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Surface Characteristics of Clinically Used Dental Implant Screws

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Surface alteration of implant screws after function may be associated with mechanical failure. This type of metal fatigue appears to be the most common cause of structural failure. The purpose of this study was to evaluate surface alteration of implant screws after function through an examination of used and unused implant screws via scanning electron microscopy (SEM). In this study, abutment screws (Steri-oss, 3i, USA), gold retaining screws (3i, USA), and titanium retaining screws (3i, USA) were retrieved from patients. New, unused abutment, and retaining screws were prepared for a control group. Each of the old, used screws was retrieved with a screwdriver. The retrieved implant complex of a Steri-oss system was also prepared for this study. SEM investigation and energy dispersive spectroscopy (EDS) analysis of the abutment and retaining screws were then performed, as well as SEM investigation of a cross-sectioned sample of the retrieved implant complex. In the case of new, unused implant screws, as-manufactured circumferential grooves were regularly examined and screw threads were sharply maintained. Before ultrasonic cleansing of old, used implant screws, there was a large amount of debris accumulation and corrosion products. After ultrasonic cleansing of old, used implant screws, circumferential grooves were examined were found to be randomly deepened and scratching increased. Also, dull screw threads were observed. More surface alterations after function were observed in titanium screws than in gold screws. Furthermore, more surface alteration was observed when the screws were retrieved with a driver than without a driver. These surface alterations after function may result in screw instability. Regular cleansing and exchange of screws is therefore recommended. We also recommend the use of gold screws over titanium screws, and careful manipulation of the driver.

Keywords: surface alteration after function, implant screw, gold and titanium screw

1. INTRODUCTION

Successful implant therapy requires a dynamic equilibrium between biological and mechanical factors. The biological factors are generally considered to be multifactorial, whereas mechanical factors are associated with screw joint instability between the abutment and the implant [1]. These factors may result in screw joint instability including inadequate preload, inadequate prosthesis or screw design, poor component fit, settling of surface micro-roughness, excessive loading, and elasticity of bone [2].

Complications related to screws include screw fracture and screw loosening [3-5]. Two mechanisms of screw loosening have been investigated: excessive bending on the screw joint and settling effects. If a bending force on the implant restoration causes a load larger than the yield strength of the screw, plastic permanent deformation of the screw results. The higher the yield strength of the screw, the less the plastic deformation in the screw for a given load [3].

The other mechanism of screw loosening is based on the fact that no surface is completely smooth [5-7]. Even a carefully machined implant surface is slightly rough when viewed microscopically. Because of this micro-roughness, it is difficult completely to attain optimal contact with the surface. When the screw interface is subjected to external loads, micro-movements occur between the surfaces. Wear of the contact areas might be a result of these motions, thereby bringing the two surfaces close to each other. The magnitude of settling depends on the initial surface roughness and surface hardness as well as the magnitude of the loading forces. Rough surfaces and large external loads increase the settling. When the total settling effect is greater than the elastic elongation of the screw, the screw loose because there are no longer any contact forces to hold it [3].

In a study by Jaarda *et al.* [8], the contacting surfaces of implants were found to play a major part in the torque preload relationship and ultimately in the fatigue life of the screws. Numerous investigators have examined the implant-

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abutment screw joint. Many studies have dealt with the assembly mechanisms and it has been reported that an inaccurate interface places excessive stresses on the abutment screw joint, creating instability [1].

When torque is applied to new screws and bolts with rough textured thread surfaces, energy is applied partially toward smoothing mating surfaces and less toward elongation of the screw. After engaging the threads, the surface asperities are flattened so more input torque is applied toward elongation of the screw and production of preload [9]. Recent studies suggest that surface characteristics may influence the successful outcome of implants [10]. Finally, gold abutment screws remained more secure than titanium screws [11].

Surface alteration of implant screws after function may be associated with mechanical failure. Metal fatigue appears to be the most common cause of structural failure and occurs under repeated loading at stress levels [12].

Therefore, the purpose of this study was to evaluate surface alteration of implant screws after function through the examination of used and unused implant screws via SEM.

2. EXPERIMENTAL PROCEDURE

2.1. Materials (Table 1)

2.1.1. Abutment screws

The Steri-oss abutment screw (Bausch & Lomb company, USA) was retrieved from a patient. The loading time before retrieval was 4.4 years. The 3i abutment screw (Implant Innovations Incorporated^{TM}, USA) was also retrieved from a patient. The loading time before retrieval was 1.6 years. Each of the old, used abutment screws was retrieved with a screwdriver. New, unused Steri-oss and 3i abutment screws were prepared for the control group (Figs. 1 and 2).

2.1.2. Retaining screws

The 3i gold and titanium retaining screws were retrieved from a patient and the loading time before retrieval was 1.6 years. New, unused 3i gold and titanium retaining screws were prepared for the control group (Figs. 3 and 4). Each of the old retaining screws was retrieved with a screwdriver.

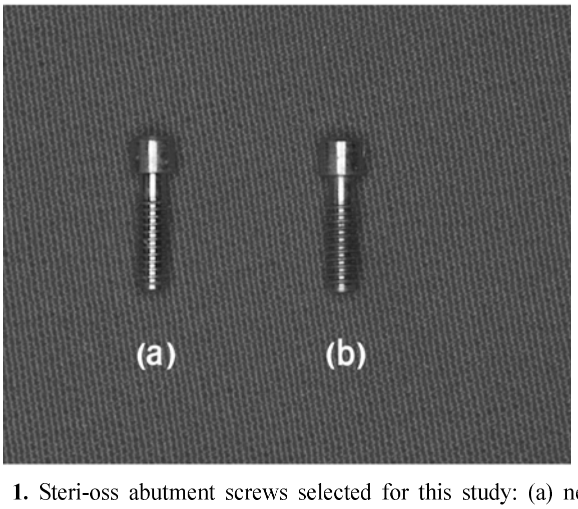


Fig. 1. Steri-oss abutment screws selected for this study: (a) new, unused screw, and (b) old, used screw.

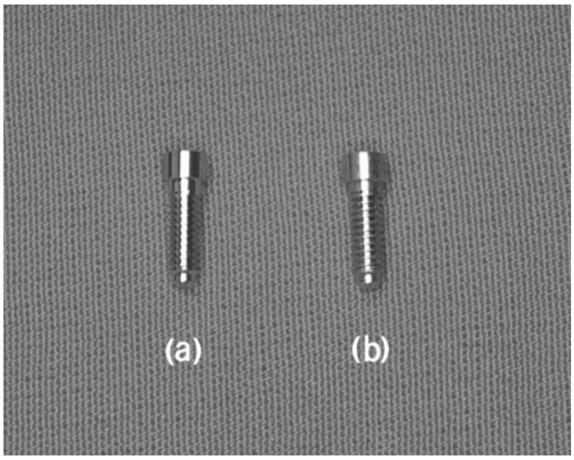


Fig. 2. 3i abutment screws selected for this study: (a) new, unused screw, and (b) old, used screw.

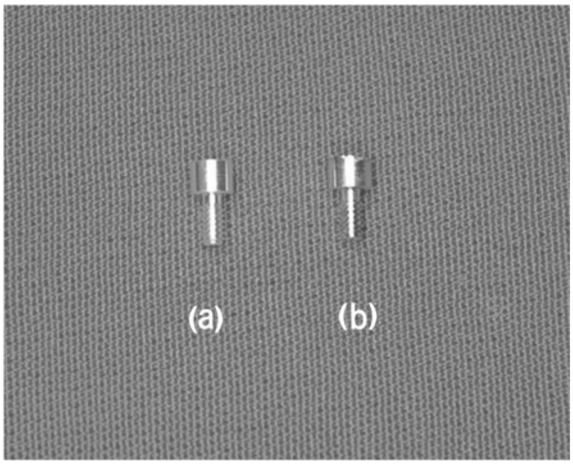


Fig. 3. 3i gold retaining screws selected for this study: (a) new, unused screw and (b) old, used screw.

2.1.3. Retrieved implant complex

A Steri-oss implant complex of the left first and second molars was retrieved due to peri-implantitis in the patient (Fig. 5). The loading time before retrieval was 4.4 years. The implant complex was retrieved with a trephine. The abutment screws and retaining screws were not unscrewed. The retrieved implant complex and surrounding tissues were washed in saline solution and immediately fixed in 10 % buffered formalin.

2.2. Methods

2.2.1. SEM investigation and EDS analysis of abutment and retaining screws

The surfaces of new abutment screws and retaining screws

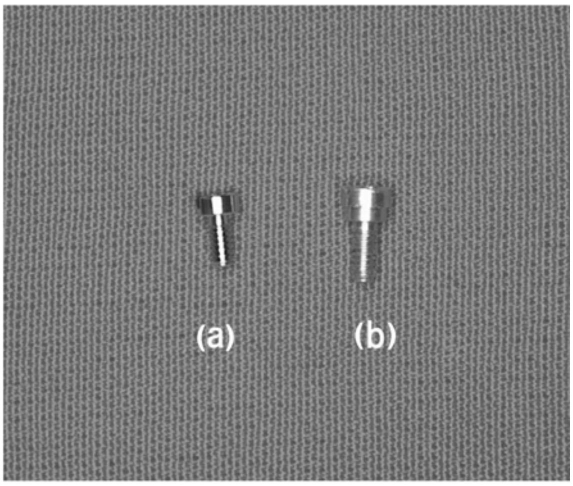


Fig. 4. 3i titanium retaining screws selected for this study: (a) new, unused screw and (b) old, used screw.

Fig. 5. Retrieved implant complex of Steri-oss system.

as delivered by the manufacturer were investigated via SEM (XL 30s, Philips, Netherland) at magnifications of up to ×1,000. A tungsten tip was used where micromanipulation

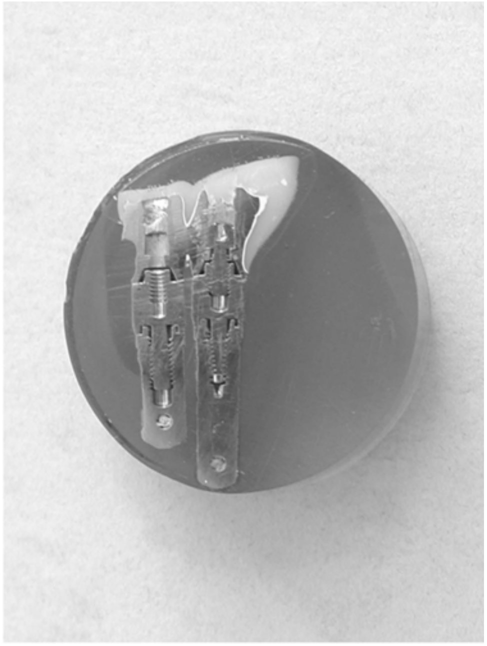


Fig. 6. Cross-sectioned sample of retrieved implant complex.

of the specimens was carried out under SEM investigation. Care was taken not to touch the thread surfaces of the abutment screws and retaining screws so as to avoid contamination of the surfaces.

Retrieved old abutment screws and retaining screws were also investigated by scanning electron microscopy. The old abutment screws and retaining screws were subsequently cleaned in liquid soap and water in an ultrasonic cleaner. After cleansing, theses screws were also evaluated by scanning electron microscopy. EDS was performed on the abutment screws and retaining screws using an EDS (S-3000N HITACHI, Japan).

2.2.2. SEM investigation of cross-sectioned sample of retrieved implant complex

2.2.2.1. Cross-section of retrieved implant complex

A cross-section of the retrieved implant complex was made by mounting the sample in a translucent thermoses type liquid unsaturated polyester. The mounting media (Epovis, Cray Valley Inc) is a 2-part system made up of a resin and hardener. The two components were mixed together and poured over the sample and allowed to cure overnight. Once

Table 1. Types of screw selected for this study

Kind of screw \ Implant system & Screw material	Implant system	Screw material
Abutment screw (unused, used screw)	Steri-oss, 3i	Titanium
Retaining screw (unused, used screw)	3i,	Titanium, gold
Retrieved implant complex (used screw)	Steri-oss	Titanium

Steri-oss: Bausch & Lomb company, USA
3i: Implant Innovations Incorporated™, USA

the mount was hardened, the sample was ground using a silicone carbide-type sandpaper (120 grit of finer). Mounts were ground through a series of progressively finer grit papers down to a 4000 grit finish. Final polishing was carried out with a plano cloth and 1 μm Al_2O_3.

The retrieved implant complex was cross-sectioned until the half of retaining screw and the half of abutment screw were remained (Fig. 6).

2.2.2.2. SEM investigation of cross-sectioned sample

The sample was cleaned in liquid soap and water in an ultrasonic cleaner and then evaluated via scanning electron microscopy.

3. RESULTS

3.1. SEM investigation and EDS analysis of abutment screws

Scanning electron microscopy of old abutment screw surfaces showed a large amount of accumulation on the surfaces (Fig. 7). EDS analysis verified that the accumulation consisted of carbon, oxygen, etc. These organic substances consisted of plaque and food debris. Table 2 shows the surface composition and contaminants on the used abutment screw.

After ultrasonic cleansing, EDS on the old abutment screw surfaces verified that these abutment screws consisted of titanium and aluminum (Fig. 8). Accumulation on the old abutment screw surfaces was verified to be organic plaque products.

In the case of old abutment screw surfaces, preexisting grooves in the new abutment screw surfaces appear to have been randomly deepened and new scratches appeared. The unused abutment screw surfaces presented a surface structure characterized by parallel circumferential machining grooves. The old abutment screw surfaces have dull screw threads resulting from tightness in the fixture (Figs. 9 and 10).

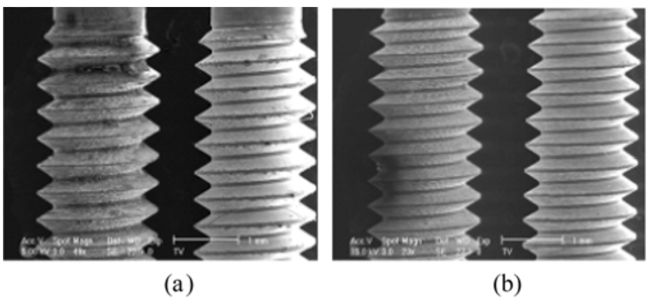


Fig. 7. SEM micrographs showing the used and unused abutment screw surfaces of Steri-oss system (magnification ×50): (a) before ultrasonic cleansing and (b) after ultrasonic cleansing.

Table 2. Surface composition and contaminants of used abutment screw

Screw Type	Screw Area evaluated	Elements detected	SEM Observations
Steri-Oss Abutment Screw	Screw root	C,O,P,Ti,Si	organic film and food debris
	Screw crest	C,O,P,Ti,Al	organic film and food debris

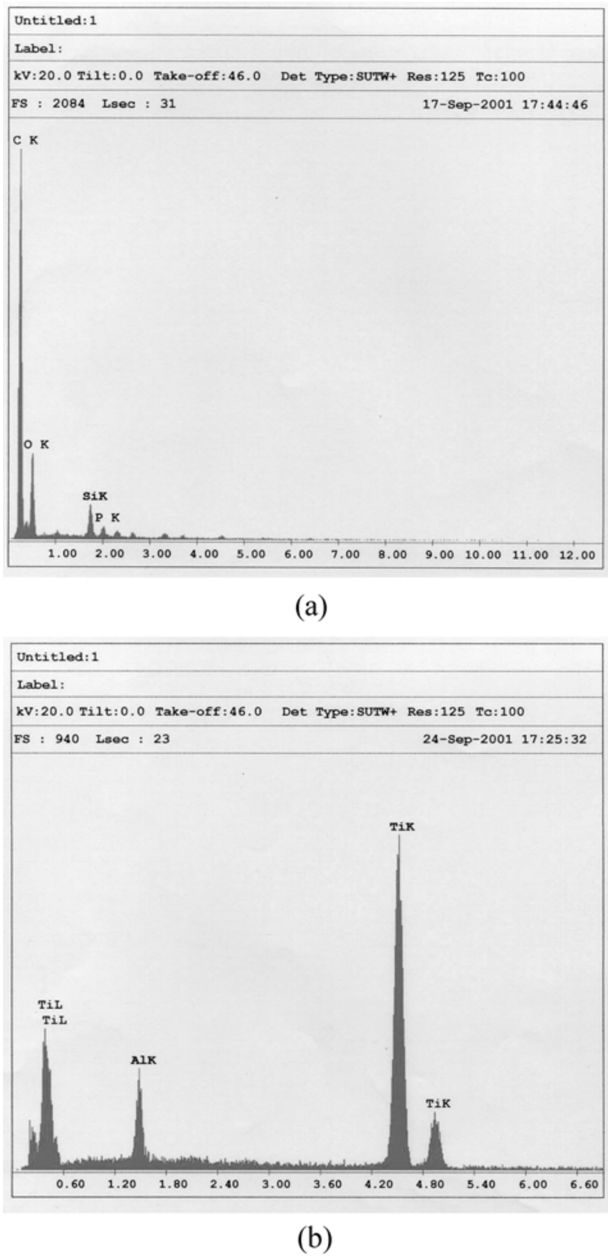
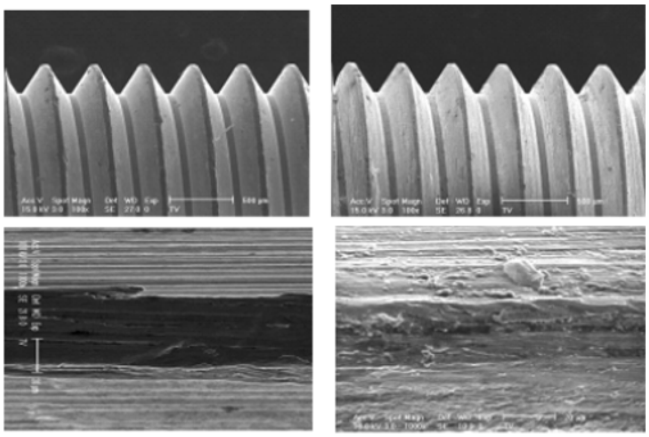


Fig. 8. EDS analysis on used abutment screw surfaces: (a) before ultrasonic cleansing and (b) after ultrasonic cleansing.

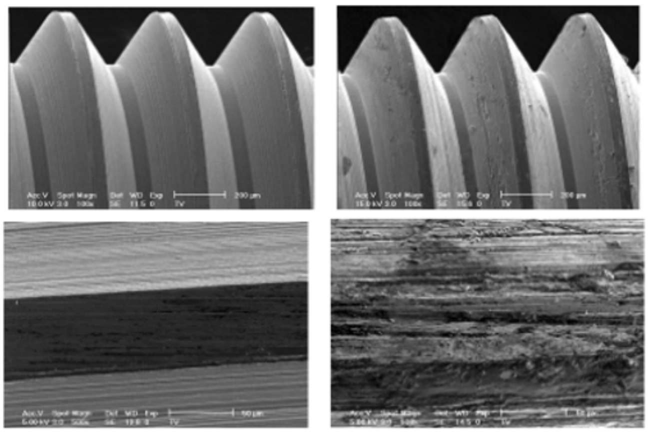
3.2. SEM Investigation and EDS Analysis of retaining screws

Similar to the old abutment screw surfaces, circumferential grooves appeared to have been randomly deepened after use and new scratches appeared (Figs. 11 and 12). SEM of



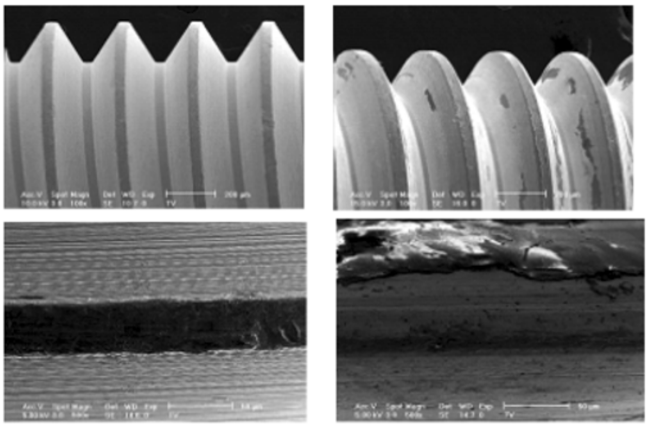
(a) (b)

Fig. 9. SEM micrographs showing abutment screw surfaces of Steri-oss system (magnification ×100, ×1000): (a) unused screw and (b) used screw.



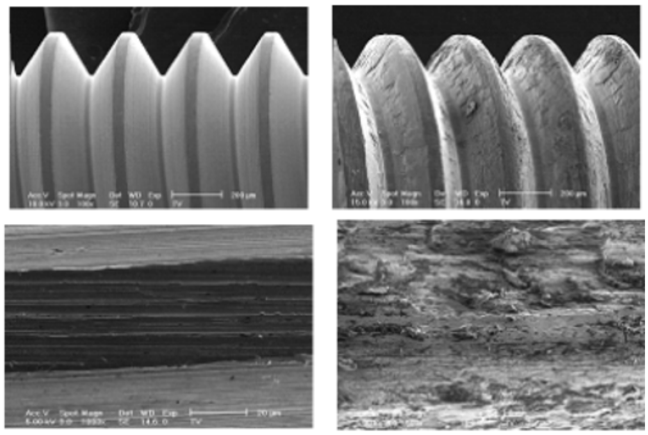
(a) (b)

Fig. 10. SEM micrographs showing abutment screw surfaces of 3i system (magnification ×100, ×1000): (a) unused screw and (b) used screw.



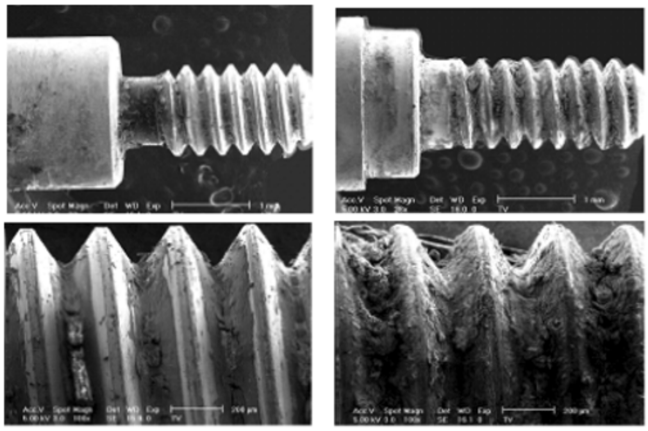
(a) (b)

Fig. 11. SEM micrographs showing gold retaining screw surfaces (magnification ×100, ×1000): (a) unused screw and (b) used screw.



(a) (b)

Fig. 12. SEM micrographs showing titanium retaining screw surfaces (magnification ×100, ×1000): (a) unused screw and (b) used screw.



(a) (b)

Fig. 13. SEM micrographs showing used retaining screw surfaces before ultrasonic cleansing (magnification ×30, ×100): (a) gold screw and (b) titanium screw.

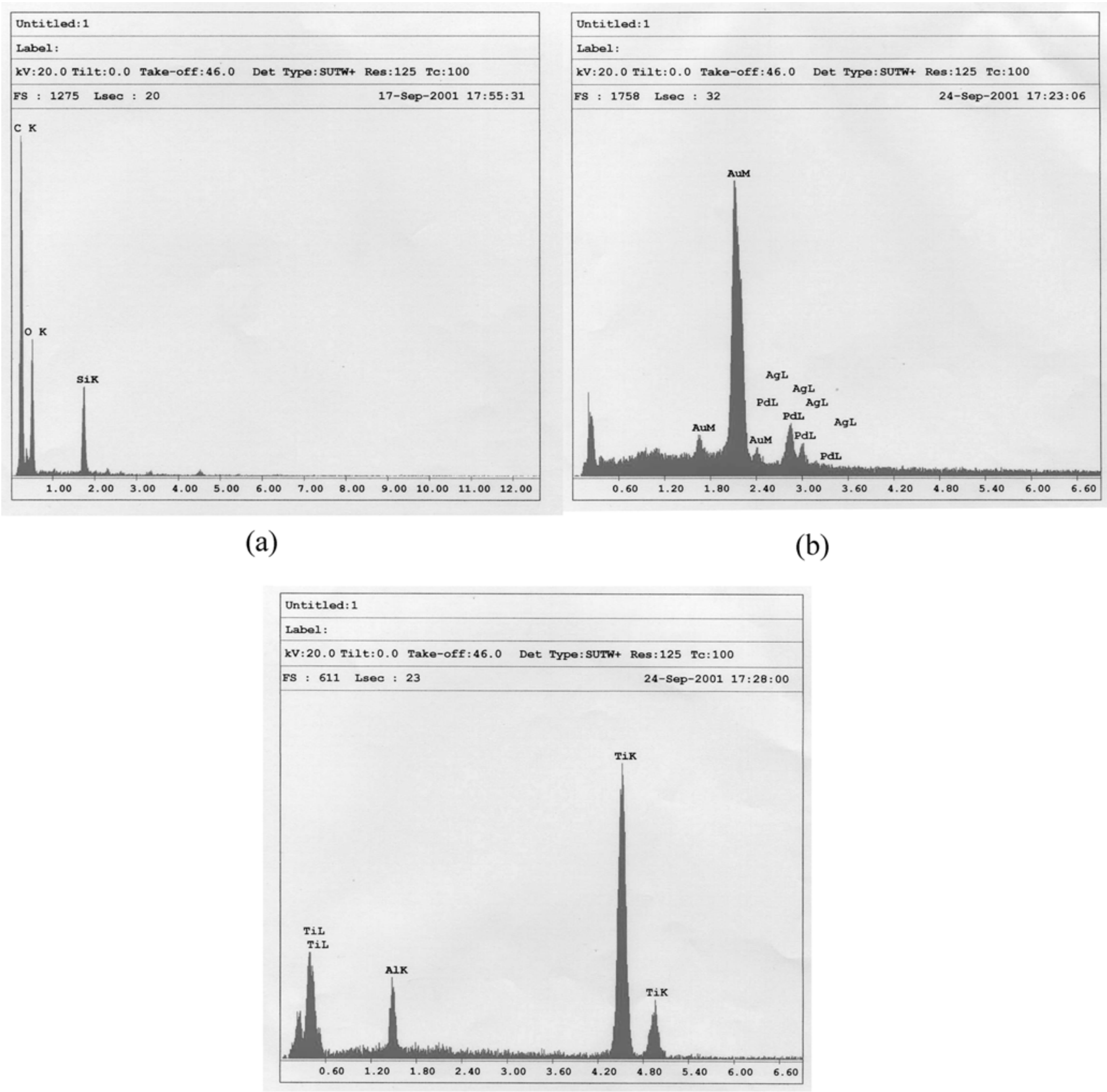
old retaining screw surfaces showed a great deal of accumulation on the surfaces (Fig. 13). EDS analysis verified that these accumulations are plaque (Fig. 14). EDS peaks identified C, O, P, Si and Ti elements as organic film and food debris.

Old retaining screws had relatively greater plaque accumulation on the surface than the old abutment screws.

Surface alterations after use were observed more in titanium screws than in gold screws. In addition, the gold screw surfaces were smoother than the titanium screw surfaces.

3.3. SEM Investigation of cross-sectioned sample of retrieved implant complex

In this study, cross-section sample retrieved from an implant complex refers to screws that were not retrieved



(c)

Fig. 14. EDS analysis on retaining screw surfaces: (a) before ultrasonic cleansing, (b) after ultrasonic cleansing of gold screw, and (c) after ultrasonic cleansing of titanium screw.

with a screwdriver. Screw surfaces were not touched or manipulated so it similar with in oral cavity. One retaining screw and one abutment screw were removed by cross-section. In the case of screws retrieved without a screwdriver, surface alteration after use was found, but screw thread blunting was not significant (Fig. 15).

4. DISCUSSION

Very high long-term success rates are reported for titanium osseointegrated implants [12,14]. In a study by Lekholm *et al.* [15], an accumulative implant success rate of 93.3 % as a mean for both jaws was found.

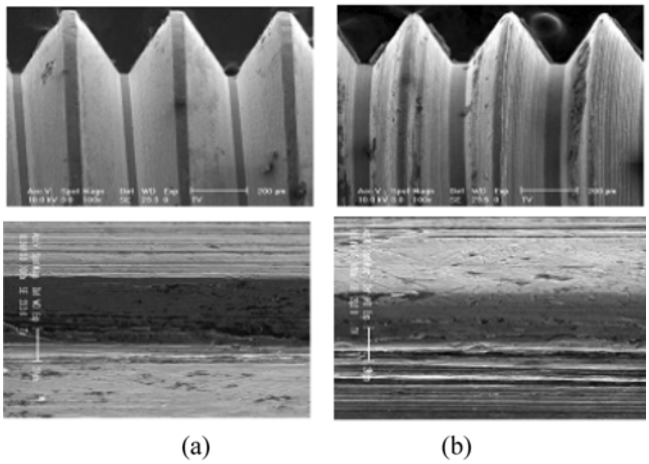


Fig. 15. SEM micrographs showing the screw of retrieved implant complex (magnification ×100, ×1000): (a) abutment screw and (b) retaining screw.

Changes in the surface structure observed on the threads of screws after use are difficult to explain [9]. A study by Rangert *et al.* [16] identified fatigue as the failure mechanism. In a study by Takeshita *et al.* [17], SEM analysis showed the presence of linear scratches, indicating the development of fatigue cracks, likely due to repeated tensile stresses [12,17].

The purpose of the present study was to evaluate surface alterations of implant screws after function through an examination of old and new screws via SEM. We examined old and new screws via SEM, and EDS was performed on screws. Screws retrieved without a screwdriver were also examined using SEM.

It is well-established that fatigue failures occur through crack formation, which then propagate through the specimen. All cracks in the present study seen under SEM began in notches on the surface of the components [18].

In this study, retaining screw surface alteration was more prevalent than abutment screw surface alteration. This may be related to a more frequent occurrence of retaining screw fracture than abutment screw fracture [10].

Patterson and Johns [19] provided a theoretical analysis of the fatigue life of retaining screws and concluded that application of the correct torque resulted in long screw fatigue life. Binon promoted the concept of a weak link for components. The proposed weak link is the retaining screw, which connects the gold cylinder to the transmucosal titanium abutment. This retaining screw should fracture before any other component does. This concept is widely accepted but has never been scientifically validated [20].

In a study by Jörneus *et al.* [3], the design of the screw head, screw material, and tightening torque were demonstrated to be significant parameters for screw joint stability [3,21]. The single most significant factor that determines the bolting characteristics of the screw is the construction material, and manufacturers have made numerous changes in that regard. The friction resistance between the titanium of the implant thread and the titanium of the screw threads, resulting in part from "galling," a form of adhesive wear that occurs during the intimate sliding contact of two like materials, limits the preload characteristics of titanium screws. Hence, transition has been made to the gold-alloy screw. Gold-alloy screws have a lower coefficient of friction, can be tightened more effectively to higher preloads, and will not stick to titanium [22,23].

In this study, old titanium retaining screw surfaces had more plaque accumulation, scratches, and grooves than old gold retaining screw surfaces. In addition, gold screw surfaces were smoother than titanium screw surfaces.

The difference in surface defects between gold and titanium screws can be explained in terms of the formation of oxides, such as TiO and TiO_2 [24,25]. In the case of the gold screw, the surface is not activated for noble metals. Therefore, gold screw surfaces can be protected without oxidation film. In contrast, in the case of the Ti screw, Ti forms oxides on the surface that protect against aggressive ions. However, the Ti screw surface will easily be dissoluted at the broken TiO_2 film, which is formed for the tightening and loosening process of the screw. The formation rate of scratch and plaque is accelerated in the region of the broken TiO_2 layer [25].

In this study, gold screw had better influence than titanium screw on surface alteration of implant screws after function. Therefore, we recommend the use of gold screws rather than titanium screws. Since it appears to be difficult to predict the longevity of implants, prevention of screw failure can only be achieved by regular examination that includes cleansing, as well as by the exchange of implant screws.

5. CONCLUSIONS

The purpose of this study was to evaluate screw surface alteration of implant screws after function through the examination of old and new screws via SEM. The following results were obtained:

(1) In the case of new, unused implant screws, as-manufactured circumferential grooves were regularly observed and screw threads were sharply preserved.

(2) Before ultrasonic cleansing of old, used implant screws, significant accumulation and corrosion products were observed.

(3) After ultrasonic cleansing of old, used implant screws, circumferential grooves were found to be randomly deepened and scratching increased. Also, dull screw threads were observed.

(4) More surface alterations after function were observed in titanium screws than gold screws. In addition, more surface alteration was observed for screws retrieved with a driver than those retrieved without a driver.

These surface alterations after function may result in screw instability. Regular cleansing and exchange of screws is recommended. We also recommend the use of gold screws rather than titanium screws, and careful manipulation of the driver.

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