and some other disorders like Bulimia nervosa increases the incidence of implant failing. Some other causes that contribute to implanting failure are osteomyelitis, Infection/ peri-implantitis and insufficient bone-attachment due to overburden. Some tribological and electrochemical causes such as wear and corrosion also speed up above mentioned explanations, contributing to the failure of implant.[3, 4]

Inside living tissues, no metallic substance is fully immune to ionization or corrosion. The existence of a defensive oxide coating, as mentioned earlier, release of corrosion products and holds the current flow and at a low stage. However, Mechanical interference of the oxide coating allows the surface of the metal to deteriorate by mechanisms such as corrosion and wear. In the oral environment, certain forms of electrochemical corrosion can occur since saliva produces violent anions, including chlorides, which allow the oxide layer to degrade and contribute to metal ions being emitted to the underlying tissues. There are different variables on which the electrochemical activity of Ti-based implants depends such as implant structure, anion concentration, pH, buffering ability and surface properties.[7]

Wear, another method of deterioration, relates to substance surface deformation due to the mechanical contact among opposing planes.[7] For the implant's long term stability, the abrading resistivity of synthetic dental substances is very important.

Similarly, fretting corrosion is another deterioration process that relates to the slight oscillating motions in the corrosive oral atmosphere among two communicating materials such as bone-implant and plates-screws etc. Tribocorrosion is referred to as the parallel activity of mechanical and electrochemical contact between products exposed to respective movement like corrosion and wear happening concurrently. The above-described deterioration processes (tribocorrosion, corrosion, wear)) induce the freeing of mineral ions/ waste into the surrounding implant area. Metal waste **induces** a **flow** of signalizing particles resulting in osteoclast cell activation and differentiation, contributing to peri-implant bone resorption/osteolysis. The implant and bone bond is then lost resulting in detached implant. Aseptic detachment is the implant loosening without bacterial infection. The titanium embedded area also transforms dark. This is because when the oxide coating is disrupted, the surface of titanium undergoes passivation. In such circumstances, the mechanism of passivation shapes so much of the TiO2 oxide layer that the area becomes black.[8]

Titanium implants under corrosion: The intensity of the corrosion phase rely on (i) pH; (ii) the oxide layer formed; (iii) the electrolyte composition and concentration; and (iv) oxygen vacancy movement through the film.[9] **Figure 1** demonstrates different kinds of corrosion to which the components are susceptible.

In TiO2, Ti has a concentration of O to Ti that progressively ranges from the TiO2 film to a far decreased bulk ratio.[10] Pan et al**.** proposed that the duplex surface consist of an internal barrier surface and an external penetrable and less durable coating built on the facet of Ti alloys [11].

To avoid dental caries, fluorides are typically used in toothpastes and mouthwash. When dental implant oxide films has reaction with fluoride mixture and form the molecules of titanium fluoride. Many structural defects in the oxide layer are induced by lattice parameters of these substances, and the bulk content is thus more vulnerable to electrochemical attack.[6]

The electrochemical actions of Zr5Ti, Zr25Ti, Zr45Ti are tracked by D. Mareci et al. He changed surface in artificial saliva comprising approximately 0.2, 0.5, and 1 percent sodium fluoride concentrations simulating dental rinse fluoride concentrations. He demonstrated that the thermal oxidation of ZrTi alloys in air at 500 C for 2 h dramatically decreased the impact of fluorides on ZrTi corrosion behavior.

The outermost layer when enriched with TiO2 decreased oxide film dissolution caused by fluoride ion presence.[12] Overall, the function of the oxide layer in issuing corrosion resistance in most unfavorable oral cavity environments consisting of different pH, acid assault, and the existence of chemical compounds like sodium fluoride, cetylpyridinium chloride and hydrogen peroxide is substantiated by these studies.

Wear of Titanium Dental Implants: The agitation activity of cortical bone was examined, when titanium grade 2 and the TC4 compound were applied to compact bone. In the case of bone-TC4, the abrading depth and friction coefficient detected seems to be raised more than that of commercially pure titanium bone. The erosive wear and desquamate have been described as a cortical bone wear procedure [13]**.** It is therefore necessary to produce highly wear resistant material or to use titanium alloy surface modification to mitigate its ability at the bone-implant interface against natural cortical bone. Cast Ti-6Al-7Nb was found to exhibit greater wear resistance than CP-Ti (grade 2 and 3**)** due to higher toughness and the presence of acicular ά phase two-phase microstructure in prior β grain**.**[14] Additionally, to the use of alloying components to enhance wear properties, the surface of the implant may even be polished. Because of the increased mechanical properties and wear tolerance, the poly-ether-ether-ketone (PEEK) was covered with Ti-6Al-4V. The samples were incorporated through the hot-pressing the PEEK veneer onto Ti-6Al-4V cylinders. Experiments on wear were conducted in artificial saliva at 30 N charging, 1Hz frequency with a stroke duration of 3 mm, using Al2O3 as the contrary body. The friction coefficient and basic wear rate were, as predicted, lower than the uncoated sample of Ti-6Al-4V. This indicates that the chewing loads, wear resistance and boost biocompatibility[15] can be managed by using the PEEK/TI−6Al-4V combination.

A variety of conditions, such as fretting, slippage, spinning, or impingement in a corrosive medium, can lead to tribocorrosion, which is the combination of corrosion and wear. Figure 2 depicts the tribocorrosion process as a diagram.

Tribocorrosion Under Sliding and Fretting Conditions: The failure mechanism may ensue at the junction between the implant and the alveolar bone during occlusal motion. The typical slipping velocity used in the fretting-corrosion experiments is between 0.2 and 1.8 mm/s in a small range, while the average touch pressure ranges from small values (333 MPa) to elevated ones (12 GPa). At a standard frequency of 1 Hz, the chosen reciprocating amplitudes vary between 50 and 180m, but are typically between 1 and 40 Hz.[16, 17]

Ti-29Nb-13Ta-4.6Zr is capable of passivating under both slipping and fretting corrosion even after passivation [18]as shown by Diomidis et al. There is a thorough analysis of the effect of inorganic compounds and of proteins on the passivation actions during fretting-corrosion.[19]

Prevention from Corrosion and Wear: Besides enhancing the biological reaction, better chemical and mechanical properties may be accomplished by changing the microstructure of the implant, as the structural morphology and the grain size regulate the abrasion and corrosion behavior of the metallic biomaterial [20]. As a dental implant, lower manufacturing costs, higher degradation tolerance and outstanding biocompatibility allow CP-Ti an acceptable candidate. However, the big downside is the poor ability to resist wear and power of CP-Ti as opposed to more Ti alloys. To boost the mechanical properties of CP-T, attempts have been made by using multiple processing methods to achieve higher strength nanocrystalline materials that often show improved biocompatibility properties.[18, 21]

Powder metallurgy is a modern, encouraging procedure that makes it possible to produce implant materials of mini grain and sub-grain size with comparable and superior mechanical effects such as stiffness, flexible strength and fatigue limit to those acquired by commercialized used manufacturing procedures.[22] Nanomaterials are categorized to minerals and nanoparticles that are nanocrystalline. NCM are polycrystalline majority materials in the nanometer scale, with grain sizes (less than 100 nm). A significant volumetric content of the atoms is situated at the grain boundary atoms (20–50 percent) because of the incredibly small measurements, and their technical desirable effects render them a good nominee as an implant material. The short-lived metabolic activity of mesenchymal stem cells and human osteoblasts was tested by Lucie Ostrovska et al. for extreme -fine grain titanium products, which, therefore, manifested higher level mechanical effects and long-term efficiency. Although decreased cell numbers were seen by human mesenchymal stem cells, osteoblasts showed a better reaction in terms of spreading and attachment.[23]

Interaction of Titanium particles with Hard Tissue: Aseptic implant detachment is another big problem which starts off by eroding debris and is distinguished by bone-prosthesis interface osteolysis.[24] There are two ways by which the equilibrium between bone resorption and bone formation can be disrupted by titanium debris: directly, by differentially triggering osteoblasts and osteoclasts.[25] or indirectly, by inducing the secretion of inflammatory cytokines formed by lymphocytes and macrophages.[26, 27]

Other researchers have stated that titanium ions can effect the disparity of osteoclasts by influencing the appearance of nuclear component B ligand (RANKL) and osteoprotegerin (OPG) receptor activator in osteoblastic-cells in vitro.[28] In addition, it has been seen that human osteoclast predecessor which interact with titanium will distinguish between adult osteoclasts and that mature cells. They might corrode metal substrate and accumulate particles in response.[29]

In 2017, Pettersson et al. demonstrated that in macrophages, titanium particles produce a pro-inflammatory reaction. Titanium solution filtration (pore size 0.22 µm) impacted macrophages but not effective in reducing cytotoxicity at elevated concentrations. The researchers identified the requirement for IL-1β activation to provide a main and a secondary signal. The secretion of IL-10, IL-6, IL-8, IL-1β, granulocyte-macrophage colony-stimulating agent and interferon-alone had a small impact on titanium particles (25 µm) alone. Nevertheless, titanium particles intensify the secretion of IL-1β in dose-dependent manner in cell cultures prepared with Escherichia coli LPS (100 ng/ml). There can be an effect on the degree of accumulation of particles, their surface region, and their form. In certain studies, collection of particles showed reduced toxicity plus minor effect on cell gene expression than nanoparticles in cells.[30]

Interaction of Titanium particles with Soft Tissue: Soft tissue when come in contact with metals are exposed to electrochemical activity that release ions from metal debris. With host-derived proteins, these ions may form complexes that can stimulate the immune system. The lymphocyte reaction to serum protein complexed with metal from implant alloy deterioration was studied in vitro,[31] and pellets of cobalt chromium molybdenum alloy (Co-Cr-Mo, ASTM F-75) were inoculated into serum by a healthy subject to stimulate naturally occurring metal implant-alloy deterioration. In these experiments, the lymphocyte multiplication reactivity to metalloprotein degradation products from titanium and Co-Cr-Mo alloys was demonstrated. The reaction was extreme among metals synthesized with large molecular mass proteins, and it was more with Co-Cr-Mo than titanium-alloy complexes.

Reports stated that the particles can adopt inter and intra-cellular pathways to the connective tissue.[32] The effect of titanium particles on the equilibrium of oral epithelial cells was examined by an in vitro research. The epithelium was deemed a physical shield with potential to suppress an intrinsic immune response.[33] By evaluating BRCA1 and CHK2, the two indicators of DNA destruction and genomic uncertainty, the authors evaluated the DNA destruction response to titanium particles emanating from five separate implant planes. Not all planes produced toxic particles in vitro analysis.

Certain responses to titanium particles have also been seen by fibroblasts [33]**.** When displayed to particles of 1 to 3 μm diameter, the fibroblasts raised their ex-pressure RANKL via the COX-2/PGE2/EP4/PKA pathway. In addition, the development of fibroblasts and a decline in their proteolytic and collagenolytic activities have been identified at low particle concentrations.[34]

When fibroblasts from peri-implant granulation-tissue were exposed in vitro to TiO_2 particles, P. gingivitis, or a mixture of particles and microorganisms, the cumulative exposure had the greatest impact on gene expression of TNF-α and protein output of TNF alpha, interleukin-6, and IL-8.[35] Thus, titanium molecules can participate to the aggravation of inflammation in peri-implant tissues induced by biofilm-associated bacteria.

Interaction of Titanium particles with Peri-Implant Tissues: The titanium particles are phagocytized by macrophages as shown by EDX study. The soft tissues owing to therapeutic mobility in around 10 failed implants.[36] Macrophages filled with metal-like objects were also histologically found in peri-implant mucosa in two cases of pyogenic granuloma.[37] Moreover, it was observed that metal molecules were found in 63 out of 153 oral mucosal biopsies in the region of connective tissue close to the cover screws of titanium submerged implants extracted six months after implant placement.[38] The particles have been observed in both extra and intracellularly.

The same investigators tested the cells depilated from the peri-implant sheath with roughly 15 implants and 15 non-diagnosed peri-implantitis implants for involving metal particles.[38] With a micro brush, samples were gathered. Although teeth were not exposed to particles, all tests of peri-implant mucosa display particles within and outside epithelial cells and macrophages, with or without a recognition of peri-implantitis. In the peri-implantitis specimens, a spectrometric study showed a higher concentration of titanium relative to the stable ones, while all control samples were negative. These results indicated the existence of titanium molecules, beyond titanium pollution from another source, as the result of surface wear of the implants.

After 6 months of implant insertion and abutment link, the biopsies were taken of 13 patients. [39] Proof of metal-like particles at month 6, with a decrease in thickness of the epithelium to connective tissue. Each specimen inside the connective tissue fronting the cover screw was observed in month 6, to have an inflammatory infiltrate.

36 biopsies of peri-implant soft tissue surrounding implants with peri-implantitis were examined in a retrospective research.[40] Seven tests showed that titanium particles were present. Out of other unfamiliar particles noticed, 19 tests were positive for electrodes that may come from dental cement, for instance Al, Zr and Si. The inflammatory infiltrate largely composed of plasma cells.

CONCLUSION

It has been concluded that apart from functional and metabolic reasons, the corrosion and wear of implants in the oral cavity also contribute to implanting failure. In the oral environment implants seem to undergo Wear, Fretting corrosion and Tribocorrosion.

The above-described deterioration processes induce the letting go of metal charged particle/debris into peri-implant area leading to cascade of events contributing to implanting failure. The intensity of the corrosion phase turn on the oxide layer formed, the electrolyte concentration and composition, pH and the oxygen vacancy movement through the film.

It has been proven via different studies that the titanium ions and particles are released from dental implants and can be found in peri-implant tissues and blood vessels from where they can be systemically distributed to the spleen, liver and abdominal lymph nodes.

Furthermore, titanium oxide layer used to provide corrosion resistance has mutagenic potential and Chronic inflammation can be also seen after implant prosthesis. Greater cytotoxicity and higher changes in gene expression are seen when it comes to the particle size and concentration, also in the presence of small nanoparticles at higher concentration.

Therefore, tribocorrosion is one of the crucial deterioration system that results in the loss of dental implants. The effects of tribocorrosion should be reduced to upgrade the service period of dental implants by evolving up to date new dental implant materials by improving the surface of the implants or using nobler alloying elements via different techniques and surface treatment.

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