Removal torque of screw and cement retained cantilever fixed prosthesis on angled abutment after cyclic loading

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Abstract

Objective: The objective of this study was to investigate the effect on dental implants, after dynamic cyclic loading, of abutment types and restoration designs on the removal torque values of abutment screws on anterior cantilever fixed prostheses.

Materials and methods: Forty Simple Line II fixtures (Dentium, Seoul, Korea) were divided into 4 groups, I.) Cement-retained, straight abutment, II.) Cement-retained, angled abutment, III.) Screw-retained, straight abutment, and IV.) Screw-retained, angled abutment. An anterior cantilever fixed prostheses was casted with non-precious alloy and assembled for all implant components. The removal torque values of the abutment screws were measured using a digital torqued gauge before and after cyclic loading. A cyclic force between 30-300 N was applied at 30° to the long axis of the prosthesis at 14.0 Hz for 5×10^{5} cycles. Two-way ANOVA was used to examine the effect of abutment types and restoration designs on the RTV after cyclic loading (α = 0.05).

Results: The means and standard deviations of the changes of removal torque values were 9.70 ±1.32 N•cm, 11.35 ±1.75 N•cm, 10.33 ±1.20 N•cm, and 11.40 ±1.26 N•cm for groups I, II, III and IV, respectively. One abutment screw in group III, which was screw-retained with straight abutment, was fractured. According to two abutment types, the changes of removal torque values of angled abutments in both cement- and screw-retained abutment groups were significantly higher than those with straight abutments ($P < .05$). From SEM analysis of groups II, III and IV, wear facets were larger and deeper than in group I, especially in the specimen with a fractured screw.

Conclusions: Only the abutment types had a significant effect on the change of removal torque value. For both cement- and screw-retained anterior cantilever fixed prostheses, the changes of removal torque values of angled abutment groups after cyclic loading were significantly higher than in those of straight abutment groups.

Key words: abutment, cantilever, cyclic loading, implant, removal torque value, screw loosening

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Introduction

Treatment planning of osseointegrated dental implants should be started from the final prosthesis in order to determine the orientation and the angulation of implant placement.[1-4] In the upper anterior region, the correct position of an implant is one of the most important factors to achieve ideal esthetic and functional results. Angled abutments were used to establish an ideal position of restoration without compromising the implant dimension and position or need of ridge augmentation.[4-6]

Although a ridge augmentation can be performed, there have been reports of unsatisfactory results. For upper anterior regions, long-term esthetic outcomes are required after ridge augmentation and implant placement procedures, but mucosal recession and bone resorption were also found in long-term studies.[7,8]

When placement of two adjacent anterior maxillary teeth is required, the best choice is to place two standard diameter implants that are parallel to each other and aligned along the long axis of the axial forces.[5,9] However, if the mesio-distal dimension between two adjacent roots is not enough, it is essential to use two small diameter implants, which can have a risk of failure under loading. In addition to this risk there may be other limitations, such as bone concavity and anatomical limitations. Thus, it is better to change the treatment plan and use only one single standard diameter implant with a cantilever prosthesis.[9-11]

Regarding previous studies of cantilever fixed prostheses with dental implants, common clinical complications were usually mechanical complications, for examples, screw loosening, porcelain veneer chipping or fracturing.[12-16] One of the most important causes of screw loosening is a bending force generated from off-axis loading, which can easily occur with a cantilever prosthesis.[15,17-21]

This study was conducted to simulate the condition of occlusal loading on implants with a cantilever fixed prosthesis in order to investigate the effects of cyclic loading on the screw joint stability. This study was designed to test a null hypothesis that abutment types and restoration designs have no significant effect on removal torque values of the screws of anterior cantilever fixed prostheses on an implant after cyclic loading.

Materials and methods

Forty Simple Line II fixtures with 4.3-mm-body diameter and 10-mm-length, 2.0-mm-G/H (Dentium) were divided into four experimental groups as shown in table 1.

Each Simple Line II fixture was embeded at the center of a cylindrical polyvinyl chloride tube using epoxy resin.

There was no screw-retained abutment available in this implant system. For the screw-retained groups, straight and 15^{o} angled screw-retained abutments were casted from Metal-Casting Abutment Co-Cr (4.8-mm-diameter, Dentium) with Ni-Cr alloy (AURILOY® N.P.(V), San Diego, CA) (Figure 1).

Table 1 Restoration design and abutment type of 4 experimental groups

Group	N	Restoration design	Abutment type
I	10	Cement-retained	Straight
II	10	Cement-retained	Angled
III	10	Screw-retained	Straight
IV	10	Screw-retained	Angled

a b

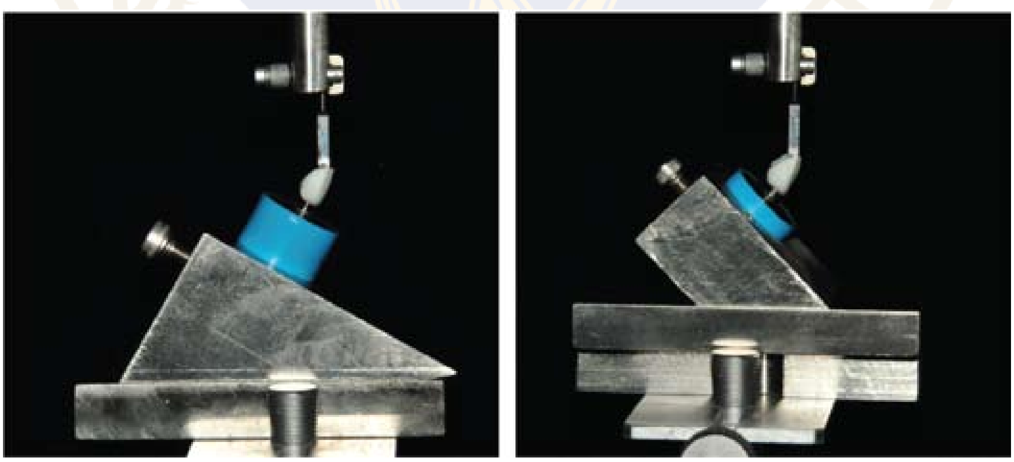
Figure 1 Customized (a) straight and (b) angled abutment, before casting

Tooth no. 11 and 12 (FDI two-digit notation system) were removed from the typodont (Nissin, Kyoto, Japan) and filled with pink wax (Cavex, Haarlem, Netherlands). Then, the model was duplicated using polyvinyl siloxane impression material (Silagum®, DMG, Hamburg, Germany) and the impression was poured with a dental stone (Whip mix Corporation, Louisville, KY). Four stone models were made.

Each fixture analog was held to the mandrel of a dental surveyor (Ney®, DENTSPLY International Inc, York, PA) and embedded into the stone model at upper right central incisor location, which was drilled with a carbide bur in the axis of the left central incisor. The fixture was fixed with the dental stone and covered with the pink wax. The finished line of the analog fixture was at the same level as the gingival margin of the adjacent tooth. For angled abutments, analog fixtures were placed at 15° labial to the long axis of the left central incisor.

Groups I and II (Cement-retained)

The superstructures were produced using a lost-wax technique. A wax pattern was fabricated on a Dual Abutment (4.8-mm-diameter, 7.0-mm-height, Hex, Dentium) for group I, and on an Angle Abutment - Octa (15-degree, 4.8-mm-diameter) for group II, which was connected to the fixture analog with an abutment screw. Full anatomy of the two-unit cantilever bridge was created where the right maxillary central incisor was abutment, and right lateral incisor was the pontic. The incisal edges of these two teeth were cut off to create a flat surface at 30° from the long axis of the teeth, for the loading point (Figure 2).



a b

Figure 2 The incisal edge of two wax-up teeth was cut off to create a flat surface at 30° angles to the long axis of the teeth, which was the area of loading point in both (a) straight and (b) angled abutments.

All wax patterns were sprued (GEO wax wire, Renfert®, Hilzingen, Germany), invested with phosphate-bonded investment (Jelenko Dental Health Products, Armonk, NY) and casted with Ni-Cr alloy (AURILOY® N.P.(V), San Diego, CA). All superstructures were finished and polished with a non-precious metal polishing kit (Renfert®, Hilzingen, Germany) following standard procedure.

Groups III and IV (Screw-retained)

Similar to the cement-retained groups, ten wax patterns for each group were made using the same techniques. Screw holes were created on all the restorations. The difference from the cement-retained group was that all wax patterns were casted with non-precious alloy on the abutment. All superstructures were finished and polished with a non-precious metal polishing kit (Renfert®, Hilzingen, Germany) following standard procedure.

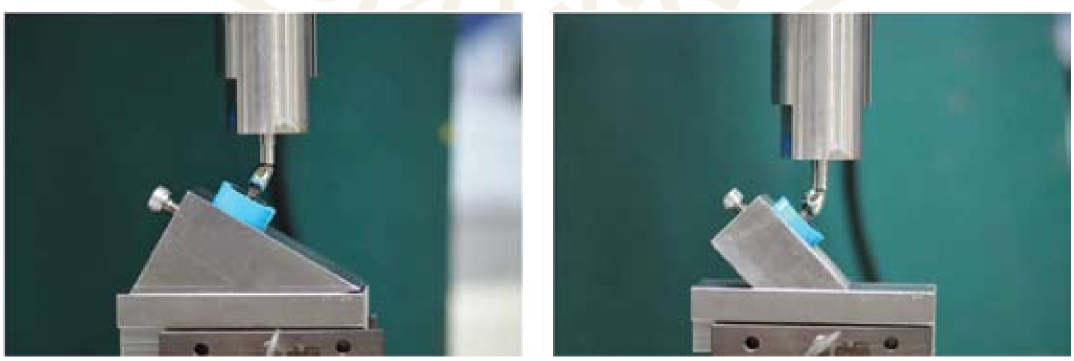
Before cyclic loading, 30 N•cm torque was applied to all specimens according to the manufacturer's instructions using a digital torqued gauge (MARK-10®, PLUG&TEST™, Copiague, NY)

According to a protocol suggested by many authors[4,21-24], a second screw tightening was applied at 10 min after the first torque in order to achieve the optimum preload. The specimens were left for 15 min before the pre-loading removal torque (RTVb) of the abutment screw was measured. The abutment screw was re-tightened using the previous method at 10 min after measurement.

Each implant-abutment-superstructure assembly and the customized 2-point 4-mm cylinder rod with rounded head was firmly mounted in The ElectroPuls™ E1000 (Instron Corp., Canton, MA). Loading force was applied to the specimens for 5×10^5 cycles. The axis of the two-cylinder rod jig was simultaneously contacted to the flat surface of both central and lateral incisors (Figure 3). Cyclic loading between 30 to 300 N was applied at 14.0 Hz. Cyclic loading was performed in a laboratory. Five hundred thousand cycles at 14 Hz was considered as 6 months in this clinical situation, which is a routine recall for dental implants.[4] The post-loading removal torque (RTVa) of all abutment screws was measured and recorded with the same digital torqued gauge.

The difference of removal torque before and after cyclic loading was referred to as the change of removal torque value (RTVb - RTVa = ΔRTV).

The mean ΔRTVs and standard deviations of the abutment screws in each group was calculated and recorded. Shapiro-Wilk tests and



a b

Figure 3 (a) Groups I and III (straight abutment), the specimen was aligned into a mold which was 30° from the axial line. (b) Groups II and IV (angled abutment), the specimen was aligned into a mold at a 45° angle from the axial line.

Levene's tests were used to test normality and homogeneity variances of the data, respectively. Two-way ANOVA was used to examine the effect of abutment types and restoration designs on the RTV after cyclic loading. All statistical analyses were performed with SPSS® Statistics 20.0 (IBM® Corp., Armonk, NY) at a 95% confidence level. (P < .05)

Results

Removal torque value of the abutment screw

In group III one crown was dislodged due to a screw fracture at the head of the screw. Therefore, this specimen was excluded from the study.

The means and standard deviations of removal torque before (RTVb) and after (RTVa) cyclic loading, and changes of the removal torque value (RTVb-RTVa) are summarized in table 2. For all groups, the removal torque values before cyclic loading were decreased from the recommended applied torque value (30 N·cm), which was a result of embedment of relaxation of the abutment screw. The removal torque values were also decreased after cyclic loading. The actual torque values, after retorque (RTVb) and after cyclic loading (RTVa) are displayed as a percentage of the original torque value and shown in table 3.

Two-way ANOVA demonstrated no interaction between abutment types and restoration designs (P > .05). Only the abutment types had a significant effect on the change of removal torque value (P < .05). For the angled abutment groups, the changes of removal torque values after cyclic loading of both the cement- and screw-retained restorations were significantly higher than those of the straight abutment groups.

SEM analysis

The abutment screws before and after cyclic loading were randomizing selected for SEM analysis at magnification 1,000x. Illustrations of the screw surfaces at the third thread of all groups are showed in figure 4a-f.

Table 2 Removal torque analysis

Removal torque values (N·cm)				
Group	N	RTVb ± SD	RTVa ± SD	ΔRTV ± SD
I	10	24.0 ± 1.2	14.3 ± 1.5	**9.7 ± 1.3**
II	10	24.1 ± 0.9	12.7 ± 1.4	**11.4 ± 1.8**
III	9	23.9 ± 1.0	13.6 ± 1.5	**10.3 ± 1.2**
IV	10	23.9 ± 0.9	12.5 ± 1.3	**11.4 ± 1.3**

RTVb = removal torque value before cyclic loading, RTVa = removal torque value after cyclic loading, ΔRTV = changes of removal torque values between the before- and after-cyclic loading.

Table 3 Ratio of removal torque values

Ratio of removal torque values (%± SD)				
Group	N	RTVb	N	RTVa
I	10	80.0 ± 3.9	10	47.7 ± 4.9
II	10	80.2 ± 3.1	10	42.3 ± 4.8
III	10	79.6 ± 3.2	9	45.2 ± 5.1
IV	10	79.7 ± 3.0	10	41.7 ± 4.2

Ratio = measured RTV / applied RTV(30 N·cm) x 100%, RTVb = removal torque value before cyclic loading, RTVa = removal torque value after cyclic loading

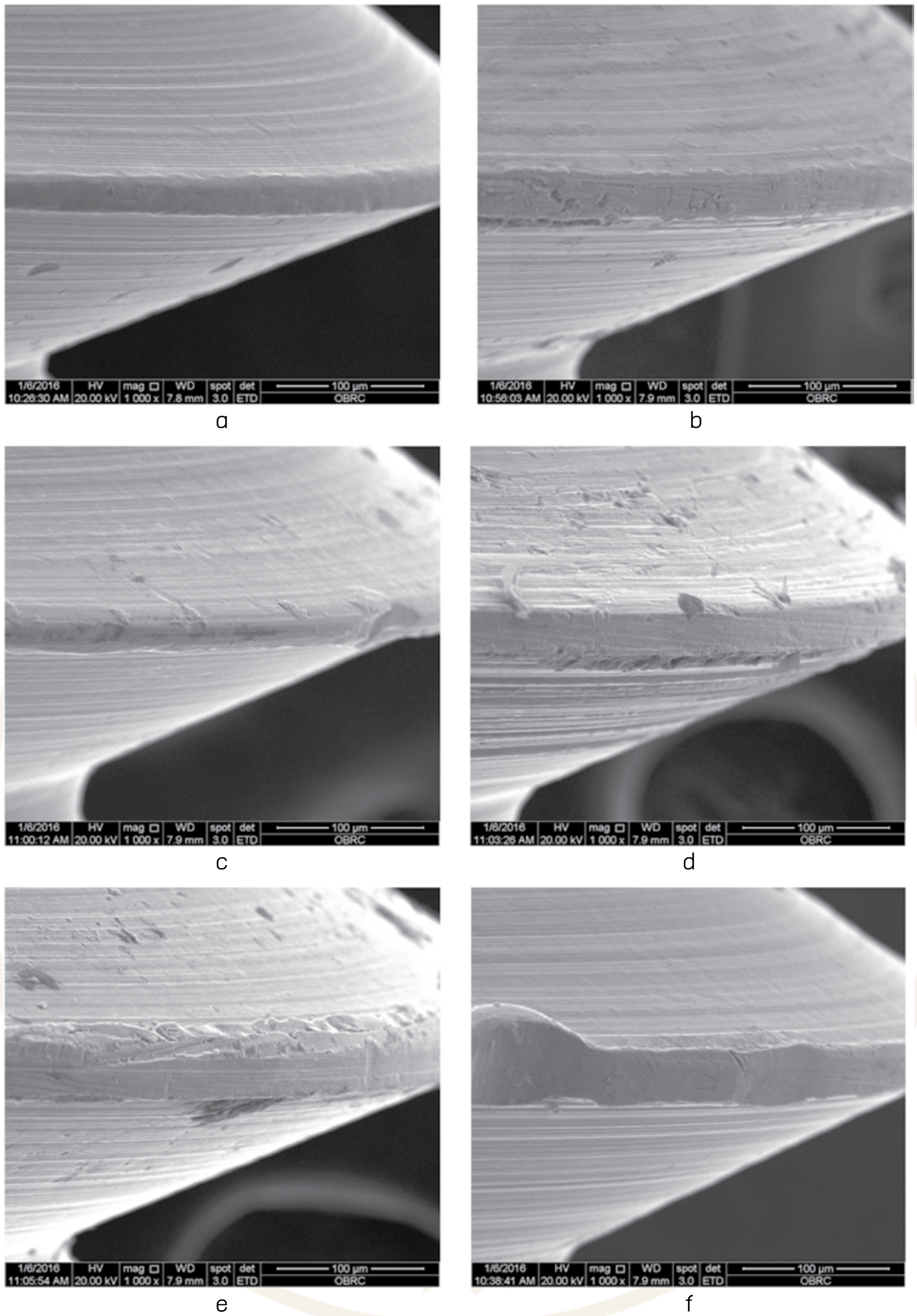


Figure 4 SEM of the third thread of the abutment screws; (a) before cyclic loading, (b-f) after cyclic loading of groups I-IV and a fractured screw.

The abutment screws of all experimental groups were examined at the surface. Wear facets were found at the crest of the thread, which were damaged from cyclic loading. The facets of groups II (figure 4c), III (figure 4d) and IV (figure 4e) were larger and deeper than that of group I (figure 4b), which was the cement-retained, straight abutment group, especially in the fractured screw specimen (figure 4f).

Discussion

In this study, a 2-unit anterior cantilever fixed prosthesis was fabricated with a 4.3-mm diameter dental implant at the upper central incisor. Cyclic loading was applied to the central and lateral incisors simultaneously, which was designed to simulate occlusal function in a clinical situation that occlusal contact at pontic area could not be avoided.

The loading points were at the middle of the flat palatal surface of the two teeth that contact with surfaces from the lower incisor teeth. The cantilever part should not contact in centric occlusion and eccentric contact should be kept at a minimum. However, these cantilever contacts might occur in some patients. Normally, the angle between the axis of the upper and lower anterior teeth is 30^{o}.[25,26] For the straight abutment groups, a 30^{o} angle stainless steel mold was used to create the correct angle for the testing. For the 15-degree angled abutment groups, a 45^{o} angle stainless steel mold was used. According to ISO 14801:2007, the guideline for testing was as follows: no pre-angled abutment of an anterior tooth should be $30^{o} \pm 2^{o}$ angle with the loading direction.

The cyclic loading machine was set at 30-300 N with 14 Hz. Therefore, the force per one tooth was about 15-150 N, which is close to the force calculated for the anterior bite force in a human.[25,26]

In this study, the abutment screw was torqued at 30 N•cm using a digital torqued. However, this torque was not the expected value from the applied force. The embedment of relaxation would result in 2-10% of preload loss by flattening the high spots at the screw surfaces. Therefore, re-tightening with 30 N•cm was recommended at 10 min after the first tightening. It is believed that the required preload can be achieved with this procedure. In this study, the mean RTVs before cyclic loading of all groups was about 80% of the given torque value.

According to the results of this study, the mean RTVs of each group after cyclic loading was lower than that before cyclic loading. However, from statistical analysis, the only factor that affected the RTVs was the type of abutment, for examples, straight and angled abutment. In both cement-retained and screw-retained restoration, the mean RTVs of the angled abutment group was lower than that of the straight abutment group. This may be because of the effect of the bending force. In cases when angled abutment was used, the stress level was increased after cyclic loading compared to straight abutment, which caused screw loosening.[5]

For cement-retained abutments, both straight and angled abutment materials are commercially pure (cp) grade 4 Titanium or unalloyed titanium. These materials are excellent in biocompatibility and corrosion resistance. Due to the limitations of this study, cement-retained restoration was cp grade 4 titanium, but screw-retained abutments was non-precious alloy. The properties of the two materials are different, especially in corrosion resistance, which might affect the joint stability of the implant components.[5,27] The changes in removal torque values of the cement-retained groups were slightly less than those of the screw-retained groups, but the results were not significantly different. This might be because of the testing environment, which was in ambient consition, therefore, corrosion did not affect the removal torque values.

Within the limitations of this study, the abutment types (straight and angled abutments), significantly affects were noted in the changes of removal torque values (RTVs) of the abutment screws of anterior cantilever fixed prosthesis on the implants after cyclic loading. The changes of removal torque values (RTVs) in the angled abutment groups were significantly higher than those of the straight abutment groups. ($P < .05$)

The restoration designs (screw- and cement-retained restorations), were not significantly affected on the changes of RTVs of the abutment screws.

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