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Review

# Degradation mechanisms and future challenges of titanium and its alloys for dental implant applications in oral environment

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ABSTRACT

*Objective:* For many decades the failure of titanium implants due to corrosion and wear were approached individually and their synergic effect was not considered. In recent past, developments and understanding of the tribocorrosion aspects have thrown deeper understanding on the failure of implants and this has been reviewed in this article extensively.

*Methods:* Medline, google scholar and Embase search was conducted to identify studies published between 1993 and 2016 which were related to the analysis of degradation mechanism which the dental implants undergo after implantation.

*Results:* *In-vitro* tests has been extensively carried out to evaluate the tribocorrosion behavior of titanium based dental implants. However, there is still a lack of knowledge about the tangible behavior of materials under *in-vivo* condition, because the *in-vitro* experiments are conducted using different testing protocols and conditions (solutions, pH, time, equipment, and testing parameters). Hence, there is an urgent need to perform round-robin test in different laboratories which will help to overcome the gap between *in-vitro* and *in-vivo* conditions.

*Conclusion:* Tribocorrosion has been identified as the major degradation mechanisms that result in the failure of dental implants. Hence, it is of utmost importance to improve the service period of dental implants by reducing the tribocorrosion effects through developing new dental implant materials using nobler alloying elements or through modifying the surface of the implants. In order to have a thorough understanding of tribocorrosion behavior and failure mechanisms, round robin test are to be conducted and new protocols/standards are to be developed for the testing of implants.



**Contents**



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## 1. Introduction

Dental implants are surgically fixed substitutes for roots of lost or non-functional teeth. Restorative dental materials help to repair damage to teeth caused by gum disease, poor bone density or trauma. The restoration of teeth is very important because tooth damage, loss or dysfunction may cause speech disorders and may even lead to deterioration of the temporomandibular joint with severe pain [1]. Although bridgework and dentures address the cosmetic problem of missing teeth, they fail to restore proper chewing functions. Permanent implants, on the other hand, exert appropriate force on the jawbone and keep them functional and healthy [2]. Due to further developments in dental care technologies, a tremendous growth in dental implants and prosthetics market has been observed during the past few years. Hence, there is an extensive need of better quality dental materials, which not only helps to restore the functions of teeth but also causes less harm to the human body.

The choice of the dental implant materials, their manufacturing processes, biocompatibility and long-term stability in line with medical ethics and professional codes of practice are therefore crucial. Materials such as ceramics and metal alloys are extensively used for the fabrication of dental implants. Ceramics either make up the entire implants or can be applied in the form of a coating onto the metallic core. An ideal implant should be biocompatible, possess higher strength, fatigue and fracture toughness behavior and should be able to withstand the reactive environment it is exposed to inside the human body [4]. In addition, the stiffness/modulus of elasticity should be as close to that of bone to prevent stress-shielding effect. Stress-shielding effect arises when there is a mismatch between the strength of two materials [3]. Among the different metallic materials employed as implants, the use of stainless steel has been restricted as an internal fixation device because of its poor fatigue strength and high susceptibility to pitting and galvanic corrosion. Similarly, cobalt–based alloys suffer from poor fatigue strength and possess comparatively high modulus of elasticity than other implant materials used. In addition, the ion release from these materials has been found to have carcinogenic effect [4]. Thus, the above mentioned reasons make titanium and its alloys the ultimate choice as dental implants because in addition to exhibiting superior biocompatibility and high strength to weight ratio, Ti-alloys also exhibit low modulus of elasticity and enhanced mechanical properties such as high fatigue strength (140–1160 MPa) and fracture toughness. Various titanium dental implants are available commercially and are classified into groups based on their shape (cylindrical, conical, hybrid) and the type of connection to the prosthetic component such as Morse taper, internal hexagon, external hexagon and dodecagon [5]. Remarkably, their corrosion resistance stems from the high affinity of Ti towards oxygen which results in the formation of a thin and stable passive oxide layer that protects the bulk material from reactive species [6]. The oxide layer formed on Ti alloys typically consists of $TiO_2$ but may coexist along with other titanium oxides such as TiO and $Ti_2O_3$ [7]. The thickness of the oxide film formed are <10 nm and offer high resistance to a variety of chemical attack thereby making Ti-based implants highly corrosion resistant in the oral environment.

The main aim of this review is to focus on the degradation mechanism of titanium dental implants along with the various surface treatments utilized to improve the performance and service life of dental implants. Based on an extensive review performed, the future challenges in the field of implant dentistry are also identified and presented.

## 2. Materials and methods

The electronic search was performed using Medline (PubMed), Embase, Google scholar, book chapters and Prorequest dissertations and theses database. Grey literature such as reports were also used to analyze the current status and future scope of dental implant market. The MESH term used were: dental implants AND market, wear and dental implants, corrosion and oral environment, tribocorrosion and artificial saliva, toxicity and debris, surface modification and alloying, new dental alloys and corrosion resistance, anodization AND titanium plasma spray (TPS), nitriding, cryogenic treatment, coating AND titanium. Languages were limited to French and English. The time period of the literature search was between March – September 2016 and there were no exclusions made based on the year of published paper. Mendeley V.1.15 was used to manage the references. Important criteria's for inclusion of articles were: Fig. 1 shows the flowchart illustrating the inclusion and exclusion criteria and study flow for the systematic review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.

## 3. Discussion

### 3.1. Clinical aspects

Osseointegration is a term that refers to the formation of a direct functional and structural connection between living bone and an artificial implant and is governed by a variety of surface properties such as composition, roughness, wettability, surface energy, surface tension, orientation and texture [8]. In particular, the important factor that determines osteogenesis is the adsorption of specific proteins onto the metal surface. The adsorption of surface proteins should be such that the bioactive peptides which helps cell-binding is available for the incoming proteins. The initial process involving the complex interplay of various signaling molecules and inflammatory mediators which leads to osteoconduction and osteoinduction takes place a period of about 21 days [9]. It has been found that there exists a critical level of micromotion (50 and 150 μm) above which fibrous encapsulation prevails over osseointegration [10].

Widely accepted protocol for the successful placement of endosteal implants involves a traumatic surgical technique and healing period of at least 3 months with no-load to promote regeneration and prevent fibrous encapsulation. In contrast, another method which ensures quicker recovery is by adopting for immediate loading involving a