Effect of Dynamic Cycles and Abutment Angle on The Screw Stability of Standard and Narrow Implants: An In vitro Study

Mehmet Esad Guven¹*, Aslihan Usumez²

¹ Department of Prosthodontics, Faculty of Dentistry, Necmettin Erbakan University, Konya, TR
² Private Practice, Dentalplus Implantology Center, Bakirkoy, Istanbul, TR

* Corresponding Author: Mehmet Esad Guven E-mail: meguven@erbakan.edu.tr

ABSTRACT

Objective: Screw loosening in implant-supported crowns is a common issue, leading to potential mechanical and biological complications. This study aimed to evaluate the combined influence of cyclic loading, abutment angulation, and implant diameter on screw torque loss in dental implants.

Material and Methods: A total of 80 bone-level implants, divided into standard and narrow diameters, underwent cyclic loading protocols. These implants were paired with straight and 15-degree angled abutments. The study assessed the reverse torque values (RTV) before and after loading, with a primary focus on the effects of cyclic loading, abutment angulation, and implant diameter on screw torque loss.

Results: Cyclic loading protocols and screw diameter significantly influenced screw torque loss. Standard diameter implants exhibited higher RTV compared to narrow diameter implants. While the role of abutment angulation was less definitive, narrow diameter implants with angled placements showed a pronounced decrease in RTV. The study also highlighted that even with optimal preload values, a percentage of the initial preload is lost, potentially leading to screw loosening.

Conclusion: Cyclic loading and screw diameter are pivotal determinants of screw torque loss in dental implants. The study underscores the need for careful consideration of implant diameter and abutment angulation, especially in narrow diameter implants with angled abutments, to ensure optimal implant stability.

Keywords: Dynamic loading; Cyclic loading; Reverse torque value; narrow implant; angled abutment

INTRODUCTION

Screw loosening is a commonly encountered problem with implant-supported crowns, which might lead to mechanical and biological complications. The tightening of the screw generates a clamping force between the implant fixture and the abutment that is known as preload, which pulls these two components to each other and withstands any external force or load applied. Optimal preload is achieved when the stress exerted on the screw reaches 60% to 75% of the screw material’s yield strength. However, mechanical complications such as instability, micro-movement, screw loosening, and screw fracture occur when the external force exceeds the preload.

In addition, even if optimal values are reached, 2% to 10% of the initial preload is lost due to the embedment relaxation of the implant screw, which may also lead to screw loosening. Therefore, the amount of remaining preload is a critical factor for the screw stability and can be expressed by the removal torque value (RTV), which is the amount of rotational force required to loosen the screw. Nevertheless, even without the loss of torque, RTV is lower than the initial preload due to the settling effect.
Cyclic loading has been shown to have a significant effect on abutment screw loosening in dental implants. Studies have demonstrated that dynamic cyclic loading can cause torque loss and lead to the loosening of abutment screws (14-17). The degree of loosening may vary depending on factors such as the implant system used, the type of abutment material, and the loading direction (14, 16). Cyclic loading can result in a gradual decrease in clamping force and rotational movement of the crown or titanium base (18). Additionally, it has been observed that cyclic loading can affect the resistance to rotation of abutment screws (9). These findings highlight the importance of considering the effects of cyclic loading when evaluating the stability and longevity of dental implant restorations.

The effect of abutment angle on abutment screw loosening has been studied in several research papers. A study by Al-Zordk et al. (19) evaluated the impact of abutment angulation on screw loosening in an in vitro study. The results indicated that screw loosening increased with increasing abutment angulations. However, another study by Jalalian et al. (20) found that lateral cyclic loading, which can be considered as an indirect measure of abutment angle, had no significant effect on screw loosening in Morse taper implant-straight abutment connections.

Understanding the combined effect of cyclic loading, implant diameter, and abutment angle on abutment screw loosening is crucial for optimizing dental implant treatments. This study evaluates the potential influence of cyclic loading, abutment angulation, and screw diameter on screw torque loss in dental implants. The findings will advance our understanding of the factors influencing screw stability and provide valuable insights for implant treatment planning and protocol optimization.

Based on the aforementioned findings, three null hypotheses have been established. Firstly, the null hypothesis (H₀1) states that different cyclic loading protocols do not have a significant effect on screw torque loss. Secondly, the null hypothesis (H₀2) posits that abutment angulation has no significant effect on screw torque loss. Lastly, the null hypothesis (H₀3) proposes that implant diameter does not have a significant effect on screw torque loss.

**MATERIAL and METHODS**

In the current study, a total of 80 bone level implants were utilized. Among these, 40 standard diameter implants (Tapered Plus 10 mm length, 3.5 mm Ø, BioHorizons, Birmingham, USA) were randomly paired with 20 straight abutments (Internal 3.5 mm Straight Esthetic Abutments, BioHorizons, Birmingham, USA) and 20 abutments angled at 15 degrees (Internal 3.5 mm, 15 Angled Esthetic Abutments, BioHorizons, Birmingham, USA) in commonly use on anterior region. Additionally, 40 narrow diameter implants (Bone Level optimoss 10 mm length, 3.2 mm Ø, BioInfinity, Istanbul, Türkiye) were randomly paired with 20 narrow straight abutments (BSAJN1 Junior straight abutment, Bio-Infinity, Istanbul, Türkiye) and 20 abutments angled at 15 degrees. (BAEJI5N1 Junior narrow esthetic abutment, BioInfinity, Istanbul, Türkiye) A priori power analysis (power = 95%, f= 0.22, α= 0.05) based on the results of the study of Mulla et al. (21) was performed, and 10 specimens per IAC–abutment pairs were deemed sufficient. For cyclic loading, a total of 300,000 cycles (equivalent to 15 months) and 600,000 cycles (equivalent to 30 months) were determined (15).

The implant/abutment/cycles combinations were divided into eight groups as follows:

- **SS-3:** Standard diameter implant with straight abutment subjected to 3\times10^5 cycles (n=10), SS-6: Standard diameter implant with straight abutment subjected to 6\times10^5 cycles (n=10), SA-3: Standard diameter implant with 15-degree angled abutment subjected to 3\times10^5 cycles (n=10), SA-6: Standard diameter implant with 15-degree angled abutment subjected to 6\times10^5 cycles (n=10), NS-3: Narrow diameter implant with straight abutment subjected to 3\times10^5 cycles (n=10), NS-6: Narrow diameter implant with straight abutment subjected to 6\times10^5 cycles (n=10), NA-3: Narrow diameter implant with 15-degree angled abutment subjected to 3\times10^5 cycles (n=10), NA-6: Narrow diameter implant with 15-degree angled abutment subjected to 6\times10^5 cycles (n=10).

Before conducting the tests, three assemblies consisting of implants, screws, and abutments were randomly selected and matched. To embed the implants, a cast-ämid material (Polikim, Polimer Chemical Industries, Kocaeli, Türkiye) was used, which has a Young’s modulus similar to that of bone, as recommended by Rho et al. (22). Custom castamid blocks were designed using Solidworks software (Solidworks 3D CAD; Massachusetts, USA) for both angled and straight abutment groups (Figure 1A). The upper surface of the angled abutment group was angled at 45 degrees, while that of the straight abutment group was angled at 30 degrees, in order to standardize a 30-degree load on anterior implants in accordance with ISO 14801 criteria (ISO 14801:2007, 2007) (Figure 1B,1C).

**Figure 1:** (A) Implant-houses design in software according to ISO 14801. (B) manufactured castamid blocks and paired implant abutments.
Additionally, implant houses were designed for narrow diameter implant groups with a diameter of 3.2 mm and a depth of 7 mm, as well as for standard diameter implant groups with a diameter of 3.5 mm and a depth of 7 mm. These designs were then milled using an industrial CNC milling machine (Deckel Maho DMU 60 MonobLOCK 5 axis, DMG Mori Akiengesellschaft, Bilafat, Germany). The implants were inserted into the blocks using an implant-level driver with a torque of 60 Ncm and a torque ratchet, mimicking the process of placing implants into the bone. (Figure 2) All implants were securely embedded in their respective osteotomy sites with a 3 mm space between the implant neck and the surface of the epoxy resin. (23) (ISO 14801:2007, 2007).

![Figure 2: The implants insertion into the blocks with torque ratchet.](image)

The procedure for designing crowns on abutments involved the utilization of a desk-top IOS (Dental Wings Inc. 7 series, 2251 Letourneux, Montreal, Quebec, Canada) to scan the abutments and then transfer the data to a virtual environment. The external shapes of the crowns were created through CAD software (Dental Wings DWOS 7 software, Letourneux, Montreal, Quebec, Canada) for 40 abutments consisting of 20 standard and 20 narrow straight abutments, as well as 20 standard and 20 narrow angled abutments that were suitable for simulating the #11 central incisor (Figure 3A). Laser sintering devices (EOSint M270, EOS GmbH Electro-optical System, Munich, Germany) along with Cr-Co (Chrome-Cobalt) (Cara CoCr SLM, Heraeus Kulzer GmbH, Hanau, Germany) alloy were used to manufacture the crowns (Figure 3B). A cement gap of 40μm was set in the soft-ware for the crowns, and a screw hole was engineered on the buccal surface with a diameter matching that of the abutment screw to ensure direct access to the screw after-cyclic loading.

The intaglio surfaces of Co-Cr crowns and abutments underwent cleaning with steam pressure at 2 atm for a duration of 10 seconds followed by sandblasting with 50 micrometers of Al2O3 at a pressure of 1 bar from a distance of 15 mm. The surfaces were then steam cleaned for 15 seconds and air dried. The intaglio surface of the crowns was subsequently treated with a universal primer (Monobond Plus, Ivoclar Vivadent, Liechtenstein) applied for 60 seconds, followed by the application of resin cement (Multilink Hybrid Abutment, Ivoclar Vivadent, Liechtenstein) and curing as per manufacturer’s recommended guidelines (Figure 4A-4B). Before measuring the initial reverse torque values, the Castamid block specimen was securely attached to a custom-made metallic mounting fixture using metallic screws to ensure that it remained perpendicular to the parallelometer holder. The screws and inner surface of all implants were subsequently subjected to a 1 mL saline wash to emulate the conditions of the oral environment (24). In adherence with the manufacturer’s guidelines, we employed a digital torque gauge (Checkline TSD-50 screwdriver by ELECTRUMATIC Equipment Co. Inc, Lynbrook NY, USA) mounted with original screwdriver tips provided by the respective manufacturers. The abutment screws were tightened as close as possible to the manufacturer’s recommended torque values, which were 30 Ncm for standard diameter implants and 25 Ncm for narrow diameter implants. The Initial Torque Value (ITV1) was recorded for each restoration. (Figure 4C) Subsequently, after an hour had elapsed, the screw was loosened, and the maximum value recorded was denoted as RTV. This entire process was repeated three times for each sample to simulate real clinical and laboratory scenarios. After calculating the average, the resulting value was saved as RTV1. After measuring RTV1, all samples were subsequently re-tightened to the recommended torque value using the new abutment screw, following the procedure outlined above, and recorded as ITV2.

![Figure 4: Placement of kestamid blocks with (A) straight (B) angled abutment samples into chewing simulator housing. C) applying torque with digital torque gauge.](image)

Figure 3: (A) CAD image of crowns and access hole design. (B) Buccal view of laser sintered manufactured crowns.
The crown–implant pairs after being tightened were then mounted on the chewing simulator (CS-4.2, SD Mechatronik GmbH, Feldkirchen-Westemmer, Germany) at a 30° degree off-axis from the loading direction (1, 2, 5, 9, 21, 25, 26). A software program (Excel, Microsoft Corp.) was used to randomize the specimen positions on the chewing simulator.

The crowns underwent cyclic loading at a frequency of 1.6 Hz, with a 50 N load, to simulate various aging procedures. A 6mm steel tip was used to apply the load on the singulum region. The vertical displacement of the tips was 1.5 mm, while the lateral displacement was 0.7 mm. Following cyclic loading, the crowns were once again checked, and peak RTVs were recorded (RTV2). The percentage torque loss following 1 h (ITV1 and RTV1) after cyclic loading (ITV2 and RTV2) were calculated using the given formula (27):

\[
((\text{ITV}−\text{RTV}) / \text{ITV})×100 \tag{1}
\]

Loss ratio of reverse torque (LRT) between initial and after loading (%) was calculated by using the formula:

\[
((\text{RTV1}-\text{RTV2}) / \text{RTV1}) \times 100 \tag{2}
\]

**Statistical Analyses**

Repeated measures ANOVA was utilized to compare the means of the initial and post-loading reverse torque value ratios among various groups and subgroups. Post-hoc tests were conducted using Tukey’s method at a significance level of 0.05. Mauchly’s W test was utilized to assess sphericity, while normality was assessed using the Shapiro-Wilk test and homogeneity of variances was assessed using Levene’s test. All assumptions were met. LRT values were analyzed using one-way ANOVA. Differences in means greater than the Tukey post-hoc value were considered statistically significant at a P < 0.05 level. Statistical analysis was performed using Jamovi version 2.3.21 (Jamovi Inc, USA).

**RESULTS**

Mean ± SD of initial, after loading reverse torque loss ratio and % differences RTV’s are presented in (Table-1) and (Figure 5).

The table demonstrates that the factor "RTV Cycles" and its interaction with the variable "Group" have a significant impact on the dependent variable (p<0.05). This highlights the importance of considering temporal changes and group distinctions during the analysis. It was observed that RTV1 was significantly higher than the RTV2 across all the groups (p<0.05).

Upon comparison of RTV measurements before and after loading, it was found that all standard diameter subgroups (SS-3, SS-6, SA-3, SA-6) showed a significantly higher RTV compared to all narrow diameter subgroups (NS-3, NA-6, NS-3, NA-6) (p<0.05). Initially, there were no observable differences in the subgroups within both standard and narrow diameter implants (p>0.07). Regardless of the cycle count, no significant disparities were observed between the subgroups within the standard diameter groups (p>0.535).

Among the narrow diameter groups, the NS3 group had a significantly lower torque loss compared to the NS-6, NA-3, and NA-6 groups (p<0.007). While the NS-6 group showed a significantly reduced torque loss compared to the NA-6 group (p=0.04), its values were similar to those of NA-3 (p=0.9). There was no significant difference between the NA-3 and NA-6 groups (p=0.88).

When evaluating the LRT values between the initial and after-loading phases, the standard diameter groups demonstrated a statistically significant lower LRT compared to the narrow diameter groups (p<0.01). Among the standard diameter groups, the SA-6 group displayed a more pronounced percentage torque change compared to the SS-3, SS-6, and SA-3 groups (p<0.05). No significant variance was found between the SS-3, SS-6, and SA-3 groups (p>0.80). Among the narrow diameter groups, the NS3 group exhibited a notably reduced LRT in comparison to the NS-6, NA-3, and NA-6 groups (p<0.05). While the NS-6 group aligns closely with the values of NA-3 (p=0.97), it demonstrated a significantly reduced LRT value when compared to the NA-6 group (p=0.04). The NA-3 and NA-6 groups, on the other hand, exhibited comparable LRT values.

**Table 1:** Descriptive statistic ((mean ±standard deviation and median (min-max) values) of In-nital, after loading and % differences of RTV’s. Uppercase letters indicate differences be-tween groups, and lowercase letters indicate differences between RTV1 and RTV2.

<table>
<thead>
<tr>
<th>Group</th>
<th>Initial (%RTV1)</th>
<th>Mean± SD</th>
<th>Median (Min-Max)</th>
<th>After Loading (%RTV2)</th>
<th>Mean± SD</th>
<th>Median (Min-Max)</th>
<th>% Difference (LRT)</th>
<th>Mean± SD</th>
<th>Median (Min-Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS-3</td>
<td>7.28±0.93 Aa</td>
<td>7.22 (6.1-8.53)</td>
<td>11.9±2.40 Ab</td>
<td>11.5 (8.15-17.57)</td>
<td>4.99±2.35 Aa</td>
<td>4.51 (2.02-10.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-6</td>
<td>8.3±0.96</td>
<td>8.43 (6.57-9.67)</td>
<td>13.17±2.48 Ab</td>
<td>13.2 (10.16-13.63)</td>
<td>5.31±2.67 Aa</td>
<td>5.07 (1.46-9.25)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA-3</td>
<td>6.85±1.53 Aa</td>
<td>7.12 (3.33-8.47)</td>
<td>12.4±2.44 Ab</td>
<td>11.5 (8.3-16.3)</td>
<td>5.52±2.69 Aa</td>
<td>4.3 (2.28-10.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA-6</td>
<td>5.66±1.44</td>
<td>5.22 (3.53-8)</td>
<td>14.89±1.78 Ab</td>
<td>14.35 (13.3-19.3)</td>
<td>9.78±1.58 B</td>
<td>9.19 (7.93-12.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-3</td>
<td>18.8±1.74 Ba</td>
<td>19.2 (15.47-20.93)</td>
<td>31.56±1.63 Bb</td>
<td>31.6 (28.8-34)</td>
<td>15.71±1.31 C</td>
<td>15.82 (13.71-17.64)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS-6</td>
<td>18.61±1.77 Ba</td>
<td>19.07 (15.47-20.67)</td>
<td>35.8±2.15 C</td>
<td>35.4 (33.2-40)</td>
<td>21.18±3.24 DE</td>
<td>20.28 (17.33-26.67)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NA-3</td>
<td>20.39±1.14 Ba</td>
<td>20.73 (18.73-21.73)</td>
<td>36.6±3.05 CDb</td>
<td>36.6 (32.8-40.8)</td>
<td>20.3±4.82 B</td>
<td>19.55 (14.29-26.97)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NA-6</td>
<td>20.15±1.12 Ba</td>
<td>19.73 (18.93-21.73)</td>
<td>39.72±1.92 Db</td>
<td>39.6 (37.2-43.6)</td>
<td>24.48±3.16 E</td>
<td>24.43 (19.9-30.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

The primary aim of this study was to examine the impact of cyclic loading protocols, abutment angulation, and implant diameter on screw torque loss. The findings obtained from the analysis offer significant insights that contradict the proposed null hypotheses.

According to our first null hypothesis (H₀₁), which states that different cyclic loading protocols do not have a significant effect on screw torque loss, our findings suggest the opposite for narrow and standard diameter implants. The table's data clearly demonstrates that the factor "RTV Cycles," along with its interaction with "Group," significantly influences the dependent variable. Our study shows that RTV1 values were considerably higher than RTV2 values in all groups, ultimately indicating that cyclic loading protocols play a critical role in determining screw torque loss, contradicting H₀₁. Coppede et al. (28) found comparable outcomes in their study, which examined the impact of mechanical loading and repeated installation/removal cycles on torque loss in internal tapered connection abutments. Likewise, Cardoso et al. (29) demonstrated that consistent insertion and removal cycles caused a gradual decline in screw removal torque. Cho et al. (30) demonstrated that cyclic loading reduced the RTV, irrespective of whether it had an external or internal hex connection.

The second null hypothesis (H₀₂) proposed that abutment angulation has no significant impact on screw torque loss. No significant differences were observed among sub-groups for standard diameter implants. However, in narrow diameter implant groups, the placement at an angle affected screw loosening values. Therefore, H₀₂ cannot be definitively rejected. Research has shown that implant diameter is critical in withstanding loads, as demonstrated by Allum et al. (31). This study demonstrate that narrow diameter implants have lower resistance to loads. However, Sousa et al. (32) found that angled abutments have a lower capacity to maintain the initial preload value.

By increasing the number of cycles, it can be possible to enhance the visibility of the interaction between the diameter and angle.

The third null hypothesis (H₀₃) asserts that implant diameter does not have a significant impact on screw torque loss. Our study provides compelling evidence against this hypothesis. Specifically, we found that the standard diameter groups experienced significantly higher RTV than the narrow diameter subgroups. Additionally, the NS-6 group in the narrow diameter categories demonstrated a substantial decrease in torque loss when compared to other groups. These results clearly highlight the effect of screw diameter on torque loss and lead us to reject H₀₃. Shenov-Yona et al. (33) investigated the effect of dynamic loading on implant diameter, and This study found that implant diameter has a significant impact on fatigue behavior, with narrow implants (3.3 mm diameter) failing to show typical fatigue behavior.

The "percentage torque change" assessment provided additional evidence against hypothesis H₀₃. The groups with standard diameters showed a statistically significant lower likelihood ratio test (LRT) compared to the groups with narrow diameters. Moreover, the variations in torque change percentages within the groups highlighted the influence of screw diameter on the outcomes. The preload value determines the magnitude of torque applied to each screw. In the case of narrow diameter implants, a lower initial torque value was used, resulting in a reduced preload value (4). This phenomenon is likely to have negatively affected the stability of the screw-abutment connection during dynamic loading in narrow diameter groups. Zipprich et al. (34), in their study investigating the effects of tightening torque, screw head angle, and abutment screws on the preload force, found that the tightening torque showed an approximately linear correlation with preload force.
In present study, although the number of threads and neck design of the screws, material type used were the same. Variations in screw diameter (1.8 mm versus 1.6 mm) led to distinct ITV’s as recommended by manufacturers, coupled with differences in preload force. Such disparities might have influenced the results observed.

In summary, our findings provide a robust challenge to the proposed null hypotheses. Cyclic loading protocols and screw diameter emerge as significant determinants of screw torque loss. Although the role of abutment angulation remains less clear in our data, future research may focus more on the interaction of angulation, diameter, and cyclic loading number. As with all studies, it’s essential to consider the potential limitations and the specific context in which the research was conducted. Further studies, potentially with a broader range of implants and more varied loading protocols, will be invaluable in refining our understanding of these dynamics.

CONCLUSION

Within the limitations of this study:

1. Dynamic loading protocols tend to reduce reverse torque values.
2. Narrow diameter implants yield lower reverse torque values and higher loss ratio reverse torque when subjected to the same dynamic loading protocol.
3. Particularly in narrow diameter implants with angled abutment placements, there’s a more pronounced decrease in reverse torque values and percentage torque loss. Caution should be exercised regarding abutment-implant stability when especially using narrow diameter implant with angled abutments.

Acknowledgements: None

Conflict of interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contributions: Conceptualization, M.E.G. and A.U.; methodology, M.E.G.; software, M.E.G.; validation, A.U.; formal analysis, M.E.G.; investigation, M.E.G.; resources, M.E.G.; data curation, A.U.; writing—original draft preparation, M.E.G.; writing—review and editing, A.U. and M.E.G.; visualization, M.E.G.; supervision, A.U.; project administration, A.U.; All authors have read and agreed to the published version of the manuscript.

Ethical approval: The present study was conducted in strict accordance with the principles outlined in the Declaration of Helsinki. Ethical approval for the study was obtained from the appropriate ethics committee, and all participants provided informed consent before participating in the study.

REFERENCES


Copyright © 2023 The Author(s); This is an open-access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), (CC BY NC) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. International Journal of Medical Science and Discovery.