Bio-Tribocorossion in Dental Implants

Dr. K. Sheela[1], Arun Kumar. T.M. [2], Lalith Kumar. R[2], Dr. Rathika Rai[3]

[1]MDS, Senior Lecturer, Department Of Prosthodontics, Dr.M.G.R.Educational &Research Institute, Thai Moogambigai Dental College &Hospital, Chennai

[2]CRRI, Dr.M.G.R.Educational &Research Institute, Thai Moogambigai Dental College &Hospital, Chennai

[2]CRRI, Dr.M.G.R.Educational &Research Institute, Thai Moogambigai Dental College &Hospital, Chennai

[3]MDS, Principal, Department Of Prosthodontics, Dr.M.G.R.Educational &Research Institute, Thai Moogambigai Dental College &Hospital, Chennai

ABSTRACT:-

Tribocorrosion is the material degradation process by the combined action of wear and corrosion. Bio-tribocorrosion is the new description for the tribocorrosion process of a material. Dental implants are increasingly used with a high success rate. Titanium and its alloys is the frequent choice of material for implants. Tribocorrosion of a material depends on the physical, chemical, mechanical, structural and chemical properties of their surface, which also includes the passive layer on the material. Naturally the passive films are less than 10μm but they have a strong influence on tribocorrosion. Oral cavity is a complex environment where diet, human saliva and oral biofilms form the corrosive substances. And also during mastication micro-movements occur between the joint which leads to wear. This review paper focused on the wear and corrosion process of implants in the oral environment and also the harmful effects of this process. This review gathers knowledge from various electronic databases aiming to contribute for a better understanding on Bio-tribocorrosion process of a material in the oral environment.

Keywords:-

Dental implants, Corrosion, Failure of implants, Micro-organism

INTRODUCTION:-

Dental implants have been increasingly accepted worldwide. According to American Academy of Implant Dentistry[AAID], two million people using implant each year with the survival rate of 91.5% after 16-22 years [1]. But implants fail mainly due to overload and infections .

Tribocorrosion can be defined as degradation of material surface by the combined action of chemicals, mechanical wear and electrochemical corrosion [2]. Bio-tribocorrosion is the designation used to describe the tribocorrosion behavior of materials in biological environments, as it happens with instruments used in the medical field and devices inserted in the human body. Tribocorrosion is the combination of two phenomenon tribology and corrosion. Tribology is the study of interacting surfaces in relative motion, friction, lubrication and wear. Corrosion is the complete deterioration of the substance.

Dental implants and orthodontic appliances are good example of ''Tribocorrosion''. Tribocorrosion of a bio-material depends on physical, mechanical, structural and chemical properties of their surfaces. Mechanically depends on load application, pressure and type of motion. Corrosion depends on the pH of the environment, temperature, chemical constituents [3]. Titanium and its alloys are widely used in dentistry because of their biocompatibility and excellent corrosive resistance formed by the passive oxide layer [$TiO2$] when they contact with the air. It has the properties of antibacterial action and inhibits bacterial infections.

Dental implants undergo cyclic micro-movements at the bone/implant or at the implant/abutment during mastication which leads to wear and material loss [4,5]. Due to interaction with the bone surface, passive oxide[$TiO2$] films formed on the titanium degrade in the presence of oral fluids in sliding contacts and cause implant wear . The corrosion products and the wear particles were released from the metallic implants (micro gaps) can lead to inflammatory responses which ultimately results in prosthesis failure [6]. The inflammatory process can lead to loss of mechanical integrity of implants and induces the micro-movements which compromise the peri-implant tissues health . By reducing the material loss by tribocorrosion phenomena the success rate of an implant material can be increased. This articles gives an overview of causes and various methods of prevention of tribocorrosion

DISCUSSION :-

In the last three decades, the implant dentistry has reached significant advances in the clinical use of oral and maxillofacial implants [7]. Oral implants are used to replace the missing teeth and also to rebuild anchorage and to provide anchorage in orthodontic treatments.

Different types of materials can be used in dental implants and prostheses. In dentistry, metals are frequently used due to their high strength, durability fracture resistance. But they are more susceptible to environmental attack chemically and lack the proper teeth appearance. Commercially pure titanium is mostly used to produce dental implant fixture while abutment is fabricated from various metallic alloys like titanium based alloys, gold and silver-palladium alloys, chromium-cobalt-molybdenum alloys or ceramic materials like zirconia and alumina.

Titanium implants has been successfully used in dentistry as endosseous and subperiosteal implants [8]. Commercially pure titanium is most widely used. Recently titanium alloys containing Ti;6Al;4V (Grade 5) (90% Titanium, 6% Aluminum, 4% Vanadium) have been increasingly used [9]. Titanium has very high corrosion resistance and excellent biocompatibility. Titanium is the most compatible material for its corrosion resistance against bio-inertness, body fluids and high fatigue limit by the formation passive oxide layer. Titanium reacts with oxygen readily and forms titanium dioxide, a passive layer [10]. This protective layer is 1-2 nm in thick and reaches the thickness of 25nm within four years [11]. This oxide film is strongly adhered, insoluble and present as a barrier to the surrounding environment.

Titanium has a property of direct contact with the bone after implantation without cementation [12]. Titanium has a strong osseointegration tendency after short period of implantation by the development of close bone-to-implant apposition. An ideal dental implant material should integrate with the host tissue and also have the anti-microbial properties.

Even though dental implants have a high success rate, it fails at some point of time. Reports revealed that edentulous maxilla showed (10-20%) higher failure than mandible (1-5%) [7]. The failure of dental implant is contributed by the combination of biomechanical factors and biological factors and also patient specific etiological factors. In biomechanical factors micro-movements in implant system between various components are the main problem. A poor fit between crown-abutment or abutment-implant joint result in increased displacement of structural parts which lead to tribiological damage under mastication or occlusal forces [7]. Among biological factors, microbial infection (peri-implantitis) (most common), low osseointegration kinetics, bone resorption, fibrous tissue formation, effect of wear debris / corrosion products / ions released because of sliding between the implant root and the surrounding tissues which leads to biologically originated failures .

Human saliva is produced about 1-1.5L per day. It is mainly produced by the major exocrine glands – parotid, submandibular, sublingual. It is secreted at pH of 6-7. It constitutes water (99%) and organic & inorganic compounds [7]. Saliva has the viscous property provided by the glycoproteins (e.g., mucin) in the acquired pellicle that can resist wear on dental surfaces and protects it .Khan et al. [3] reported that in the presence of albumin, wear rate is reduced on Ti13Nb13Zr, Ti6Al7Nb, Ti6Al4V. But Hiromoto et al [3] had found that albumin has no effect on fretting corrosion of titanium and Mathew et al [3] revealed that lipopolysaccharides [LPS] has a negative effect in artificial saliva on wear/corrosion of titanium. And LPS can induce the biofilm accumulations.

In implant infection the first and the important step is that the microbial adhesions followed by formation of biofilm by micro-organisms . In oral cavity several areas can be covered by microbial colonization embedded in extracellular matrix known as biofilms, which is composed of polysaccharides, proteins, nucleic acids and water . Local pH values, bacterial toxins, acid secretion influence composition of biofilms . In oral cavity that is in both the soft and hard tissue {tooth and restorations} microbial adhesions take place.

In biofilm formation the most susceptible areas are micro-gaps and retentive areas; this area has a strong impact on corrosion and wear process . Microbes colonize mostly on rougher surfaces than on smooth surfaces that leads to leakage of ions on surrounding tissues that leads to infection . After implantation, epithelial and connective tissue contact with the part of the margin of implant fixture and the remaining part of an implant is in contact with oral fluids and abutment.

In literature, 2.5 to 60μm gaps present between implant fixture and abutments were reported . As the microorganisms is less than 10μm, it can easily colonize these gaps and gets accumulated with corrosion products. In the implant connection and in the prosthetic micro-gaps, the presence of oral fluids and biofilms can lead to the loss of mechanical integrity of the abutment screw that will get unscrewed [7].Recent studies have shown that titanium based implants forms metallic debris in high concentration containing metallic degradation products which leads to chronic health problems which includes hepatic and renal lesions [13]. Titanium shows the property of allergy and metal hypersensitivity in some patients [14].

In-spite of its super biocompatibility, the prevalence of allergy {0.6%} is noted in titanium implants [14].

The main reason for surface treatment of titanium and its alloys are it helps in reducing the tribological behavior and improving the corrosion resistance and osseointegration of the implant. Surface treatments improves the surface hardness of the material by various techniques such as surface oxidation, physical deposition like ion implantation and plasma spray coatings and also thermo-chemical surface treatments like nitriding, carburizing and bording [15,16]. These plasma spray treatment has a disadvantage of delamination and degradation of coating layer and the removal of debris which acts as third wear particles [17].

Mechanical wear can happen during placement of implants, fitting of dental prosthesis, mechanical cleaning during therapy of peri-implantitis and also during micro-movements of implants and its supra-structure. Two types of mechanism of wear have been reported; one is fretting wear refers to chipping and another one is adhesive wear refers to plastic deformation.

The highest stress is produced by the masticatory forces at the last of chewing cycle when the slipping motion stops as they reach the centric occlusion which leads to localized abrasion wear of the dental surfaces. Among the occlusal force axial load promote the transfer of stress via the dental implants to the bone; while oblique loads produce the overload on both the implant and the bone tissue, promotes the failure of an implant system by fatigue wear.

The shock absorbing ability of dental implant is very low than normal teeth because there is no periodontal ligament around the implant like the normal teeth. To reduce the stress distribution to the bone an intra-mobile element is added in the titanium, but the micro-movements take place in the prosthetic joints.Titanium has very high corrosion resistance and excellent biocompatibility by the formation of titanium oxide a protective film with the oral environment [3]. The strength of the oxide is determined by the structure and the thickness of the film [18].

Titanium oxides has a high corrosion resistance against different test solutions like artificial saliva, Ringer's solution or physiological saline solution (0.9% NaCl) [7]. Titanium can withstand the action of dilute sulfuric acid, hydrochloric acid, chloride solutions and most organic acids [19]. However, this protective film TiO2 can destroy in the presence of corrosive substances such as fluorides, lactic acid, carbamide peroxide (urea peroxide) and hydrogen peroxide [3]. This breakdown of passive film can lead to corrosion failure such as inter granular attack, pitting or corrosion fatigue.

Previous studies reported that at high fluoride concentrations, degradation of titanium surfaces occurs as localized corrosion process, namely pitting corrosion [3]. Studies have revealed that minimum concentration of fluoride 30 ppm HF can promote a localized corrosion. Tribocorrosion is the degradation process of material by the combined action of wear/friction and corrosion. Electrochemical dissolution and wear results in degradation of metallic implants but most commonly occurs by the combination of these two [20,21]. To investigate the bio-tribocorrosion of materials various electrochemical techniques are used [7]. They are Open-Circuit Potential (OCP) monitoring, potentiostatic control during sliding, electrochemical impedance spectroscopy (EIS) [22,23], micro-electrochemical techniques [24].

On mastication friction can remove the TiO_2 film which leads to a material' loss and failures of dental implants and prosthesis . Metallic ions were released from the corrosion and wear processes from the titanium and these wear particles and metallic ions can be seen near the surrounding tissues, related to the inflammatory reaction. During rubbing, hard less materials (first body) is removed which is accounted by mechanical and electrochemical mechanism [3]. As a consequence, by plowing and metal degradation there will be plastic flow with metal ejection and forms the third bodies (wear particles).

When the wear particles contact with the environment, it forms solid oxide by oxidation that can modify the mechanism of contact. This forms a brittle oxide layer that can increase the mechanical wear and involves in third body abrasive mechanism. The solid oxide can dissolve the titanium and an ions released by the electrochemical reactions. Studies have reported that after the implantation or restoration, formation of biofilm and plaque accumulation occurs mostly around the abutment, which may lead to peri-implantitis, an inflammatory reaction with loss of osseointegration at the dental implant interface causing the loosening of the fixture and finally the removal of the implant

Due to loss of material by bio-tribocorrosion in implants and prosthesis, wear debris and ions are released and that have linked to tissue inflammatory reactions . Some studies have reported that a high relationship is present between the amount of peri-implant inflammation and the magnitude of alveolar bone loss surrounding implants which can be faster than natural tooth because of periodontal ligament presence in natural teeth, an inflammatory response .

In oral implants, biological side effects may include early failure by lack of osseointegration, peri-implant mucositis i.e., inflammatory lesion in mucosa, peri-implantitis, aseptic bone loss and loosening of implant. Pruritus, redness, swelling, vesicular lesions of skin are the symptoms of titanium allergy in implantation like pacemakers, endo-prostheses, implants, and screws. In the oral cavity, these reactions are limited in tissues contact with the dental implants directly.

However, titanium readily forms the passive layer by high reactivity toward oxygen with the environment and does not exist in free form. But this titanium dioxide reacts with proteins which could provoke the hypersensitivity reactions. Metallic ions and wear particles can promote the bone resorption by the activation of macrophages, neutrophils and T-lymphocytes with elevation of cytokines . Wear particles of all classes (including titanium) can be seen in the vesicles of macrophage cytoplasm in the liver, spleen and lymph nodes which was originated from the prosthesis.

CONCLUSION:

The presence of oral fluids and biofilms in the implant internal connection and prosthetic microgaps can contribute to the loss of mechanical integrity of the abutment screw that will get unscrewed . Furthermore, during unscrewing, a tribological contact will be present, while the environment can be altered due to extra micro-leakage. Though titanium ionic release was higher in the presence of biofilm, the disruption of polysaccharide chains during sliding between these contacting surfaces resulted in the formation of organic "rolls" which provided wear protection to the metallic substrate . However, long-term biological effect of circulating metals is not completely known and it can be determined by the detection and characterization of these metal-protein complexes.

REFERENCES :

1. Cruz HV, Henriques M, Teughels W, Celis JP, Rocha LA. Combined influence of fluoride and biofilms on the biotribocorrosion behavior of titanium used for dental applications. Journal of Bio-and Tribo-Corrosion. 2015 Sep 1;1(3):21.
2. Menezes PL, Nosonovsky M, Ingole SP, Kailas SV, Lovell MR, editors. Tribology for scientists and engineers. New York: Springer; 2013.
3. Souza JC, Henriques M, Teughels W, Ponthiaux P, Celis JP, Rocha LA. Wear and corrosion interactions on titanium in oral environment: literature review. Journal of Bio-and Tribo-Corrosion. 2015 Jun 1;1(2):13.
4. Butt A, Lucchiari NB, Royhman D, Runa MJ, Mathew MT, Sukotjo C, Takoudis CG. Design, development, and testing of a compact tribocorrosion apparatus for biomedical applications. Journal of Bio-and Tribo-Corrosion. 2015 Mar 1;1(1):4.

5. Alves SA, Bayón R, de Viteri VS, Garcia MP, Igartua A, Fernandes MH, Rocha LA. Tribocorrosion behavior of calcium-and phosphorous-enriched titanium oxide films and study of osteoblast interactions for dental implants. Journal of Bio-and Tribo-Corrosion. 2015 Sep 1;1(3):23.
6. Asserghine A, Filotás D, Németh B, Nagy L, Nagy G. Potentiometric scanning electrochemical microscopy for monitoring the pH distribution during the self-healing of passive titanium dioxide layer on titanium dental root implant exposed to physiological buffered (PBS) medium. Electrochemistry Communications. 2018 Oct 1;95:1-4.
7. Cruz HV, Souza JC, Henriques M, Rocha LA. Tribocorrosion and bio-tribocorrosion in the oral environment: the case of dental implants. Biomedical tribology. 2011 Jul:1-33.
8. Rizzo AA. Proceedings of the consensus development conference on dental implants. J Dent Educ. 1988;52:678.
9. Li SJ, Yang R, Niinomi M, Hao YL, Cui YY. Formation and growth of calcium phosphate on the surface of oxidized Ti–29Nb–13Ta–4.6 Zr alloy. Biomaterials. 2004 Jun 1;25(13):2525-32.
10. Bergs T, Kammann S, Fraga G, Riepe J, Arntz K. Experimental investigations on the influence of temperature for Laser Metal Deposition with lateral Inconel 718 wire feeding. Procedia CIRP. 2020 Jan 1;94:29-34.
11. Weszl M, Tóth KL, Kientzl I, Nagy P, Pammer D, Pelyhe L, Vrana NE, Scharnweber D, Wolf-Brandstetter C, Joób Á, Bognár E. Investigation of the mechanical and chemical characteristics of nanotubular and nano-pitted anodic films on grade 2 titanium dental implant materials. Materials Science and Engineering: C. 2017 Sep 1;78:69-78.
12. Massaro C, Rotolo P, De Riccardis F, Milella E, Napoli A, Wieland M, Textor M, Spencer ND, Brunette DM. Comparative investigation of the surface properties of commercial titanium dental implants. Part I: chemical composition. Journal of Materials Science: Materials in Medicine. 2002 Jun 1;13(6):535-48.
13. Nuevo-Ordóñez Y, Montes-Bayón M, Blanco-González E, Paz-Aparicio J, Raimundez JD, Tejerina JM, Pena MA, Sanz-Medel A. Titanium release in serum of patients with different bone fixation implants and its interaction with serum biomolecules at physiological levels. Analytical and bioanalytical chemistry. 2011 Nov 1;401(9):2747.
14. Asserghine A, Filotás D, Nagy L, Nagy G. Scanning electrochemical microscopy investigation of the rate of formation of a passivating TiO2 layer on a Ti G4 dental implant. Electrochemistry Communications. 2017 Oct 1;83:33-5.
15. Carapeto AP, Serro AP, Nunes BM, Martins MC, Todorovic S, Duarte MT, André V, Colaço R, Saramago B. Characterization of two DLC coatings for joint prosthesis: The role of albumin on the tribological behavior. Surface and Coatings Technology. 2010 Aug 15;204(21-22):3451-8..

16. Ma G, Gong S, Lin G, Zhang L, Sun G. A study of structure and properties of Ti-doped DLC film by reactive magnetron sputtering with ion implantation. Applied Surface Science. 2012 Jan 15;258(7):3045-50.
17. Liu F, Wang F, Shimizu T, Igarashi K, Zhao L. Formation of hydroxyapatite on Ti–6Al–4V alloy by microarc oxidation and hydrothermal treatment. Surface and Coatings Technology. 2005 Sep 22;199(2-3):220-4.
18. Zhu X, Chen J, Scheideler L, Reichl R, Geis-Gerstorfer J. Effects of topography and composition of titanium surface oxides on osteoblast responses. Biomaterials. 2004 Aug 1;25(18):4087-103.
19. Lide D. Handbook of Chemistry and Physics, 86th edn. CRC.
20. Ong KL, Lovald S, Black J. Orthopaedic biomaterials in research and practice. CRC Press; 2014 Feb 21..
21. Jacobs JJ, Gilbert JL, Urban RM. Current concepts review-corrosion of metal orthopaedic implants. Jbjs. 1998 Feb 1;80(2):268-82.
22. Ponthiaux P, Wenger F, Drees D, Celis JP. Electrochemical techniques for studying tribocorrosion processes. Wear. 2004 Mar 1;256(5):459-68.
23. Souza JC. Biotribocorrosion behavior of titanium in simulated oral environments.
24. Assi F, Böhni H. Study of wear–corrosion synergy with a new microelectrochemical technique. Wear. 1999 Dec 1;233:505-14.