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Review Article

Tribo-corrosion and titanium particles: A conducive factor for implant complication

Rutuja N Jivane[1], Sangeeta Muglikar[1], Roza R. Baviskar[2,*]

[1]*Dept. of Periodontics, M A Rangoonwala College Of Dental Sciences and Research Centre, Pune, Maharashtra, India*
[2]*Dept. of Oral Medicine and Radiology, M A Rangoonwala College Of Dental Sciences and Research Centre, Pune, Maharashtra, India*

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ABSTRACT

In dentistry, titanium and its alloys are utilized for implants due to their unique blend of chemical, physical, and biological properties. These alloys are employed in both cast and wrought forms. The fractures of the alloy-abutment interface, abutment, or implant body are caused by the long-term presence of corrosion reaction products and ongoing corrosion. Implant failure results from the combined effects of stress, corrosion, and bacteria.

1. Introduction

Dental implants are non-reactive, synthetic substances that are implanted within the maxilla and/or mandible to address tooth loss and facilitate the restoration of missing orofacial structures due to factors such as injury, tumors, and congenital anomalies.[1]

For a significant duration, titanium has been effectively employed as a material for implants. In the field of dentistry, titanium finds extensive application due to its exceptional attributes, including its resistance to chemical reactions, mechanical strength, lack of harmful properties, and compatibility with biological systems.[2]

The oral tissues experience a constant barrage of both chemical and physical stimuli, along with the metabolic activities of around 30 bacterial species (with a total salivary bacterial count of approximately five billion/ml of saliva). Remarkably, despite this, oral tissues generally manage to maintain their health. Saliva contains numerous viruses, bacteria, yeast, and fungi, along with their byproducts like organic acids and enzymes, epithelial cells, remnants of food, and components from gingival crevicular fluid.

Teeth operate within one of the most challenging environments within the body, subjected to significant fluctuations in temperature. Various factors, such as temperature, the amount and quality of saliva, the presence of plaque, pH levels, protein content, and the physical and chemical attributes of consumed substances, as well as the overall oral health status, have the potential to impact the process of corrosion.[3]

The utilization of dental implants for addressing both complete and partial edentulism has become a fundamental approach within the field of restorative dentistry. Different materials are being used for dental implants. Metallic biomaterials adhere to typical patterns of metal degradation within varying environmental conditions. When exposed to non-metallic elements in the surroundings, metals undergo chemical reactions that result in the creation of chemical compounds, often referred to as corrosion products.

* *Corresponding author.*
E-mail address: rozabaviskar@gmail.com (R. R. Baviskar).

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Corrosion, is the slow and progressive 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. Corrosion is elucidated as the interaction process between a solid material and its chemical surroundings, resulting in the depletion of material, alterations in its structural traits, or compromise of structural integrity.[4]

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. For dental implant, bio compatibility depends on both mechanical and corrosion/degradation properties of the material.[5] A dental implant constitutes a mechanical system that experiences tribo-corrosion at the point where the implant and abutment alloy meet, often leading to material deterioration.

Tribo-corrosion involves the examination of both wear and corrosion phenomena, resembling an irreversible transformation of materials caused by the simultaneous interplay of chemical, mechanical (wear), and electrochemical (corrosion) reactions that transpire on surfaces engaged in contact. Dental implants and prostheses are also susceptible to these occurrences. This phenomenon can be particularly harmful to relatively softer materials, resulting in pronounced local deformations and material loss, similar to the micro-fatigue phenomenon.

In addition to the notable mechanical concerns, a matter of considerable apprehension is the potential for the release of products formed due to corrosion, as well as the flow of corrosion-related electrical currents, which could lead to localized inflammation, reactions, and other harmful effects within the physiological environment.[6]

1.1. *There are mainly two types of corrosion*

1. Chemical
2. Electrochemical

Other types of corrosion are

Stress Corrosion: it mainly occurs because of metal fatigue occurred due to corrosive environment.

Crevice Corossion: It occurs between two close surfaces in narrow surfaces where the oxygen exchange is not possible.

Microbial Corrosion: Microbials also can affect the corrosion of metals. Acids formed as a byproduct during glycolysis pathways of micro-organisms, reduces the pH causing favourable environment for corrosion.[7]

The effect of corrosion on dental implants can vary as Implant fracture, cellular response, bone loss and osteolysis, local reactions can occur as pain and swelling.

Corrosion has the potential to greatly reduce the fatigue life and overall strength of the material, resulting in the mechanical breakdown of the implant. Nickel and chromium trigger Type-IV hypersensitivity reactions within the body, behaving as haptens, carcinogens, and mutagens. These elements can prompt various cytotoxic responses, including the reduction of certain enzyme activities, disruption of biochemical pathways, as well as the initiation of carcinogenic and mutagenic processes.

Titanium alloys have demonstrated the ability to integrate well with bone and soft tissue environments. Nevertheless, there is a concern that these alloys contain notable quantities of alloying elements with distinct morphologies and crystallization patterns. This discrepancy might impact the process of osseointegration, particularly due to the presence of corrosion byproducts containing aluminum and vanadium.

The formation of corrosion byproducts has been associated with the development of localized pain or swelling around the implant site, even in the absence of infection, and it can also lead to secondary infections.

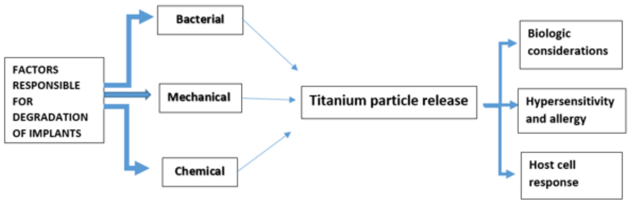

Fig. 1: Effects of titanium particle release on host

2. Implant and Bone Relation

Titanium particles disrupt the equilibrium between bone resorption and bone formation through two mechanisms: firstly, by directly triggering distinct activations of osteoclasts and osteoblasts, and secondly, by indirectly stimulating the release of inflammatory cytokines produced by lymphocytes and macrophages.

3. Implant and Immune Interaction

Titanium particles has the ability to initiate activation of the immune system, triggering a pro-inflammatory reaction in macrophages, T lymphocytes, and monocytes. This activation leads to the release of inflammatory cytokines such as granulocyte–macrophage colony-stimulating factor (GM-CSF), prostaglandin, TNF-α, IL-1β, and IL-6.

4. Implant and Tissue Cells Interaction

The electrochemical process possesses a pronounced inclination to release ions, which subsequently combine with host proteins, triggering immune system activation. The in vitro study investigated the lymphocyte response to serum protein complexes formed with metal particles from implants. Furthermore, an elevation in the expression of

Toll-like receptor-4 and bacterial LPS was detected in the gingival epithelium upon injecting 9 ppm titanium ions.[8]

4.1. Strategies to prevent corrosion

1. New implant materials can be used Ti-Ga, Nb, Ta, Mo, Zr, Sn.
2. Suface treatments can be done by Biomimetic coatings, Cryogenic treatments, Nanocoatings, Nitriding.
3. Other methods of surface roughening like Titanium plasma Spraying, Grit blasting, Acid etching, Anodisation can be done to prevent implant corrosion.

5. Discussion

Meyer et al.[9] through an in-vivo investigation, substantiated the existence of titanium within peri-implant bone following the introduction of implants into the porcine jawbone. Scanning electron microscopy revealed a profusion of titanium particles surrounding implants featuring rough surfaces, along with increased particle accumulation in the crestal part of the bone Suárez-López del Amo et al.[10] corroborated these findings through their research involving diverse implant surfaces (including sandblasted large-grit, acid-etched/hydrophilic, dual-acid-etched, sandblasted large grit acid-etched, fluoride-modified, and large grit, phosphate-enriched titanium oxide). They identified round elongated or small angular titanium fragments within the crestal region of the osteotomy site. Sridhar et al.[11] explored the impact of initial colonization by planktonic bacteria on the implant surface. Their study revealed that following a 22-day immersion of implants in Streptococcus mutans suspensions, observable corrosion attributes emerged, manifesting as microscopic deformations, slight rusting along the implant's edges, pitting deformations, and discoloration.

Research conducted by Mathew et al.[12] demonstrated that lipopolysaccharides (LPS) derived from bacteria triggered the exchange of ions between saliva and titanium. Consequently, this led to a reduction in corrosion resistance and an elevation in the roughness of the titanium surface. In general, heightened LPS concentration and lower pH levels have a tendency to amplify titanium corrosion. In an in vitro investigation, Deppe et al.[13] showed that oral implants have the potential to initiate the liberation of particles that become detached from their surface during the process of being inserted into bone. Mathew et al.[14] conducted a study investigating the correlation between LPS and the deterioration of titanium surfaces. Their findings indicated that LPS, a membrane component of gram-negative bacteria, has an adverse impact on the corrosion characteristics of both pure titanium and TiAIV alloy. Additionally, the generation of hydrogen peroxide (H202) during inflammatory responses negatively influences the corrosion resistance of titanium.[15] Furthermore, the release of particles also has ramifications for biofilm formation, the accumulation of bacterial endotoxins, and the health of peri-implant tissues.[16]

Zavanelli and colleagues noted that the Ti-6Al-4V alloy displayed the greatest fatigue value, with no notable distinctions when contrasted with commercially pure titanium. The dissolution of titanium indicates the occurrence of corrosion on the surface of the dental implant. The noteworthy connection between titanium dissolution and peri-implantitis underscores the role of corrosion as a significant consideration in peri-implantitis investigations. Research has identified the presence of titanium particles in peri-implant tissues, although no statistically significant proof of a link between dissolved titanium and peri-implantitis has been documented.[17]

Epithelial cells shed from peri-implant tissues have revealed the presence of titanium particles, and instances of foreign bodies comprising both titanium and cement have been identified within the soft tissue of implants afflicted by peri-implantitis.[18] Furthermore, analyses of bone and soft tissue biopsies obtained from peri-implantitis sites have unveiled the existence of titanium elements.[19]

Olmedo and co-researchers introduced exfoliative cytology as a method to evaluate the occurrence of titanium particles within cells shed from the peri-implant mucosa. Through the analysis of combined samples, the researchers observed a higher concentration of titanium in the peri-implantitis group when compared to implants that were deemed healthy.[20]

Previous research has documented the immunological impact of titanium corrosion products, which contribute to exacerbating the host's inflammatory response and intensifying bone loss within periimplantitis lesions. This is achieved through an escalated release of pro-inflammatory cytokines such as TNF-α, IL-β AND RANKL by host cells, in the presence of titanium products.[21]

Pathogens like s. mutans possess the capability to induce corrosion by generating an acidic environment, while LPS and pathogens like P. gingivalis have a strong tendency to bind to these corroded titanium surfaces. It's noteworthy that titanium doesn't exhibit bacteriostatic properties for most bacterial species, thereby creating a conducive environment for colonization.[22]

Furthermore, investigations have demonstrated that the expression of TLR-4, a receptor for LPS, in gingival epithelium exposed to titanium ions was heightened compared to exposure to pure titanium. This suggests that titanium ions could potentially heighten the susceptibility of gingival epithelial cells to microorganisms present in the oral environment.

6. Conclusion

Due to its biocompatibility, strong resistance to corrosion, and high tensile strength, titanium emerges as the prevailing choice for dental implant fixtures. This is evident in clinical outcomes, marked by impressive survival rates and enduring stability over the long term. Nonetheless, degradation byproducts and particles resulting from wear have been detected in both oral and extra-oral tissues as a consequence of titanium particle release from dental implants. This release occurs due to factors such as mechanical wear, exposure to chemical agents, and interaction with substances produced by adherent biofilm and inflammatory cells.

There exists a biological plausibility suggesting a connection between the existence of titanium particles and ions, biological complications, and corrosion. However, there is insufficient substantiated evidence to establish a linear sequence of causal events in one direction.

Titanium particles and ions disrupt the regular functioning of cells, consequently elevating the likelihood of inflammation in diverse scenarios. Research findings indicate that inflammation adversely affects the structure and function of biofilm and contributes to corrosion. Despite concerns regarding potential adverse effects, titanium continues to maintain its prominence‘.

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None.

8. Conflict of Interest

None.

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Author biography

Rutuja N Jivane, Post Graduate Student https://orcid.org/0009-0002-3793-5582

Sangeeta Muglikar, Professor and Head

Roza R. Baviskar, Post Graduate Student https://orcid.org/0000-0002-5923-0762 This

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