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Effect of Lateral Cyclic Loading on Screw Loosening in Morse Taper Implant-Straight Abutment Connection

Ezatollah Jalalian, Arash Zarbakhsh, Sarvenaz Zare and Hamed Karimi Pour

ABSTRACT

Background: **Screw loosening is a common problem that can lead to mechanical and biological failure of dental implants. This study aimed to assess the effect of lateral cyclic loading on screw loosening (detorque value) in Morse taper implant-straight abutment connection.**

Methods: **This in vitro, experimental study evaluated 12 dental implants with Morse taper implant-abutment connection. Dental implant-abutment assemblies were mounted in transparent acrylic resin blocks with 45-degree angle relative to the acrylic surface. The abutment screw was torqued to 30 N/cm by a digital torque-meter and retorqued after 10 minutes. The assemblies were then randomly divided into two groups (n=6). In the test group, lateral cyclic loads with 75 N magnitude and 1 Hz frequency were applied at 45-degree angle relative to the longitudinal axis of the fixture. After 500,000 cycles, the detorque value was measured at the implant-abutment interface by a digital torque-meter. The assemblies in the control group did not undergo cyclic loading. The detorque values were compared between the two groups using the Student t-test (alpha=0.05).**

Results: **The mean detorque value was 23.17±1.33 N/cm in the control and 21.3±3.38 N/cm in the test group. According to the Student t-test, this difference was not significant (P=0.4).**

Conclusion: **According to the present results, application of lateral cyclic loads had no significant effect on screw loosening (detorque value) of Morse taper implant-straight abutment connection but insignificantly increased the torque loss.**

Keywords: Dental Implants, dental implant-abutment design, torque.

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I. Introduction

Abutment screw loosening is a common complication that can lead to dental implant or abutment fracture, reduction of occlusal loads, and failure of osseointegration [1]-[4]. The reported prevalence of screw loosening ranges from 0% to 13% [5], [6]. In vitro studies have also demonstrated high prevalence of screw loosening [7], [8]. Microgap formation at the dental implant-abutment interface is a major problem that can lead to mechanical complications such as the abutment screw loosening and fracture, abutment fracture, and implant body fracture, as well as biological complications such as peri-implantitis and peri-implant mucositis [9],[10]. The implant-abutment connection type may be internal or external connection. Internal connection has different subtypes based on its geometry such as the conical connection or Morse taper [11]. The prevalence of screw loosening is higher in external hexagon connection compared with other connection types, which is due to its mechanical properties under dynamic loading [12], [13].

Several factors are involved in the occurrence of screw loosening such as the restoration design and dimensions, prosthetic misfit, inadequate tightening torque, excessive bending of the screw and screw fatigue [1], [2], [11], biomechanical loading [14]-[17], screw type and design [18], masticatory forces, presence of parafunctional habits, implant system, implant-abutment connection geometry, and connection precision [2], [19]-[21]. Occlusal forces play a key role in abutment screw loosening as well. Preload is an important mechanical factor in prevention of screw loosening and its fracture. Preload refers to the load generated when tightening the screw, and determines the clamping force [21], [22]. Preload depends primarily on the applied torque and secondarily on the type of material, screw head, thread design, and surface roughness. Preload is the only force that prevents the separation and detachment of the abutment from the implant body under occlusal forces. If the occlusal forces exceed the preload, screw loosening may occur and subsequently, eccentric forces and compressive loads may cause screw loosening [14], [23]. Abutment screw loosening increases the micromovements and microgap at the implant-abutment interface, and results in microleakage through the interface and eventual biological complications such as bone loss [2].

The prevalence of screw failure in the first year after loading is reportedly 5.3%. This rate reaches 5.8% to 12.7% after 5 years [7], [22], [24]. Reference [25] were the first to suggest possible microleakage of microorganisms through the implant-abutment interface. The consequences of screw loosening and microgap formation can be categorized into two groups: (I) biological complications such as peri-implant mucositis, peri-implantitis, crestal bone loss, and halitosis, and (II) mechanical complications such as abutment screw loosening and fracture, abutment fracture, and implant fracture [9], [26].

Several techniques have been proposed to minimize the risk of screw loosening such as application of correct preload to the screws, narrow occlusal table, centric occlusal contacts, decreasing the cantilever length, flattening of cuspal slopes, and reduction of abutment length [11], [15], [27], [28].

Fatigue refers to repeated application of loads in the subcritical threshold (lower than fracture strength) to a material that eventually results in its fracture [29]. Considering the fact that fatigue cyclic loading can lead to failure of implant-abutment connection, long-term studies are imperative on the stability of implant-abutment connection under cyclic loads [29]. Some previous studies have assessed the effects of abutment screw material on screw loosening, effect of long-term fatigue on reverse torque, effects of abutment screw length on reverse torque and microgap formation, and effect of lateral cyclic loading on dental implants [19], [27]-[29]. This study aimed to assess the effect of lateral cyclic loading on screw loosening (detorque value) in Morse taper implant-straight abutment connection. The null hypothesis was that lateral cyclic loading would have no significant effect on screw loosening in Morse taper implant-straight abutment connection.

II. Materials and Methods

This in vitro, experimental study was conducted on 12 dental implant-abutment assemblies. The minimum sample size was calculated to be 6 in each group (a total of 12) according to previous studies [30], [31] assuming the mean standard deviation of 1.8, minimum detorque difference of 3 units between the two groups, $\alpha=0.05$, and $\beta=0.2$, using Minitab software.

Implantium dental implants (Dentium, Dentium, Korea) with Morse taper implant-abutment connection type, internal hex anti-rotation and tapered abutments were used in this study. Dental implants had 10 mm length and 4 mm diameter, and straight abutments had 6 mm length and 1 mm collar height.

Dental implants were first mounted in acrylic molds with 45-degree angle relative to the vertical axis (Fig. 1). For this purpose, round molds with 34 mm diameter and 19 mm height were used. The molds were filled with transparent auto-polymerizing acrylic resin (Meliodent Heraeuk Kusler GmbH, Germany). A surveyor (JM Ney Co. Bloomfield, CT, USA) was used for correct mounting of dental implants in acrylic molds with 45-degree angle relative to the vertical axis [32]. After completion of acrylic polymerization, straight abutments (6 mm length, 1 mm collar height) were tightened on dental implants, and the abutment screw was tightened by a digital torque-meter (Lutron Electronic Enterprice Co. Taiwan) to 30 N/cm torque according to the manufacturer's instructions [30], [33]. To compensate for the settling effect, the abutment screws were retorqued to 30 N/cm after 10 minutes using a digital torque-meter [30], [33].

The specimens were coded 1 to 12, and were randomly assigned to the test and control groups (n=6). The test group specimens underwent cyclic loading in a chewing simulator (Chewing Simulator CS-4, SD Mechatronik, Germany) by applying 75 N load with 1 Hz frequency at 45-degree angle relative to the longitudinal axis [30], [31]. Both vertical and horizontal loads were applied to the assemblies. A total of 500,000 cycles were applied, corresponding to 20 months of mastication in the oral environment (Fig. 2) [34]. The control specimens did not undergo cyclic loading and were stored at room temperature. The detorque values were recorded by an examiner blinded to the group allocation of specimens by a digital torque-meter.

Data were analyzed using SPSS version 22, and the detorque values in the test and control groups were compared using the Student t-test at 0.05 level of significance.

Fig. 1. Dental implant mounted in a mold with 45-degree angle relative to the vertical axis.

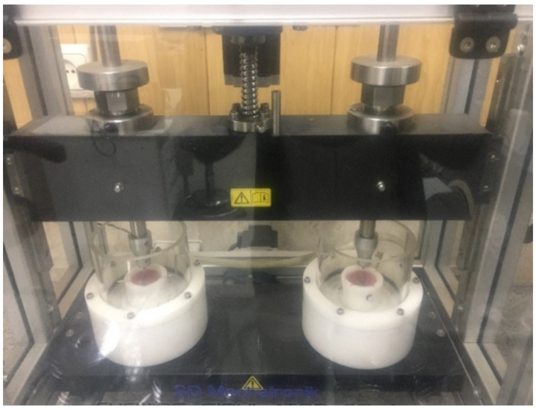

Fig. 2. The test group specimens underwent cyclic loading in a chewing simulator (Chewing Simulator CS-4, SD Mechatronik, Germany) by applying 75 N load with 1 Hz frequency at 45-degree angle relative to the longitudinal axis

III. Results

The mean detorque value was 23.17±1.33 N/cm in the control and 21.3±3.38 N/cm in the test group. According to the Student t-test, this difference was not significant (P=0.4). Screw loosening did not occur in any specimen either.

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IV. Discussion

This study assessed the effect of lateral cyclic loading on screw loosening in Morse taper implant-straight abutment connection. The null hypothesis was that lateral cyclic loading would have no significant effect on screw loosening in Morse taper implant-straight abutment connection. The results showed that lateral cyclic loading had no significant effect on the detorque value, and screw loosening did not occur in any specimen. Thus, the null hypothesis of the study was accepted.

Reference [35] reported a non-significant reduction in the mean reverse torque value in external hex dental implants following cyclic loading, which was similar to the present findings, although they tightened the abutments to 32 N/cm torque, which was higher than the value in the present study. They also performed centric and eccentric cyclic loading and showed that the reverse torque was better preserved in application of eccentric, compared with centric, loads. Thus, irrespective of the connection type, type of abutment, direction of load application, and magnitude of the applied load, screw loosening can lead to torque loss. Reference [12] evaluated the effects of mechanical cyclic loading on different abutment types in tapered (16-degree and 11.5-degree) internal connection dental implants. The assemblies were subjected to 1,200,000 load cycles and dynamic compressive test with 50 N load and 2 Hz frequency at 30-degree angle, and they reported torque loss. The loosening value significantly decreased compared with the initial tightening torque in all groups approximately by 50%. Their results were in agreement with the present findings. However, the high magnitude of torque loss in their study may be attributed to high mechanical loading cycles (1,200,000) corresponding to 5 years of clinical service (versus 500,000 cycles applied in the present study, corresponding to 20 months), as well as higher frequency of cycles in their study compared with the present study (2 Hz versus 1 Hz). Moreover, they had a larger sample size (40 assemblies). Reference [34] evaluated screw loosening in UCLA-type abutments following cyclic loading and showed that cyclic loading, irrespective of the use of cast or pre-machined abutments, caused torque loss, which was in line with the present findings. However, the magnitude of torque loss in their study was greater than that in the present study, which may be due to differences in implant-abutment connection type (external hex in their study versus Morse taper in the present study), variations in the magnitude of applied loads, and storage of assemblies in distilled water at 37°C in the process of cyclic loading in their study. Reference [33] evaluated screw loosening in interchangeable abutments connected to internal hex implants after cyclic loading. They reported the fracture of 86% of recently tightened abutments and 57% of implants in ANAVA Solid group, which was different from the present observations. They applied 150 N load with 30-degree angle relative to the implant axis with 6 Hz frequency for 1 million cycles. Difference between the results of the two studies may be attributed to the use of different implant and abutment systems, different magnitudes of cyclic loads applied, and frequency of cycles (which in their study was twice the value in the present study). Reference [2] evaluated the effects of lateral oblique cyclic loads on screw loosening in implants with internal and external hex connection types. They applied 500,000 cycles of 50 N load at 45-degree angle, which was similar to the cyclic loading protocol adopted in the present study. They reported a significant difference in the percentage of torque loss between the two groups. Also, they reported an increase in the percentage of torque loss after cyclic loading, which was similar to the present finding. Reference [14] evaluated the effect of internal torque and cyclic loads on screw loosening in implants with external hex connection. They applied 74,000 cyclic loads at 4.4 Hz frequency corresponding to 3 months of clinical function. Moreover, they torqued the assemblies to 20 N/cm. They reported a mean torque loss of 31.51% prior to cyclic loading in the conventional and 28.14% in internal torque implants. Torque loss significantly increased in both groups after cyclic loading and reached 59.27% in the conventional and 62.22% in the internal torque group. The two groups were not significantly different in torque loss before or after cyclic loading. The present study, similar to [14] showed an increase in torque loss. However, the difference between the two groups was not significant in the present study, which may be due to shorter retorque time in the present study (5 minutes versus 10 minutes in their study), lower torque value in this study (30 N/cm versus 20 N/cm in their study), and different connection type (Morse taper versus external hex). Reference [21] compared the removal torque value after mechanical cyclic loading among customized titanium abutments, straight titanium abutments, and hybrid zirconia abutments. They measured the removal torque value after 0 (control), 50,000, and 1000,000 cycles. Load (15 to 250 N/cm) was applied with 15 Hz frequency at 30-degree angle, and they reported higher initial removal torque value in the control group. However, the removal torque value was not significantly different between the two experimental groups subjected to different cyclic loading protocols or with different abutments. Their methodology was different from ours since they applied variable dynamic loads at much higher frequency (15 Hz versus 1 Hz) and had a larger sample size (45 assemblies). Thus, their results cannot be accurately compared with the present findings. Reference [35] evaluated the effect of cyclic loading frequency on abutment screw loosening in an external hex dental implant system and reported that long-term cyclic fatigue protocols had significant effects on reverse torque values under centric lateral loading, which was different from the present findings. The present study showed that cyclic loading had no significant effect on the reverse torque. Difference between their results and the present findings may be due to different sample size (15 assemblies in their study), different frequency of load cycles (1,000,000 cycles) and differences in the abutment screw, implant type, and tightening torque values, which can all affect the preload. On the other hand, anti-rotational hexagon in the present study conferred resistance against lateral cyclic loads and resulted in reduction of micromovements of the abutment screw. Consequently, cyclic loading had no significant effect on the detorque value. The obtained results can also be due to a number of factors. Eccentric lateral cyclic loads applied to the specimens might not have been transferred to the abutment screw and thus, a significant reduction in preload did not occur. Optimal stress is created following bending of the abutment screw during eccentric lateral loading, and at the same time, shear and compressive forces are generated due to the close contact of screw threads (male) and internal implant threads (female). When the lateral surface of the threads is subjected to frictional contact following eccentric lateral loading, optimal plastic deformation and minimum deformity of the abutment screw occur, leading to acceptable adhesive wear.

In implant treatment, when excessive loads are applied to the screw, it undergoes plastic deformation (due to axial and flexural loads), and this deformation leads to screw loosening and its eventual fracture [36]. In the present study, screw loosening did not occur in any group, which indicates that the residual torque values may be sufficient for a relatively long period of time, and cyclic loads have a limited effect on the detorque value and screw loosening. In case of occurrence of a significant reduction in detorque value due to inappropriate loadings, additional adhesive wear may possibly occur. Under such circumstances, the surfaces are fused, and a larger flaking area is seen on the screw and internal implant thread surfaces [35], [37], [38]. However, further studies are required to determine the threshold of cyclic loading that decreases the preload of abutment screw.

The abutments used in the present study were made from titanium alloy. The chemical composition of the titanium alloy, its manufacturing process, and its surface treatments can all affect the occurrence of abutment screw loosening [39]. The implant-abutment connection type also plays an effective role in screw loosening. Screw loosening in external hexagon connection type occurs due to vibrations and micromovements during function [40], [41]. It appears that external connection has a poor resistance against screw loosening because all the external force parameters are concentrated in the abutment screw. Screw loosening has a lower frequency in internal connection because the oblique position of the fixture relative to the abutment connection surface causes mechanical stability of the abutment due to friction and wedging effect [42], [43]. Reference [44] showed that use of anti-rotational component in implant system decreased the frequency of screw loosening, and the torque value sufficed (irrespective of the abutment connection type).

The important roles of optimal tightening of the abutment screw [45], [46], conformity of the components, low fabrication errors [47], and the magnitude of preload [18] in the stability of implant-abutment interface have been well documented. However, due to the availability of limited number of studies on the effects of long-term cyclic loading on screw loosening, a clinical decision cannot be made with certainty on this topic. Also, the reliability of the reported frequency values for screw loosening before and after cyclic loading should be further scrutinized due to the occurrence of plastic deformation and presence of cold welding.

This study had some limitations. It had an in vitro design, which limits the generalizability of the results to the clinical setting. Small sample size, and evaluation of only one type of implant-abutment connection were among other limitations of this study. Further studies are required to better simulate the clinical setting by applying different load cycles with higher frequencies and different angulations. Also, the cyclic loading threshold that causes a reduction in preload should be determined in further investigations. Last but not least, the frequency of screw loosening before and after cyclic loading based on the occurrence of plastic deformation and presence of cold welding should be evaluated.

V. Conclusion

According to the present results, application of lateral cyclic loads had no significant effect on screw loosening (detorque value) of Morse taper implant-straight abutment connection but insignificantly increased the torque loss.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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