Microscopic Feature of Fractured Implant in Practical Dental Use*1

Hidenori Era1, Yasuyuki Mastushita2, Mayumi Miura1,*2 and Katsuhiko Kishitake1

1Department of Material Science, Faculty of Engineering, Kyushu Institute of Technology, Kitakyushu 804-8550, Japan
2Faculty of Dental Science, Section of Oral Rehabilitation, Kyushu University, Fukuoka 815-8582, Japan

Patients suffer considerable pain from fracture of placed implants. In order to reduce the number of fracturing failures in future and to obtain a better understanding of fracturing, a fractured implant has been investigated by means of radiography, scanning electron microscopy and transmission electron microscopy from a metallurgical viewpoint. The blade type implant of Ti-5V alloy has a virgin microstructure of a low density of dislocation with a dispersion of fine precipitates. Further dislocations and twins are introduced into the implant due to repeated loading in use, resulting in possessing a large amount of lattice defects until fracturing. The dislocations are considered to assist calcium penetration and to bring about intergranular fracturing near the surface of the implant. Striations are extensively observed at a center portion of the implant, indicating that the fracturing is caused by fatigue. Microscopic investigations reveal that the fracturing is initiated by some elements such as calcium in saliva in accordance with high density of lattice defects and developed through the fatigue by repeated loading.

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1. Introduction

Missing teeth due to periodontal disease and traffic accidents have been restored with the removable partial or complete denture hitherto. Recently, the dental implant treatments1) have been increasing. Dental implant treatment means that the artificial root made of titanium is placed in the bone, and the occlusal superstructure is connected to it, and occlusal function is restored with the superstructure. Since there is no mobility of the denture, and no need to connect between remaining teeth and partial denture, the patients’ satisfaction is higher.2) The success rate of this treatment is higher than 90% and seems to be very predictable.3) However, an implant prosthetic reconstruction is not always successful. A very small number of implant fracture cases, 6 to 7 years after placement, were reported.4) Almost fractures are observed at the implant neck portion. The remaining implant body is rigidly connected to the bone. Therefore the removal of the fractured implant includes living bone reduction, it is very painful to the patient. In order to improve this treatment, mechanical causes of the fracture are analyzed, because it is important to decrease such mechanical risks.

There have been many studies on fracture of retrieved broken dental implants.5–9) The purpose of this study is to investigate the biomechanical causes of the implant fracture by means of transmission electron microscopy and fractography and we reports on microstructural findings of fractured and intact implant.

2. Experimental Procedure

A blade type implant as shown in Fig. 1 was applied to a patient. The implant was placed in the bones of a patient which fractured after 6 years. The fractured implant was taken from the patient and used to observe macroscopic and microscopic features. To obtain a macroscopic information, optical photographs and conventional transmission X-ray photographs (radiographs) were taken. Fractured surface of implants was observed by a scanning electron microscope (SEM). After finishing SEM observation, a thin plate was cut out from the fractured implant. The thin plate was mechanically ground down to a thickness of 50 μm. The ground plate was further thinned by the focused ion beam (FIB) where the fractured surface was coated by carbon and tungsten to protect from damage by gallium ion. The very thin film was observed by a transmission electron microscope (TEM) equipped with an energy dispersion X-ray (EDX) spectrometer. Acceleration voltage of TEM was 300 kV.

3. Results and Discussion

3.1 General View

Fig. 1 Photograph of blade type implant.
of the blade type implant. It is seen from the oral view that the implant and remaining teeth are connected each other and there was slight inflammation around the implant cervix. Severe bone loss is observed around the implant neck portion (see radiograph). Fracture occurs at the neck portion as indicated by arrow and the portion is highly stressed when a bending moment is applied. Patient complained the mobility of implant superstructure 6 years after implant placement. When the superstructure was cut and removed, implant body was rigidly connected to the bone. On the other hand, the remaining abutment teeth were slightly moved. The removed implant is shown in Fig. 3 where the implant and two remaining teeth were tightly connected. An observation of the radiograph together shows that fracturing occurs from right to left side in this case.

3.2 Structure Prior to Placement

Chemical composition of the implant was analyzed by EPMA equipped with EDX and WDX spectrometers. Titanium and vanadium were detected from the spectrum and other element such as aluminum was not detected. The quantitative analysis from WDX result indicates that the titanium base alloy implant contains vanadium of 5 mass%. It is known that there are many types of titanium base implant and the most frequent alloys in use are generally pure Ti and Ti-6Al-4 V alloy as reviewed by Weiss and Semiatin.10) However, Vijayshankar and Ankem11) have reported on an implant made of Ti-15V alloy and reports on the alloy composition of implant are a very few. The implant of this study has a rather low level of vanadium, that is, Ti-5V alloy and the alloy of implant is also in a rare case. Figure 4 shows TEM image of virgin microstructure of the blade type implant. The blade type implant exhibits some dislocations and fine precipitates. Precipitate spot was not detected but matrix spots strongly revealed in the electron diffraction pattern. It is found from the diffraction analysis that the matrix is of $\alpha$-titanium. The precipitates are considered to be of $\beta$ phase from the phase diagram.12) Considering the alloy composition and the TEM structure, the implant of this study...
is similar with a pure titanium implant to some extent with respect to mechanical properties.

3.3 Fracture of Implant

Figures 5(a) and (b) show SEM images of fractured surface of the implant. In a low magnification image of Fig. 5(a), large step is observed in the left side that corresponds to finally fractured area. White lines are observed in the center region of the fractured surface. These lines are the so-called striations which are traces of fatigue failure fronts. Figure 5(b) shows a higher magnification image at right-bottom side of Fig. 5(a). Although the fractured surface is rather complex, the surface shows to an extent evidence of the intergranular fracture. At the side surface of the implant, wavy lines had been introduced and these lines are considered to be the slip bands formed by repeated loading in the mouth. The fracture occurred from the right side to left side, and this fracturing process implies intergranular and fatigue failures.

Figure 6 shows a TEM image of cross section of the fractured implant. The upper side corresponds to the fractured surface. Regions of black, white and gray contrast in the upper area are of W-coating, C-coating and some reacted products, respectively. A detailed analysis of the reacted products is shown in Fig. 7. The gray region of the reacted product consists of titanium and calcium as shown in Fig. 7(a). As shown in electron diffraction pattern (Fig. 7(b)), the gray region exhibits a ring pattern constructed from small diffraction spots, indicating that the region is composed of very fine grains. From the diffraction analysis, the fine grains have CaTi structure. It is not clear why the fine CaTi grains form here. However, there exist intrinsic calcium in the saliva and the titanium implant is extrinsically placed in the patient’s mouth. These elements are possible to react to each other through a repeated loading between the crack surfaces of the upper and lower pieces of the fracturing implant.

As shown in Fig. 6, the implant has a very complex structure which implies high dislocation density (compare with Fig. 4(a)). There also exist a few bands in the middle region of the photograph (T1 and T2) which are twins. The dislocations and twins are introduced by repeated loading.

To investigate a detail microstructure near the surface of the fractured implant, diffraction and EDX analyses were performed at the points P1 through P4. Figure 8 shows selected area electron diffraction patterns obtained from the points P1 through P4 where the interval of the measured points was 200 nm and the selected area was 200 nm. The reciprocal lattice vectors of $(a_1^* - a_3^*)$ and $e^*$ mean [110]$_{\text{e-Ti}}$ and [001]$_{\text{e-Ti}}$ directions, respectively. The first diffraction pattern was adjusted to rebuild the symmetrical orientation.
The pattern deviates from the symmetrical to unsymmetrical orientation as the area goes downward. The unsymmetrical patterns were tilted in the TEM to bring about the symmetrical orientation measuring the tilting angle. The measured values are shown in Fig. 9. The grain is distorted by 2 to 3 degrees around the reciprocal lattice vectors in a very short distance of 1 μm, indicating that the grain near the surface undergoes severe deformation. EDX spectra at the points of P1 through P5 (see Fig. 6) are shown in Fig. 10. Peaks of aluminum, chlorine, calcium and titanium can be observed. The peak of aluminum is from column of TEM. It is noted that areas of P1 through P5 contain chlorine and calcium. The broad peak at energy levels corresponding to calcium and titanium becomes narrow with each increase in distance from the fractured surface, suggesting that calcium concentration decreases in the inner part of the implant. Figure 11 shows chemical compositions of calcium and chlorine as a function of the distance. Chlorine holds a constant level of 0.1 at% up to 1 μm while the amount of calcium shows a higher value of 1.5 at% near the surface and decreases gradually with increasing distance. The implant made of titanium may intrinsically contain chlorine because ELI grade sponge titanium contains about 0.1 at% chlorine. On the other hand, it is thought that calcium penetrates into the implant, passing through the high density of dislocations.

The implant is subjected to repeated loading which brings about a high density of dislocation in the implant near the fracturing surface and slip bands on the side surface of the implant. These defects may assist the penetration of calcium and the penetrated calcium may cause intergranular fracturing especially in the area near to the surfaces. Repeated loading also leads to the development of fatigue failure at the middle stage of fracturing. Thus, an understanding of these combined factors is very important for knowing causes of fracturing of implants. This knowledge can be of practical use in the field of modern dentistry.

4. Summary

Fractures of dental implants have occurred after the placement in last six years. Since the fracture of implant is very painful in patients, the fracturing of implants must be reduced. This study has aimed to investigate a microscopic feature of a fractured implant for practical use to understand the factors cause fracturing, and to provide ideas for implant
designing. The results obtained here are summarized as follows:

1. The root of implant strongly connects to the bone and fracturing generally takes place at the neck portion of the implant.

2. A high density of lattice defects such as dislocations and twins are introduced into the implant due to repeated loading during biting and/or clenching at night.

3. Defects induced by repeated loading are a strong factor in causing calcium penetration, which brings about intergranular fracture near the surface. Repeated loading also causes fatigue failure at the center region of the implant.

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