Screw loosening and changes in removal torque relative to abutment screw length in a dental implant with external abutment connection after oblique cyclic loading

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PURPOSE. This study investigated the effects of abutment screw lengths on screw loosening and removal torque in external connection implants after oblique cyclic loading. **MATERIALS AND METHODS.** External connection implants were secured with abutment screws to straight abutments. The abutment-implant assemblies were classified into seven groups based on the abutment screw length, with each group consisting of five assemblies. A cyclic load of 300 N was applied at a 30° angle to the loading axis until one million cycles were achieved. Removal torque values (RTVs) before and after loading, and RTV differences were evaluated. The measured values were analyzed using repeated measures of analysis of variance with the Student-Newman-Keuls multiple comparisons. **RESULTS.** All assemblies survived the oblique cyclic loading test without screw loosening. There was a significant decrease in the RTVs throughout the observed abutment screw lengths when the abutment-implant assemblies were loaded repeatedly ($P<.001$). However, the abutment screw length did not show significant difference on the RTVs before and after the experiment when the abutment screw length ranged from 1.4 to 3.8 mm ($P=.647$). **CONCLUSION.** Within the limit of this experiment, our results indicate that the abutment screw length did not significantly affect RTV differences after oblique cyclic loading when a minimum length of 1.4 mm (3.5 threads) was engaged. These findings suggest that short abutment screws may yield stable clinical outcomes comparable to long screws in terms of load resistance. ***[J Adv Prosthodont 2018;10:415-21]***

KEYWORDS: Screw length; Implant; Cyclic loading; Removal torque; Screw loosening

INTRODUCTION

Dental implants have undergone many changes and developments. Nevertheless, various complications such as osseointegration loss, soft and hard tissue defects, and biomechanical problems have been reported continuously.[1-3] The most common mechanical complication associated with implant-supported restorations is abutment screw loosening. In several clinical reviews on the implant-retained prostheses, abutment screw loosening was reported as the most frequently encountered problem.[4-6] Despite the large number of clinical and *in vitro* studies, the cause of abutment screw loosening remains unknown. Other studies reported that implant-abutment assemblies were stable, and abutment screw loosening was rare.[7,8] Additionally, while some *in vitro* studies reported a reduction in removal torque values (RTVs) after cyclic loading,[9,10] others reported no significant reduction.[11,12]

Screw loosening leads to instability of the implant-abutment connection and the formation of a micro-gap, which may provoke the fracture of implant components.[13] The gap can cause the infiltration of microorganisms, which is harmful for the surrounding tissues.[14] Additionally, loosening or failure of implant screws may result in component failure that may require more extensive repair.[15,16] Several factors are involved in screw loosening including tightening force,

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design, and screw material.[16,17] Preloading of the screw joint is essential for the prevention of screw loosening.[18] If the preload fall below a key point, joint stability may be affected, which may impair the stability of the screw joint.[12,19] To reduce screw loosening and related complications, studies on the screw designs are needed since the best design has still not been identified. Therefore, it is necessary to study the influence of the length of the abutment screw and the difference in RTVs before and after loading, based on the screw length.

Until now, however, few studies have investigated the viability of short abutment screws. We previously showed that daily temperature changes in the mouth did not have a deleterious effects on implant joint stability when a short abutment screw with a minimum of 3.5 threads was used.[20] We also showed that implant abutment screws with a minimum of 3.5 threads were sufficiently resistant to maximum occlusal forces without significant increases in peak and/or break strains.[21] However, the aforementioned study focused on the minimum load required to break the abutment screw and investigated whether short screws could withstand the maximum occlusal load under static conditions. Because fatigue dynamic loading is considered to be more representative of the oral environment, fracture or loosening of abutment screws should be assessed under eccentric oblique cyclic loading conditions.

This study, therefore, investigated the effects of different abutment screw lengths on screw loosening and changes in removal torque after cyclic loading by measuring torque values after the loading of an external connection implant. Our null hypotheses were as follows: (1) the RTVs before and after cyclic loading would not be significantly different in any of the experimental groups, and (2) there would be no difference in the RTVs among groups with different screw lengths before or after loading.

MATERIALS AND METHODS

Implants-13 mm long and 4.3 mm in diameter-were manufactured using grade 4 pure titanium and with external hex connections specifically for the present study (Hexplant, Warantec Co. Ltd., Seoul, Korea).[22,23] Straight implant abutments of 9 mm in height and abutment screws were made of Ti-6Al-4V ELI titanium alloy (Warantec, Seoul, Korea). The abutment screws were divided into groups depending on their lengths and number of threads (seven groups, five abutment screws per group). The shortest abutment screws, group 1, were 1.4 mm in length and consisted of 3.5 threads. The next groups were 0.4 mm longer each and had one extra thread each. So, the number of abutment screw threads in groups 2 to 6 was 4.5 (1.8 mm), 5.5 (2.2 mm), 6.5 (2.6 mm), 7.5 (3.0 mm), and 8.5 (3.4 mm), respectively. The longest, group 7 were 3.8 mm in length and had 9.5 threads (Table 1, Fig. 1).

In accordance with the ISO 14801:2007 protocol,[22] arrangements of the assemblies and experiment setup were conducted basically. The implant fixtures and abutments were tightened with the abutment screws using a torque of 30 Ncm in accordance with the manufacturer's recommendation. All screws were retightened 10 minutes later in the same way for minimizing embedment relaxation among the mated threads.[23] Measurements of RTVs were performed 5 minutes later with a digital torque gauge (MTT03-12, Mark-10 Co., Hicksville, NY, USA). These RTVs were measured before loading and were referred to as pre-RTVs. For cyclic loading, the screws were retightened as described previously. The implant-abutment assemblies were positioned into the metal holder (Fig. 2) at a 30° inclination relative to the axis of loading. A total of 35 metal caps were fabricated with hemisphere-shaped heads and attached to the abutments prior to loading with a zinc phosphate cement (Elite Cement 100; GC Co., Tokyo, Japan) as described previously.[11] Cyclic loading was conducted using a universal testing machine (E3000, Instron, Canton, MA, USA). For all assemblies, loads of 300 N were applied until one million cycles were achieved at a frequency of 15 Hz. Testing was performed in random sequences. After loading, the RTVs were measured again and referred to as post-RTVs. Differences between pre-RTVs and post-RTVs were calculated and referred to as RTV differences. Repeated measures analysis of variance with Student-Newman-Keuls multiple comparisons was performed to analyze the measured data. Statistical significance was set at a P value < .05.

Fig. 1. A photograph of the abutment screws used in the current study. From left to right, the screws are 1.4 - 3.8 mm in length (in 0.4 mm increments) with 3.5 - 9.5 threads (in one thread increments).

Table 1. Experimental groups according to the abutment screw length

Group	Abutment screw length (number of thread)
1	1.4 mm length (3.5 threads)
2	1.8 mm length (4.5 threads)
3	2.2 mm length (5.5 threads)
4	2.6 mm length (6.5 threads)
5	3.0 mm length (7.5 threads)
6	3.4 mm length (8.5 threads)
7	3.8 mm length (9.5 threads)

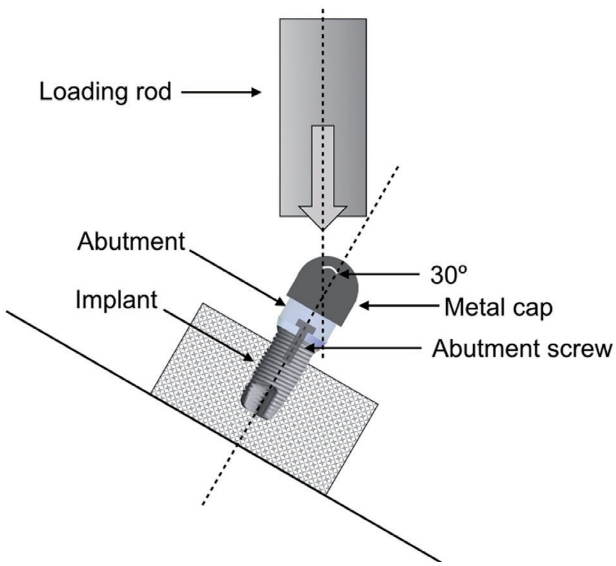

Fig. 2. Schematic of the cyclic loading experiment. The implant-abutment-abutment screw assemblies were designed to receive loads at a 30° angle relative to the loading axis.

RESULTS

The assemblies of all groups survived the oblique cyclic loading test without screw loosening. Additionally, none of these assemblies showed evidence of decementation of the metal cap. The results of repeated measures analysis of variance and multiple comparisons are shown in Table 2 and Table 3. The mean and standard deviation of the pre- and post-RTVs (in Ncm) and the RTV differences (in Ncm) for each group are shown in Table 4 and Figure 3. A significant decrease in the RTVs was noted for all abutment screws of different lengths when the abutment-implant assemblies were loaded repeatedly ($P < .001$). The overall mean of the post-RTVs tended to be smaller than that of the pre-RTVs (Table 5).

Figure 3 shows the distribution of the pre- and post-RTVs according to the abutment screw length. When the abutment screw length ranged from 1.4 to 3.8 mm, the abutment screw length did not show significant difference on the RTVs among the experimental groups before the experiment as well as after the experiment ($P = .647$).

Table 2. Results of repeated measures analysis of variance

Repeated measures analysis of variance				
Variables	DF	Mean square	F value	Significance
Group	6	6.58	0.71	0.64064
Error	28	9.20		

Table 3. Results of multiple comparisons

Student-Newman-Keuls Multiple Comparisons	
Group (screw length)	Subset
	1
1 (1.4 mm)	19.28
6 (3.4 mm)	19.49
7 (3.8 mm)	19.72
5 (3.0 mm)	20.04
4 (2.6 mm)	20.55
3 (2.2 mm)	20.87
2 (1.8 mm)	21.53
Significance	0.647

Table 4. Mean RTV (SD) before and after the oblique cyclic loading and mean RTV difference (SD) according to the abutment screw length

Group (screw length)	Pre-RTV	Post-RTV	RTV difference
1 (1.4 mm)	23.78 (2.86)	14.78 (4.62)	9.00 (3.92)
2 (1.8 mm)	26.62 (1.89)	16.44 (2.40)	10.18 (1.29)
3 (2.2 mm)	25.72 (1.87)	16.02 (2.28)	9.70 (2.96)
4 (2.6 mm)	25.64 (2.41)	15.46 (2.69)	10.18 (2.47)
5 (3.0 mm)	25.52 (1.53)	14.56 (1.91)	10.96 (1.71)
6 (3.4 mm)	24.40 (3.51)	14.58 (1.90)	9.82 (3.56)
7 (3.8 mm)	24.88 (2.89)	14.56 (3.12)	10.32 (4.99)

Table 5. Mean RTV before and after the oblique cyclic loading

	Sample size	Mean RTV	SD
Pre-cyclic loading	35	25.22	2.44
Post-cyclic loading	35	15.20	2.68

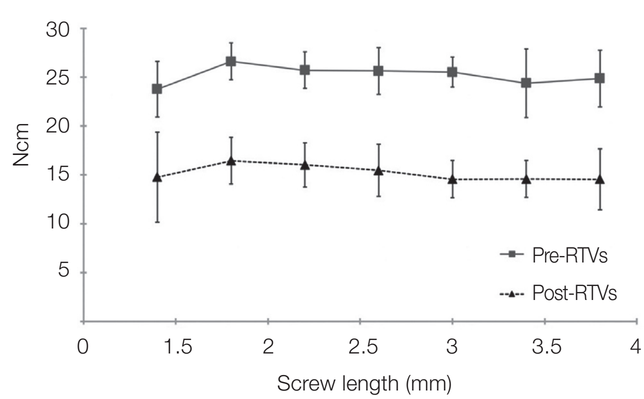

Fig. 3. Distribution of the RTVs before and after cyclic loading.

DISCUSSION

The first null hypothesis was rejected based on significant differences between the pre- and post-RTVs in all groups. Although the screws were retightened to 30 Ncm before the loading experiment, the initial preloads were lower, with all groups having lower post-RTVs than pre-RTVs. Abutment screw loosening in implant-retained prostheses is a concern in dental fields. One study reported screw loosening in 12.7% of single-tooth restorations and 6.7% of partial fixed prostheses.[24] A multicenter study revealed that abutment screw loosening occurred at a rate of 9.6% over a period of 8 years.[25] This complication was reported in 49% of maxillary and 20.8% of mandibular implant restorations.[26] However, Theoharidou *et al.*[7] revealed that abutment screw loosening in single-implant restorations was rare and that the stability of the implant-abutment connection was preserved in more than 97% of cases. Vigolo *et al.*[8] reported that, over a 5-year period, only 21 of 1935 implants (1.2%) underwent screw loosening. *In vitro* studies showed somewhat differential results. Sakamoto *et al.*[10] reported that the RTVs of an external connection implant decreased after cyclic loading with loads of 300 N, while no decrease in the RTVs was observed for an internal connection implant. Katsuta and Watanabe[9] also reported that the abutment screws in external connection implants were significantly loose after one million cycles of torsional loading. However, Khraisat *et al.*[11] reported that the RTVs of an external connection implant could be preserved after one million cycles of eccentric lateral cyclic loading. It was reported that post-RTVs were significantly higher than pre-RTVs in both external and internal connection implants after one million loading cycles.[12] The two latter studies used relatively low loads of 50 N and 0 to 100 N, respectively. The current study used oblique cyclic loading to apply constant stress, which simulated dynamic mastication *in vitro*.[27] Various loads, ranging from 50 to 450 N, have been applied in studies on cyclic loading.[11,12,23,28-30] This study used a load of 300 N, based on results showing that fixed partial dentures retained by implants had an average maximal posterior biting force of 35 - 330 N.[31] The bending of abutment screw has been considered especially harmful to implant restorations.[32] Despite the decrease in RTV after loading, screw loosening was not observed in any group, which implies that the preload was not lost completely while maintaining the joint stability.

Regarding the second null hypothesis, the outcomes of the present study suggest that the abutment screw length did not significantly affect screw loosening after oblique cyclic loading when a minimum screw length of 1.4 mm (3.5 threads) was engaged. The mean RTV difference was not significantly correlated with the abutment screw length. Within the limit of this study, the abutment screws with more than 3.5 threads engagement showed the possibility to withstand the loading. It was reported that engaging of three or more threads was suitable to sustain joint stability of the implant after fracture load,[21] thermocycling,[20] and repeated tightening and loosening[33] tests. Long abutment screws showed greater resistance to fracture than short screws when static forces were applied to implant assemblies.[21] However, short abutment screws resisted and tolerated the maximum biting force with a minimum of 3.5 threads engagement. Nonetheless, because loads in clinical situations are not applied under static conditions, screw fracture and loosening must be assessed under dynamic conditions to assess the influence of screw length. Screw loosening was evaluated by measuring RTVs before and after cyclic loading, similar to other studies.[12,23,28] Previous *in vitro* cyclic loading studies used three to six samples per each group to investigate changes in RTVs in implant-abutment assemblies.[9,11,23] This present study used five samples per group. A limitation of the current study is the small sample size, which could have led to the insignificant differences among groups. Further studies with a greater number of samples would be necessary to ensure strong conclusions.

Clinically, the results indicated that using long abutment screws may not have a significant mechanical advantage in reducing the rate of screw loosening and related complications. It was reported that, since most of the load was applied to the upper three to four threads, the engaged number of threads might not be very important, and friction could be reduced with a minimum engagement.[34] Mechanically, early strain was found to be diminished around the position of the third or fourth screw thread, indicating that at least three engaged threads are required to maintain the integrity of the upper prosthesis to the implant.[17] All screws in the present study had at least 3.5 threads, allowing the redistribution of the internal stress among the first three threads. In the event of an initial abutment screw fracture, an alternative abutment screw 1.4 mm or longer in thread length may be adequate for enduring changes caused by masticatory function, screw retightening, and temperature change in the oral cavity. Abutment screw fracture is a frequent complication of dental implants. Removing the screw remnant from the implant after a fracture is both challenging and time consuming.[35-37] A 12-year retrospective study showed that screw fractures occurred most frequently among components in external connection implants, and the fractured screws were not retrieved in 6.2% of cases.[38] From the clinical point of view, when screw fracture occurs, it is important to remove the fractured remnant. However, the complete removal of the fractured remnant may be difficult in some cases. Forcible removal of the fractured remnant of the screw inside the fixture may place the soft and hard tissues as well as the implant in jeopardy. If the inside of the implant is damaged, conventional screws may not be used. In this case, a short screw could be used as an emergency cure for a short time as the result of the current study. Time and expense may be saved if a short abutment screw is available, but further clinical studies are required to ascertain these speculations.

Several studies have assessed screw loosening after one million cycles, which is equivalent to loading over a period of 40 months.[11,12,23] Therefore, the mechanism underlying joint failure may be associated with this reduction in post-cyclic RTV. Long-term application of clinical loads may exacerbate micro-movements of the abutment, as well as screw fatigue, leading to reduction in the reverse torque.[39] An accurate fit at the implant joint can improve the securing of the components and load distribution in the assemblies. In addition, proper regular checks and retightening of abutment screws are required to maintain implant/abutment assemblies. From the results of this study, screw retightening during periodic checks is necessary to maintain joint stability. At delivery of the prosthesis, several tightening would be beneficial because a reason of the screw loosening is the settling effect that induces 2 - 10% preload loss.[40] It was found that retightening the screw 10 minutes later diminished torque loss by 17 - 19%.[19] Proper retightening helps maintain the preload.[41,42] External or internal connection design of implants is thought as a factor that affects implant-abutment stability.[43] It was reported that internal connection implants were more stable than external connection implants.[5,44] The loosening rate of the external connection implants was shown to be between 6 to 48%.[45] Friction between the coronal mating sides and the screw clamping force could contribute to the stabilization of implant-abutment assemblies in internal connection implant systems.[46] However, it was also reported that the incidence of abutment screw looseness was not different between external and internal connection implants.[12] Further experiments will be needed to determine the exact effect of screw length on screw loosening in the internal connection implant systems.

In the present study, loads were delivered 30 degrees off the center line of the assemblies according to the ISO protocol.[22] This ISO protocol describes a method for fatigue testing of dental implants and their premanufactured prosthetic components. The ISO defines that this protocol simulates the functional loading of implant components under 'worst case' conditions and establishes loading force to be applied with a hemispherical contact surface for load transfer, attached to the free end of the connecting part.[22] Thus, a combination of bending, shear, and compression loads was applied to the specimens in this study. In the clinical point of view, the metal caps used had a hemisphere shape, which is unlikely to mimic posterior crown restorations. This shape could help distribute the forces. However, under clinical conditions the buccsl and lingual cusps of the restorations may limit the sliding of the loading tips, which could cause screw looseness. Additional studies using tooth-shaped prostheses are needed in the future. In this study, the same screw was used for each sample throughout the experiment like in other studies.[11,12,23] An important event at the screw joints is the settling process. Since the internal structure and the screw are not perfectly manufactured without irregularity, rough surfaces are smoothed out by retightening and the preload loss happens.[40] Although we followed the general clinical procedure, deformation of the screws might have taken place during the first tightening process, which could have influenced the later results because new screws were not used for the retightening after the first measurement.

The causes of screw loosening are multifactorial, and therefore the appropriate choice of screw design and material, the control of occlusal forces, and the passive fit of components are required during implant-supported restorations. Cyclic loading simulates masticatory function under clinical conditions. However, controlled *in vitro* studies cannot include all clinically relevant variables. Thus, care should be taken when extrapolating the results of this study to clinical situations. In this study, a unidirectional force was delivered according to the ISO standard. However, in clinical conditions, horizontal movements such as grinding occur, and therefore clinical studies are needed. Theoretically, long abutment screws could shift the center of rotation apically from the upper area.[47] Long screws have more threads that engage the implant and abutment. These features may help distribute the applied loads to the implants and surrounding bone more efficiently, making long screws more resistant to fracture. Additional studies will be required to investigate the long-term clinical efficiency of short screws.

CONCLUSION

The influence of the length of implant abutment screw on screw loosening was investigated after oblique cyclic loading. The post-RTVs were lower than the pre-RTVs regardless of the abutment screw length. The length of implant abutment screws and number of abutment threads did not aggravate screw loosening or affect the RTVs, within the limitation of the current experiment. The engagement of 3.5 threads might be used clinically as a minimum length requirement to maintain the implant-abutment connection

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