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Identification of failure mechanisms in retrieved fractured dental implants

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Dental implants treatment complications include mechanical failures. These complications were considered minor until now but several clinical trials showed that mechanical complications are common in implantology and in implant rehabilitation. The aim of the study was to perform a detailed systematic failure analysis on Ti–6Al–4V and CP-Ti retrieved dental implants.

A total number of 10 CP-Ti and 8 Ti–6Al–4V retrieved fractured dental implants and implant parts were collected and there metal composition was identified using SEM–EDX (energy dispersive X-ray spectroscopy).

The identification of the implants failure mechanisms was done by comparing the fracture surfaces of retrieved fractured dental implants to fracture surfaces of implants fractured in lab conditions in room air, and also in an environment mimicking the intraoral environment, which includes artificial saliva and fluoride (exemplar testing). The analysis was done by using Scanning Electron Microscopy (SEM).

The overall fracture mechanisms that were identified on the retrieved Ti–6Al–4V and of CP-Ti dental implants were identical to those found on fatigue fracture surfaces of the specimens' fractured in lab conditions. No evidence was found for corrosion products on the metal surface, which might suggest the operation of a corrosion processes participating in the crack formation.

This study clearly shows that fatigue is the main failure mechanism for Ti–6Al–4V and CP-Ti retrieved dental implants. The fractographic analysis showed that implants and their parts might be broken at relatively low cyclic load levels, of the kind that matches the load levels generated during mastication.

1. Introduction

The use of dental implants as a treatment option for the rehabilitation of missing teeth is met with a very high success rate. Despite this, complications associated with this treatment do exist, which may eventually lead to the loss of both the implant and the prosthesis. Late treatment failures can be caused by mechanical complications which may involve screw loosening and/or fracture, abutment fracture and implant fracture.

A systematic review, on survival and complications of dental implants, after a follow up time of at least 5 years, showed that mechanical complications are common, including fracture of abutments and screws with the incidence of 2.5%, after a

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follow up time of 10 years. Fracture of implants, a relatively rare event, showed a cumulative incidence of 1.8% after a follow up time of 10 years [1].

A long term retrospective cohort study, which evaluated the outcome of implants therapy over a period of 10–16 years, showed that mechanical complications, which include implant fracture, abutment fracture, fracture of the implant's screw and prosthesis porcelain fracture all had an incidence of 31%, as compared to 16.9% for biological complications [2].

Today, dental implants are made of either pure (CP) titanium or titanium alloys. Among the latter, Ti–6Al–4V has been a main biomedical titanium alloy used for the fabrication of dental implants [3]. The high physico-mechanical properties of those materials, i.e. relatively low Young's modulus (important when the implant is to be matched to bone structure for instance), high fatigue and corrosion resistance, and excellent biocompatibility are all important properties of the titanium alloys that makes them a suitable choice for implant material [4,5].

Detailed fracture analyses of retrieved fractured dental implants are quite rare in the dental and in the biomechanical literature alike. That is because the incidence of fractures of dental implants and implant parts is rather low. Most fractured implants are left in the alveolar bone after fracture because of the difficulty to retrieve them. In most cases, the fracture surface of the implants, which is essential for fracture analysis, is destroyed or heavily damaged to a point that renders fractographic analysis impossible. In parallel, there are no clear and conclusive professional directives for the handling and preservation of fractured implants and implants' parts.

Yokoyama et al. [6] compared retrieved fractured dental abutment screw, made of CP-Ti, to an as-received abutment screw, by using SEM (Scanning Electron Microscope) and microstructural examination. The fracture surface of the retrieved fractured screw showed mixed ductile fracture and fatigue striations. The authors postulated that the fracture was caused by trans-granular stress corrosion cracking, without performing a detailed comparison with the fracture surface of the as-received screw, fractured by fatigue, in vitro conditions (exemplar testing).

Scanning electron (SEM) fracture surface analysis of six fractured CP-Ti dental implants, which had fractured intra orally after an average duration of 30 months, was carried out by Choe et al. [7]. The analysis claimed to have identified fatigue striations in all six specimens. Yet, the SEM fractographic pictures did not reveal a conclusive identification of fatigue or of the final fracture mode, because of the rather low magnification (X0.5 K) used in the article. Moreover, the authors concluded that the development of corrosion is the main reason for the failure of the collected fractured dental implants. Yet, no evidence of corrosion (corrosion products or pitting) could be identified in any of the presented SEM pictures.

Manda et al. [8] made a detailed fracture analysis of a single fractured CP-Ti implant and abutment screw. The broken parts were stored in 10% buffered formalin solution before being examined by SEM. The results showed that the fracture surface was covered by calcium, phosphorous and oxides. Even though, fatigue striations could be identified on the fracture surface. The authors concluded that the organic Ca/P depositions were an integral part of the mechanism which had led to the observed failure. While the organic deposits were carefully identified by those authors in order to assess the composition of the environment the implant was placed in, they covered large parts on the fracture surface, thereby hampering the progress of the fracture analysis. The authors did not show how or when the deposits were formed on the fracture surface, nor did they identify any effect on the material's microstructure. Nevertheless they concluded that these organic deposits played a role in the fracture process.

SEM fractographic analysis of seven fractured CP-Ti hollow dental implants, which had fractured intra orally after an average of 36 month, was reported by Sbordone et al. [9]. The SEM pictures published on the results showed clear fatigue striations; nevertheless, the authors identified cleavage type fracture as the failure mechanism. In addition, those authors did not show a comparison to hollow implants, fractured under lab conditions (exemplar testing), which could have shed additional light on the operating fracture mechanisms.

The above-mentioned studies illustrate the partial nature of the failure analyses carried out on CP-Ti implants so far. Yet, one can expect an increased incidence of mechanical complications as time passes. Therefore, a systematic analysis of fractured surfaces, which includes proper specimen handling and cleaning techniques, a large sample size, exemplar testing if necessary is highly desirable both for dental practitioners, implants' manufacturers and designers alike.

2. Materials and methods

2.1. Specimen collection

Twenty-four, in vivo fractured implants or implant parts, were collected for failure analysis. Unfortunately, no medical record of the retrieved fractured dental implants was made available. No information about the implant: intra-oral location, service years, carried prosthesis, proximity to additional implants or eventual bone loss. Likewise, no information was available about the patient, such as gender, age, oral status and habits. Consequently, the broken parts were investigated on purely technical grounds without addressing the related medical issues.

The first step was a macroscopic examination of the fracture surfaces in order to identify the fracture surface conditions and if a fracture mode analysis could be done using a binocular. Six implants were in poor condition (destruction during the extraction procedure) which hampered any practical observation from of the fracture surface at the macroscopic level, and were consequently set aside.