Fatigue Properties on the Failure Mode of a Dental Implant in a Simulated Body Environment

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This study undertook a fatigue test in a simulated body environment that has reflected the conditions (such as the body fluid conditions, the micro-current of cell membranes, and the chewing force) within a living body. First, the study sought to evaluate the fatigue limit under normal conditions and in a simulated body environment, looking into the governing factors of implant fatigue strength through an observation of the fracture mode. In addition, the crack initiation behavior of a tungsten-carbide-coated abutment screw was examined. The fatigue limit of an implant within the simulated body environment decreased by 19% compared to the limit noted under normal conditions. Several corrosion pits were observed on the abutment screw after the fatigue test in the simulated body environment. For the model used in this study, the implant fracture was mostly governed by the fatigue failure of the abutment screw; accordingly, the influence by the fixture on the fatigue strength of the implant was noted to be low. For the abutment screw coated with tungsten carbide, several times the normal amount of stress was found to be concentrated on the contact part due to the elastic interaction between the coating material and the base material.

Keywords: biomaterial, plating, scanning electron microscopy, dental implant, fatigue test

1. INTRODUCTION

Since the early study of osseointegration, dental implant therapy has been widely used to improve the dental function of patients who are completely or partially edentulous [1-6].

However, in spite of the vast volume of promising research on implant operations and processes, a large number of implant fracture cases have been reported [7,8]. Especially for failures that occur after a certain period of time upon implanting (refer to the example in Fig. 1), it is necessary to review fatigue durability.

Past studies focusing on the fatigue strength of implants were mostly carried out under normal conditions in a laboratory [9-11]. In other words, they did not consider complex reactions involving various factors (such as body fluids, the micro-current in the cell membrane, and the chewing force) within the mouth. These studies cannot therefore be regarded as studies that have reflected the many different biodynamic properties within the body of a patient who has received an implant.

Because the passive film of titanium and its alloys, which are widely used for dental implants, are highly elaborate, they generally do not corrode in the soaking test, even after several years within a simulated body environment [12-16]. Despite this fact, several corrosion damage cases have been reported recently in persons (and animals) who have undergone an implant operation [17-20]. An actual case of corrosion damage, as shown in Fig. 2, was discovered on the stem surface of a coxa implant (9 years and 2 months after the surgical operation) that was removed from a human body [21].

The passive film used in these applications can fracture especially when some type of stress other than that from the bio-environmental elements is repeatedly applied. The film can fracture due to the slippage of the material surface caused by the fatigue load. It has been shown that corrosion can progress before the passive film even forms on a newly generated exposure part [22].

If corrosion progresses due to repeated stress, a corrosion pit typically forms at that location. The corrosion pit can develop into a crack due to a concentration of stress. In the case of dental implants, a crack can occur at the location of a pit due to the repeated chewing force. It can then develop into a fatigue crack which may ultimately lead to the fatigue fracture of the implant.

Lately in the manufacture process of implants, the corro-
sion-resistance and weakness of the mechanical properties have been improved through the use of pure titanium and its alloys and through various treatments on the surfaces of the fixture, the abutment and the abutment screws. Especially in order to prevent loosening of the abutment screws, which is commonly observed in an implant system, various studies relative to a surface treatment have been conducted [23-25].

If dissimilar materials of different properties are coated or attached onto a single material, stress concentration can arise around the contact part due to the difference in the elastic moduli of the two materials. For example, the GS II abutment screw model of an Osstem Implant is coated with tungsten carbide (WC). In this case, stress concentration occurs at the interface between the coating layer and the basic material. Stress when concentrated in this way can result in a reduction of the overall fatigue strength of the abutment screw when a fatigue crack is generated at the spot where the cleavage facet of the tungsten carbide layer arises. Accordingly, when performing the surface reforming treatment of the materials, these points should not be overlooked.

By using the dental implant that is widely used at the present time, this study has carried out the fatigue test under the normal conditions and the simulated body environment reflecting factors within the body mentioned previously. First, this study attempts to evaluate the fatigue limit under normal conditions and in a simulated body environment and to investigate the governing factors of the implant fatigue strength through an observation of the fracture mode. In addition, the crack initiation behavior of a tungsten-carbide-coated abutment screw is examined.

2. EXPERIMENTAL PROCEDURE

2.1. Specimen

This study used the GS II model of Ostem Implant as the implant specimen. The fixture was the internal type made of titanium, measuring 4 mm (ø) by 11.5 mm (L). The abutment was the hex standard type, at 5 mm (ø) and 2 mm (L) (Gingival/Height). The base material of this abutment screw consists of Ti-6Al-4V, and its surface is coated with tungsten carbide at a depth of 2 µm to 3 µm.

2.2. Test method

The 30 N·Cm coupling between the fixture and the abutment using abutment screws was done with a digital torque wrench using the method recommended by the manufacturer.

A hemispherical loading member onto which the load was applied during the test was prepared in accordance with the ISO 14801 specification (International Standard of Dental Implant Fatigue Tests) [26] and was fixed onto the specimen using epoxy resin.

The frequencies pertaining to the loading, temperature and waveform in the cyclic loading assessment were determined according to the standards. The loading method and specimen installation process were carried out as shown in Fig. 3 using a load ratio of R = 0.1 and a sine wave for the loading waveform. Regarding the test devices and procedures used in this study, we used a fatigue tester (with a maximum fatigue load of 1000N) with the linear motor method prepared appropriately for the overall test conditions as suggested by ISO 14801.

The fatigue test under normal conditions was performed at a test speed of 15 Hz according to the international standards and at a room temperature of 20 ± 5 °C. The fatigue test under the simulated body environment was performed at a speed of 2 Hz in a liquefied test condition meeting international standards.

A schematic diagram of the simulated body environment test device is shown in Fig. 4.

Accelerated test conditions are generally applied when performing a fatigue test under in-vitro conditions in a sim-