DETORQUE FORCE OF TiN-COATED ABUTMENT SCREW WITH VARIOUS COATING THICKNESS AFTER REPEATED CLOSING AND OPENING

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Statement of problem. When TiN coating is applied to the abutment screw, occurrence of greater preload and prevention of the screw loosening could be expected due to decrease of frictional resistance. However, the proper thickness of TiN coating on abutment screw has not been yet reported.

Purpose. The purpose of this study is to find out the appropriate TiN coating thickness by evaluating the detorque force and the surface change of titanium abutment screw with various TiN coating thickness.

Material and methods.

1. Material

Thirty five non-coated abutment screws were prepared for TiN coating. TiN coatings were prepared by Arc ion plating method. Depending on the coating deposition time(CDT), experimental groups were divided into 6 groups(CDT 30min, 60min, 90min, 120min, 150min, 180min) and those of 1 group was not coated as a control group. Each group was made up of 5 abutment screws.

2. Methods

FE-SEM(Field Emission Scanning Electron Microscoper) and EDX(Energy Dispersive X-ray Spectroscopy) were used to observe the surface of the abutment screw. Electric scales was used to measure the weight of the abutment screw after the repeated closing and opening of 10 trials. Detorque force was measured with digital torque gauge, at each trial.

Results.

1. As the coating deposition time increased, the surface became more consistent and smooth.
2. As for the abutment screws that were TiN coated for more than 60 minutes, no surface change was found after the repeated closing and opening.
3. The TiN coated abutment screws showed less weight change than the non-coated abutment screws.
4. The TiN coated abutment screws showed higher mean detorque force than the non-coated abutment screws.
5. The abutment screw coated for 60 minutes showed the highest mean detorque force.

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Conclusion. The coating layer of proper thickness is demanded to obtain consistent and smooth coating surface, resistance to wear, and increased detorque force of the abutment screw. In conclusion, the coating deposition time of 60 minutes indicated improved mechanical property, when TiN coating was conducted on titanium abutment screw.

Key Words
Detorque force, Abutment screw, TiN

Recently, the use of osseointegrated implants has become popular in single tooth restoration, and partially edentulous and fully edentulous restoration. Regardless of the type of performed restoration, in most cases, a screw connection is used between the abutment and the implant. However, implant abutment screw loosening has remained a problem in restorative practices.[1,2] Abutment screw loosening was reported in large number of studies and ranged from 2% to 45% of the abutment.[3-6] The screw loosening does not occur when the clamping force of the screw exceeds the joint separating forces acting on the assembly.[7-12] Joint separating forces may exceed clamping forces when implant assemblies are subject to non-axial loading because of implant position or angulation, or excessive occlusal forces.[13] Cantilever designs may amplify forces on screw joints due to the lever effect and should, when possible, be avoided.[14]

Preload is the term that describes the tension generated in the screw upon tightening and is a direct determinant of clamping force. As the abutment screw is torqued down, preload is generated within the screw, placing the abutment/implant assembly under compression.[15,16] The strength of the preload is a combination of the frictional forces in the mating threads and screw head, the metallurgical properties of the screw, and the applied closing torque.[16] Micromovement, component surface wear, and embedment relaxation during functional loading may gradually erode the preload and cause progressive slippage and screw joint failure.[16,17] When torque is applied to a new screw, about 90% of the input torque is used to overcome friction and only 10% to induce preload.[18] For this reason, a few manufactures altered the surface of abutment screws to reduce the friction coefficient and obtain a higher preload.[19,20] The most well- known abutment screws are Gold-Tite of 3i(3i, Florida, USA) and TorqTite of Steri-Oss(Nobel Biocare, Göteborg, Sweden) and WCC of Osstem(Osstem, Busan, Korea). Martin et al reported that Gold-Tite and TorqTite abutment screws with enhanced surfaces helped in reducing the friction coefficient and generated greater rotational angles and preload values than conventional screws.[2] Drago reported that the use of Gold-Tite square abutment screws, torqued to 32Ncm, maintained a stable abutment/implant connection that was successfully used in clinical practice for one year.[21]

Titanium nitride(TiN) coating is the most general and popular coating method and used to improve the properties of metallic surface for industrial purposes. This coating layer of 2-3μm thickness renders the surface scratch-proof and is considered to be clinically stable.[22] TiN is used as a hard coating for metal cutting tools like drills and burs, and forming tools such as dies and punches because it has high hardness, low friction coefficient and good resistance to adhesive wear. Additionally, it has a golden appearance and is useful for ornamental purposes. TiN coating has been applied to clinical dentistry since early times. Clinical trials in which coated crown, partial fixed denture and removable prostheses made from casting dental alloy with TiN had been performed by several dentists.[22] Kim et al reported that TiN coating of abutment screw helped to reduce the risk of screw loosening and improved the stability of screw joint.[23] When TiN coating was applied to the abutment screw, frictional resistance would decrease, and as a result, a greater preload and prevention of the screw loosening effect could be expected. However, the proper thickness of TiN coating on abutment screw has not been reported yet.

The purpose of this study is to find the appropriate TiN coating thickness by evaluating the detorque force and surface change of titanium abutment screw with various TiN coating thickness.

MATERIAL AND METHODS

1. Material

Thirty five non-coated GSII abutment screws (Osstem, Busan, Korea) were prepared for TiN coating. They were randomly selected and divided into 7 groups. Depending on the coating deposition time(CDT), experimental groups were divided into 6 groups: group A(CDT 30min), group B(CDT 60min), group C(CDT 90min), group D(CDT 120min), group E(CDT 150min), group F(CDT 180min). TiN was respectively coated on the specimens of 6 groups, and those of 1 group(group G) was not coated as a control group. Each group was made up of 5 abutment screws(Table Ⅰ, Fig. 1).

2. Methods

1) TiN coating using Arc ion plating

TiN coatings were prepared by Arc ion plating method. To control the coating thickness, each group had the variation of coating deposition time, such as 30, 60, 90, 120, 150, and 180 minutes.

2) Mounting of implant fixtures

The implant fixtures used in this study were GSII of internal conical joint design (diameter 4mm and length 13mm; Osstem, Busan, Korea). Abutments used GS Transfer Abutment of hex standard design(diameter 5mm and gingival height 3mm and abutment height 5.5mm; Osstem, Busan, Korea). Thirty five pairs of implant fixtures and abutments were respectively selected. A specimen was composed of a assembly of a fixture, an abutment and an abutment screw. Each fixture was mounted in liquid unsaturated polyester. After the

Table Ⅰ. Classification of groups

Group	Specimen No.	Coating deposition time	Applied torque
A	5	30 min	30Ncm
B	5	60 min	30Ncm
C	5	90 min	30Ncm
D	5	120 min	30Ncm
E	5	150 min	30Ncm
F	5	180 min	30Ncm
G*	5	None	30Ncm

* : Control group

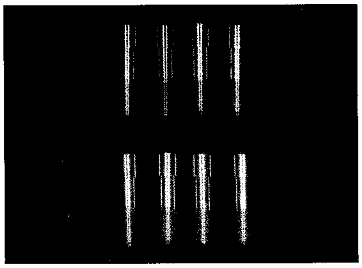

Fig. 1. Abutment screws used in this study.

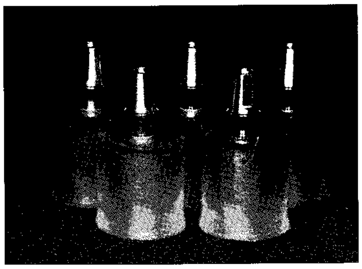

Fig. 2. Fixture and abutment connection.

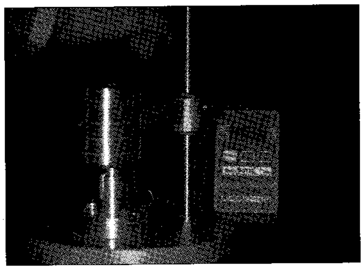

Fig. 3. Measurement of detorque force.

mounting media was completely hardened, the abutment was connected to each fixture(Fig. 2).

3) Surface investigation of the abutment screw by FE-SEM and EDX

FE-SEM(Field Emission Scanning Electron Microscoper) was used to observe changes of surfaces of the abutment screws after the repeated closing and opening of 10 trials. The surface of each abutment screw was observed at 100 magnifications, and then screw crest, valley, and slope were observed at higher magnifications: 1,000, 10,000, 100,000 and 500,000 magnification. Before and after the repeated closing and opening, qualitative analysis was conducted by means of EDX(Energy Dispersive X-ray Spectroscopy).

4) Measurement of abutment screw weight

In order to compare the wear resistance of various TiN coating thickness on a abutment screw, the weight of the abutment screw was measured by electric scales(GENIUS ME, Sartorius, Germany) before and after the closing and opening of 10 trials.

5) Measurement of detorque force

The implant mounted fixture blocks were fixed in a specially devised specimen-holding apparatus before the repeated closing and opening. Each abutment was secured to a implant fixture by abutment screw with recommended torque value(30Ncm) using a finger screw driver(Osstem, Busan, Korea) and a torque wrench(Osstem, Busan, Korea). The finger screw driver was used to fix the abutment screw till thread mating components were slightly contacted. The torque wrench was used to tighten the screw to 30Ncm. It was used to insure that an accurate and reproducible force was applied to each abutment screw. The abutment screws were repeatedly tightened and removed for 10 trials. The number of trials included several try-in of abutment screw up to final setting. Sample with abutment screw tightened was fixed in the customized jig for the measurement of detorque force. The detorque force was measured with digital torque gauge(Mark-10 Corp., New York, U.S.A., Fig. 3).

3. Statistical analysis

SPSS statistical software for Windows(SPSS Inc., Chicago, U.S.A.) was used for statistical analysis. One-way ANOVA(Tukey test; level of significance, $P<0.05$) and validity test of Microsoft Excel were used for the comparison of the mean detorque forces and the tendency of detorque force change between the coated groups and the non-coated group.

RESULTS

1. Surface investigation

1) Before the repeated closing and opening

According to the observation of the surface at the magnifications of 100 and 500,000, the non-coated surfaces of control group(group G) showed a somewhat rough surface, while TiN particles adhered to the surface of the coated groups. As the coating thickness increased, the size of the adhered TiN particles grew bigger at the same magnification(Fig. 4). As a result of qualitative analysis of coating surface by using EDX, Ti, Al, and V were detected in the non-coated control group(group G), which was verified as Ti-6Al-4V alloy. In the experimental group, other than Ti, Al, and V, TiN was additionally detected. As the coating thickness increased, the EDX qualitative analysis showed greater portion of TiN ingredient than Ti, Al, and V ingredient(Fig. 4).

2) After the repeated closing and opening

Compared with the surface investigation before the repeated closing and opening, the surface change on all groups was not observed in low magnification FE-SEM. However the high-powered FE-SEM analysis of Group A and Group G showed noticeable changes in screw threads after the test. The separation of coated TiN was detected in abutment screws of Group A, and Group G turned out to show wear surface and scratches. On the other hand, the surface change of other groups was not detected by the high-powered FE-SEM(Fig. 5). According to the qualitative analysis of coating surface using EDX, the surface ingredient did not show any difference compared with the analyzed before the repeated closing and opening.

2. Measurement of the abutment screw weight

According to the measurement of the abutment screw weight before and after the repeated closing and opening, Group G represented the most remarkable weight change, and Group A represented the most remarkable weight change among TiN coated groups(Table II).

In comparison with other groups, Group G, showed a statistically significant difference($P<0.05$, One-way ANOVA).

1) Statistical significances were tested by one-way of variances among groups
2) The same letters indicate significant difference between groups based on Tukey test

3. Measurement of detorque force

Table III shows the mean detorque forces of each trial. Group B had a higher mean detorque force than other groups. The TiN coated groups showed higher detorque force than group G(Non-coated). All groups had a increasing tendency of detorque force as the closing and opening were repeated to the 3rd or the 4th trial. Furthermore, in the repeated trials after the 3rd or the 4th trial, the detorque forces showed a decreasing tendency. In the 3rd or the 4th trial, all groups had maximal mean detorque force(Fig. 6). There was a statistically significant difference between Group B and Group G($P<0.05$, One-way ANOVA). In the terms of maximal value, minimal value, and all trial detorque forces, Group B was higher than Group G. After the 4th trial, although Group B and Group G revealed declining tendency of mean detorque forces, Group G showed a steeper declining slope compared with Group B. In coated groups, such as Group A, B, C, D, E, and F, despite the fact that every absolute mean detorque force was different, the tendency of detorque

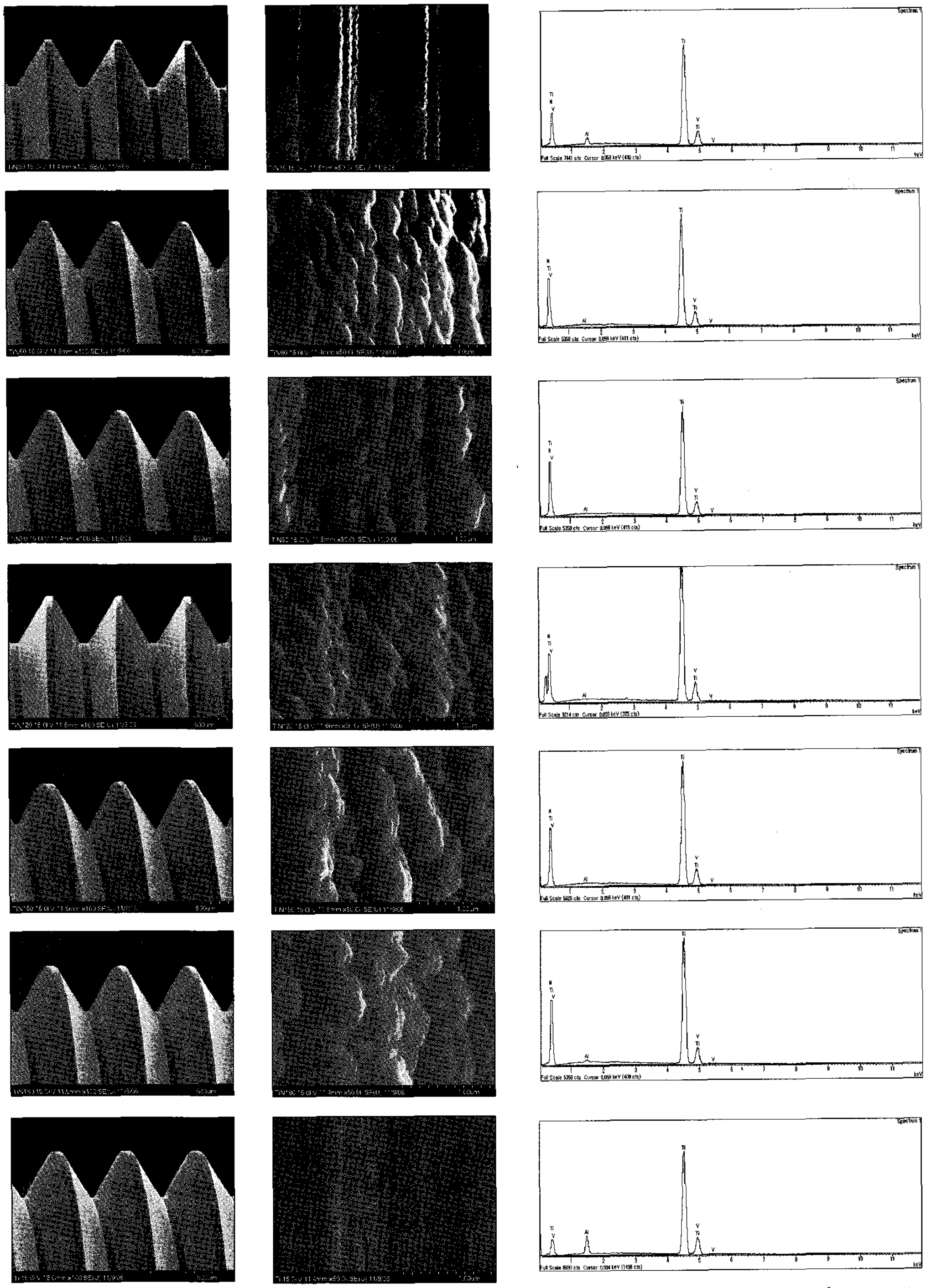

Fig. 4. FE-SEM micrographs & EDX showing the coating surface and the ingredient of each group before the repeated closing and opening (Left : ×100, Middle : ×500,000, Right: EDX).

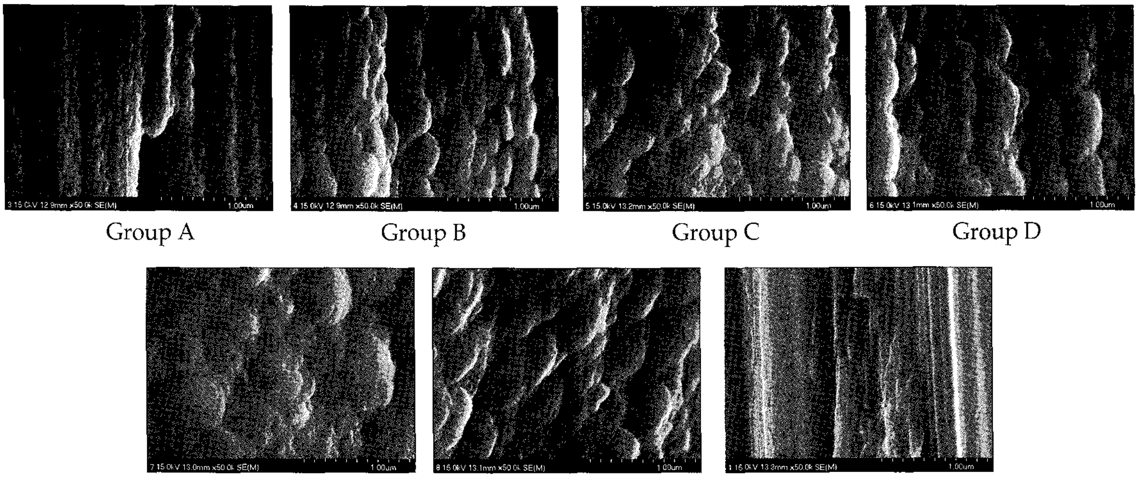

Fig. 5. FE-SEM micrographs showing coating surface of each group after the repeated closing and opening($\times$ 500,000).

Table II. The weight difference of the abutment screw between before and after the repeated closing and opening

Group	Mean weight difference(g)	S[2]	P-value[1]
A	0.000020±0.000016	f	
B	0.000012±0.000025	e	
C	0.000004±0.000006	b	
D	0.000012±0.000022	d	<0.05
E	0.000000±0.000010	a	
F	0.000008±0.000015	c	
G	0.000076±0.000011	a,b,c,d,e,f	

1) Statistical significances were tested by one-way of variances among groups
2) The same letters indicate significant difference between groups based on Tukey test

Table III. Mean detorque force of each group

Group	Mean detorque force(Ncm)	S[2]	P-value[1]
A	26.06±0.51	c,d	
B	27.51±0.52		
C	26.61±0.44	d	
D	25.66±0.44	c	<0.05
E	25.19±0.45	b,c	
F	24.63±0.57	a,b	
G	24.01±0.89	a	

1) Statistical significances were tested by one-way of variances among groups
2) The same letters indicate non-significant difference between groups based on Tukey test

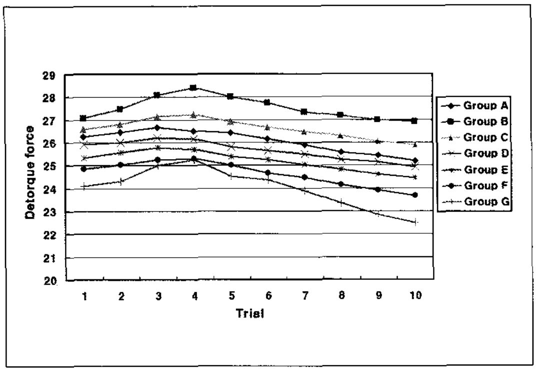

Fig. 6. Comparison of mean detorque force among groups.

force transition was similar. There was a statistically non-significant difference between Group F and Group G($P<0.05$, One-way ANOVA). Although the maximal detorque force of Group F was almost the same as Group G, the general tendency of detorque force change was different. Additionally, the mean detorque forces between Group F and Group G, except for the 4th trial, showed considerable large differences.

1) Statistical significances were tested by one-way of variances among groups
2) The same letters indicate non-significant difference between groups based on Tukey test

DISCUSSION

The prevalent method to reduce the screw loosening is known as the application of dry lubricant coating on abutment screw.[24] The purpose of the lubricant is to reduce the frictional coefficient and obtain a higher preload. The need for coating with lubricant has been introduced long ago. The friction coefficient during the surface contact between titaniums gradually increases, as the tightening and loosening are repeatedly performed. Such an increase of the frictional coefficient effects the galling and seizing tendency of the titanium. The beneficial properties of TiN film are low friction coefficient, high hardness and good wear resistance. Considering these properties of TiN coating, TiN coating can be an alternative coating method; Koo et al applied TiN coating to abutment screws and examined those surface characteristics. As a result, abutment screws revealed salient improvement of mechanical properties.[25] Also, Kim et al reported that the titanium abutment screw coated with TiN scored a higher mean detorque force than the titanium abutment screw.[26] In addition, Lee et al applied TiN coating of various thickness to titanium alloy disks and examined on the mechanical property. In this study, Lee et al reported that CDT(coating deposition time) of 60 min and 180 min indicated coating thickness of 1.05㎛ and 2.10㎛ respectively, suggesting coating thickness greater than 2㎛ showed homogenous and smooth coating surface with high-quality mechanical property.[27] However, we consider that the study of Lee et al has a limitation in application of clinical practice due to it' s study based on TiN coated disk, not a TiN coated abutment screw. Therefore, the purpose of this study is to investigate the detorque force and the surface change of titanium abutment screw of various TiN coating thickness.

1. Coating surface investigation

According to the researchers including Mezger, TiN coating showed improvement of the properties on wear-resistance, corrosion-resistance, and surface hardness.[22] When clamping torque force was applied to a screw surface with micro-roughness such as pores or micro-cracks, the loading excelling the yield strength causes plastic deformation of the screw surface.

The mechanism of screw loosening is based on the fact that the surface is not completely smooth. Even a carefully machined implant surface is slightly rough when viewed with a microscope. Because of this micro-roughness, no two surfaces are in complete contact with one another. When the screw interface is subjected to the external loads, micromovements occur between the surfaces. Wear of the contact areas might be a results of these motions, thereby bringing the two surfaces close to each other.[28] The magnitude of settling depends on the initial surface roughness and surface hardness as well as the magnitude of the loading forces.[19] Rough surface and large external loads increase the settling. When the total settling effect is greater than the elastic elongation of the screw, the screw becomes loose due to lack of contact forces to hold the screw.[29] Sakaguchi et al, reported that 2-10% preload disappeared by the influence of settling effect.[30]

Based on the study of Sopwith suggesting that only 3-4 screw thread is enough to fix upper structure, the observation of screw surface was focused on the upper 3-4 screw thread in this study.[31]

According to the observation of the abutment screw surface before the repeated closing and opening by use of FE-SEM, while Group G(Non-coated) surfaces showed traces of manufacturing process, other coated groups showed relatively consistent and smooth surfaces. As the coating thickness increased, the size of the adhered TiN particles grew bigger at the same magnification. As the coating thickness increased, the EDX qualitative analysis showed greater portion of TiN ingredient than Ti, Al, and V ingredient. This fact indicated that the surface-attached TiN ingredients increased as the coating deposition time increased. TiN proportion beyond certain thickness level was observed equally, due to the penetrating depth limitation of the incident beam from FE-SEM. When the surface of TiN coated abutment screw was observed after the repeated closing and opening, the abutment screws coated with TiN for more than 60 minutes did not show surface change, and the exfoliation of TiN coating was observed at Group A. In comparison between before and after the repeated closing and opening, the difference of EDX value was not revealed. According to this result, it is considered that the repeated closing and opening did not affect the ingredient composition change of the coating surface.

On the basis of this result, when abutment screw is coated with TiN for homogeneous and consistent coating surface and the decrease of plastic deformation of coating surface at the repeated closing and opening, the abutment screw is required to be coated with TiN for more than 60 minutes.

2. Measurement of abutment screw weight

The major factor causing the screw loosening can be low wear resistance of the coating material, which can also lead to the plastic deformation and the exfoliation of the coating film. Therefore, the coating material of abutment screw requires high wear resistance to minimize screw loosening. Wear resistance was not directly measured on the abutment screw due to it' s small size and thread shape. Thus, this study evaluated the wear resistance by means of the changes of abutment screw weight at before and after the repeated closing and opening.

As shown in Table II the reduction of weight at before and after the repeated closing and opening was remarkable in Group G. There was a statistically significant difference between all groups ($P<0.05$, One-way ANOVA). However, the weight difference was too small to appreciate. As for the comparison of the abutment screw among the groups, the TiN coated abutment screws showed less weight change than the non-coated abutment screws. Therefore, the abutment screw requires TiN coating for the decrease of abutment screw wear at the repeated closing and opening.

3. Measurement of detorque force

In all groups, the detorque force showed an increasing tendency until the 3rd or the 4th trial, and a declining tendency from the 3rd or the 4th trial to the 10th trial. The increasing tendency through the 1st to the 3rd or the 4th trial is due to the gradual decrease of irregular surface between the fixture and the abutment screw by the settling effect. The decreasing tendency from the 3rd or the 4th to the 10th trial is due to the gradual increase of friction between the fixture and the abutment screw by mechanical wear. In the analysis of the tendency of the detorque force transition, the settling effect and the mechanical wear were not independent phenomenons. The influence of settling effect was more remarkable up to the 3rd or the 4th trial, while the influence of adhesive or mechanical wear was more remarkable from the 3rd or the 4th trial to the 10th trial. In TiN coated groups, Group B showed maximal detorque force and slight declining tendency of mean detorque force. In every trial, the detorque forces of Group B were higher than those of Group G. In addition, Group B had slighter declining tendency than Group G.

This result shows that TiN coated abutment screw has advantages over non-coated titanium abutment screw on every aspect.[32] The mechanical properties of the TiN coated abutment screw such as low friction coefficient and improved hardness are considered to contribute in the increase of the detorque force and the decrease of the loosening of the abutment screw. When applied on the abutment screw, the Group B TiN coating thickness indicated the highest mean detorque force.

CONCLUSION

In this study, for the determination of proper TiN coating thickness, we used implant system having internal conical type. Surface change and detorque force of abutment screw with various TiN thickness was measured for evaluating proper coating thickness after the repeated opening and closing. According to the result of this study, we obtained the following conclusions.

1. As the coating deposition time increased, the surface became more consistent and smooth.
2. In abutment screws that were TiN coated for more than 60 minutes, no surface change was found after the repeated closing and opening.
3. The TiN coated abutment screws showed less weight change than the non-coated abutment screws.
4. The TiN coated abutment screws showed higher mean detorque force than the non-coated abutment screws.
5. The abutment screw coated for 60 minutes showed the highest mean detorque force.

The coating layer of proper thickness is demanded to obtain consistent and smooth coating surface, resistance to wear, and increased detorque force of the abutment screw. In conclusion, the coating deposition time of 60 minutes (Group B) indicated improved mechanical property, when TiN coating was conducted on the titanium abutment screw. Therefore, the TiN coating can be one of the resolution for the loosening of the abutment screw.

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