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Effect of implant abutment connection designs, and implant diameters on screw loosening before and after cyclic loading: In-vitro study

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ABSTRACT

Aims. The purpose of this in-vitro study was to evaluate the screw loosening of two different forms of implant abutment connection designs, and two implant diameters by measuring removal torque value (RTV) before and after cyclic loading.

Materials and methods. Twenty implant fixtures were divided equally into 2 groups (N = 10): group I fixture with conical hybrid connection (CH), and group II fixture with internal hex connection (IH). Each group was divided equally into two subgroups according to implant diameters: subgroup A (3.3 mm), and subgroup B (4.2 mm). Each fixture was vertically placed in the center of an acrylic resin block. The samples were fixed to the jig, and an implant abutment connected it with a 20 Ncm tightening torque. The samples were subjected to eccentric cyclic loading (at a distance of 5 mm) away from center of abutment at 100,000 cycles. A digital torque gauge was used to evaluate screw loosening by measuring RTVs in (Ncm) before and after cyclic loading. The removal torque loss ratio before and after cyclic loading and the removal torque loss ratio between before and after cyclic loading were calculated and analyzed using the SPSS statistical analysis.

Results. For ***GI*** the initial removal torque loss ratio measurement was (14.45 ± 3.18) and decreased significantly after loading, it was (11.47 ± 3.64). For ***GII*** the initial removal torque loss ratio measurement was (20.47 ± 4.99) and increased significantly after loading, being (35.35 ± 4.26). There is no significant effect upon screw loosening for two implant diameters.

Conclusion. Within the limitations of this study, the results suggested that conical hybrid connections showed a better screw stability than an internal hex connection. Therefore, the use of conical implants can be promoted as they have better screw stability compared to other systems.

1. Introduction

Implant failure may be due to bad oral hygiene, poor bone quality, compromised medical status of the patient and biomechanical factors. Various authors have confused the importance of biomechanical factors such as type of loading, the bone implant interface, the length and diameter of the implants, the form or characteristics of the implant surface, the prosthesis type and the quantity or quality of the sur-

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rounding bone [1]. Despite the high medical advancement of implants, there are various problems observed after a 3 year follow up, the problems have been an abutment screw fracture, soft tissue penetration, mucosal imitation then screw loosening [2].

A common problem associated with the prosthetic application of dental implants is loosening and fracturing of screws that hold the prosthesis to the implant which is induced by way of insufficient tightening torque, settling effect, vibrating micro-movement, excessive bending and fatigue [3], inappropriate implant position, inadequate occlusal design or crown anatomy, variant of hex dimension, mild differences in fit and accuracy, tension on abutment and cylinder from ill-fitting restorations, as well as improper screw design [4,5].

Several researches have been performed together with the intention of accomplishing an accurate and stable connection between the components of implant systems. The connection is accomplished by means of bolts created by the union between the implant and the prosthetic element [6]. The longevity regarding the implant-abutment connection has been recognized as a primary determinant for the long-term success of a dental implant [7,8]. The main challenge in the development of implant abutment connection design depends on lowering the incidence concerning mechanical problems while improving the soft/hard tissue and the prosthetic interface [9,10].

Several factors related to screw design and fabrication can increase or decrease the risk of abutment or prosthetic screw loosening in a metal-to-metal screw system. These primarily are related to preload. In addition, factors that affect abutment screws also include component fit, hex height (or depth), and platform diameter. A flat-head screw is preferred for prosthetic screws. A flat-head screw distributes forces more evenly within the threads and the head of the screw and is less likely to distort a nonpassive casting. As a result, the dentist can more easily identify the nonpassive casting [11,12].

The fixture design allows the preload torque applied to the screw to stretch the male component down the 30 degree angle of the female component of the screw to help fixate the metal components. However, this screw design places most all of the torque in the first few threads. As a result, most manufacturers only have a few threads on their abutment screw designs. The most common design is a flat head, long-stem length with six threads to achieve optimal elongation [13].

The diameter of the screw may affect the amount of preload applied to the system before deformation. The greater the diameter, the higher the preload that may be applied and the greater the clamping force on the screw joint [14]. Most abutment screws of different implant manufacturers are of similar size.

An implant abutment connection can be internal or external, depending on if a geometric characteristic extends above the coronal surface or below. External connection was firstly used clinically and dominated the market for the past two decades until a number of internal connection designs become popular and have rapidly taken over the world market in recent years [15].Currently, there are over 20 specific geometric variants of implant abutment interfaces commercially available.

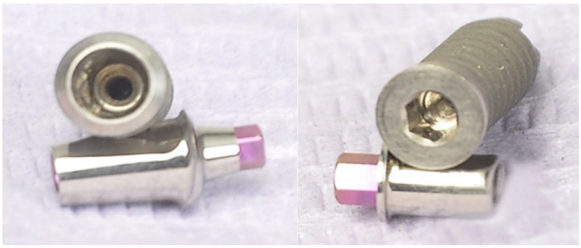

Fig. 1 – Conical hybrid and internal hex implant with matched titanium abutment.

Table 1 – Materials used in this study.

Group	Connection design	Diameter
GI	Conical hybrid connection	G I A: 3.3 mm G I B: 4.2 mm
GII	Internal hex connection	G II A: 3.3 mm G II B: 4.2 mm

Implant diameter is an essential factor in the mechanical stability of an implant. Distribution and magnitude of stresses within an implant are influenced by the implant dimensions and geometry as documented by several authors [16]. Small diameter implants (3.0 to 3.4 mm) were developed [17], so it would be beneficial to decrease the quantity of augmentations necessary for implant insertion. This may assist aged patients or patients with general medical problems who would benefit from implant therapy with reduced surgical invasiveness. The other essential indication, for which narrow diameter implants would be beneficial, are small interdental or interimplant gaps, which are often determined in the premolar or incisor region [18].

Dynamic cyclic loading used to simulate masticatory function mimic oral cavity that might lead to a biological and mechanical complication of implant abutment connection. Also it is a reliable method to test the effect of mechanical fatigue on the implant abutment joint stability [19].

Accordingly, this study was conducted to inspect the effect of two implant abutment connection designs, and two implant diameters on screw joint stability by comparing the removal torque loss ratio of the abutment screw before and after cyclic loading.

2. Material and methods

A total of twenty implant fixtures with a length of 11.5 mm (Schütz Dental GmbH, Dieselstr. 5-6.61191 Rosbach/Germany) were used in this study and divided into two groups of 10 according to the implant abutment connection designs: Conical hybrid connection design (CH) (Group 1), Internal hexagonal connection design (IH) (Group 2) (Fig. 1). Two implant diameters were used in this study for each group (3.3 mm diameter, 4.2 mm diameter). Titanium vertical screw with flat head design was used; each abutment had titanium screw with same length, diameter, thread, and head design (Table 1).

Samples blocks were made in a stainless steel split mold, blocks were designed to fit into recesses in a stainless steel

Fig. 2 – Block construction using stainless steel split mold.

form (20 mm long, 20 mm wide, and 3 mm thick). At the center of the mold surface a small opening with the same width of the implant mount was made, and the implant fixture was screwed vertically to its mount through this centralized opening. Autopolymerized acrylic resin material was mixed according to the manufacturer's recommendation and poured inside the split mold and left for polymerization while the implant fixture embedded in it. After polymerization the acrylic blocks were removed from the mold by unscrewing the fixture and the implant fixture was placed vertically and perpendicular to the base in the center of the blocks and the implant top became flushed with resin block level (Fig. 2).

For each selected titanium abutment (6 mm head height & 1 mm gingival height) a metal tube was fabricated to fit accurately on the abutment. The metal tube was casted using a lost wax technique according to the manufacturer's recommendations, and was then finished and checked to ensure that each tube fitted accurately on its corresponding abutment (Fig. 3).

A digital torque gauge (HTG2- 200Nc, IMADA, Toyohashi, Japan) was used to ensure an accurate application of force to the abutment screw (Fig. 4).

Fig. 3 – Stainless steel metal tube.

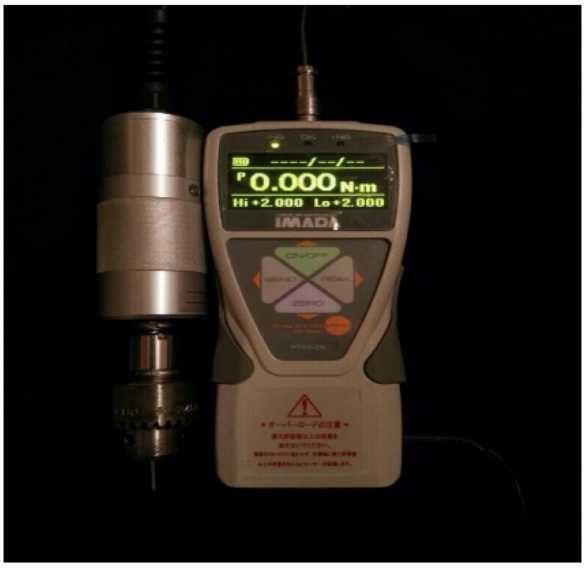

Fig. 4 – Digital torque gauge.

A customized rigid metal mounting jig was designed, as a holding device to ensure solid fixation of the sample while recording the measures. The torque gauge was held firm so that the long axis of the implant with the driver was seated in the screw head, and rotated clockwise until the abutment screw had been tightened to 20 Ncm as recommended by the manufacturer. Ten minutes later a torque of 20 Ncm was reapplied with the same digital torque gauge to compensate for the settling effect of the screw and thus to assist in achieving the optimum preload [20]. A further ten minutes later, the initial removal torque value was measured using the digital torque gauge and recorded.

The custom –made jig was fabricated for placing the implant on the load frames of the loading machine which had a socket to tightly close the implant blocks. After the abutment connection and setting of the metal tube using resin cement, a universal testing machine was used to apply a cyclic load to the specimen.

All samples were mounted in the lower fixed compartment of a computer controlled universal testing machine and samples were submitted to 100,000 mechanical cycles under a load

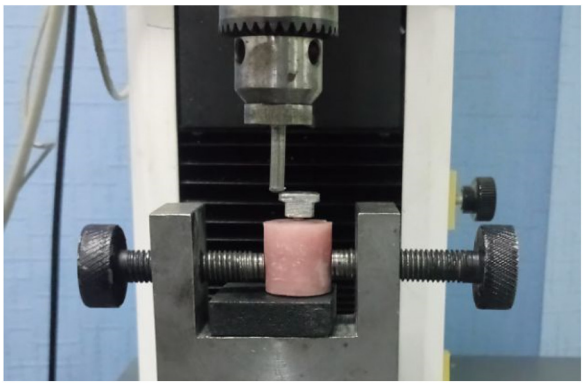

Fig. 5 – Application of cyclic loading.

of 130 N, at a rate of 2 Hz (at a distance of 5 mm) away from the center of the abutment (Fig. 5).

After cyclic loading, the loading machine was stopped to measure screw loosening. The postload removal torque value was measured after cyclic loading using the same digital torque gauge and recorded.

Each loss ratio of removal torque was calculated using following formula [19].

$$\text{Loss ratio of removal torque before loading (\%)} = \frac{\text{Tightening torque} - \text{initial removal torque value}}{\text{Tightening torque}} \times 100$$

$$\text{Loss ratio of removal torque after loading (\%)} = \frac{\text{Tightening torque} - \text{postload removal torque value}}{\text{Tightening torque}} \times 100$$

$$\text{Loss ratio of removal torque between before and after loading (\%)} = \frac{\text{initial removal torque value} - \text{postload removal torque value}}{\text{initial removal torque value}} \times 100$$

T test and ANOVA were used to compare the mean of the initial and postload removal torque loss ratio between different groups and subgroups followed by pair-wise Tukey's post-hoc tests at a 0.05 level of significance. Differences between mean greater than Tukey post-hoc value were considered significant ($P < 0.05$). Statistical analysis was performed by using (SPSS program. Version 20. Inc. Chicago, USA).

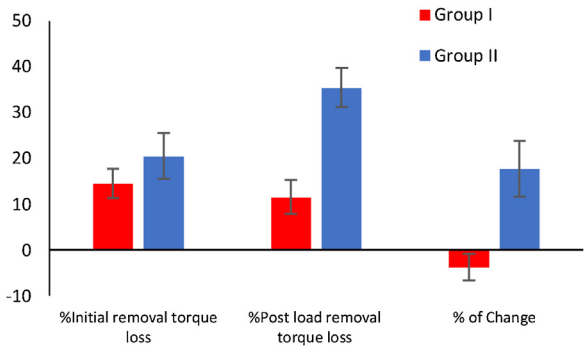

Fig. 6 – Mean ± SD of initial and postload removal torque loss ratio and % difference in removal torque loss for GI, GII.

3. Results

Mean ± SD of initial and postload removal torque loss ratio and % difference in removal torque for two groups are presented in (Table 2) and (Fig. 6).

For GI, the initial removal torque loss ratio measurement was **(14.45 ± 3.18)** and decreased significantly after loading, it was **(11.47 ± 3.64)**. This difference is statistically significant ($P < 0.05$).

For GII, the initial removal torque loss ratio measurement was **(20.47 ± 4.99)** and increased significantly after loading, it was **(35.35 ± 4.26)**. This difference is statistically significant ($P < 0.05$).

In comparison between two groups **GI** and **GII** in initial and postload removal torque loss ratio and the % difference in removal torque, it was found that there is significant difference between the two groups ($P < 0.05$).

Table 2 – Mean ± SD of initial and postload removal torque loss ratio and % difference in removal torque for GI, GII.

Groups		%Initial removal torque loss	%Post load removal torque loss P-value	Paired Test	% difference in removal torque loss
GI		14.45 ± 3.18	11.47 ± 3.64	**<0.001***	−3.78 ± 2.92
GII		20.47 ± 4.99	35.35 ± 4.26	**<0.001***	17.64 ± 6.14
T-Test	**T**	−4.54	−19.01		−9.11
	P-value	**<0.001***	**<0.001***		**<0.001***

Table 3 – Results of *ANOVA test* for loss ratio of removal torque between two implant diameters in groups.

	Loss ratio of initial removal Torque	ANOVA		Loss ratio of postloadrmoval Torque	ANOVA		Loss ratio of difference between initial and postload removal torque	ANOVA	
	Mean ± SD	F	P-value	Mean ± SD	F	P-value	Mean ± SD	F	P-value
GIA	15.75 ± 2.43	7.52	<0.001*	13.10 ± 3.04	13.99	<0.001*	−3.40 ± 2.42	27.30	<0.001*
GIB	13.15 ± 3.43			9.85 ± 3.59			−4.15 ± 3.45		
GIIA	20.50 ± 5.52			36.80 ± 5.24			18.67 ± 6.21		
GIIB	20.45 ± 4.70			33.90 ± 2.51			16.61 ± 6.22		

Tukey's Test

	IA & IB	IA & IIA	IA & IIB	IB & IIA	IB & IIB	IIA & IIB
% Initial removal torque loss	0.51	0.07	0.07	**0.002***	**0.002***	1.00
% Post load removal torque loss	0.22	**<0.001***	**<0.001***	**<0.001***	**<0.001***	0.32
% of change	0.98	**<0.001***	**<0.001***	**<0.001***	**<0.001***	0.78

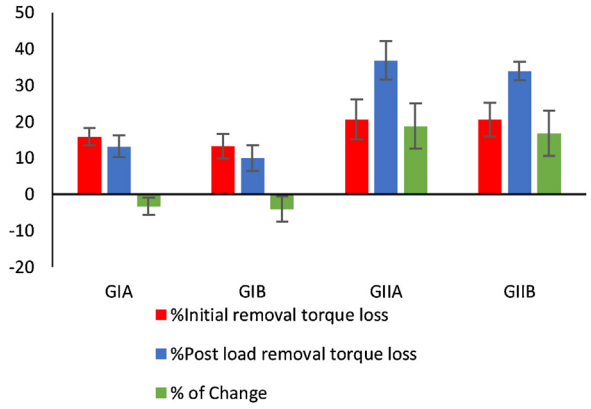

Fig. 7 – Comparison of loss ratio of removal torque between subgroups. A: Loss ratio of removal torque before loading, B: Loss ratio of removal torque after loading, C: Loss ratio of removal torque between before and after loading.

A one way ANOVA test was performed to compare the mean of initial and postload removal torque loss ratios and the % difference in the removal torque for GIA, GIB, GIIA, GIIB. The test revealed significant difference between groups ($F = 7.52$ $p = <0.0001$), ($F = 137.99$ $p = <0.0001$), ($F = 27.30$ $p = <0.0001$). Pair-wise Tukey's post-hoc tests showed a non-significant difference between GIA and GIB, also between GIIA and GIIB ($p > 0.5$) as shown in (Table 3) and (Fig. 7).

4. Discussion

Implant longevity is a major demand for all implantologists. Great efforts were exerted across several years of research to formulate clear and conclusive criteria of the optimal design, material, surface topology, and procedures for implantation. The proper design and characteristics of implant-abutment connection or engagement are one of the priorities if a durable implant is being considered. Consequently, the particular concern of that connection might change the overall loading and distribution of generated stress in the bone surrounding the fixture [21]. Mechanical factors, such as the implant-abutment connection fit and the abutment screw preload are considered as important factors involved in implant rehabilitation [22].

During the occlusal load preload loss occurs which can affect an implant-abutment connection stability and may cause screw loosening and fracture. Along with the mechanical failure of the implant prosthesis, may cause biological complication such as inflammation of tissue around implant, gingival growth, and fistula formation [23].

Abutment screw loosening in single-tooth implants is caused by two factors: vertical cantilever force on the implant due to occlusal contact; and lateral biting force such as balancing contact. Several techniques have been recommended to decrease screw loosening: (1) centering the occlusal contact (2); flattening cuspal inclination (3); applying the correct torque when tightening the abutment screw; (4) narrowing the buccolingual width of the crown; and (5) reducing the cantilever length [24,25].

An occlusal load is applied to the superstructure section of an implant, then transferred to the abutment which then transfers the load to the fixture and bone through the implant abutment and implant bone connections. Therefore, the implant-abutment connection has an important role in modifying this load. A well-designed implant abutment connection leads to high rotational stability. Finally, a steady interlocking fit between implant and abutment lowers the incidence of micromovements and ensures that the retaining screw will remain in place without being exposed to screw loosening or screw breakage [26].

Distribution and magnitude of stresses within an implant are affected by the implant dimensions and geometry as documented by some researchers [16]. Theoretically, if the implant system diameter increases, the preload loss caused by the bending load during the functional movement relatively decreases due to the increased area between the abutment and the fixture [27].

A key objective of this investigation was to raise the awareness of clinicians in terms of screw loosening and joint stability.

The metal tube was fabricated in this study on the selected abutments with a flat occlusal surface to standardize the loading area throughout the investigation and facilitate load application permitting contact with the piston of the testing device [28].

In this study a 20 Ncm tightening torque was applied to the abutment screw. Application of the optimum torque to the implant-abutment complex is critical for long-term successful prosthetic implant restoration. A specific torque is recommended for each screw for different implant systems according to their respective manufacturers [29].The tightening force should be applied again 10 min after screw tightening for the first time to minimize surface settling [30].

Load was applied eccentrically 5 mm away from the center of abutment [27,31] to simulate intraoral lateral forces [32]. A number of studies have investigated the influences of eccentric loading by using fatigue tests and dynamic cyclic loading to simulate masticatory forces. Khraisat et al. [33], investigated the influence of lateral cyclic loading on abutment screw loosening in an external hexagon implant system. They found that reverse torque values were better preserved under eccentric lateral than under centric lateral loading.

Chewing forces of adult individuals with natural dentition and those with prosthetic rehabilitation are between 50 N and 2440 N, showing a decreasing pattern from molars to incisors [34], in our study applied force chosen is 130 N and frequency of 2 Hz were applied for the simulation of more actual clinical situations, The frequency of cycles is reported in the literature as ranging from 1 to 19 Hz [35]. It was clarified that in a day, an individual typically performs three episodes of chewing lasting 15 min, with a frequency of 60 cycles per minute (1 Hz); this generates 2700 chewing cycles per day so 100,000 cycles corresponds to around one month [36].

In the current study, the results showed that there is a significant difference in removal torque loss ratio before and after application of dynamic cyclic loading and between before and after cyclic loading for two different connection designs.

The conical hybrid connection had the lowest percentage of initial and postload removal torque loss when compared with internal hexagon connection, this difference is statistically significant. Compared with the internal hexagon connection,

torque loss was not obtained in the conical hybrid connection after cyclic testing.

The cone connection showed that postload torque values that were higher than the initial torque due to the cold welding on the implant abutment interface. This condition results from the friction between the two surfaces, which differ slightly. The pressure created by the insertion force determines the maintenance of the connection [37].

In the internal cone connection type implant system, the tightening torque is driven by not only the screw height but also the wedge effect due to the conical abutment sinking, and the load is mainly supported by the internal slope of the fixture. Therefore, the stress that occurs in the abutment screws has been known to be relatively smaller than that in the external butt joint [38]. The cold welding inherent to this system favors the torque gain because of the friction between the conical abutment and the internal implant surfaces [39], which provides high stability.

Conical abutments were superior in terms of sealing, microgap formation, torque maintenance, and abutment stability. The review indicated that implant systems that use conical implant-abutment connections provide better results in terms of abutment fit, stability, and sealing. These design features could lead to improvements compared to nonconical connection systems [40].

The greater stability of the internal connections, especially the cone connection, is important because it provides more predictable rehabilitation with greater longevity and success rates. This connection provides higher resistance at the implant/abutment interface, anti-rotational characteristics, and resistance to loosening of the screw [41].

In the current study, the results showed that there is no statistically significant difference in removal torque loss ratio before and after application of dynamic cyclic loading for two implant diameters small diameter (3.3 mm) and standard diameter (4.2 mm).

These results were in agreement with a longitudinal study, which compared small diameter (3.3 mm) and standard diameter (4.1 mm) implants; there was therefore no statistically significant difference between the two implant diameters used [42].

Additionally, the data from this study agreed with Ivanoff et al. [43] and Kido et al. [44] who demonstrated that removal torque increases because of wider implant diameters. However, the difference was not statistically significant. Furthermore, despite the reduced dimensions and resistance to loading forces, no differences were recorded between the survival of small diameter (3.0 and 3.25 mm) and standard diameter (3.75 and 4.25 mm) implants.

5. Conclusions

Within the limitations of this *in-vitro* study, the results showed the followings:

1. The conical implant abutment connection designs provide more biomechanically suitable prosthetic options than other designs.
2. A standard diameter was more advantageous in terms of the torque loss rate than that of a smaller diameter.
3. Results of this study showed that the implant diameters (3.3 mm, 4.2 mm) did not have a significant impact on screw loosening after a 100,000 cycles.

6. Recommendations

1. Further studies should be carried out to evaluate the removal torque loss ratio of different connection designs after repeated loads.
2. An in vivo study is required to evaluate removal torque and screw loosening for different connections. As it is likely that microbial colonization and marginal gap formation from screw loosening can result in soft tissue inflammation leading to implant failure.
3. Further studies should be carried out to evaluate the effects of different abutment collar lengths and the angulation on screw loosening after mechanical cyclic loading.
4. Further studies should be carried out to evaluate the effects of different CAD/CAM abutment on screw loosening after mechanical cyclic loading.

Ethics approval and consent to participate

Approval for this research was obtained from the Research Ethics Committee, Faculty of Dentistry, Tanta University. The design and procedures of the present study were accomplished according to the research guidelines published by the Research Ethics Committee, Faculty of Dentistry, Tanta University.

Consent for publication

Not applicable.

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Authors' contributions

All authors read and approved the final manuscript, and contributed equally to this work.

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