EFFECT OF THE SURFACE MODIFICATIONS AND THE USE OF WASHER ON THE REVERSE TORQUE OF THE IMPLANT PROSTHETIC GOLD RETAINING SCREW

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The screw loosening is one of the complications that happen frequently in dental implant prostheses. The purpose of this study was to evaluate the changes of reverse/loosening (opening) torque of the screw according to the surface modifications by sandblasting and 24K gold electroplating as well as to determine the possibility of the clinical use of a washer in dental implant.

The reverse torque of 4 experimental conditions(control, sandblasted, use of washers, electroplasted) was measured by digital torque gauge (Model MGT50Z, Mark-10 Corp., 458 West John Street Hicksville, NY 11801 USA). Electronic torque controller (Nobel Biocare DEA 020) was used in fastening the gold screws into abutment replicas. Mixed Linear Model Analysis method was used for statistical analysis. To examine the changes of screw thread surface, microphotographs were taken by Olympus PME-3 metallurgic microscope (Olympus Optical Co. Ltd., Tokyo, Japan).

Within the limitations of this study, the following results were drawn:

1. The surface modifications of the gold screws and the use of a washer have significantly affected the reverse torque value compared to the control group ($P<0.01$).
2. Sandblasting and electroplating treatments demonstrated significantly higher reverse torque value than that of control group.
3. The use of a washer may be one of the useful clinical methods that prevent the screw loosening. However, further studies are necessary for the material selection and design of the washer.

Key Words
Implant, Gold Screw, Reverse Torque, Sandblasting, Electroplating, Washer

In jaws restored with dental implants, combined mandibular loads can induce varying and complex stresses throughout the prosthetic devices.[1] It is believed that if there loads are abnormally high or frequent, potential problems may arise in the implant system such as: (a) gap creation at the prosthesis screw-prosthesis or abutment screw-abutment interface,[2] (b) fracture or loosening of prosthesis or abutment screw,[3] (c) fracture or plastic deformation of prosthesis,[3] (d) implant fatigue/fracture,[4] (e) marginal bone loss[5,6] and (f) bone fracture.[7]

The screw loosening is one of the complications that happen very frequently in dental implant restorations. In clinical studies, 6%～40%[9-11] of retaining screws were loose at the recall check after original tightening. The precise frequency of implant screw loosening is difficult to determine. Some articles that have described clinical trials, and their associated complications briefly mention screw loosening, whereas others completely ignore or fail to define screw loosening as a problem.[8] The retention of the screws directly relates to preload. It has been found that the application of higher preloads generally decreases the frequency of loosening. There is a limit, however, to the amount of preload that can be applied because of yield and fracture concern.[15] Preload is determined by applied torque, screw alloy, screw head design, abutment alloy, abutment surface and lubricant.[14] If the applied torque is too low, screw loosening occurs, if the torque is too high, then screw fracture can take place.[18]

The aim of this study was to find out whether the reverse/loosening (opening) torque of the screw changes or not when the surface of the screw modified by sandblasting and electroplating with 24K gold and to determine the possibility of the clinical use of a washer in dental implant.

MATERIALS AND METHODS

Brånemark gold screw (Unigrip Multi-unit NP/RP) was used for the experiment. Experiment was carried out by measuring the reverse/loosening torque of the gold screws that were grouped by the surface modification and the use of washer. Normal gold screws (with no surface modification, no washer) were measured as control group for the purpose of comparison. 4 experimental groups were as follow :

Group Ⅰ	:	Control	(C1-C10)
Group Ⅱ	:	Sandblasted	(S1-S10)
Group Ⅲ	:	Washer	(W1-W10)
Group Ⅳ	:	Gold electroplated	(E1-E10)

Sandblasted group was the gold screws that were sandblasted by 50 micron Alumina particle and had rough surface. Group Ⅲ was the gold screws tightened with the aluminum washers that were made for gold screws and had 0.3 mm thickness. Group Ⅳ was the screws that were electroplated with 24K gold by about 1 micron thickness (Fig. 1). 10 gold screws were assigned for each experimental group and total 40 gold screws were used for the experiment.

Electronic torque controller (Nobel Biocare DEA 020) was used in fastening the gold screw into abutment replica. It has a preset value of torque (10/20/32/45Ncm) and speed (high/low). Reverse/Loosening torque was measured by digital torque gauge (Model MGT50Z, Mark-10 Corp., 458 West John Street Hicksville, NY 11801 USA) (Fig. 2). It has the measuring torque range of 50 ozin (35 Ncm) and the accuracy of 0.5% of full scale of 1 digit, i.e. 0.3 ozin (about 0.2 Ncm).

Before the experiment, the accuracy of the electronic torque controller was evaluated using the digital torque gauge. The Brånemark healing abutment was fastened in the chuck of the digital torque gauge and the torque generated by the electronic torque controller was delivered to the digital torque gauge through the healing abutment. The peak torque value was taken when the electronic torque controller was stopped after the electronic sound which indicates that the applied torque reached the preset torque value. Total 20 consecutive readings of the peak torque value were used in the evaluation of the accuracy of the torque controller.

Abutment replica was embedded in orthodontic resin. Resin block with abutment replica was fixed to the immobile base by wrench. A gold retaining screw was fastened to the replica by the electronic torque controller (DEA 020, Nobel Biocare) with a preset amount of 10 Ncm (low speed) (Fig. 3). The controller rheostat (pedal) was activated until the electronic sound (beep) was heard. For the accuracy of the delivered tightening torque, the tightening of the screw was repeated 3-5 times. Digital torque gauge was engaged in the internal hex of the gold retaining screw by the hex driver tip specially made for the experiment. Reverse torque was applied to the

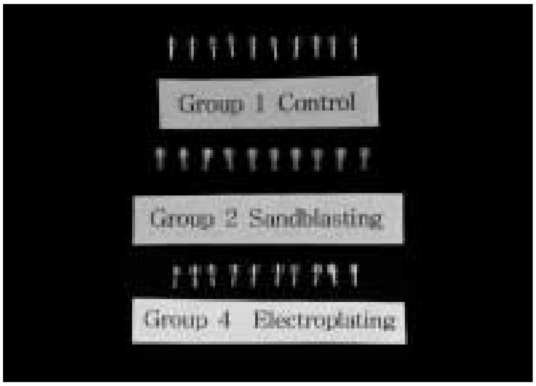

Fig. 1. Gold screws(Group Ⅰ, Ⅱ, Ⅳ)


Fig. 2. Digital torque gauge

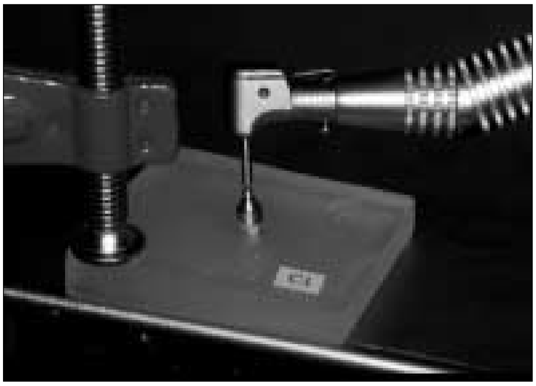
Fig. 3. Tightening of a gold screw


Fig. 4. Measuring of the reverse torque

screw by hand and its peak value (Reverse/Loosening torque) was measured (Fig. 4). At tightening and measuring, the axis of torque applied was maintained parallel to the axis of the gold screw, but no attempt was made to precisely control the axis.

All gold screws were measured for reverse/loosening torque except one screw for each group (total 4 screws) that would be used for examining the thread surface of the intact gold screw. Each gold screw of the group was measured 20 times consecutively and 180 reverse/loosening torque values of 9 screws for each group were gained.

After measuring 20 times, 5-7 screws for each group were selected arbitrarily and used in measuring reverse/loosening torque until the screw was unable to tighten. The number of measurement was limited to maximum 100 (times) if the screw withstood the repeated measuring.

For the statistical analysis, Mixed Linear Model Analysis method was used. Trend curve (statistically analyzed curve that shows the overall pattern of the data) was calculated for each group and examined for the difference.

The microphotography of the thread surface was taken by Olympus PME-3 metallurgic microscope (Olympus Optical Co. Ltd., Tokyo, Japan). The change of the thread surface of the screw was examined as the number of measurement increase by taking the microphotograph before the measurement, after the 20 times of the measurement and the 100 times of the measurement.

Table Ⅰ. Torque Values of the Electronic Torque Controller

No. of Measurement	Torque (Ncm)	No. of Measurement	Torque (Ncm)
1	10.01	11	10.36
2	10.05	12	10.12
3	11.06	13	10.82
4	10.61	14	9.91
5	10.47	15	11.80
6	9.52	16	10.99
7	10.85	17	9.94
8	10.43	18	10.96
9	10.68	19	9.70
10	11.76	20	10.29
Mean Torque Value		10.51	
SD		0.62	

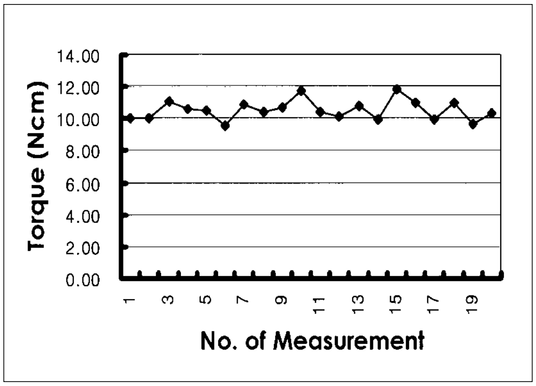

Fig. 5. Torque values of the electronic torque controller

RESULTS

1. Evaluation of the accuracy of the electronic torque controller

Table Ⅰ and Fig. 5 show the tightening torque values of the electronic torque controller. Mean tightening torque of the electronic torque controller was 10.51 Ncm and standard deviation (SD) was 0.62. It was slightly higher than the preset 10 Ncm of the torque controller. But as compared to the former studies[18] about the accuracy, the reliability of the device was regarded as good enough to assume that the relatively constant tightening torque was delivered to the gold screws.

2. Changes of the experimental condition

There were some changes of the experimental conditions. Firstly, in order to find out whether the number of the repeated tightening of the screw influence the reverse torque, the screw was tightened repeatedly 5 times for one measuring after 20 consecutive measurement of the reverse torque (First 20 consecutive measurements were done by the screws that were tightened repeatedly 3 times). Second change of the experimental condition was the decreasing of the limit of the maximum number of the measurement. The measurement of group Ⅰ, Ⅱ, Ⅳ (Control, Sandblasted, Electroplated group) was so good that some screws of the groups could be measured up to 100 times. But before measuring the reverse torque 50 times, the large number of the gold screws in the group Ⅲ (Washer group) were in the trouble that the tightening of the screw was no more impossible. So the maximum number of the measurement was limited to 50 (times) in the group Ⅲ.

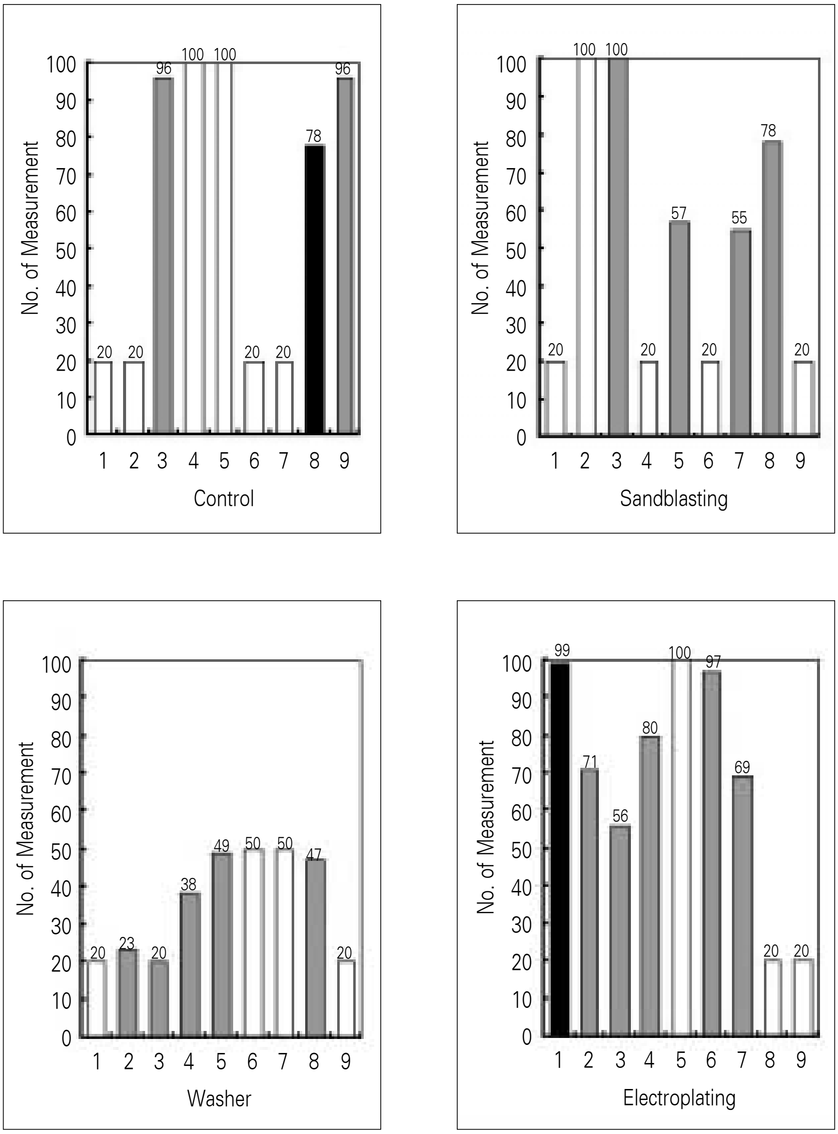

Fig. 6. Status of the screws during the experiment

3. Results of measuring the reverse torque

Problems statistics

50% (18) of total 36 gold screws used were in trouble during the experiment. Major portion of the trouble was the destruction of internal hex of the screw head (16 screws) and the other trouble was the fracture of the screw at the threaded region. Those screws in trouble could not be measured no more. So in case of the troubled-screws, the reverse torque values within the measuring number of the trouble were included in the experiment. Fig. 6 shows the status of the screws during the experiment. White color is the screw measured without any problem and grey color is the screw that the destruction of internal hex happened during the measurement.

Two black bars are the screws that the fracture happened.

Measurement of the reverse torque

With the reverse torque data, the graphs of the number of measurement versus the reverse torque was made. Fig. 7-10 are the graph of the 1-20 consecutive reverse torque values of 4 groups and Fig. 11-14 are of the 1-100 consecutive reverse torque values of 4 groups (group Ⅲ has a short graph because of the limitation of the No. of measurement).

Mixed Linear Model Analysis method was used for the statistical analysis of the data to find out that there are statistically significant differences in the reverse torque value among groups. Fig. 15, 16 are the Trend curves of the groups (Fig. 15 is of the 1-20 consecutive reverse torque values of 4 groups and Fig. 16 is of the 1-100 consecutive reverse torque values of 4 groups).

As for the graphs of the 1-20 consecutive reverse torque (Fig. 7-10, 15), all 4 groups assumes generally similar pattern of slow increment of the torque as the No. of measurement increase. Group Ⅰ, Ⅱ, Ⅳ (Control, Sandblasted, Electroplated groups) show relatively same slope of the increment pattern, but group Ⅲ (Washer group) shows the impression of the more steep increment and remarkably low intercept of the initial reverse torque. In the aspect of the intercept of the graph, there was a statistically significant difference ($p<0.0001$) among the 4 groups ex-

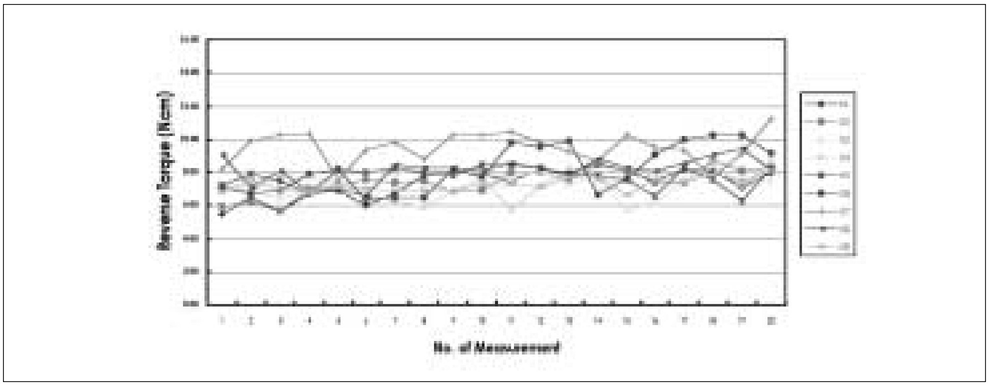

Fig. 7. Reverse torque of the group Ⅰ (control group) (1-20)

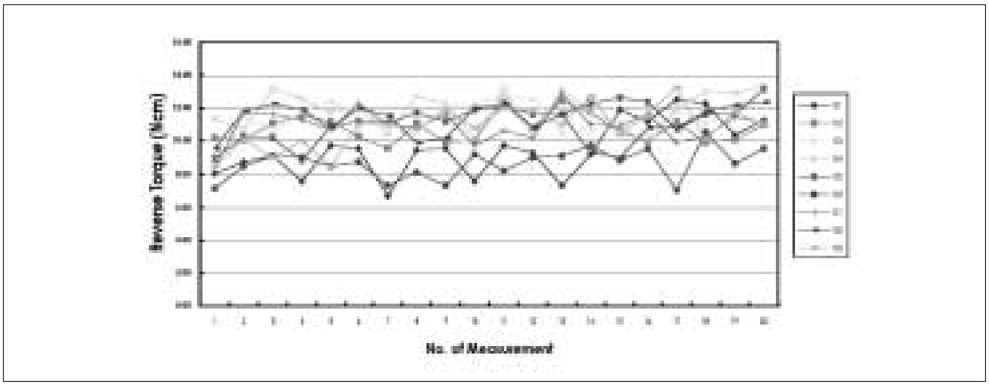

Fig. 8. Reverse torque of the group Ⅱ (sandblasted group) (1-20)

cept group I (Control) vs group Ⅳ (Electroplated) (p=0.1099). The slopes of the 4 groups did not have statistically significant differences (p>0.05) except the case of the comparison with the group Ⅲ (Washer group). Group Ⅲ (Washer group) showed the remarkable difference with other groups in slope

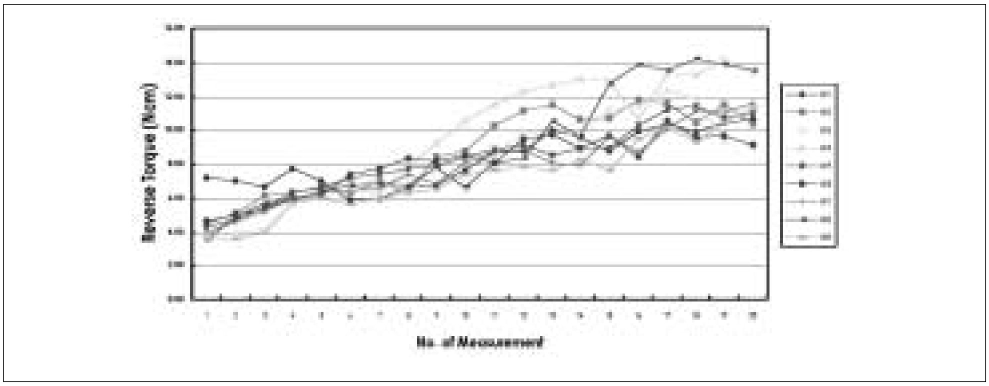

Fig. 9. Reverse torque of the group Ⅲ (washer group) (1-20)

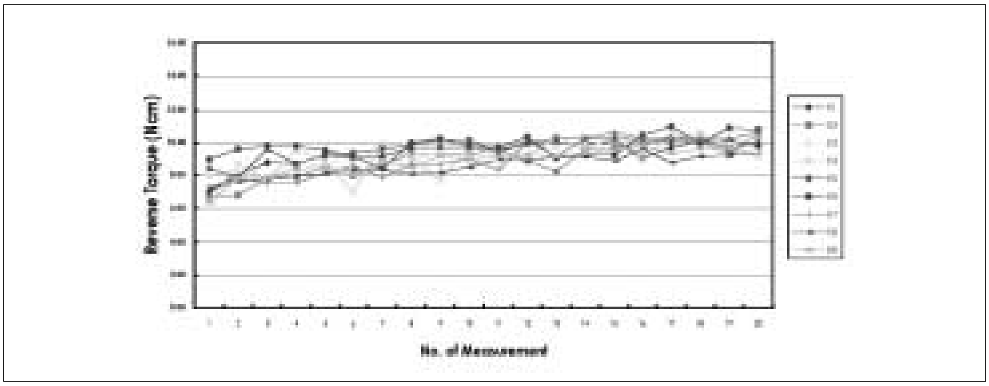

Fig. 10. Reverse torque of the group Ⅳ (electroplated group) (1-20)

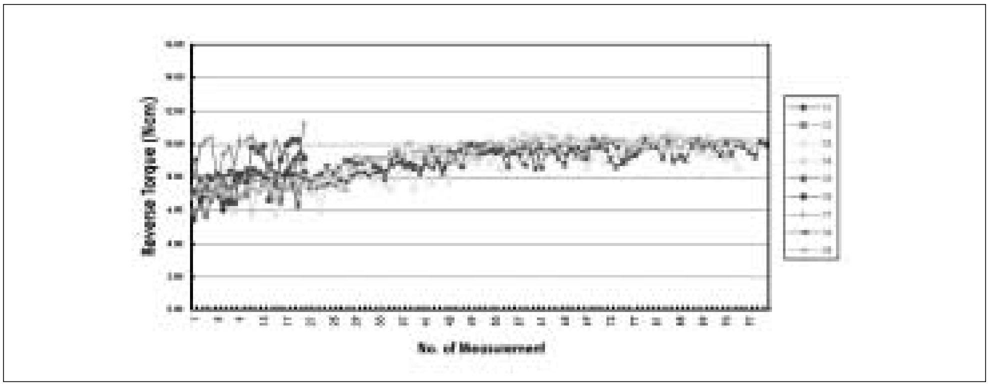

Fig. 11. Reverse torque of the group Ⅰ (control group) (1-100)

(p<0.0001). In comparison of the deviation of the reverse torque values, group Ⅱ (Sandblasted group) has the more large deviation than other groups (group Ⅰ, Ⅳ), and group Ⅳ shows the most little deviation (the most consistent reverse torque along the number of measurement) among group Ⅰ, Ⅱ, Ⅳ.

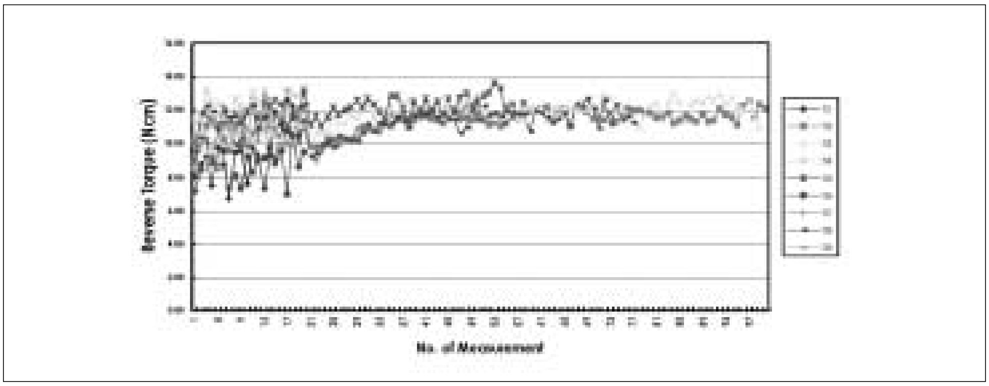

Fig. 12. Reverse torque of the group Ⅱ (sandblasted group) (1-100)

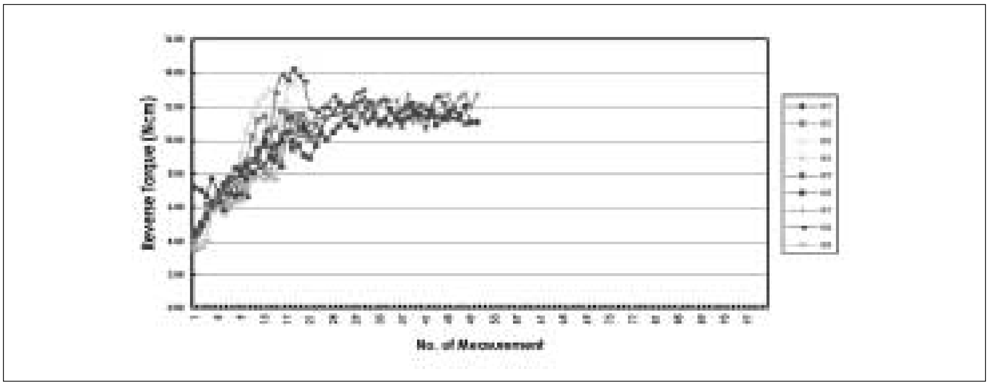

Fig. 13. Reverse torque of the group Ⅲ (washer group) (1-100)

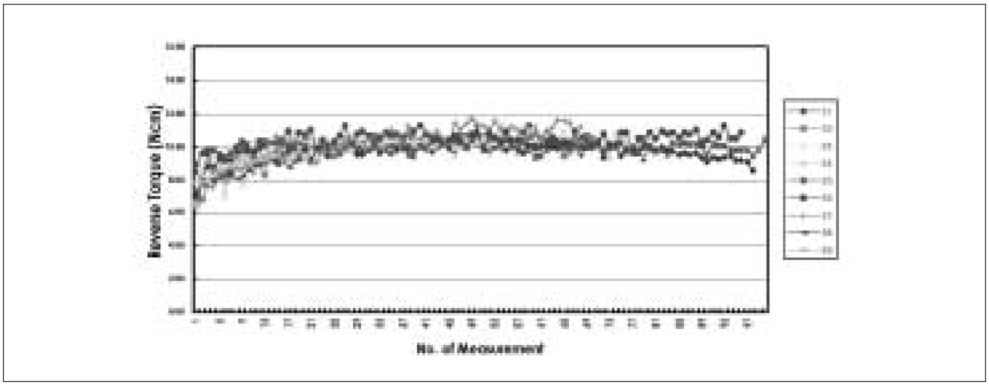

Fig. 14. Reverse torque of the group Ⅳ (electroplated group) (1-100)

Because group Ⅲ (Washer group) has a large amount of the change (large slope of data) in the reverse torque along the number of measurement, overall deviation of group Ⅲ is more large than any other groups. But more steep incremental pattern of group Ⅲ makes the comparison with group Ⅰ, Ⅱ, Ⅳ difficult.

As for the graphs of the 1-100 consecutive reverse torque values (Fig. 11-14, 16), there is a similarity in the pattern among the groups that the reverse torque value slowly increases to the peak and decreases after the peak. Like the graphs of the 1-20 consecutive reverse torque values, group Ⅰ, Ⅱ, Ⅳ show relatively similar overall pattern compared to group Ⅲ (Washer group). The torque values of group Ⅰ, Ⅳ (Control, Electroplated groups) are more consistent than group Ⅱ (Sandblasted group) through all the measured values. The number of measurement needed to reach the peak torque value was different among the 4 groups. In the group Ⅱ (Sandblasted group) the reverse torque reached the maximum peak value at around the 70th measurement. Group Ⅳ (Electroplated group) reached at around the 55th measurement and group Ⅲ (Washer group) was at around the 35th measurement. Group I (Control group) didn't have the peak value in the range of the experiment (total 100 measurement) and the reverse torque value of the group I continuously increased. So the estimating of the peak value of the group I was impossible. In case of the group Ⅲ (Washer group) the reverse torque increased with a steep slope, reached its peak ear-

Table Ⅱ. Mixed Linear Model Analysis

Label	Comparison			Num DF	Den DF	F Value	Pr > F
Intercept	Control	vs	Sandblasted	1	32	119.37	<.0001*
	Control	vs	Washer	1	32	97.30	<.0001*
	Control	vs	Electroplated	1	32	20.66	<.0001*
	Sandblasted	vs	Washer	1	32	366.87	<.0001*
	Sandblasted	vs	Electroplated	1	32	41.65	<.0001*
	Washer	vs	Electroplated	1	32	189.50	<.0001*
Slope	Control	vs	Sandblasted	1	1887	0.00	0.9650
	Control	vs	Washer	1	1887	250.67	<.0001*
	Control	vs	Electroplated	1	1887	2.40	0.1216
	Sandblasted	vs	Washer	1	1887	245.65	<.0001*
	Sandblasted	vs	Electroplated	1	1887	2.12	0.1457
	Washer	vs	Electroplated	1	1887	228.30	<.0001*
T^2 (Pattern)	Control	vs	Sandblasted	1	1887	0.54	0.4607
	Control	vs	Washer	1	1887	166.20	<.0001*
	Control	vs	Electroplated	1	1887	7.43	0.0065
	Sandblasted	vs	Washer	1	1887	159.31	〈.0001*
	Sandblasted	vs	Electroplated	1	1887	3.42	0.0647
	Washer	vs	Electroplated	1	1887	147.36	<.0001*

* There is a statistically significant difference in comparison.

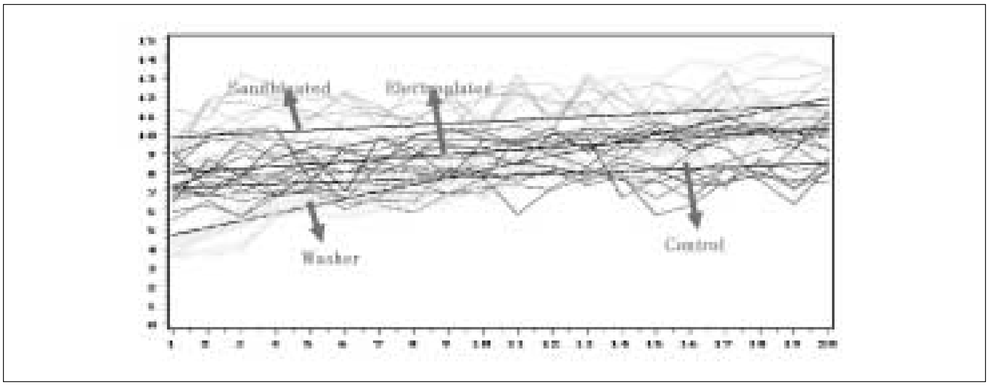

Fig. 15. Result of statistical analysis (1-20)

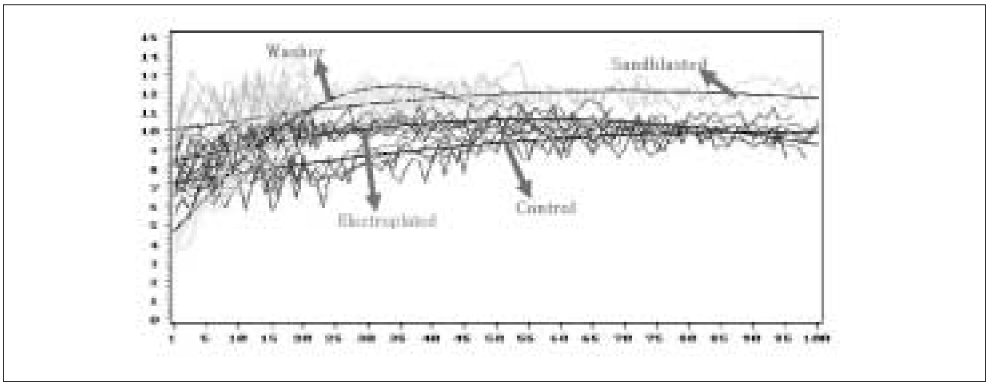

Fig. 16. Result of statistical analysis (1-100)

ly in the measurement and also decreased quickly. All intercepts of the 4 groups were significantly different each other ($p<0.0001$). Except group Ⅲ (Washer group), slopes were similar ($p>0.05$).

Table Ⅱ is the summary of the statistical analysis in which the difference among the 4 groups can be said statistically significant or not. In the tables it can be said that the torque values of group Ⅲ (Washer group) are always different from other groups in intercept, slope and overall pattern of graph (all comparisons with the washer group always had significant difference, p-values are smaller than 0.0001).

In the Trend curves (Fig. 15, 16), it can be said that the values of the group Ⅱ, Ⅲ (Sandblasted, Washer groups) are higher than that of the group I (Control group) in almost all number of times of measurements. In case of Group Ⅲ (Washer group) the torque value is the most high among the 4 groups although the range of the value that is the most high is small compared to the maximum number of the measurement and the initial measurement was much lower than control group.

4. Surface Microphotography

Using Olympus PME-3 metallurgic microscope (Olympus Optical Co. Ltd., Tokyo, Japan), the topography of the thread surface of the gold screw was taken at the initial, after the 20th measurement and after the 100th measurement. Because group Ⅲ (Washer group) was supposed to have the same topography with group I (Control group),

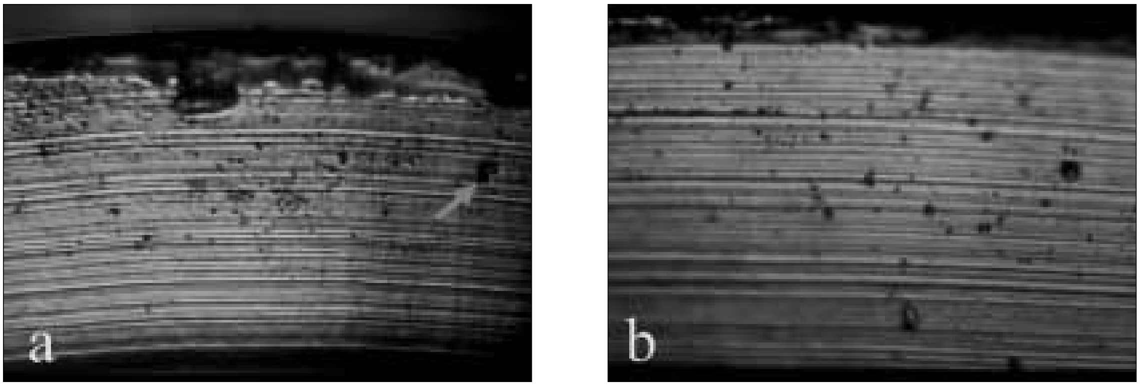

Fig. 17. Microphotograph of thread surface (control group) (a) X100 (b) X200

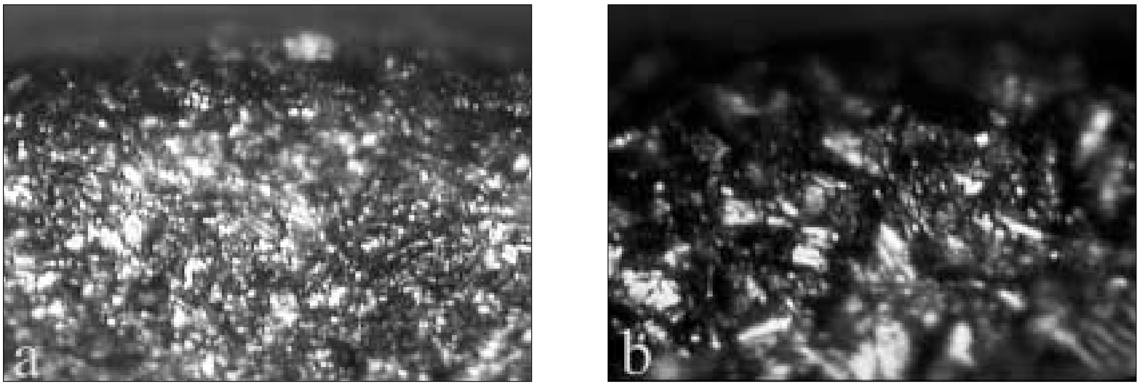

Fig. 18. Microphotograph of thread surface (sandblasted group) (a) X100 (b) X200

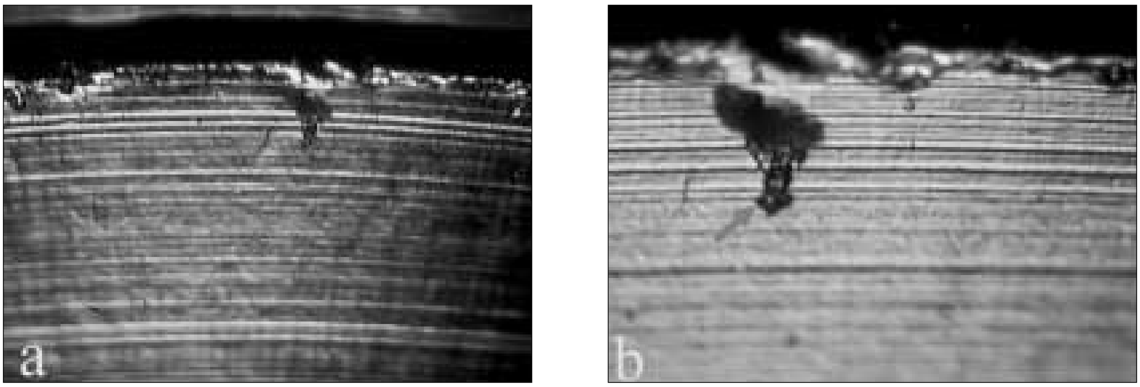

Fig. 19. Microphotograph of thread surface (electroplated group) (a) X100 (b) X200

so the microphotography of the group Ⅲ was excluded in the experiment.

Comparison of the initial surface topography of the gold screw

Fig. 17-19 show the initial surface topography

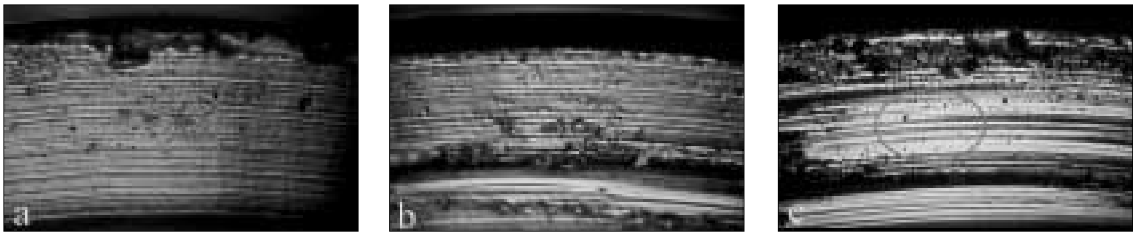

Fig. 20. Control group (a) initial (b) after 20 measuring (c) after 100 measuring

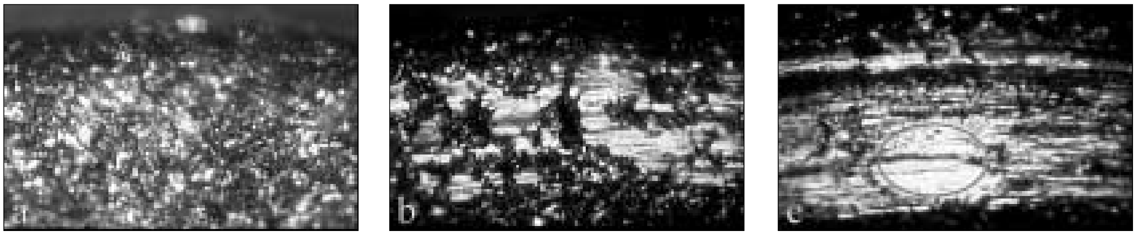

Fig. 21. Sandblasted group (a) initial (b) after 20 measuring (c) after 100 measuring

Fig. 22. Electroplated group (a) initial (b) after 20 measuring (c) after 100 measuring

of the gold screw. There are several micro-grooves in the surface of the thread (group Ⅰ, Ⅳ, Fig. 17, 19) which are very uniformly aligned along the thread surface and supposed to have been created at the procedure of making the thread of the gold screw through milling by the manufacturer. Although the screws were not used for any purpose, the surface of the screw thread shows several defects (indicated by arrows in group Ⅰ, Ⅳ, Fig. 17a, 19b). Group Ⅳ (Electroplated group, Fig. 19) seems to be more yellowish because of coating the surface with 24K gold. The surface of the group Ⅱ (Sandblasted group, Fig. 18) was very rough and irregular by sandblasting but the gross alignment of the thread was not deformed.

Comparison of the surface topography with the No. of measurement (repeated tightening)

Fig. 20-22 show the effect of the repeated tightening of the screw on the thread surface. As the number of measurement (the number of the repeated tightening of the screw) increase, the thread surface of the screw seems to be flattened and smoothened by the frictional force and more shining than the initial state of the surface with the uniformly arranged micro-groove (circles in the Fig. 20c-22c). Moreover, instead of the uniformly arranged micro-grooves which are supposed to have been made during manufacturing the screw, the large grooves with more irregular alignment were created in the surface (arrows in Fig. 20b, 21c, 22b, 22c). The number and size of the defect was increased (group Ⅰ, Ⅳ, Fig. 20, 22). In the group Ⅳ (Electroplated group), the gold-coated surface undergone the frictional force and the partial wearing-off of the gold coating happened (Fig. 22a-c).

DISCUSSION

When a retaining gold screw is tightened on the dental implant by torque, a force called "preload" is developed within the screw.[16] Preload is generated mainly by applied torque and related to several other factors.[14] Preload keeps the screw threads tightly secured to the screw' s mating counterpart and holds the parts together by producing a clamping force between the screw head and its seat.[13] The screw elongates, placing the shank and threads in tension. The elastic recovery of the screw creates the clamping force that pulls the prosthesis and implant together. So in order to make screws remain tightly without loosening, the increment of preload within the screws by increasing the applied torque may be useful. But excessive torque that exceeds the yield strength of the screw creates permanent deformation in the screw, leading to screw fracture over time arising from load fatigue.[12] There is a limitation in increasing the applied torque. Optimal tightening torques can be calculated using 75% of the ultimate torque to failure values.[14]

The frictional forces are complicatedly related to the tightening and loosening of the screws. In tightening the gold screw, the friction acts as an obstacle for screws to reach high preload. Burguete et al. suggested the concept of "optimum torque" and "design torque".[12] All the applied torque by the torque-generating devices do not convert into the preload enough to protect the screws from loosening. The small part of the applied torque is consumed by the frictional force. The rest of the torque applied participates in generating preload. Optimum torque is that which actually achieves the optimum preload and design torque is that which is necessary to deliver optimum torque to the screws. Haack et al. explained this by the work which is carried out by the frictional force.[13] He suggested that when torque is applied to new screws and bolts with rough-textured thread surfaces, energy is applied partially toward smoothening mating surfaces and less toward elongation of the screw and that thread friction is higher for the first tightening and loosening of a screw; then after repeated tightening and loosening cycles, friction decreases. After all, it can be said that in tightening a screw the reduction of the frictional effect induces appropriate preload. As for the loosening of screws, the friction prevents the screws from losing the preload and loosening of the screws in result. Burguete et al. also explained that the preload is maintained by the frictional forces in the threads and that the greater the joint preload, the greater will be the resistance to loosening, because the frictional forces between the threads will be greater and a large external force is required to cause slippage.[12]

In consequence, the friction plays the directly opposite role in between the tightening and loosening of the screws. But there are a lot of the factors that have an influence on the preload and retention of the screws. So it is not clear that there will be the optimum amount of the friction for the maximum preload and retention of the screw and how we can find it.

The purpose of this experiment was to find out the effect of the surface modification of the gold screws (the change of the frictional characteristics of the gold screws) and the use of washer on the screw retention by measuring the reverse/loosening torque. To increase the friction the thread surface of the screw was sandblasted and to decrease the friction the surface of the screw was gold-coated by electroplating. It is expected that group Ⅳ (electroplated group) may show the higher reverse torque than control and group Ⅱ (sandblasted group) may show the lower reverse torque than control. But being different from the expectation, group Ⅱ showed the highest reverse torque among the groups (except washer group). Group Ⅲ (Washer group) was the lowest among the groups at first but the reverse torque increased steeply to the level that surpasses all the other groups.

Overall pattern of the data was that the reverse torque gradually increased, reached at its peak value and decreased after the peak. Group Ⅲ (washer group) showed the most steep change of the torque. These results differ from that of Weiss et al.[17] In the study of recording the changes in opening torque values due to multiple consecutive closures of abutment screws at a constant torque, Weiss concluded that the repeated opening and closing of implant abutment screws caused the progressive loss of torque retention and this was probably due to a decrease in the coefficient of friction between the mating components. In the study of Weiss et al. the opening torque of the abutment screw had only decreasing tendency and no region of increment within 200 consecutive measurements. But in this study there was the region of increasing in the reverse torque values at the initial time of the measurement (Fig. 16). This means that the energy delivered to the screw by the tightening torque is applied partially toward smoothing mating surfaces and less toward elongation of the screw at first and that after repeated tightening and loosening cycles the surface asperities are flattened so more input torque is applied toward elongation of the screw and production of preload.[13]

Group Ⅱ (Sandblasted group) showed higher reverse torque than group Ⅰ, Ⅳ (control, electroplated group). Despite of increased friction the reverse torque increased. This strongly suggests that the friction is not the only influencing factor on the reverse torque (screw retention) and it can be said that the increase of the frictional factor only may not increase the retention of the screw.

Washers are widely used to prevent screw loosening in engineering.[15] There were some studies about the use of washers in dental implant system. Versluis et al. used FEM study in the investigation.[15] The simulation indicated that an aluminum washer may significantly increase the tolerance of a screw against loosening. In the study of the effect of washer made of stainless steel on reverse torque displacement of the screw, Korioth et al. concluded that inclusion of a conical spring washer significantly increased the amount of rotational displacement need to completely loosen a screw.[16] In both studies, the focus is at the deformation or displacement of the screw needed to loosen the screw. In this experiment the reverse/loosening torque of the screw with an aluminum washer was measured directly and compared with control. In case of the group Ⅲ (Washer group) the reverse torque was very low compared to other groups at first but increased with the steep slope, surpassed the level of the peak values of other groups, reached its peak early in the measurement and also decreased quickly. The initial low reverse torque can be explained by the mechanism that the part of the energy generated by the tightening torque was used in the deformation of an aluminum washer and the energy needed to deform the washer decreased gradually so the reverse torque increased. But the aluminum washer is not useful in clinical application that the initial low reverse torque is so lower than control. There should be more study about the material, design of the washer.

The number of repeated tightening per one measuring and the deviation of the reverse torque values are related to each other. Increasing the number of repeated tightening per one measuring reduced the deviation (Fig. 23 illustrates that the data within circle (of small number of repeated tightening) is more deviated over the mean value than the data out of the circle). So it can be said that the more repeated tightening produces the more reliable torque value.

In the microphotography of the thread, not only the flattening and smoothening of thread surface by

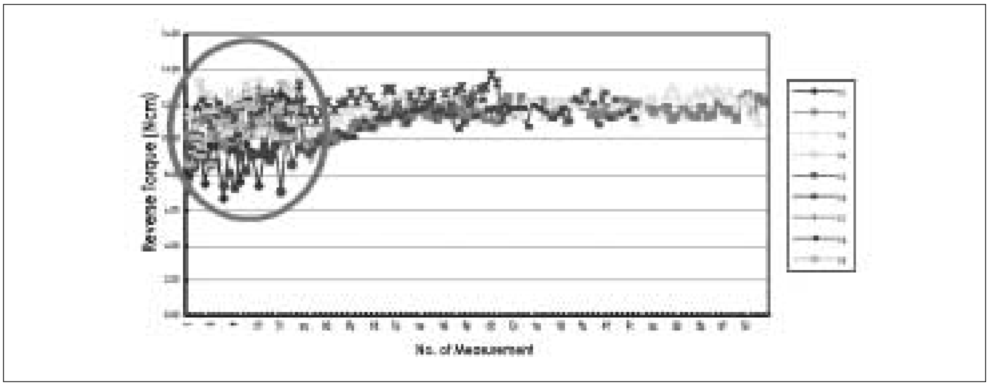

Fig. 23. Reliability of transfered torque by repeated tightening

friction but also the formation of defects, deep grooves by the surface deformation of the thread material happened. It strongly suggests that the screw tightening is not the simple process in which the mating surfaces are lightly contacted with the frictional force, but the process that the thread surface can be deformed by the heavy contact of the surfaces.

There are many limitations and factors that may produce errors in the results. In this experiment, only the reverse torque of screws was measured. The reverse/loosening torque alone cannot make it clear that the tendency of the screw loosening is reduced by the surface modification and use of washer in the gold screws. There can be error in tightening and loosening of the screw. In the experiment the tightening and loosening of the screw was carried out by hands, so the axis of the applied torque and the axial load cannot be standardized. The forces of the muscular activity by the autonomous reflex may affect the tightening/reverse torque. Fixation of the devices may produce the more reliable results. Instead of the abutment, abutment replica was used in the experiment and gold cylinder was not used. The difference of materials (titanium of abutment versus stainless steel of abutment replica) may affect the reverse torque but the overall pattern of the data would not be affected. The results about the group Ⅲ (washer group) are insufficient for the definite evaluation of the clinical usefulness of a washer.

CONCLUSION

Within the limits of this study, the following conclusion was drawn:

1. The surface modification of the screw and the use of a washer have changed the reverse torque value significantly compared to the control group.
2. Sandblasted group and electroplated group showed the increased reverse torque compared to the control group.
3. The use of a washer may be one of the useful clinical methods that prevent the screws from loosening. But there should be another study about the material and design of the washer.

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