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Review

Tribocorrosion and oral and maxillofacial surgical devices

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Abstract

The release of metal ions or material particles, or both, into tissues that surround implanted medical or dental devices can create postimplantation complications. These rare but disturbing events are mainly caused by the mechanical movements of the components of the implant against each other, coupled with the influences of local biochemical and electrochemical factors. Mechanical movement of the components of implants against each other results in friction and wear, the study of which is called tribology. The tribology of an implanted device depends on the patient's activity and is affected by variables such as load, frequency, and the surface properties of the components of the implant that are in contact. Local biochemical and electrochemical factors include the ambient pH, and concentrations of protein and oxygen. The effect on local tissues and extracellular fluid can produce biochemical or electrochemical responses to the implant material in the surrounding solution, which is termed corrosion. The combined effect of these mechanical, biochemical, and electrochemical factors is known as tribocorrosion.

In this paper we will provide a brief overview of the basic principles of tribocorrosion, and its current status and future perspectives, to create awareness and interest, and to inspire research into its effects on implantable devices in oral and maxillofacial surgery. The information garnered from such investigations, appropriately applied, will not only improve present devices but also will lead to the development of superior ones, ultimately improving care and outcomes for patients.
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Introduction

Various types of implants have been developed to repair or replace injured or diseased body parts such as bones, joints, and teeth. Titanium (Ti) and cobalt chrome molybdenum (CoCrMo) metal alloys are the most common materials used in metal-containing implants because of their biocompatibility, resistance to corrosion, good mechanical properties, and low inflammatory potential.[1,2] To minimise the clinical and economic impact on individual patients and society in general it is imperative that implants have longevity, and should ideally last for the duration of the patient's life.[3–7]

However, there have been reports of early failure of implants as the result of loosening and osteolysis of the host bone.[1,8–12] Wear and corrosion of material facilitates particulate debris, both micrometre and nanometre-sized, and formation of metal ions that act as bioreactive species that cause adverse tissue responses.[13–17] This may lead to failure of implants that necessitates revision or replacement. One of

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the ways to make implants stable in situ, thereby increasing their functional life, is to improve the mechanical, corrosive, and biocompatible properties of the materials from which they are made.

Unlike other physical or industrial systems, a metal implant is exposed to a complex biochemical and electrochemical environment when in contact with a body fluid (such as synovial fluid or blood). The pH of these fluids is in the range of 7.4–7.6. Studies have shown that crevice corrosion in metal devices can lower pH.[17–20] The ideal metal implant therefore needs both excellent resistance to corrosion, and mechanical properties that satisfy the tribological stresses placed on it during function in a fluid system.

Definition of tribocorrosion

Tribology is the study of friction, wear, and the lubrication of materials, whereas corrosion relates to chemical aspects of material degradation in mechanical systems.[21–23] Tribocorrosion is a relatively new research field that combines the fundamentals of tribology (friction, wear, and lubrication) and corrosion. It has drawn attention from scientists and engineers over a wide range of research domains because of the implications of tribocorrosion in daily life, and the potential associated economic consequences. The tenets of tribocorrosion are relevant to numerous applications from the environment – to space exploration – to the medical device industry. In the field of medical devices, orthopaedic surgery has become the leader in tribocorrosion research as implanted alloplastic total joint replacement devices are constantly exposed to friction and wear in the presence of potentially corrosive body fluids.

Tribocorrosion research has brought important mechanical data and clinical insights to total alloplastic orthopaedic devices.[23–25] It is pertinent, therefore, to consider the application of established tribocorrosion standards and research principles developed and tested in orthopaedics[11,13–19,26–28] to oral and maxillofacial implantable devices such as maxillomandibular fixation plates and screws, dental implants, and alloplastic temporomandibular joint (TMJ) replacement devices.[1,29–36]

Basic principles of tribocorrosion

In tribocorrosion, a tribosystem has 3 interrelated components: tribology (friction, wear, and lubrication), corrosion (materials and environmental factors), and biochemistry (interactions between cells and protein) (Fig. 1).

Tribocorrosion, when coupled with corrosion, is capable of inducing erosion of solid particles and cavities, abrasion, and fretting of material surfaces.[37–39] A main cause of tribocorrosion is when 2 or more materials move mechanically, such as rubbing, sliding, and contact. The rate of corrosion of material and surfaces, and wear, is not well understood.

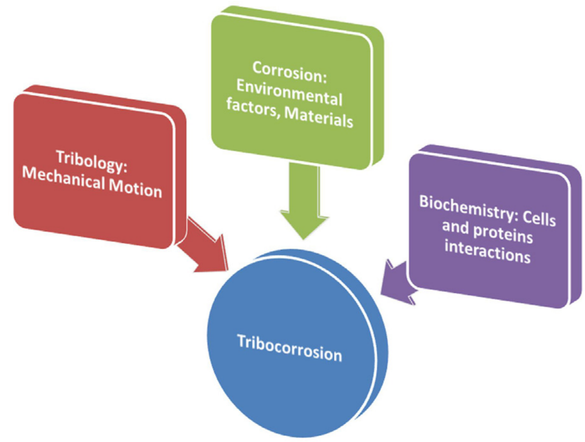

Fig. 1. Definition of tribocorrosion.

However, the key factors that influence corrosion of material and surfaces are the surrounding environment and the properties of the material. Using tribocorrosion testing, it is possible to study the impact of mechanical and electrochemical variables on the surface of the material and the underlying degradation mechanisms.[22–24,40–42]

Strong corrosion-resistant surfaces are able to form a thin metal oxide surface film that creates a barrier to prolong transfer of a charge between the environment and the material. However, as the material undergoes mechanical motion, the oxide film begins to erode and diminish, which allows the surrounding environment to come into contact with the material directly. The loss of the metal oxide layer permits a transfer of charge between the material and the surrounding environment, which initiates degradation and corrosion of the material. Evidence of corrosion includes, but is not limited to, pitting of the surface with variable size and location of grains, indentations, and bidirectional lines.[37,43] Such observations are shown in Fig. 2, which shows the microscopic image of the surface of the retrieved TMJ implant.

History and current status of tribocorrosion

As tribocorrosion is a relatively new field of study, many experiments are underway to understand the mechanism of corrosion and mechanical wear. The history of tribocorrosion goes back 4 decades.[43,44] However, systematic investigation of the subject first appeared in the early 90s.[21,22,45,46] These studies focused mainly on industrial applications, and classified tribocorrosion into several categories including sliding wear-corrosion, abrasion-corrosion, microabrasion-corrosion, and erosion-corrosion.[21,45–50] Ponthiaux et al.[21] investigated electrochemical techniques to study a synergistic corrosion-wear material degradation model by including sliding contacts in an electrically conductive solution. The tribocorrosion performance of thin films of layers of metal oxide and material coatings are currently being explored. Wood et al.[48,49] reported that the main factors that influenced

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