CHANGES OF ABUTMENT SCREW AFTER REPEATED CLOSING AND OPENING

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Statement of problem. Wear as a result of repeated closing/opening cycles may decrease the friction coefficient of screw head, threads, and other mating components and, consequently, resistance to opening gradually decreases. It may cause screw loosening, which is one of the most common failures in implant prosthesis.
Purpose. The purpose of this study is to evaluate the changes on the head and thread surface of the abutment screws after repeated closing and opening through the examination of tested screws in SEM(scanning electron microscope).
Materials and methods. Five species of abutments were selected (3i-three, Avana- two) respectively by two pieces. The implant fixtures were perpendicularly mounted in liquid unsaturated polyesther(Epovia, Cray Valley Inc.) with dental surveyor. Each abutment was secured to the implant fixture by each abutment screw with recommended torque value using a digital torque controller. The abutment screws were repeatedly tightened and removed 20 times with a digital controller. FESEM (field emission scanning electron microscope, Netherland, Phillips co., model:XL 30 SFEG) was used to observe changes of each part caused by repeatedly closing/opening expeiment. First, the Photomicrographs of pre-test screws provided by each manufacturer were taken. The changes of each screw were investigated after every fifth closing and opening experiment with FESEM. Scaning electron microscope photomicrographs of each screw were taken four times.
Results. As the number of closing and opening was increased, the wear or distortion of hexed or squared slot that contacted with the driver tip was more severely progressed. Wear or distortion of hexed slot was more severe than that of squared slot and it was more remarkable in the titanium screw than in the gold screw. All the tested screws showed that the width in the crest of their screw thread decreased gradually as the test was proceeded.
Conclusions. Conclusively, we recommend the clinical use of gold screw, a periodic exchanges of abutment screws and avoiding repeated closing/opening unnecessarily. We also suggest a more careful manipulation of the abutment screw and screw-driver and using of abutment screw with an acute-angled slot design rather than an obtuse-angled one. Finally, it is suggested that the new slot design and the surface treatment for enduring wear or distortion should be devised.

Key Words
Surface alteration after repeated closing/opening, Wear or distortion, Gold and titanium screw, Periodic exchange

In recent years, the use of osseointegrated implants to retain single-tooth restorations has gained popularity.[1-6] Most implant systems use more than 1 screw to attach the final restoration to an implant body. One common problem associated with single-tooth implants has been the loosening or fracturing of abutment or retaining screws.[5,7-9] Whether the restoration is screw retained or cemented on an abutment prepared by the restorative dentist, the threat of abutment or retaining screw loosening remains a potential problem.

Jemt et al[10,11] reported that 26% of gold retaining screws and 10 of the 23 abutment screws (43%) became loose during the first year. Becker and Becker[1)] described screw loosening in single-implant restorations of molars with nonrotating abutments secured with gold screws and reported a 38% incidence of screw loosening.

Screw loosening and/or fracture has been attributed to machining tolerances[12], component materials[13-15], metal fatigue[16], micromovement during function, off-axis loading[17,18], applied torque and preload[19], the elasticity of bone, and settling of the screws.[20,21]

Two mechanism 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, a 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.[12] The other mechanism of screw loosening is based on the fact that no surface is completely smooth.[22-24] Even a carefully machined implant surface is slightly rough when viewed microscopically. Because of this microroughness, no two surfaces are in complete contact with one another. When the screw interface is subjected to external loads, micromovements 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, it works loose because there are no longer any contact forces to hold the screw.[12]

Numerous investigators have reported that the micromovement by the external load or the vibratory forces affected on the screw loosening. Recently, articles about the effect of repeated torque on the ultimate tensile strength and the preload of slotted gold prosthetic screws, and opening torque has been published. Al Rafee et al[25] reported that the slotted gold prosthetic screw tested could be tightened and removed up to 20 times without any effect on its ultimate tensile strength. Tzenakis et al[26] noted that higher preload was achieved after the repeated use of a saliva-lubricated gold prosthetic retaining screw. They also suggested that using a gold prosthetic screw from the try-in appointment might help obtain optimal preload during final torquing at the insertion appointment. In the study by Weiss et al[27], repeated opening and closing of implant abutment screws resulted in the progressive loss of torque retention with variations of systems. This was probably due to a decrease in the friction coefficient of the mating components. Their results suggest that wear as a result of repeated closing /opening cycles may decrease the friction coefficient of screw head, threads, and other mating components and, consequently, resistance to opening gradually decreases.

Therefore, the purpose of this study is to evaluate the changes on the head and thread surface of the abutment screws after repeated closing and opening through the examination of tested screws in SEM(scanning electron microscope).

MATERIALS AND METHODS

1. Materials(Table I)

1) Abutment screw

Abutment screws that used for this experiment were respectively (Fig. 1) : 2 Gold-Tite™ Hexed Uniscrews, 2 Titanium Hexed Uniscrews, 2 Gold-Tite™ Squared Uniscrews(3i system) and 2 hex-slotted Gold Abutment screw, 2 hex-slotted Titanium Abutment screw (Avana Dental Implant System).

2) Implant fixture

The implants selected in this study were external hexagonal extention threaded implants from 3i(Hexlock 4.0D × 13mm ; 3i/implant Innovations Inc, USA), Avana Standard Fixture(Hexlock 4.0D × 10mm; Avana Dental Implant System, Korea). (Fig. 2) Total 10 implants were selected. (3i - 6 fixtures, Avana- 4 fixtures)

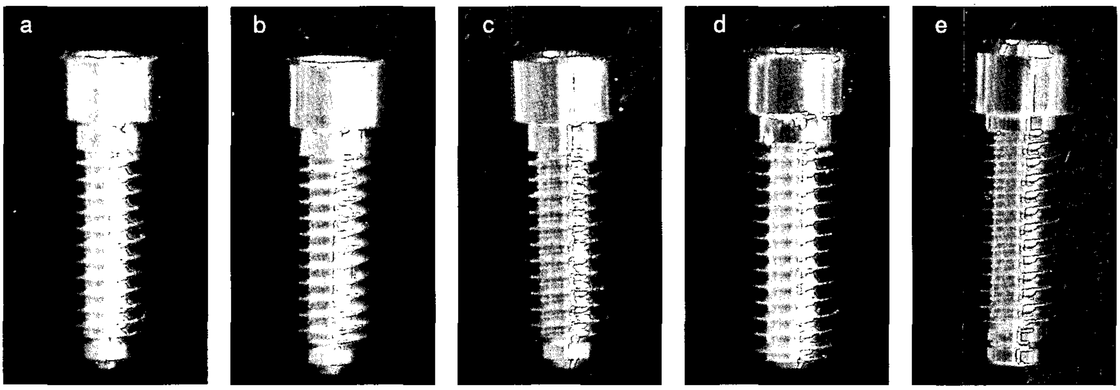

Fig. 1. Kind of abutment screws (a: hex-slotted gold screw of 3i, b: square-slotted gold screw of 3i, c: hex-slotted titanium screw of 3i, d: hex-slotted gold screw of Avana, e: hex-slotted titanium screw of Avana).

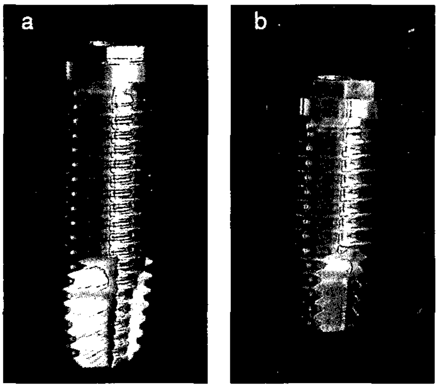

Fig. 2. Fixture for this study(a: Hexlock 4.0D × 13mm; 3i, b: Hexlock 4.0D × 10mm; Avana).

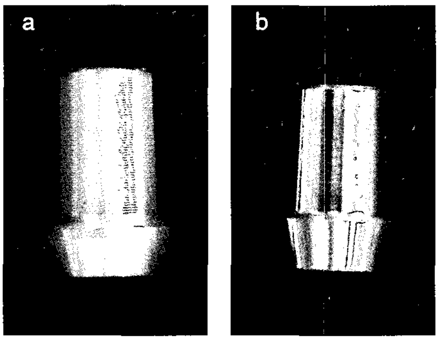

Fig. 3. Abutment for this study(a: 3i GingiHue™ Post abutment (4.1mmD × 5mmP × 2mmH), b: Avana cemented abutment (4mmD × 8mmH)).

3) Abutment

Cemented abutments for each implant system were also acquired. They were 3i GingiHue™ Post abument (4.1mmD × 5mmP × 2mmH), Avana cemented abutment (4mmD × 8mmH). (Fig. 3) (3i - 6 abutments , Avana- 4 abutments)

2. Method

1) Implant fixture mounting

The implant fixtures were perpendicularly mounted in liquid unsaturated polyesther with dental surveyor. Each one was embedded beneath the platform of fixture. The mounting media (Epovia, Cray Valley Inc.) was a 2-part system made up of a resin and hardener. The two components were mixed together and poured and allowed to cure overnight.

2) Repeated closing and opening

Mounted fixture block was fixed in specimen-holding apparatus before closing and opening.(Fig. 4-a) Each abutment was secured to the implant fixture by each abutment screw with recommended torque value using a digital torque controller(Branemark system DEA 020 Torque controller). This torque controller was used to insure that an accurate and reproducible force was

Table I. Kinds of implant system, abutments, screws and torque value used in this study

Implant system	Abutment	Screw type		Recommended torque (Ncm)
3i Innovation	GingiHue™ Post abument(4.1mmD × 5mmP × 2mmH)	Gold-Tite™ Uniscrew	Hexed	32
		Titanium alloy screw	Hexed	20
		Gold-Tite™ Uniscrew	Squared	32
Avana	Cemented abutment (4mmD × 8mmH)	hex-slotted alloy	Gold screw	32
		hex-slotted alloy	Titanium screw	20

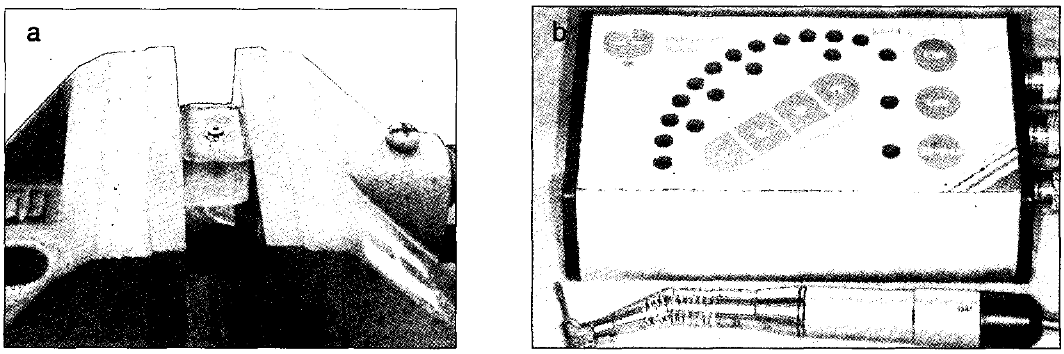

Fig. 4. a: Specimen-holding apparatus; b: Torque controller.

applied to each abutment screw. (Fig. 4-b)

The abutment screws were repeatedly tightened and removed 20 times with a digital controller. There was an intervals of 10 seconds between closing and opening. One operator who had experienced implant prosthetic restorations accomplished this operation.

3) FESEM investigation of abutment screw head and thread surface on the abutment screw.

FESEM (field emission scanning electron microscope, Netherland, Phillips co., model:XL 30 SFEG) was used to observe changes of each part caused by repeatedly closing/opening expeiment. First, pre-test screws provided by each manufacturer were taken. Each Screw was clamped and opened total 20 times respectively. The changes of each screw were investigated after every fifth closing and opening experiment with FESEM. Scaning electron microscope photomicrographs of each screw were taken four times. The thread surface of each abutment screw was observed at 100 times, and then screw crest, root, and slope were done more detailed numerical value, at 1000 times. Each abutment head was taken at 30 times. The photomicrographs of each screw head that was inclined to a gradient of 30 degrees were taken to evaluate its internal slot changes. Care was taken not to touch the thread surface of abutment screw to avoid contamination of the surface. The abutment screws were also cleansed with an ultrasonic cleaner before taking photomicrographs of each screw.

RESULTS

1. Hex-slotted gold abutment screw of 3i

As the number of closing/opening experiment increased, new scratches or groovings near hexed slot of screw head were more remarkable and the wear of hexed slot that contacted with driver tip, also was more severely progressed. The corner edge of hexed slot was gradually rounded as closing and opening repeated. (Fig. 5)

As the test was proceeded, the width of screw thread crests was partially thinner and the scratches or groovings formed in the slope near screw thread crest were toward the root of screw. Contact surfaces gradually changed from rough scratches or groovings to smooth wear surfaces as the test was repeated. Scratches and wear were also occasionally observed at the crest of screw but were not at the root of screw. (Fig. 6)

2. Square-slotted gold abutment screw of 3i

As closing/opening experiments were repeated, scratches were more frequently observed near the squared slot of screw head than hexed slot. But rounding of corner edge and the wear of squared slot were less remarkable than hexed slot. The wear of squared slot was the smallest among the tested screws. (Fig. 7)

Decrease in the width of the screw thread crests was more or less notable compared with hex-slotted gold screw. But, the other changes in the screw thread and the crest and root of thread were similar to those of hex-slotted gold screw. (Fig. 8)

3. Hex-slotted titanium abutment screw of 3i

The aspect of scratches near hexed slot was similar to that of the gold screws with hexed slot. But, rounding in the corner edge of hexed slot and the wear of hexed slot contacting with driver tip were more severe than 3i gold screws. (Fig. 9)

The width decrease in the crest of screw thread was the most regular among the tested screws and the aspect of grooving or wear in the slope was the more prominent than that of 3i gold screws. The other changes in the screw thread were equal to 3i gold screws. (Fig. 10)

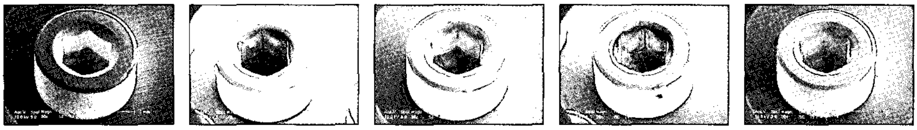

Fig. 5. Hex-slotted gold screw of 3i in SEM.

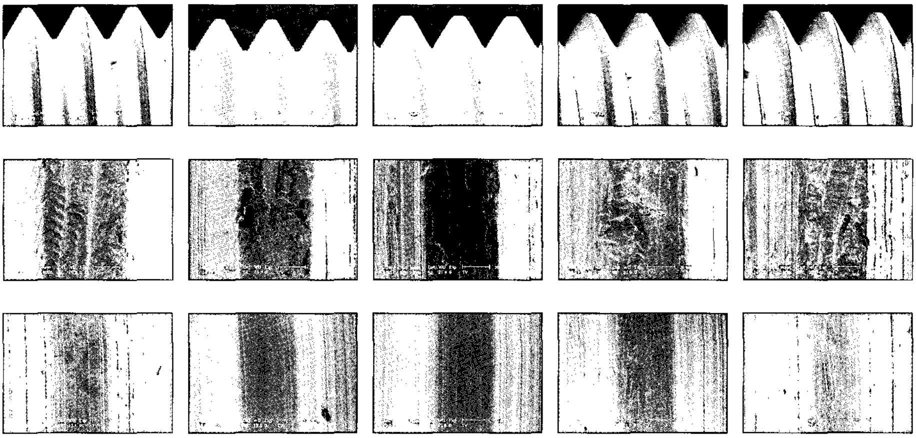

Fig. 6. Thread surface of 3i hex-slotted gold screw in SEM.

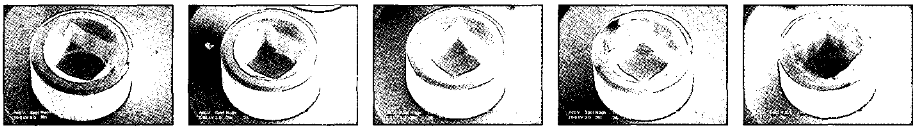

Fig. 7. Square-slotted gold screw of 3i in SEM.

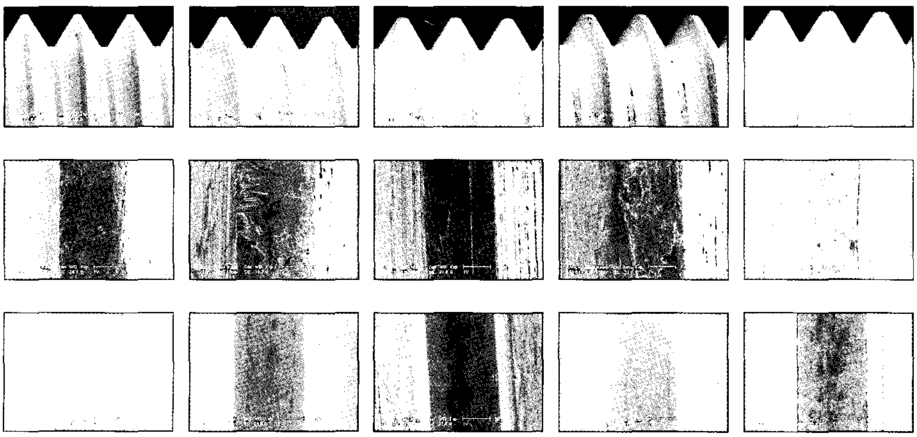

Fig. 8. Thread surface of 3i square-slotted gold screw in SEM.

Closing & Opening cycle Exam area (Magnification) | unused | 5 times | 10 times | 15 times | 20 times

ScrewHead(×30)

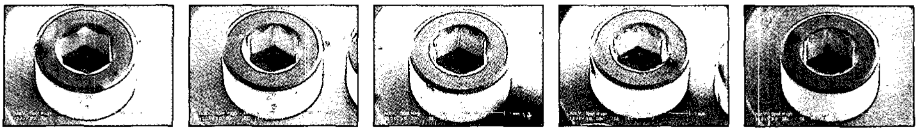

Fig. 9. Hex-slotted titanium screw of 3i in SEM.

ScrewThread(×100)

ScrewCrest(×1000)

Screw Root(×1000)

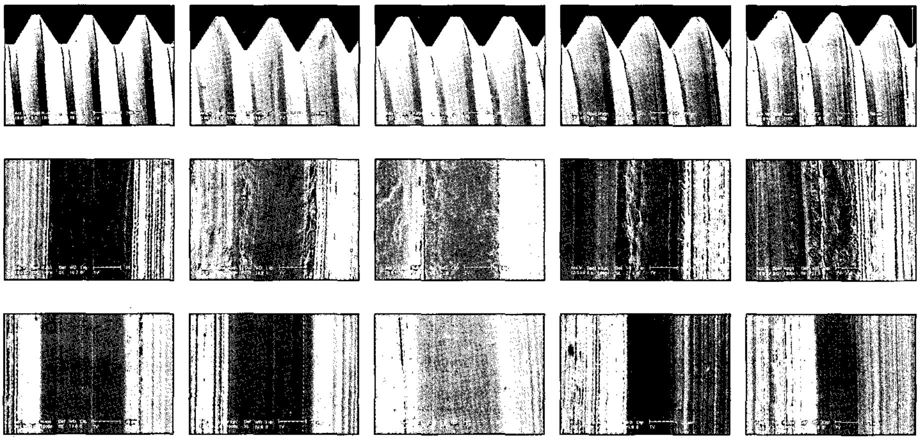

Fig. 10. Thread surface of 3i hex-slotted titanium screw in SEM.

ScrewHead(×30)

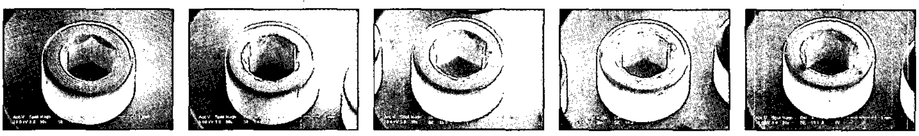

Fig. 11. Hex-slotted gold screw of Avana in SEM.

ScrewThread(×100)

ScrewCrest(×1000)

Screw Root(×1000)

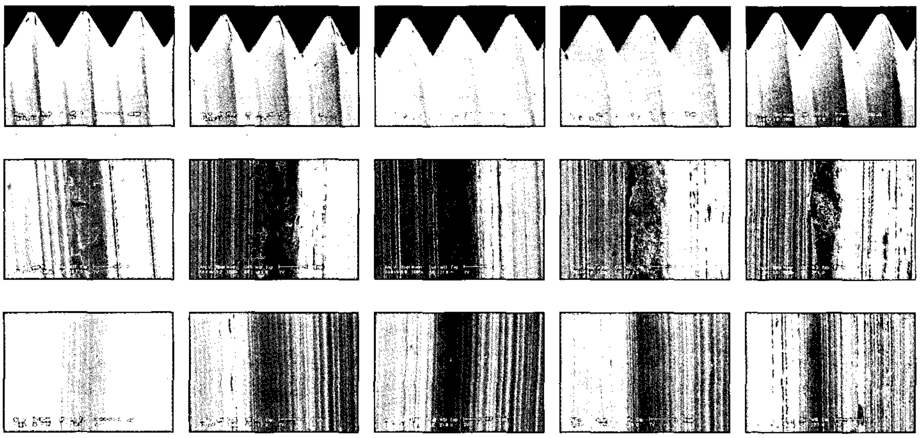

Fig. 12. Thread surface of Avana hex-slotted titanium screw in SEM.

Closing & Opening cycle Exam area (Magnification) | unused | 5 times | 10 times | 15 times | 20 times

ScrewHead(× 30)

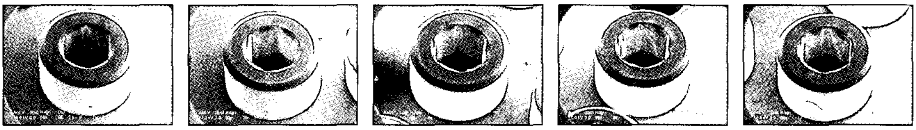

Fig. 13. Hex-slotted titanium screw of Avana in SEM.

ScrewThread(× 100)

ScrewCrest(× 1000)

Screw Root(× 1000)

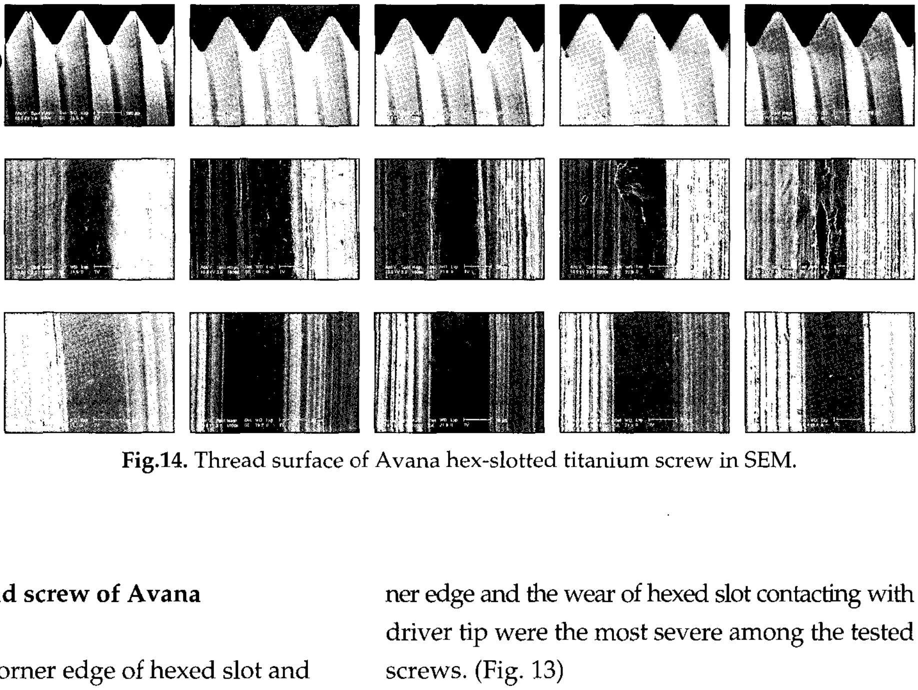

Fig.14. Thread surface of Avana hex-slotted titanium screw in SEM.

4. Hex-slotted gold screw of Avana

Rounding in the corner edge of hexed slot and the wear of hexed slot contacting with driver tip were more notable than 3i gold screws, but less than 3i titanium screws and Avana titanium screws. The aspect of scratches near hexed slot was similar to hex-slotted gold screws of 3i. (Fig. 11)

The decrease in the width of screw thread crest and groovings or wear on the thread were more regular than those of 3i gold screws, but less than those of 3i titanium screws and Avana titanium screw. The root of screw had little changes. (Fig. 12)

5. Hex-slotted titanium screw of Avana

Scratches near hexed slot, rounding in the corner edge and the wear of hexed slot contacting with driver tip were the most severe among the tested screws. (Fig. 13)

The decrease in the width of screw thread crest was regular like as Avana gold screw but less than 3i titanium screw. Groovings on the thread and the wear of screw thread crest were more prominent than 3i gold screws, but less than 3i titanium screws. The other changes in the screw thread were similar to those of the other screws. (Fig. 14)

DISCUSSION

In this study, the screws were torqued up to 20 times, which could represent 15 to 20 years of service if only tensile forces were considered. This estimation is based on the assumption that a screw would be removed and retightened a few times during try-in of the implant prosthesis and then once a year during recall and maintenance follow-up.

There were a few scratches near the slot of screw head. They may be due to the frequent contact between driver tip and flat around screw slot when driver tip repeatedly was inserted into the slot for tightening or opening a screw. They were more remarkable in the square-slotted screw than hex-slotted one. It is considered that it is because driver tip is more easily inserted into the hexed slot than squared slot.

There was a considerable wear or distortion in the internal slot of screw head that contacted with driver tip. Wear or distortion of hexed slot was more severe than that of squared slot. It is suggested that it is because an right-angled slot has tougher resistance to wear or distortion than an obtuse-angle one. Wear or distortion in the screw head slot was more remarkable in the titanium screw than in the gold screw. If wear or distortion in the slot of the abutment screw would be severely progressed, it would cause a rotational freedom between the driver tip of torque controller and internal slot of the screw head. Such a rotational freedom could decrease the effectiveness of tightening a screw. It may also have the bad influence on preload.

The ultimate aim in tightening a screwed joint is to obtain optimum preload that will maximize fatigue life while offering a reasonable degree of protection against loosening.[10] Preload is introduced in a screw when torque is applied during tightening. Preload is what keeps the screw threads tightly secured to the mating counterpart of the screw and holds the parts together by producing a clamping force between the screw head and its seat.[10,21] The abutment screw should be thought of as a stiff spring; as rotational torque is applied, this spring elongates and places the shank and threads in tension. The elastic recovery of the screw creates the clamping force that pulls the prosthesis and implant together.[10,21] Because only about 10% of the applied torque is used in the preload, small differences in the applied torque may have a major effect on the preload.[28] Therefore, it is considered that screws with square-slotted design may be better than ones with hex-slotted one in the transmission of torque and the effectiveness of tightening screw.

All the tested screws showed that the width in the crest of their screw threads decreased gradually as the test was proceeded. It was more conspicuous in the titanium screws than in the gold ones. It seems that the friction between abutment screw thread and implant body thread, when thread mate is engaged, is the cause of the width decrease in the crest of screw threads. While groovings and wear surfaces existed mainly in the inferior thread surface after first test, they were founded more remarkably in the leading edge and slope of the abutment screw threads (superior thread surface) as the test repeated. Most of the groovings and wear surfaces on the leading edge(superior) of the screw thread concentrated to the middle of the individual thread surface. This fact agreed with the results of Martin et al's study[29], in which he suggested that the leading edge of the abutment screw thread (superior surface) was in contact with the implant body thread, and the majority of the contacting surfaces were localized to the middle portion of the mating threads. He also reported that thread contact was generalized toward the apical portion of the abutment screw.

The maintenance of screw joint stability is considered a function of the preload stress achieved in the screw when the suggested tightening torque is applied. The achieved joint stability is also influenced by the geometry of the screw, the contact between the screw head and abutment screw bore, the screw threads and the screw bore internal to the implant, friction between the various implant parts, and the material properties of the screws.[10,16,30,31] Clinically, 2 factors are associated with screw loosening, loss of preload and embedment relaxation. The prime factor in their initiation is occlusal loading. In the oral cavity, these processes occur gradually with screw vibration and surface wear resulting in stretching and distortion of the screw and its threads.[28] The ultimate consequences shows movement at the implant/abutment interface and inevitably loosening of the prosthesis.

Embedment relaxation of mating surfaces results from the fact that, because of microroughness, no 2 surfaces are in complete contact with one another.[12,21] Because neither the internal threads of the implant nor the screw threads that contact these internal threads can be machined perfectly smooth, high spots will inevitably be present on both surfaces. Thus these high spots will be the only contacting surfaces when the initial tightening torque is applied to the screw and the preload developed. Embedment relaxation then occurs, whereby the rough spots actually flatten(or wear) under load, and 2% to 10% of initial preload is lost.[32] During loading, settling also will occur because the screw interface experiences micromovement and wear of the contact surface. Rough surfaces and large external loads tend to increase this effect and result in greater settling. As the screw-joint components press together, the microsurface irregularities under the screw head, in the threads, and on the contact surface of the implant and the abutment start to flatten out. This surface deformation of the contacting surfaces is called "settling". The amount of settling that occurs depends on the amount of rough spots on he contacting surfaces, the surface material hardness of the implant and the screw, and the amount of load applied to the system.[20] If the amount of settling is greater than the elastic elongation of the screw, the screw loses its ability to hold the parts together. Considering aspect of the wear on the contact surface or thread mate, the changes in the screw threads after repeated closing/opening experiments may be similar to those that caused by embedment relaxation or settling.

On closure of new screws, energy is initially expended in progressive smoothing surface asperities of mating surfaces, achieving thread engagement, screw elongation, and generation of preload.[21] Some recent publications report that friction is higher for the first tightening and loosening of a screw and that it decreases after repeated tightening and loosening cycles.[33,34] It is believed that the initial tightening and loosening sequences remove spurs and edges off the threads that were produced during the milling and tapping of the screws and implants.[35] Thread friction decreases with repeated closing and opening, and this process is claimed to cause changes in opening torsional failure on consecutive closing and opening cycles.[12,21,36]

In the study by Weiss et al[27], repeated opening and closing of implant abutment screws caused progressive loss of torque retention with variations between systems. This was probably due to a decrease in the coefficient of friction between the mating components. In an abutment implant system, resistance to opening torque is a direct function of the tension in the screw and the frictional resistance of the mating components. It is also inversely related to the vertical vector of force that results from the threads ' radial and tangential slopes. Because the vertical vectors of force resulting from the threads' radial and tangential slopes tend to open the screw, maintaining preload relies mainly on component friction. Their results suggest that wear as a result of repeated closing/opening cycles may decrease the friction coefficient of screw head, threads, and other mating components and, consequently, resistance to opening gradually decreases.

Hagiwara and Ohashi[34] noted that direct measurement of clamping force by the use of strain gauges, an extensometer, or a force washer is preferred, but torque and/or rotational angle can be used as indirect indicators of fastener tension or clamping force. He pointed out that friction is higher for the first tightening and loosening of a screw and that it decreases after repeated tightening and loosening cycles. He also note that an increase in clamping force is mostly due to the coefficient of friction between the mating threads; as the friction between the threads decreases, the preload distributed throughout the screwed joint increases. Increases in rotational angle measurements at a given torque value support the their belief that a reduction of friction increases clamping force. Abutment screw removal torque values decrease with a reduction in the friction coefficient. Hence, a reduction in the removal torque results in an increase in clamping force.[8,34] Further studies are needed to test for the point at which the reduction in friction is too high and thus may promote screw loosening.

In this study, screws with square-slotted design were more resistant to wear or distortion than those with hex-slotted one. Wear or distortion of screw slot and groovings or wear on the threads were more remarkable in titanium abutment screws. It is considered that it is due to crystal structure that determines the characteristics of each material.[37,38] Gold has a Face-Centered Cubic (FCC) crystal structure and titanium has a Body - Centered Cubic (BCC) one. Gold screw has smooth changes in it' s initial distortion. But, it has the property of work hardening as the repeated force are applied. Consequently, it has higher surface strength and resistance to distortion. Titanium screw has a brittle characteristics. As the closing and opening is repeated, titanium particles are desquamated and they cause more scratches and distortion between thread mating components. Therefore, gold screws had more beneficial results for the screw joint stability than titanium screws with regard to the changes on the screw slot and threads.

Another notable finding in our study was that the changes happened in the threads after repeated closing/opening experiments were similar to those after loading. Therefore, it is suggested that repeated closing and opening may increase the possibility of screw loosening.

Additionally, supposed that the test would be done inside the mouth, in which there ,were a few difficulties in manipulating instruments and visual approach, wear or distortion of screw slot would progress more severely.

In this study, we recommend the clinical use of gold screw, a more careful manipulation of the screw and driver and avoiding repeated closing and opening unnecessarily. we also suggest a periodic exchanges of abutment screws and the use of abutment screw with an acute- angled slot design rather than an obtuse-angled one. Finally, it is suggested that the new slot design and the surface treatment of screw head should be devised.

There were several potential limitations to this study. There were a small specimen size, some errors at the time of manufacturing and a different environment with oral cavity. Considering these factors, it is suggested that further studies should be needed.

CONCLUSION

The purpose of this study was to evaluate the changes on the head and thread surface of the abutment screws after repeated closing and opening through the examination of tested screws in SEM (scanning electron microscope).

The results were as follows ;

1. As the number of closing and opening was increased, the wear or distortion of hexed or squared slot that contacted with the driver tip also was more severely progressed.
2. Wear or distortion of hexed slot was more severe than that of squared slot.

3. Wear or distortion in the screw head slot was more remarkable in the titanium screw than in the gold screw.
4. All the tested screws showed that the width in the crest of their screw thread decreased gradually as the test was proceeded. Groovings and wear surfaces that existed mainly near the crest of thread surface after first test were toward the root of thread as the test repeated. Most of the groovings and wear on the leading edge(superior) of the screw thread concentrated to the middle of the individual thread surface.
5. The changes of screw thread were more remarkable in titanium screws than in gold ones.
6. Contact surfaces gradually changed from rough scratches to smooth wear surfaces as the test were repeated.
7. Scratches and wear of abutment screw were also sometimes observed at crest of all the tested screws.
8. There was little change at root of all the tested screws.

Conclusively, we recommend the clinical use of gold screw, a periodic exchanges of abutment screws and avoiding repeated closing/opening unnecessarily. We also suggest a more careful manipulation of the abutment screw and drive and using of abutment screw with an acute-angled slot design rather than an obtuse-angled one. Finally, it is suggested that the new slot design and the surface treatment for enduring wear or distortion should be devised.

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