REMOVAL TORQUE EVALUATION OF THREE DIFFERENT ABUTMENT SCREWS FOR SINGLE IMPLANT RESTORATIONS AFTER MECHANICAL CYCLIC LOADING

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SUMMARY

Purpose. The aim of this study was to evaluate the removal torque of three different abutment screws and pull out strength of implant-abutment connection for single implant restorations after mechanical cyclic loading.

Methods. The study was performed in accordance with ISO 14801:2007. Three implant groups (n=15) were used: group A, PW Plus® with flat head screw; group B, PW Plus® with tapered screw; and group C, Conelog® with flat head screw. All groups had the same implant-abutment connection feature: cone with mandatory index. All screws were tightened with manufacturer's recommended torque. Ten specimens in each group underwent cyclic loading (1x106 cycles, 10 Hz, and 250 N). Then, all specimens were un-tightened, measured for the removal torque, and underwent a tensile test. The force that dislodged abutment from implant fixture was recorded. The data were analysed using independent sample t-test, ANOVA and Tukey HSD test.

Results. Before cyclic loading, removal torque in groups A, B and C were significantly different (B> A> C, P<.05). After cyclic loading, removal torque in all groups decreased significantly (P<.05). Group C revealed significantly less removal torque than groups A and B (P<.005). Tensile force in all groups significantly increased after cyclic loading (P<.05), group A had significantly less tensile force than groups B and C (P<.005).

Conclusions. Removal torque reduced significantly after cyclic loading. Before cyclic loading, tapered screws maintained more preload than did flat head screws. After cyclic loading, tapered and flat head screws maintained even amounts of preload. The tensile force that dislodged abutment from implant fixture increased immensely after cyclic loading.

Key words: fatigue test, abutment screw, cyclic loading, removal torque, ISO14801.

Introduction

Abutment screw loosening, one of the most frequent complications in dental implant therapy, affects long-term stability of an implant. It causes micro-movement, and may lead to more complicated situations, such as peri-implantitis and screw fracture (1). A systematic review on the survival and complication rates of implant-supported prostheses indicated a five-year prosthetic survival rate of implant-supported single crowns of 97.2% (95% CI: 95.3-98.3). The five-year complication rate of abutment or screw loosening for implant-supported single crowns was 5.6% (95% CI: 3.2-9.6) (2).

When the abutment screw was tightened, tensile force called "preload" is generated. Axial load

generated in the screw head is transferred to the screw thread and implant contact surface. The abutment screw elongates, and elastic recovery of the screw pulls the abutment and implant fixture close together. This created force is called "clamping force." The preload is equivalent to the clamping force in magnitude, and counteracts any force or load applied to the screw (3-5). Presence of an external force exceeding the preload results in instability and micro-movement. Moreover, screw loosening may be an early warning of inadequate biomechanical design and occlusal overloading (6).

It has been reported that a 2 to 10% reduction in preload occurs within first few seconds or minutes after tightening, as a result of settling effect (7). "Settling effect" or "embedment relaxation" is a result of micro-roughness of two mating components that causes incomplete contact of two surfaces. The rough spots are flattened under the external load, leading to micromovement. The intensity of settling effect depends on initial surface roughness, surface hardness, and magnitude of loading forces. The greater surface roughness and external loads, the greater settling effect occurs (6).

Many variables influence preload value, for instance, amount of applied torque, connection type and design, screw design, material properties of the screw, adaptation between implant bore and abutment, micro-roughness on the mating surfaces of implant components, number of repeated screw insertion cycles, loading force magnitude, lubrication, saliva contamination and debris (8-12). Higher preload is achieved at higher tightening torque. The tightening torque is limited by the material yield strength of screw. The optimum torque value is 75% of the torque needed to cause screw failure (13). The optimum preload should induce a stress that is 60 to 75% of the material yield strength (13, 14), and was achieved by using the manufacturer's recommended torque and new screw components (5).

"Removal torque" is the amount of rotational force that removes the screw from the implant screw bore. Without functional loading and using recommended tightening torque (20 to 40 Ncm), removal torque is seen to be about 80 to 90% of tightening torque (15). Other parameters, such as abutment type, tightening-loosening cycles, time delay to loosening and salivary contamination, have been studied, to determine whether they affect the removal torque or not (11, 12, 15, 16).

The aim of this *in vitro* study was to evaluate the removal torque of three different abutment screws and pull out strength of implant-abutment connection for single implant restorations after mechanical cyclic loading. The null hypothesis was that there are no significant differences in removal torque and in pull out strength of implant-abutment connection.

Materials and methods

This study was performed in accordance with ISO 14801:2007 fatigue test for endosseous dental implants (17).

Three implant groups (n=15) were used: group A, PW Plus® implant (PW Plus Co., Ltd., Nakhon Pathom, Thailand) with flat head screw; group B, PW Plus® implant with tapered screw; and group C, Conelog® implant (Camlog Biotechnologies AG, Basel, Switzerland) with flat head screw (Table 1 and Figure 1). The implant-abutment connections of all groups were categorized as cone with mandatory index (Figure 2) (18).

All implant were embedded in resin blocks (Chockfast orange resin, Shannon Industrial Estate, Co. Clare, Ireland). The platform of the implant was 3 mm above the resin block, simulating 3 mm of vertical bone resorption. Straight abutments attached to metal hemisphere caps and abutment screws were tightened with a digital torque gauge (Tohnichi torque gauge, model BTGE50CN, Tohnichi Mfg. Co. Ltd., Tokyo, Japan) according to the manufacturer's recommended torque (Figure 3). Ten minutes after the first tightening, all specimens were re-tightened. Ten minutes after the second tightening, the removal torque of five specimens in each group was measured. The remaining specimens were

Table 1 - Specifications of tested implant groups.

Tested groups	Implant diameter (mm)	Material of implant /abutment	Material of abutment screw	Screw head design/ diameter (mm)	Connection type	Manufacturer's recommended torque
Group A	3.75	Titanium grade 4/ Titanium grade 4	Titanium alloy grade 23	Flat head /2.1	Octatorx-Conical connection	30 Ncm
Group B	3.75	Titanium grade 4/ Titanium grade 4	Titanium alloy grade 23	Tapered head/2.1	Octatorx-Conical connection	30 Ncm
Group C	3.8	Titanium grade 4/ Titanium alloy grade 23	Titanium alloy grade 23	Flat head /2.27	Three cams-Conical connection	20 Ncm

Figure 1
Abutment screws of tested implant (left to right): group A, group B and group C.

mounted in a 30° angled steel holder and underwent cyclic loading in a Universal Testing Machine (ElectroPuls E1000, Grove City, PA, USA) (1 x 10^6 cycles, 10 Hz, and 250 N) (Figure 4). The removal torque before and after cyclic loading was recorded and calculated as "the preload efficiency" by the following formula:

$$\text{Preload efficiency (\%)} = (\text{Removal torque/Tightening torque}) \times 100$$

After un-tightening, all specimens underwent a tensile test using a Universal Testing Machine (Model 5566, Instron Calibration Laboratory, Norwood, MA, USA) at a cross head speed of 1 mm per minute and a load cell of 1 kN. The direction of pullout force was vertical, parallel to the axis of the implant. The force was applied until the abutment was dislodged from the implant fixture, and was collected with Bluehill software, CAT No. 2603-080 (Bluehills Software Company, Whitstable, Kent, England) (Figure 5).

Statistical analysis

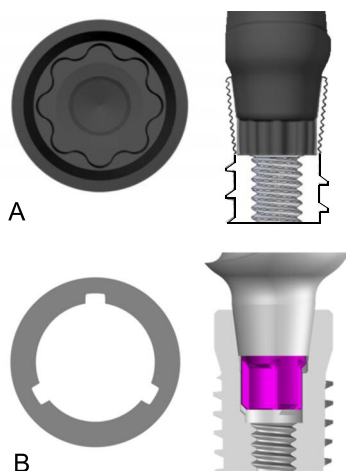All data were checked for normality at P<.05. Achieved power were calculated by post hoc

Figure 2
The implant-abutment connections of groups A & B: octatorx-conical connection (A) and group C: three cams-conical connection (B).
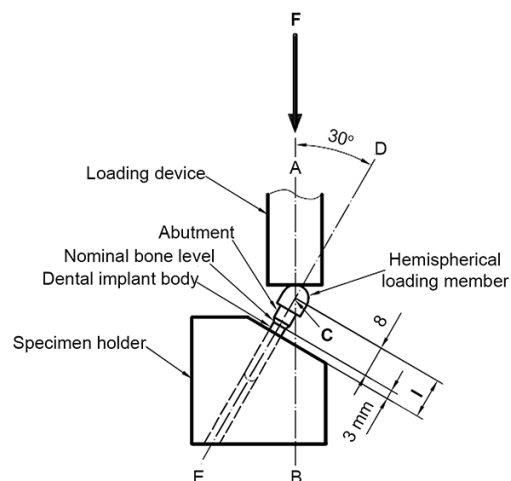

Figure 4
Schematic of test set-up (Modified from International Organization for Standardization - ISO Norm 14801 - Dentistry fatigue test for endosseous dental implants. Geneva, 2007).

Figure 3
Application of torque to abutment screw.

Figure 5
Tensile test by Universal Testing Machine (Model 5566, Instron Calibration Laboratory, Norwood. Massachusetts, USA).

power analysis with the program G*Power version 3.1.9.2 (19). The data were analyzed by independent sample t-test, ANOVA and Tukey

HSD test, using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA) at P<.05.

Results

Preload efficiency

After mechanical cyclic loading, the preload efficiency in all groups decreased significantly (P<.05) (Table 2 and Figure 6). Both before and after cyclic loading, the preload efficiency among groups differed significantly (before cyclic loading: F=48.07; df=2, after c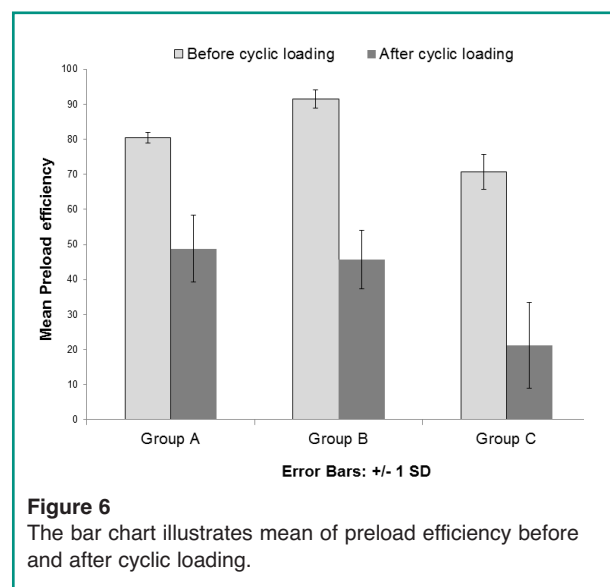yclic loading: F=17.70; df=2, P<.05). Post hoc comparisons using the Tukey HSD test indicated that the preload efficiency before cyclic loading in groups A, B and C were significantly different (Table 3). After cyclic loading, the preload efficiency in group C differed significantly from that in groups A and B, whereas there was no significant difference in preload efficiency between groups A and B (Table 4).

Tensile force

The tensile force in all groups increased significantly after mechanical cyclic loading (P<.05) (Table 5 and Figure 7). ANOVA showed a significant difference among groups (before cyclic loading: F=42.44; df=2, after cyclic loading: F=33.44, df=2, P<.05). Both before and after mechanical cyclic loading, post hoc comparisons using the Tukey HSD test indicated that tensile force in group A differed significantly from that in the other groups. On the other hand, there was no significant difference in tensile force between groups B and C (Tables 6 and 7).

Table 2 - Statistical analysis of removal torque and preload efficiency before and after cyclic loading (Mean ± SD).

Tested group	Before cyclic loading (n=5)		After cyclic loading (n=10)	
	Removal torque (Ncm)	Preload efficiency (%)	Removal torque (Ncm)	Preload efficiency (%)
Group A	24.12 ± 0.47	80.40 ± 1.55	14.64 ± 2.88	48.79 ± 9.59
Group B	27.46 ± 0.79	91.53 ± 2.62	13.70 ± 2.52	45.65 ± 8.39
Group C	14.15 ± 0.99	70.75 ± 4.95	4.23 ± 2.44	21.13 ± 12.20

Figure 6
The bar chart illustrates mean of preload efficiency before and after cyclic loading.

Discussion

From our study, ten minutes after the second tightening, the removal torque in groups A, B and C decreased: 19.6, 8.5 and 29.2%, respectively. This implies that without mechanical

Table 3 - Post hoc Tukey HSD test of the preload efficiency before cyclic loading.

Groups of specimen	Group A	Group B	Group C
Group A	-	0.001*	0.002*
Group B	0.001*	-	<0.0005*
Group C	0.002*	<0.0005*	

*Statistically significant difference (P<.05)

Table 4 - Post hoc Tukey HSD test of the preload efficiency after cyclic loading.

Groups of specimen	Group A	Group B	Group C
Group A	-	0,812	<0.0005*
Group B	0.812*	-	<0.0005*
Group C	<0.0005*	<0.0005*	

*Statistically significant difference (P<.05)

Table 5 - Statistical analysis of the tensile force before and after cyclic loading.

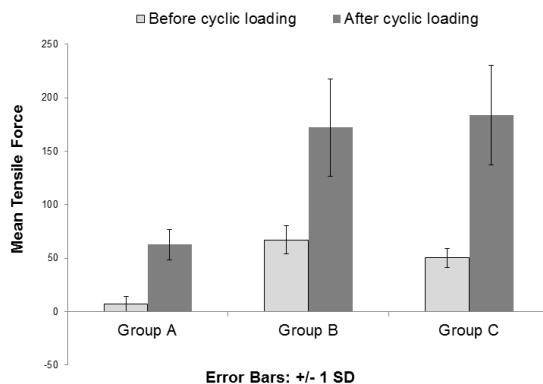| Groups of specimen	Before cyclic loading (n=5)	After cyclic loading (n=10)
Group A	6.91 ± 7.12	62.78 ± 14.16
Group B	67.20 ± 13.12	172.36 ± 45.49
Group C	50.28 ± 9.07	183.68 ± 46.59

Figure 7
The bar chart illustrates mean of tensile force before and after cyclic loading.

loading, the loss of applied force or "preload loss" occurred due to many factors (4, 5, 7, 9). Many studies state that different designs of implant-abutment connections affect the mechanical properties of implant systems, such as fatigue and fractural strength, ability to maintain screw preload against cyclic loads, and differences in survival time under dynamic loading (20-22). Moreover, characteristics of the abutment screw such as the material, surface coating, surface treatment and geometric dimensions were also affect the preload (23).
The parts of the abutment screw consist of the screw head, stem and thread (1). Groups A and C had flat-head screws, whereas group B had ta-

Table 6 - Post hoc Tukey HSD test of the tensile force before cyclic loading.

Groups of specimen	Group A	Group B	Group C
Group A	-	<0.0005*	<0.0005*
Group B	<0.0005*	-	0.082
Group C	<0.0005*	0.082	

*Statistically significant difference (P<.05)

Table 7 - Post hoc Tukey HSD test of the tensile force before cyclic loading.

Groups of specimen	Group A	Group B	Group C
Group A	-	<0.0005*	<0.0005*
Group B	<0.0005*	-	0.937
Group C	<0.0005*	0.937	

*Statistically significant difference (P<.05)

pered-head screws (Figure 1). In this study, tapered-head screws maintained more preload than did flat-head screws. However, some Authors mentioned that flat-head screws were preferable than tapered-head screws to maintain preload (8, 24). This was because flat-head screws distribute force more evenly within the thread and the head of the screws. Moreover, when the screws were tightened, tapered-head screws were distorted and gave a non-passive appearance. Consequently, stress in the screw component was developed, leading to a reduction of clamping force and loss of preload. The stem length of the tested screws in groups A, B and C were 8.4, 8.2 and 8.9 mm, respectively. The long stem length was used because it provided favorable elongation (1). The number of threads influences the friction of the screw, and most of the torque is distributed in the first few threads. The most common screw design has six threads (8) whereas the tested screws in groups A, B and C had 12, 10 and 8 threads, respectively.

Aside from screw design, the coefficient of friction, stiffness of screw material and installation protocol also affected preload. Applied to the screw, torque was counteracted by three reaction forces: stretching force within the inclined plane of the threads of the screw, reaction force caused by friction at the screw thread and reaction force caused by friction under the screw head (25). A 10% increasing in friction at the screw head causes a 50% reduction in preload. Stiffness affects the elongation of screw. High-stiffness screws decrease elongation of the screws, and, consequently, amplify initial preload loss (24).

Screw retightening ten minutes after the first tightening would compensate preload loss from the settling effect, then, lessen screw loosening (26). Screw retightening might increase initial preload in tapered-head screws more than in flat-head screws (24). This might be because there was angular misfit during machine between tapered screw head and tapered bore in implant fixture; and retightening would reduce the angular misfit because of plastic deformation of the tapered contact surface.

Preload efficiency after cyclic loading represents residual preload in the implant system. One million cycles of cyclic loading used in this study represented *in vivo* use of a dental implant

original research article

for 15 months (27). The preload efficiency in group A was not shown to be significantly different from that in group B. Differences observed between these two implant systems were largely attributable to the screw head design. As a result, it can be implied that either tapered or flat head screws maintained an even amount of preload after the implant had been functioning for a period of time.

A tensile test showed that the tensile force used to detach the abutment from the implant fixture in all groups significantly increased after cyclic loading. This might be because of 'cold welding' of the implant-abutment component (8). Cold welding is defined as increasing of removal torque with respect to tightening torque. The presence of cold welding is considered as an advantage by reducing the risk of screw loosening. On the other hand, intensive amount of cold welding can be a source for lack of retrievability (15). However, tensile force in groups A and B, which owned the same characteristic of implant-abutment connection, were significantly different. One possibility is that the implants in those groups had some differences resulting from the manufacturing process, which might affect the geometric accuracy, surface roughness and dimensional tolerance of their components. Although the implants in group C showed comparatively low preload efficiency, they manifested high detached tensile force both before and after cyclic loading. The connection of all groups was classified as the cone with mandatory index. The advantages of this connection are self-retention and a self-locking interface, which can minimize microgap formation and reduce micromovement (1, 18, 28).

Preload maintainability was one of the most essential features of implant systems that use abutment screws as the attachment method. All manufacturers suggest specific insertion torque. Those torque values recommended by the manufacturers were the suitable forces that would produce the greatest preload without damaging the components. The dentist should recognize the important features of the attachments of a chosen implant systems, follow the manufactur-

er's instruction and use the proper insertion protocol. Once screw loosening happens, a thorough investigation should be conducted to find the cause, since a minor movement can be the cause of implant failure.

Conclusions

The removal torque of the abutment screws reduced significantly after cyclic loading (1×10^6 cycles, represented *in vivo* use for 15 months) (27). Before cyclic loading, tapered screws maintained more preload than did flat head screws. After cyclic loading, tapered and flat head screws maintained even amounts of preload. The cone with mandatory index connection maintains implant-abutment together, and the tensile force that dislodged abutment from implant fixture increased immensely after cyclic loading.

Acknowledgements

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