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In Vitro Performance Evaluation Of Peek Abutment On Titanium Implants Vs Titanium Abutment On Titanium Implants At Implant Abutment Connection Interface –A Tribocorrosion Study

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ABSTRACT
Implants must be able to support masticatory loads combined with a high biocompatibility and wear resistance in the presence of a corrosive environment. In order to improve the simultaneous wear and corrosion response at the implant abutment interface, PEEK/titanium and titanium/titanium implants were assessed by tribocorrosion analyses under conditions mimicking the oral environment. The tribocorrosion tests samples were performed on a reciprocating ball-on-plate tribometer at 30N normal load in artificial saliva at 37^0C. Open circuit potential (OCP) was measured before and after reciprocating sliding tests. The worn surfaces were characterized by stereomicroscopy. The results revealed a lower wear rate on PEEK combined with a lower coefficient of friction (COF), when compared to titanium.
KEYWORDS: Tribocorrosion, Biotribocorrosion, Tribometer, Open Circuit Potential, Co-efficient of friction, Implant Abutment Interface, PEEK

1. Introduction

Replacing missing teeth with implant-supported prostheses has become an efficient and widely accepted treatment for complete and partially edentulous patients.
An implant comprises two main parts: the implant body and the prosthetic component.[1]The abutment is an intermediate component between the implant and the restoration, secured to the implant by a screw.
The implant-abutment interface (IAI) is the connection site where the implant body joins the abutment and restoration, making its clinical abilities critical for successful outcomes, as implant failure is closely related to managing the restorative phase. Selecting the appropriate IAI can enhance aesthetics, extend longevity, and ensure a structurally secure joint while preventing biological issues such as peri-implant disease and irreversible implant damage.[1]
The implant-abutment connection interface (IACI) is crucial when selecting an implant system. It is the connection site where the implant body attaches to the abutment and restoration, making its clinical performance essential for successful

outcomes.

Implant failure is strongly linked to managing the restorative phase, so choosing the right IACI can enhance aesthetics, improve longevity, and ensures structurally secure joint. It helps to prevent biological issues such as peri-implant disease and irreversible implant damage.[1]

Owing to its exceptional mechanical qualities, corrosion resistance, and biocompatibility, titanium and its alloys are used extensively in dentistry (Liu et al., 2017). These characteristics are attributed to forming a continuous, amorphous, highly adherent, and stable titanium oxide (TiO_2) layer, which protects the metal surface from oxidative degradation caused by biological fluids.[2]

Tribocorrosion can be defined as the phenomenon involving the simultaneous action of tribological effects and electrochemical processes in the form of redox reactions, triggered by an aggressive external environment, causing the deterioration of the coupled materials. In circumstances in which biological tissues and fluids exist, a bio-tribocorrosion process is initiated.[3]

Biocompatible polymers and polymer-based composite materials have been considered as potential alternatives to overcome the tribocorrosion processes occurring on titanium-based materials.

The biocompatible polymer known as poly-ether-ether-ketone, or PEEK, has attracted attention lately because of its excellent mechanical characteristics, which include a Young's modulus of about 3.6 GPa and a tensile strength of 90–100 MPa. PEEK can withstand a wide range of solutions, both organic and inorganic. This polymer can prevent corrosion on metal surfaces when used as a veneering material (Kim et al., 2004). As a result, PEEK-based composites are garnering attention as a potential substitute for titanium implants and prostheses used in dentistry and orthopedics.[3]

Since PEEK offers improved biocompatibility and resistance to wear in human body environments and titanium offers great mechanical strength, veneering PEEK on a Ti-based substrate can be helpful for biomedical joints. Such a hybrid construction can sustain the masticatory stresses in crown-abutment or abutment-implant joints while having a high wear resistance and preventing the discharge of metal ions from the substrate.[3]

It is well-documented that polymers' friction and wear characteristics in fluid environments differ substantially from those observed under dry friction conditions. Water can cause polymer surfaces to absorb and become plasticized, which changes how they wear and how much friction they have.[4]

Research by Tanaka and Evans indicates that introducing water in polymer/metal sliding interactions typically lowers the coefficient of friction. However, it may result in an increased wear rate for the polymer.[4]

Unal and Mimaroglu examined the tribological performance of carbon-reinforced PEEK composites in water-lubricated environments and found that the coefficient of friction was lower compared to dry conditions. However, friction and wear processes can result in a reduction of mechanical efficiency.[4]

The tribolayer, a mixture of organic components from oral fluids and metal particles at the interface of surfaces, plays a crucial role in implant surface properties (Wimmer et al., 2010). This layer provides corrosion protection, enhancing the longevity and performance of implants (Mathew et al., 2014b).[5]

In dental implants, the cervical area interacts with the epithelium, fibro collagenous soft connective tissue, abutment, and oral fluids (Çomute et al., 2001). Discrepancies at the implant-abutment interface can create gaps that promote microbial colonization.[5]

The oral environment presents a highly complex and aggressive setting for metallic implants from a tribological perspective (Mabilleau et al., 2006). The presence of saliva and microorganisms can have dual effects on the biotribocorrosion of dental implants. The literature lacks consensus on whether chemical or mechanical degradation is the primary factor influencing tribological behavior.[5]

Corrosion can increase titanium particles' dissolution, altering the submucosal microbiome's structure and composition and inducing higher rates of inflammatory response (Daubert et al., 2018). Material degradation may also contribute to increased crestal bone resorption and a higher risk of micro-movement and implant failure (Jung et al., 1996).[6]

The potential disadvantages of tribocorrosion extend beyond the loss of function to include significant health risks. Corrosive products can migrate from the implant to surrounding tissues, potentially causing histopathological issues. The release of particles may also trigger inflammation, the first sign of discomfort for patients, due to macrophage activity. These immune cells phagocytize and digest foreign particles, which can exacerbate inflammatory responses.[6]

Several techniques are currently available for investigating tribocorrosion, including open circuit potential (OCP), potentiostatic and potentiodynamic methods, galvanic cell measurements, and electrochemical impedance spectroscopy. These methods can be applied during sliding or in its absence, either under free potential conditions or with an imposed potential.[6]

Dalmau et al. explored the relationship between current and friction in a Ti-Nb-Zr-Ta alloy within a phosphate-buffered solution, observing that an increase in current was associated with a decrease in the coefficient of friction. The effects of concentration of silicon carbide (SiC) particles were studied by Wang et al. They applied load on a Ti-25Nb-3Mo-3Zr-2Sn alloy in Ringer's solution, finding that wear increased with higher particle concentration and lower applied load. The composition of biological fluids significantly influences the tribocorrosive behavior of materials, particularly in ion release and passive film formation, as noted by Yan et al.[6]

In a study that involved Titanium Grade V in a phosphate-buffered saline solution, Yazdi et al. found that the specific wear rate per unit of force decreased with increased load due to more excellent coverage of tribofilms.[6]

In the oral environment, organism-related factors such as metabolic, immunological, microbiological, and biochemical processes also affect the deterioration of dental implants. Tribocorrosion, when studied under biological conditions, is termed bio-tribocorrosion, which is more relevant when considering dental implants in the oral cavity. Mechanical motion can erode the protective layer, leading to direct implant-environment contact and initiating degradation and corrosion.[7]

This process generates metal ions of micrometer and nanometer sizes that trigger inflammatory responses in adjacent tissues. Titanium ions have been detected in epithelial cells and macrophages in exfoliative cytology studies of peri-implant tissues. Even at low concentrations, these ions can cause aseptic osteolysis, leading to premature loosening of dental implants and peri-implantitis.[7] Pathogens like Streptococcus mutans and Porphyromonas gingivalis can attack the TiO2 layer in the oral cavity, inducing corrosion.

These microorganisms generate acids and lipopolysaccharides (LPS), which reduce the pH of the adjoining medium. When combined with the implant's micromovements inside the bone, these components interact in tandem to cause bio-tribocorrosion, which erodes the titanium surface.[8]

Due to excellent thermal stability and its resistance to solvent attack and wear, polyetheretherketone (PEEK) is increasingly attractive for bearings and sliding applications. Numerous studies have examined the friction and wear behavior of PEEK.[8]

2. Objectives

This study aims to investigate and compare the tribocorrosion behavior of a PEEK/Titanium implant-abutment interface with that of a Titanium/Titanium interface in dental implant prostheses.

3. Scope and Methodology

In this study, a biocompatible poly-ether-ether-ketone (PEEK) polymer abutment on a titanium implant (Figure 1) was selected as the test group, while a titanium abutment on a titanium implant served as the control group (Figure 2). Each group had a block of implant and abutment. Experiments were conducted under controlled conditions: ambient temperature, atmospheric environment, applied load, and sliding velocity. A modified Fusayama artificial saliva was also prepared for tribocorrosion testing.

A reciprocating ball-on-plate tribometer was employed for friction and wear tribocorrosion tests, with an alumina ball of 10 mm diameter as the counter-body. Samples were placed in an acrylic electrochemical cell attached to the tribometer. Tests were conducted in 30 ml of Fusayama artificial saliva at 37°C, simulating the oral cavity's temperature and electrochemical environment.

Prior to reciprocating sliding tests, the open circuit potential (OCP) was recorded on Ti6Al4V for 60 minutes using a potentiostat/galvanostat.

Electrochemical measurements utilized a standard two-electrode cell, with a saturated calomel electrode (SCE) as the reference electrode and samples with an exposed area of 0.5 cm² as the working electrode. The reciprocating sliding tests were performed at a normal load of 30 N, a sliding frequency of 1 Hz, and a linear displacement amplitude of 3 mm under OCP measurement for 30 minutes.

Figure 1 Ti Implant with Peek Abutment

Figure 1 Ti Implant with Ti Abutment

After the sliding tests, the OCP was measured for an additional 60 minutes. Wear volume was estimated by measuring the lateral width of the wear scars and applying empirical mathematical equations, assuming the wear scars formed perfect ball geometries. Wear surfaces were analyzed with the help of Stereomicroscope. Data was collected by the end of the test.

4. Result and Discussion

Tests for tribocorrosion were conducted at 37^0C in artificial saliva. Both prior to and following reciprocating sliding testing, the open circuit potential (OCP) was measured. Stereomicroscopy was used to analyze the wear surfaces of co-efficient of friction.

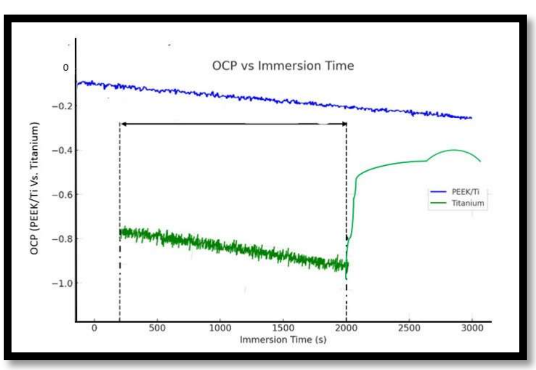
The OCP of titanium implant and titanium abutment submerged in artificial saliva stabilized at fairly steady values prior to sliding tests, suggesting the presence of a passive coating on the surface of titanium. An abrupt dip in the OCP curve was observed when the alumina ball was put onto the passive titanium film and sliding began. This drop indicated the unresisting titanium film's disintegration and exposed the new, active titanium in the wear and tear course. (Graph 1)

The OCP curve's progression for the titanium implant's PEEK abutment showed a distinct behavior. The slide did not change the OCP reported on PEEK/Ti6Al4V.

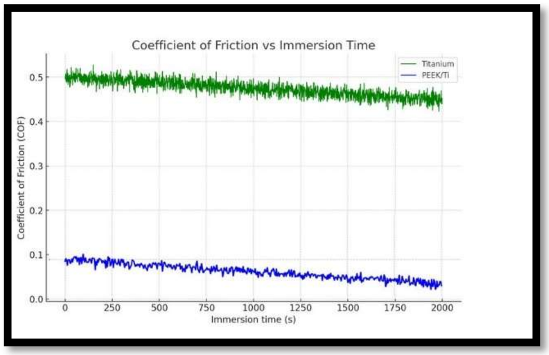
Because of the preservation of the thick layer of PEEK during sliding, there did not occur any direct contact between the alumina ball and the titanium substrate. Because of this, it is expected that the OCP values will remain constant throughout the tribocorrosion testing, as the OCP dimension illustrates. (Graph 1)

After a brief running-in period, the COF reaches a steady-state regime; nonetheless, the COF values observed on PEEK were more stable than those on Ti6Al4V. In comparison to the control group, the COF measured when PEEK (test) was involved in the contact was much lower. (Graph 2)

The visual appearance of the metallic wear surface is more severe than that of the polymeric worn sections. Ti6Al4V, then, indicates a higher degree of surface deterioration (Figure 3), which is consistent with the particular wear rate, COF, and OCP data when compared to that of PEEK. The worn surface morphology of the PEEK (Figure 4) shows a rather smooth look with minor grooves resembling the sliding direction due to the damage generated by the ceramic counterface.



Graph 1: Open Circuit potential Curves of Peek/Ti vs Ti/TI



Graph 2 COF values of Peek/Ti vs Ti/TI

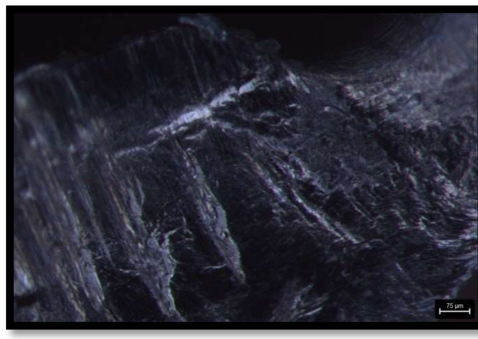


Figure 3 Stereo Microscope Image of Ti Abutment at IAI after Friction

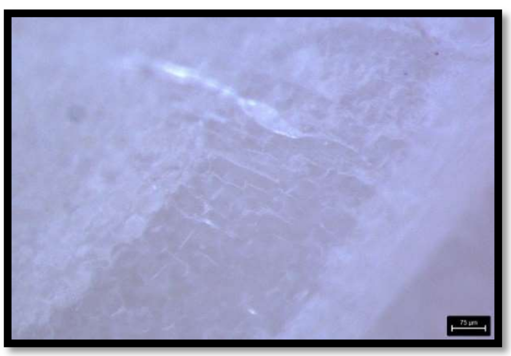


Figure 4 Stereo Microscope Image of PEEK Abutment at IAI after Friction

DISCUSSION

Dental abutments are widely Titanium or its alloys wherein the titanium corrosion is thermodynamically not favourable due to which titanium is considered as a superior dental implant material. Materials that are exposed to oral environment are mostly prone to corrosion because of the oral environment such as pH, wear at IAI, temperature etc., Saliva facilitates ion migration which causes ion release at the implant abutment interface during tribocorrosion.[9]

Tribocorrosion at the IAI leads to structural as well as mechanical failure of implant components which in turn causes peri-implantitis, oral malodor, local staining, oral edema and systemic reactions as well. Release of metal ions to the surrounding tissue from the abutments consequetively leads to oxidative damage, apoptosis, osteoblastic and cytotoxic effects leading to bone resorption. [9]

In this study, the titanium/titanium and titanium/PEEK implant abutment interfaces were subjected to ball on plate reciprocating wear tests and OCP tests in a lubricated artificial saliva medium to replicate oral conditions to evaluate the potential of tribocorrosion resulting from the relative movement between abutment and implant. The test and control groups' open circuit potential and friction coefficients were examined, and the results were compared.

In the current study, both the titanium and PEEK groups showed resistance to corrosion but the OCP value of PEEK was lesser when compared to that of titanium which shows that the ion release from the PEEK/Titanium IAI is negligible.[10]

As can be seen from the graphs, smooth abrasion of polymeric surface led to lower OCP together with a low friction and wear, which in turn determined tribocorrosion behaviour of PEEK versus titanium under the influence of artificial saliva.

The results of the present research are consistent with that of Chen et al. (2014), who observed a comparable pattern in the OCP curves pertaining to the tribocorrosion behaviour of AISI 316 stainless steel and Ti6Al4V in freshwater or seawater. Compared to Ti6Al4V alloy, AISI 316 stainless steel experienced a smaller decrease in OCP.[11]

The results of this study also support a study by Chaturvedi that described how titanium implants retain hydrogen from the oral cavity over an extended period of time, increasing the risk of brittleness and fracture. This study supported the hypothesis that there are substantially lower dispersed stresses in Zirconia type of implants.[12]

The data of the present study indicates that the PEEK alloy does not structurally and mechanically deteriorate during the masticatory process and in turn will maintain a healthy hard and soft tissue with no inflammation. The co-efficient of friction during sliding shows a steady increase in both the groups. However, the variations in the oscillations were higher in the titanium group when compared to that of PEEK. COF of titanium had higher variations which implies the corrosive nature of titanium IAI. COF of PEEK was significantly lower during the sliding testing.[13]

An increased COF leads to decreased preload values which will have poor friction and wear resistance. This in turn leads to the screw failures which shows an increased gap formation between the implant and the abutment.[14]

In comparison to Titanium, the co-efficient of friction test findings of the current research showed decreased wear on PEEK. PEEK prevented discharge of metallic ions to the surrounding tissues by shielding the titanium substrate from wear and corrosive environment. These findings are consistent with the findings published by Souza et al. (2012).[1]

In order to demonstrate experimentally that the ZTA | Grade 5 Titanium linking has a reduced wear coefficient, Xinmin Li conducted a tribological analysis of common gear materials. When exposed to corrosion, the ZTA pin corrodes much less quickly than the titanium material that is being studied.[15] The findings of Xinmin's research are pertinent to what we are investigating now.

Bordin et al. assesed the coefficient of friction among materials used as abutment and implants in the presence of a salivary pellicle and biofilm, evaluating the role of the coefficient of friction in biomechanical response of dental implants subjected to loading.[13]

Dordin et al. compared the coefficient of friction between cpTi/cpTi and cpTi/YSZ under conditions such as salivary pellicle, multispecies biofilms, and normal conditions. The researchers showed that cpTi/cpTi's coefficients of friction was significantly higher than that of cpTi/YSZ when in the presence of a biofilm and normal conditions.[13]

Bulaqi et al. probed the effect of the COF on retightening of settling effect after the abutment screw was tightened. They suggested that a reduction in the coefficient of friction leads to an increase in preloading and decrease in the settling effect.[13]

The surface morphology of the alloys was scanned using stereomicroscope for analysing corrosion pits or grooves. Visible pits and grooves were observed in the titanium group after it was subjected to the friction test. Compared to the PEEK alloy, the grooves were visibly larger and infrequent in the titanium interface. These pitted imperfections tend to trigger the corrosion process causing microleakage.[16]

The surface morphology changes may cause accumulation of debris in the IAI, which might enhance the fibroblastic phagocytosis and apoptosis. It also induces osteoclast differentiation which is an indicator of implant failure.[16]

The investigation of coefficient of friction and rate of corrosion is the only focus of the current study. To further advance the research, measurements of the materials' polarization resistance, wear depth, and wear coefficients should be made.

These are important metrics for assessing materials that are subjected to tribocorrosion.

Despite significant advancements, research on wear and corrosion in relation to implant materials still faces difficulties in determining how closely materials can likely imitate the mechanical properties of natural materials like dentin and bone. More in-depth analysis is needed to understand how materials under inquiry behave in different electrolytic conditions. Additional assessment should also be done on the interfacial connection between surfaces and any potential surface modification mechanisms.

From the results of the study, we can conclude that the degradation process is seen is both Titanium and PEEK implant abutment interface. However, the degradation and the friction are comparatively less in PEEK/Titanium implant abutment interface than that of the Titanium/Titanium implant abutment interface.

5. Conclusion

The following conclusions can be drawn within the limitations of the study;

Under tribocorrosion conditions, PEEK abutment shielded the Ti6Al4V substrates from wear and corrosion which indicates that the microleakage will be less when titanium implant and PEEK abutment is used.

PEEK established that the coefficient of friction was lower in tribocorrosion circumstances than it was on Ti6Al4V. Compared to Ti6Al4V alloy, PEEK had a specific wear rate that was lower.

When immersed in artificial saliva, PEEK's biocompatibility and low tribocorrosion mechanism degradation indicate that it has great potential as a veneering biomaterial for Ti6Al4V structures. However, in order to produce hybrid PEEK/titanium structures for biomedical applications, more tribocorrosion investigations of PEEK and PEEK-based composites on various conditions are needed.

Tribocorrosion is an intricate phenomenon involving numerous components from various technological disciplines. Without a doubt, the topic is current, but it also requires more experimental testing to increase the state of current scientific understanding. Different setup conditions, such as changing the specimen material or the solution's chemical composition, may be used. Thus, numerous clinical trials that examine the PEEK's tribocorrosive behavior in a complex biological environment that includes presence of bacteria, may be helpful.

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