The Effect of Repeated Closing Torque on Torque Loss and Angular Deviation: An In Vitro Study

Ruoyan Guo, DDS, PhD[1†]
Yantao Qian, UG[2†]
Guohai Lin, UG[2]
Run Chen, DDS[1*]

Loosening and fracturing of the central screw are common mechanical complications after implant restoration. However, the relationship between these complications and the repetitive tightening and loosening of the central screw during the fabrication and maintenance of the implant-supported restorations remains unknown. The purpose of this study was to evaluate the torque loss after repetitive tightening and loosening of the central screws on implants with different diameters as well as the changes in the angle deviation of the central screw relative to the implant. Twenty implants were divided into 2 groups based on diameter: 3.7 mm (group A) and 4.5 mm (group B) with 10 implants in each group. Each group was subdivided into 4 subgroups: A1, A2, B1, and B2 ($n = 5$). A closing torque of 15 N.cm was applied to groups A1 and B1, whereas a closing torque of 35 N.cm was applied to groups A2 and B2. Reverse torque measurements were taken 10 times for each group. The angular deviation of the central screw relative to the implant was recorded, and the surface wear of the central screw was observed under a scanning electron microscope. The data were analyzed using repeated measures 2-way analysis of variance ($\alpha = 0.05$). Torque loss showed a significant upward trend across all groups with increased tightening cycle ($P < .05$). Implant diameter significantly influenced torque loss with smaller diameters exhibiting greater torque loss ($P < .05$). In addition, the angular deviation of the central screw relative to the implant was not affected by different diameters ($P > .05$). Still, it was affected by the closing torque and the cycles of multiple tightening and loosening procedures ($P < .05$). Under a 35 N.cm closing torque, initial torque loss ranged from 9.12 N.cm to 10.98 N.cm. Peak torque loss occurred at the 10th cycle with 16.40 N.cm values for 3.7-mm implants and 12.42 N.cm for 4.5-mm implants. Repeated tightening and loosening procedures increased both torque loss and angular deviation. The diameter of the implant may impact the torque loss with a larger diameter showing less torque loss. To reduce the risk of potential complications, it is suggested that the number of tightening cycles for narrow-diameter implants be limited.

Key Words: central screws, torque loss, angular deviation, diameter, closing torque

INTRODUCTION

A central screw for securing the abutment often suffers loosening and fracturing, which are common mechanical complications after implant restoration. Previous research has consistently reported that the loosening rate of central screws in implant restoration is approximately 7%–11%, accompanied with a fracture rate of 0.6%.[1–4] This complication can potentially lead to the loosening of the abutment and even peri-implantitis.[3,4] The torque loss is one of the main reasons for central screw loosening.[5] When a screw is tightened by applying torque, it elongates and produces tension, which is called preload.[6] Only by overcoming this preload can the central screw be loosened. The torque applied when loosening the central screw is called the reverse torque, and the difference between it and the initial closing torque is referred to as torque loss. Factors influencing torque loss include closing torque, the material of the central screw and implant, surface roughness of threads, settlement of the screw, and design of the central screw head.[5,6]

In addition, dental technicians must repeatedly tighten and loosen the central screw manually during the fabrication of implant restoration. Subsequently, dentists may also repeatedly tighten and loosen the central screw during the try-in process. Furthermore, if the implant restoration breaks or needs to be removed for maintenance, the central screw must again be repeatedly tightened and loosened. Therefore, it is crucial to determine whether frequent tightening and loosening of the central screw affects the torque loss.

Haack et al[7] considered that multiple tightening and loosening smooths the central screw's surface, reducing friction and causing elongation, which gradually increases the torque value. Vinhas et al[8] demonstrated that multiple tightening and loosening resulted in a higher torque value than a single tightening. Tzenakis et al[9] found that multiple tightening and loosening of the central screw over 10 cycles increased the torque value. However, Khraisat et al[10] subjected the central

[1] Fujian Key Laboratory of Oral Diseases & Fujian Provincial Engineering Research Center of Oral Biomaterial & Stomatological Key Laboratory of Fujian College and University, School and Hospital of Stomatology, Fujian Medical University, Fuzhou, PR China.
[2] School of Stomatology, Fujian Medical University, Fuzhou, PR China.
[†] Ruoyan Guo and Yantao Qian both are the co first author.
[*] *Corresponding author,* e-mail: 362484808@qq.com
https://doi.org/10.1563/aaid-joi-D-24-00143

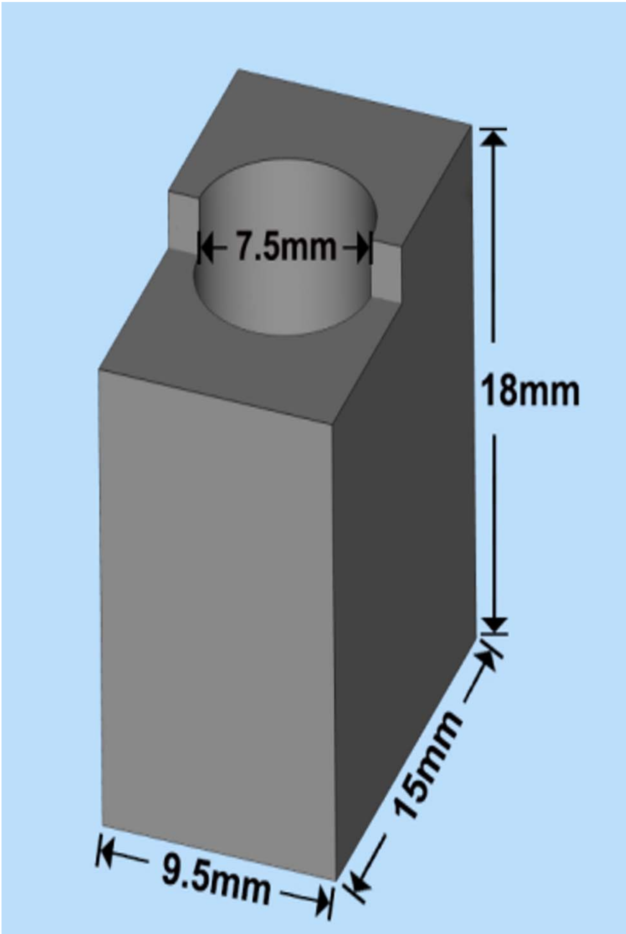

Figure 1. Resin mold design diagram.

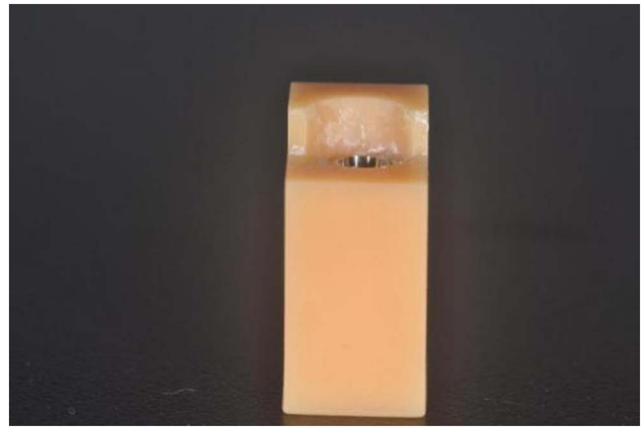

Figure 2. Implant-embedded specimen.

screws of an external hexagon implant system to dynamic loading for 1.0 million and 0.5 million cycles, discovering that long-term fatigue significantly decreased the torque values. Weiss et al[11] discovered a gradual decrease in reverse torque after 200 cycles of tightening and loosening of the central screw across 7 implant systems, attributing this to a reduction in the screw's antiloosening capability due to repeated cycles. Cardoso et al[12] found that repeated tightening and loosening of the screw reduced its reverse torque, and replacing it after 10 cycles did not affect its anti-loosening ability. Ortorp et al and Byrne et al[13,14] pointed out that the preload would decrease after repeated tightening and loosening. Copede et al[15] evaluated the Morse taper implant–abutment connection and found that the abutment's reverse torque would decrease gradually with the increase of tightening and loosening times. Therefore, there is still controversy regarding whether repeatedly tightening and loosening the central screw affects the preload.

Furthermore, implants are available in multiple diameters, and research has demonstrated that implants with differing diameters undergo varying stress.[16] Sometimes, implants with different diameters are fitted with central screws of the same size. In addition, there is limited reporting on the impact of implant diameter on the preload of the central screw. Meanwhile, there are currently very few reports on whether repeated tightening and loosening of the central screw can cause changes in its position relative to the implant even though such changes may potentially affect the mechanical properties of the central screw.

Therefore, this study assesses the changes in torque loss after repetitive tightening and loosening of the central screws on implants with different diameters. Additionally, the study aims to evaluate the angular deviation of the central screws relative to the implant after repetitive tightening and loosening cycles and to observe the surface wear of the central screws using a scanning electron microscope.

The null hypotheses were that (1) repeatedly tightening and loosening the central screw, the different diameters of implants will not affect the endpoint of the central screw relative to the implant, nor torque loss; (2) repeatedly tightening and loosening the central screw, the different closing torque will not affect the endpoint of the central screw relative to the implant, nor torque loss.

Material and Methods

Twenty new implants (Superline, Dentium, Korea) with diameters of 3.7 mm (group A) and 4.5 mm (group B) were used with 10 implants in each group as well as 20 brand-new central screws. The central screws were each randomly paired with an implant from either group A or group B using the random number method. Then, groups A and B were further divided into 4 subgroups (A1, A2, B1, and B2, n = 5).

Preparation of specimens

As illustrated in Figure 1, the resin model was created using 3D printing technology (3D printer, Times Pioneer). The implant was embedded along its axis with epoxy resin (Figure 2). A disc with an outer diameter of 5 mm, an inner diameter of 2.5 mm, and a thickness of 1.5 mm was printed. The disc was secured to the top of the central screw through bonding (Figure 3).

Figure 3. Central screw specimen.

Measurement item

Torque Loss

After inserting the central screw into the implant, a digital torque measurement device (e-Dynamic) was used to apply the preset torque to the central screw and measure the reverse torque (Figure 4). The device was calibrated before use. The closing torque was set to 15 N.cm for groups A1 and B1 and 35 N.cm for groups A2 and B2. After loading, the specimens were allowed to rest for 10 minutes. The central screw was then loosened in the reverse direction, and the peak reverse torque value was recorded. This process was repeated for 10 cycles. The difference between the preset closing torque value and the reverse torque value is defined as torque loss.

Angular Deviation

For each specimen, after the first loading to the preset torque value, the endpoint of the central screw relative to the implant was marked, and a photograph was taken. In subsequent cycles, a photograph was taken each time the central screw was tightened to the preset torque. This process was repeated 10 times. The camera position was kept fixed to ensure it remained perpendicular to the specimen surface. The photographs were then imported into software (Photoshop 2023, Adobe) to analyze changes in the endpoint position of the central screw relative to the implant. The software measured the angle based on the displacement of the marking lines (Figure 5). The measured angle represents the angular deviation.

Observation of the thread surface under scanning electron microscope (SEM)

Before the initial insertion into the implant and after the 5th and 10th cycles, the central screws were subjected to ultrasonic oscillation in anhydrous ethanol for 2 minutes. After drying, the thread surface was observed using an SEM. Marks were made on the resin disc to ensure observations were conducted at the same position (Figure 6).

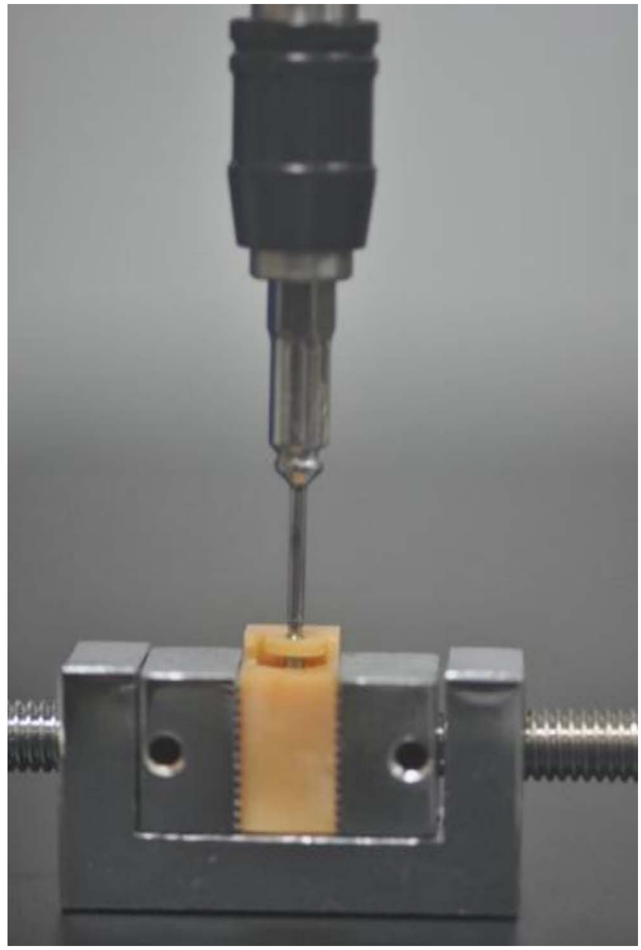

Figure 4. Torque test.

Statistical analysis

The data were analyzed using SPSS 26. The Shapiro–Wilk and Levene tests confirmed the assumptions of normal distribution and homogeneity of variance, respectively. A 2-way repeated-measures analysis of variance and multiple paired *t*-tests with Bonferroni correction were performed to analyze the effects of repeated tightening and loosening on torque loss and angular deviation ($\alpha = 0.05$).

Results

As the multiple tightening cycles increased, the torque loss in all 4 groups showed a significant upward trend ($F = 27.708$, $P < .05$, Figure 7). There was a statistically significant difference in torque loss among different diameters ($P < .05$). The torque loss increased with the cycles of multiple tightening and loosening procedures ($P < .05$). In addition, the endpoint of the central screw was not affected by different diameters ($P > .05$). However, it was affected by the closing torque and the cycles of multiple tightening and loosening procedures ($P < .05$). When the closing torque was 15 N.cm, there was no statistically significant difference in torque loss regardless of implant diameter ($P > .05$, Table 1). When the closing torque was increased to 35 N.cm, the torque loss of different diameters

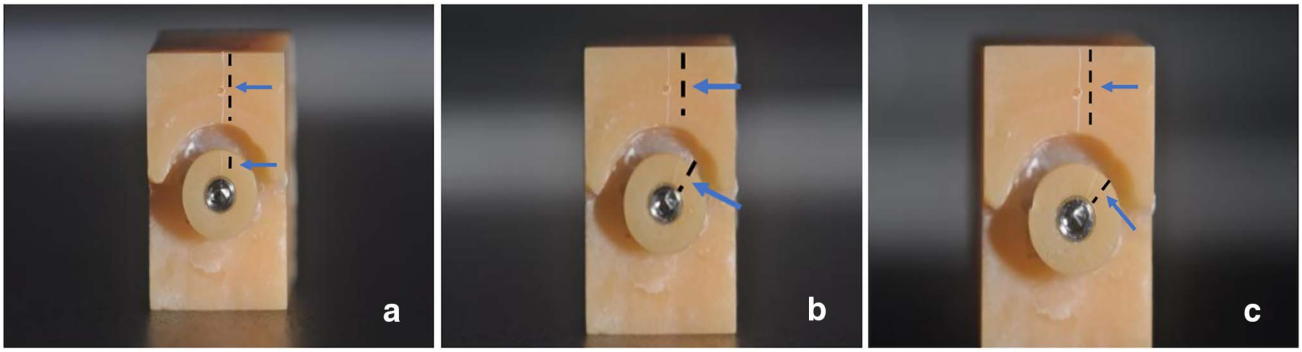

Figure 5. Position marking of central screw and angular deviation. Note position of the arrows. (a) Initial loading of closing torque. (b) Fifth loading of closing torque. (c) Tenth loading of closing torque.

varied significantly ($P < .05$). Compared with the diameter of 4.5 mm implants, the diameter of 3.7 mm implants exhibited greater torque loss. When subjected to a standard closing torque of 35 N.cm, the initial torque loss ranged from approximately 12.42 N.cm to 16.40 N.cm in both diameters of the implants. As the loss of torque gradually increased with the number of cycles ($P < .05$), the peak torque loss was found at the 10th loading (3.7 mm: 16.40 N.cm; 4.5 mm: 12.42 N.cm). According to the results of the paired *t*-test, the differences in torque loss between the first, second, and sixth of each group had statistical significance ($P < .05$), whereas the differences in torque loss between the third, fourth, and fifth of each group had no statistical significance ($P > .05$). The difference in torque loss among the seventh through 10th groups was not statistically significant ($P > .05$).

With increasing cycles of multiple tightening and loosening procedures, the angular deviation exhibited a significant upward trend in all groups ($F = 192.267$, $P < .05$, Figure 8). The diameter of the implant didn't affect the angular deviation ($P > .05$), but the closing torque was affected ($P < .05$). As the closing torque increased, the angular deviation increased (Table 2).

Observation under an SEM revealed that, with an increasing number of repeated tightening and loosening cycles, the threads of the central screws in the 4 groups exhibited varying degrees of wear. The wear predominantly occurred at the first and second threads and was more pronounced in groups A2 and B2 compared with groups A1 and B1 (Figure 9).

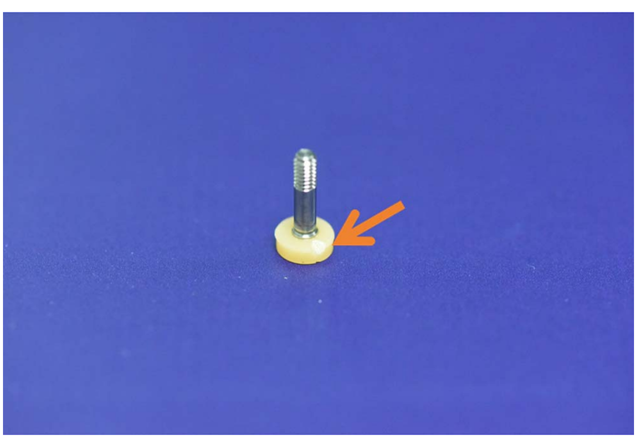

Figure 6. Marking on circular plate.

Discussion

According to the result, the null hypotheses were both rejected. There is no statistical difference in torque loss at a closing torque of 15 N.cm regardless of diameter size whereas, at a closing torque of 35 N.cm, there is a statistical difference in torque loss at different diameters. Torque loss increased with the number of multiple tightening and loosening cycles. The angular deviation was independent of diameter and depended on the closing torque's magnitude and the number of multiple tightening and loosening cycles. The more cycles and the greater the closing torque, the greater the angular deviation was.

Preload is the initial load of a screw when torque is applied. It is a crucial factor for the stability of screw connections and is influenced by various mechanical factors.[10] The relationship between closing torque and preload depends on multiple factors, including screw geometry, material properties, surface texture, lubrication, rate of tightening, and the integrity of the joint.[17] Consequently, preload refers to the torque maintained at the interface between the central screw and the implant after loading. The closing torque can represent the magnitude of preload. The difference between the closing and preload (reverse torque) is termed torque loss.

The diameter of the implant is a crucial factor influencing its mechanical stability. The implant's size and geometry affect the internal stress distribution and magnitude within the implant as noted in the Tolman and Laney[18] study. Tuzzolo[19] also showed that with an increase in implant diameter, mechanical properties, such as tensile strength and maximum bending strength likewise increase. Izabela[20] found that the abutment diameter and crown retention type did not affect torque loss, but mechanical cycling increases torque loss, especially for small-diameter implants. Implants with small diameter are more prone to fatigue, deformation, and even fracture under the action of external force.[21] In this study, it was observed that there is a statistical difference in torque loss at different diameters at a closing torque of 35 N.cm.

In comparison, there is no statistical difference at 15 N.cm. In this study, the specifications of the central screw used are

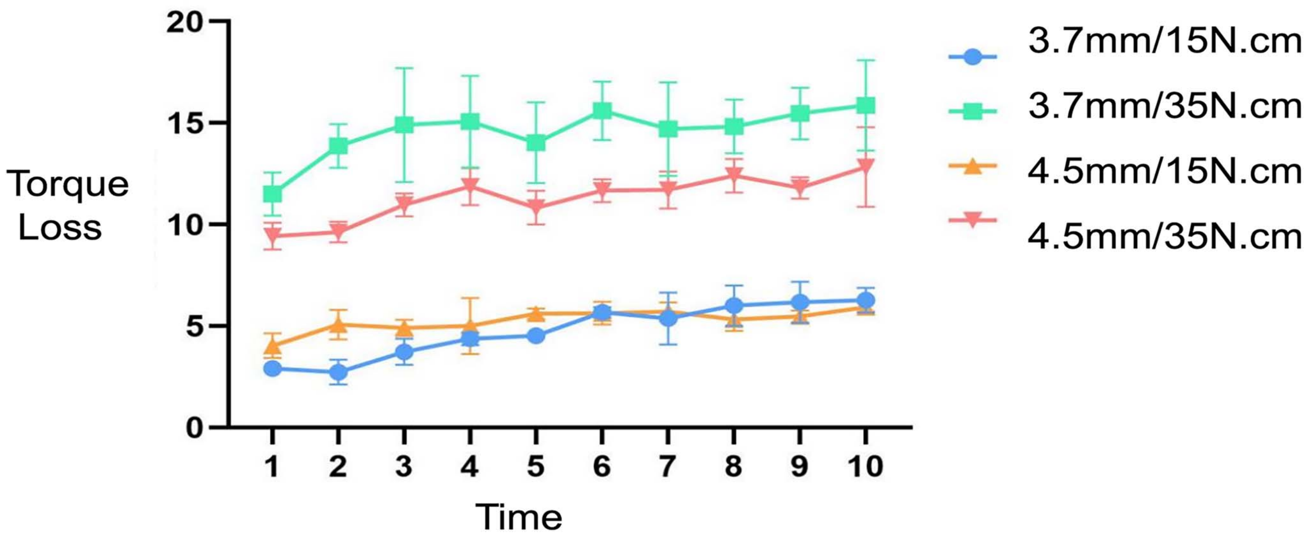

Figure 7. Line graph of torque loss for 4 groups.

consistent. Therefore, after reducing the space required for the central screw, the wall thickness of the smaller diameter implant is smaller than that of the larger diameter implant. Therefore, the axial wall of small-diameter implants may undergo more pronounced flexural deformation under the action of torque, adversely impacting the engagement between the central screw and the internal threads of the implant and consequently leading to increased torque loss.

In this study, 2 closing torque values were used. A torque of 15 N.cm was used to simulate the manual tightening of the central screw, which commonly occurs during the fixation of the abutment in the laboratory for the fabrication of the upper prosthesis as well as during clinical try-ins. For the final closing torque of the abutment, recommendations vary between 15 and 35 N.cm, depending on the implant system, central screw diameter, design, and material.[22–24] In this study, we selected 35 N.cm, which is more commonly used in clinical practice. It can be observed that the magnitude of the closing torque significantly affects the required reverse torque to loosen the central screw. In this study, significant torque loss occurred after repetitive tightening and loosening with closing torques of 15 and 35 N.cm. When the closing torque was 15 N.cm, there was no statistically significant difference in torque loss between different diameter groups ($P > .05$, Table 1). However, when the closing torque was increased to 35 N.cm, there was a significant difference in torque loss between the different diameter groups ($P < .05$). Compared with implants with a diameter of 4.5 mm, implants with a diameter of 3.7 mm experienced greater torque loss. Nirosa[25] tested reverse torque of bone and soft tissue levels with a closing torque of 35 N.cm. They found that the average reverse torque at the bone level decreased to 20.31 ± 2.55 N.cm, and at the soft tissue level, it decreased to 16.80 ± 3.25 N.cm. Fernando et al[26] mentioned that, when applying a torque of 30 N.cm, the average reverse torque was 19.1 ± 2.60 N.cm. Weiss et al[11] found that, after applying a torque of 20 N.cm to 7 different implant systems and repeating the process for 10 cycles, the maximum average reverse torque was 19.8 ± 0.7 N.cm, whereas the minimum average reverse torque was 15.0 ± 0.2 N.cm. It can be deduced that a higher closing torque induces more significant plastic deformation in the central screw and its contact surface with both the implant and abutment. The deformation of these components accumulates reverse energy, resulting in a significant decrease in reverse torque relative to the applied closing torque.

In this study, at the final tightening torque of 35 N.cm, the torque loss after the first tightening reached 9.12 N.cm. This indicates that the residual preload was insufficient, increasing the likelihood of central screw loosening. Studies[22–24] have shown that the required final tightening torque varies among different implant brands due to differences in manufacturing processes. Therefore, further experimental studies are needed to determine the appropriate final tightening torque and

Table 1

Torque loss in each group ($\overline{x} \pm s$)*

Group	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	10th	P
A1	2.88 ± 0.13^A	2.86 ± 0.47^A	3.76 ± 0.46^A	4.42 ± 0.24^A	4.50 ± 0.07^A	5.42 ± 0.38^A	5.38 ± 0.90^A	5.84 ± 0.73^A	6.14 ± 0.72^A	6.56 ± 0.69^A	<.05
A2	10.98 ± 1.05^B	13.10 ± 1.38^B	13.50 ± 2.79^B	13.94 ± 2.24^B	13.46 ± 1.61^B	15.52 ± 1.14^B	14.96 ± 1.67^B	15.48 ± 1.29^B	15.68 ± 0.96^B	16.40 ± 1.75^B	<.05
B1	3.88 ± 0.54^A	4.68 ± 0.77^A	4.68 ± 0.43^A	4.90 ± 0.98^A	5.52 ± 0.22^A	5.42 ± 0.49^A	5.60 ± 0.35^A	5.40 ± 0.41^A	5.64 ± 0.32^A	5.92 ± 0.22^A	<.05
B2	9.12 ± 0.70^C	9.36 ± 0.61^C	10.24 ± 1.07^C	11.42 ± 1.00^C	10.80 ± 0.67^C	11.12 ± 0.89^C	11.60 ± 0.66^C	12.02 ± 0.80^C	11.88 ± 0.57^C	12.42 ± 1.51^C	<.05

*Same uppercase superscript letters within the same column show no statistically significant differences among the primers ($P > .05$).

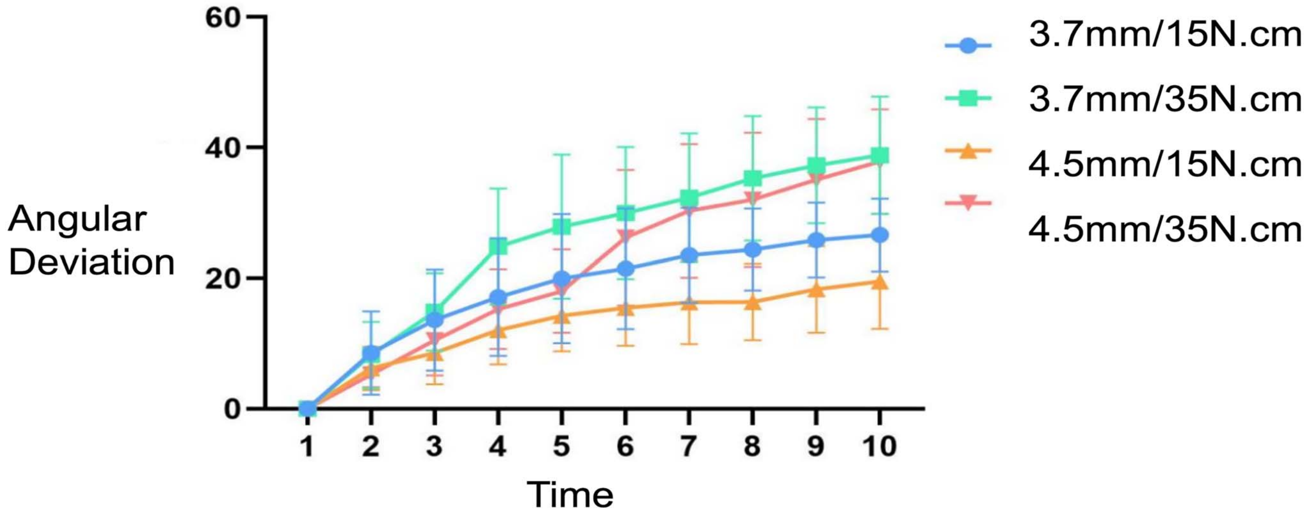

FIGURE 8. Line graph of angular deviation for 4 groups.

procedure for different implant systems to reduce central screw torque loss.

The study evaluated the positional changes of the central screw relative to the implant, namely, the angular deviation after repeated loading of the closing torque (Figure 8). Martin et al[27] have also conducted research on the change in rotation angle of central screws after torque loading, finding that, with increasing numbers of torque applications, there was no increase in the rotation angle. This is because they set the initial point as the position of the central screw when a torque of 5 N.cm was applied and then the endpoint as the position when a torque of 20 N.cm or 30 N.cm was applied. After each tightening, the surface morphology of the central screw inevitably changes, consequently altering the friction coefficient. Therefore, the initial position of the central screw under a torque of 5 N.cm varies. However, the method used in the present study is more objective and straightforward. Because the initial position of engagement between the central screw and the internal threads of the implant remains unchanged, we only need to mark the endpoint of the central screw relative to the implant at the first loading with the preset torque value to obtain the angular change after repeated loading.

In the present study, as the number of cycles increased, a significant change was observed in the endpoint position of the central screw relative to the implant. The angular deviation gradually increases. This phenomenon suggests that repeated tightening and loosening lead to thread wear, preventing the components from achieving the original closing torque in their initial positions. Consequently, new angles are generated, establishing a new meshing relationship between the components that reach the desired closing torque. The observations from an SEM support this possibility. The wear of the central screw primarily occurs at the head. When the closing torque is 15 N.cm, wear mainly appears on the first thread of the head, characterized by slight deformation and flattening of the thread peak. When the closing torque is 35 N.cm, wear predominantly occurs at the first and second threads of the head, manifested by collapse and breakage of the thread peak. Furthermore, as the number of cycles increased, both the degree and extent of wear intensified, indicating that new meshing relationships have been established in the new positions. The observation results of the central screw under the SEM corroborate the phenomenon of angular deviation.

In this study, after multiple tightening and loosening procedures using the same torque, a significant angular deviation was observed in the position of the central screw relative to the implant. Substantial torque loss occurred during the loosening of the central screw, and notable wear and damage were evident on the threads of the screw head. These findings suggest that multiple tightening and loosening increase the

TABLE 2

Angular deviation in each group ($\bar{x} \pm s$)*

Group	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	10th	P
A1	0^A	7.54 ± 4.76^A	11.52 ± 6.23^A	14.7 ± 7.34^A	17.14 ± 8.19^A	19.2 ± 7.55^A	21.96 ± 5.69^A	23.86 ± 4.88^A	25.62 ± 4.75^A	26.98 ± 4.94^A	<.05
A2	0^A	7.5 ± 3.79^A	14.36 ± 4.48^A	23.72 ± 6.65^A	27.98 ± 8.42^A	31.7 ± 9.33^A	33.96 ± 9.08^A	36.38 ± 8.32^A	38.24 ± 7.69^A	41.44 ± 7.63^A	<.05
B1	0^B	5.44 ± 2.61^B	7.72 ± 3.70^B	10.42 ± 4.50^B	12.38 ± 4.66^B	13.66 ± 4.82^B	14.72 ± 5.10^B	15.44 ± 4.40^B	17.02 ± 5.06^B	18.3 ± 5.41^B	<.05
B2	0^C	5.88 ± 1.64^C	11.22 ± 3.95^C	16.72 ± 4.79^C	19.98 ± 5.25^C	26.36 ± 7.33^C	30.86 ± 7.40^C	33.06 ± 7.76^C	35.74 ± 7.07^C	39.24 ± 6.07^C	<.05

*Same uppercase superscript letters within the same column show no statistically significant differences among the primers ($P > .05$).

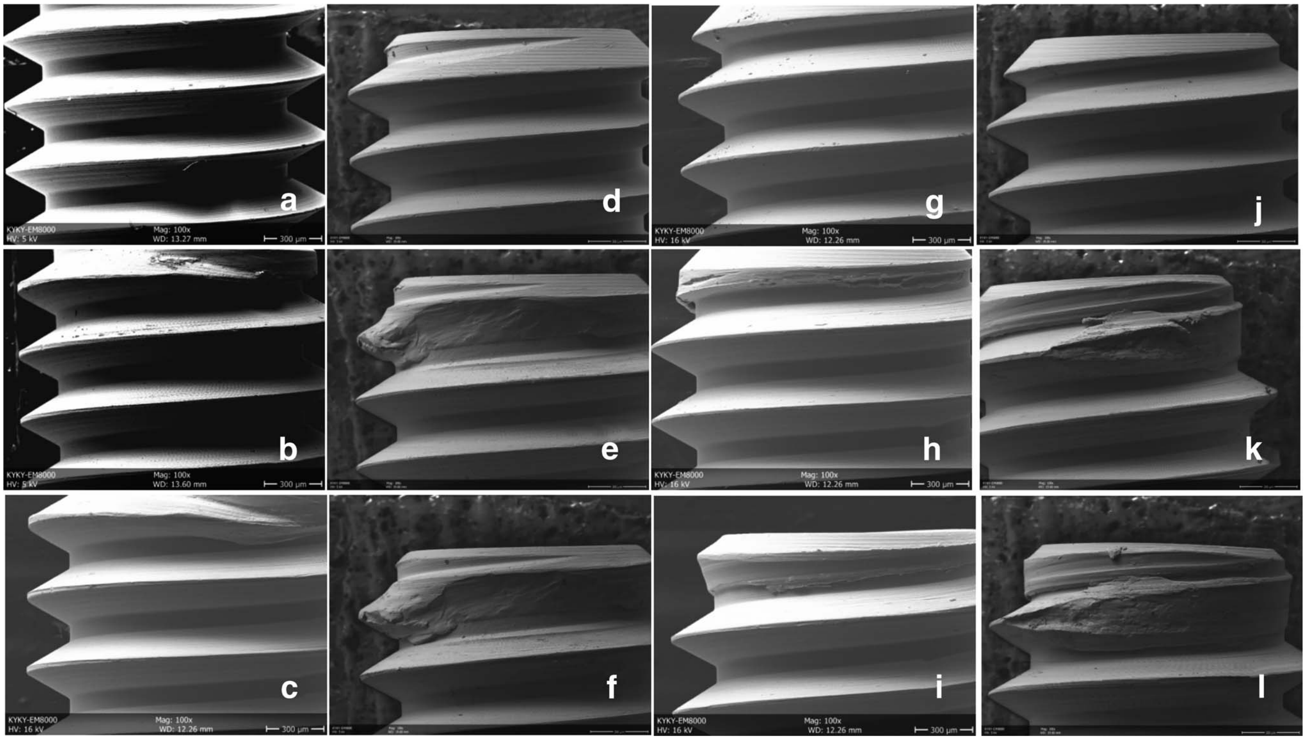

FIGURE 9. Scanning electron microscope images of central screws (×200). (a, b, c) A1 group, before applied, at the fifth and 10th cycles, respectively. (d, e, f) A2 group, before applied, at the fifth and 10th cycles, respectively. (g, h, i) B1 group, before applied, at the fifth and 10th cycles, respectively. (j, k, l) B2 group, before applied, at the fifth and 10th cycles, respectively.

risk of central screw loosening or even fracture. Therefore, it is imperative to minimize the frequency of tightening and loosening the screw. Additionally, during the fabrication of prostheses in the dental laboratory, it is advisable to utilize alternatives to the central screw. Weiss et al[11] considered that closing and opening cycles may range between 5 and 15 for average clinical and laboratory situations. Guzaitis et al.[28] argued that the central screw should be replaced with a new one after 10 cycles. The present study supports these viewpoints. Although there was no statistical difference in torque loss among the seventh to 10th cycles, the peak torque loss occurred at the 10th cycle (3.7 mm: 16.40 N.cm, 46%; 4.5 mm:12.42 N.cm, 30%). For the 35 N.cm torque group, which simulates the final restoration used, the torque loss ratio in narrow-diameter implants has exceeded 46%, undoubtedly increasing the risk of central screw loosening. Therefore, we recommend replacing the central screw after 10 uses, especially in small-diameter implants.

This study has several limitations. First, as it was conducted in vitro, the findings may not fully reflect in vivo conditions, posing a risk of extrapolation beyond the experimental context. However, investigating changes in the endpoint of the central screw relative to the implant after repeated torque applications necessitated an in vitro approach. Second, only one implant system was used in this study, and differences in implant materials between different implant systems might affect the results. Future studies incorporating a range of implant systems with more sophisticated designs are needed to validate the present findings.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

- Repeatedly tightening and loosening the central screw may lead to increased torque loss and angular deviation.
- Implant diameter appeared to influence torque loss with larger diameters tending to exhibit less torque loss.
- For narrow-diameter implants, it may be advisable to limit the central screw tightening to fewer than 10 times.

NOTE

Author contributions: RG designed the study and drafted the manuscript. YQ performed the data curation. GL was responsible for collecting data. RC was a project administrator and reviewed and edited the manuscript. This study was supported in part by the Fujian provincial health technology project (2022GGA043) and the Innovation and Entrepreneurship Training Program of Fujian Medical University (grant #KQ2023008). Ruoyan Guo and Yantao Qian contributed equally to this study (co–first author). The authors declare that they have no competing interests. All data files are available from the corresponding author upon reasonable request.

REFERENCES

1. Assuncao WG, Delben JA, Tabata LF, Barao VA, Gomes EA, Garcia IRJ. Preload evaluation of different screws in external hexagon joint. *Implant Dent*. 2012;21:46–50.

2. Katsavochristou A, Koumoulis D. Incidence of abutment screw failure of single or splinted implant prostheses: a review and update on current clinical status. *J Oral Rehabil*. 2019;46:776–786.

3. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. *Clin Oral Implants Res.* 2012;23:22–38.

4. Feitosa PCP, de Lima APB, Silva-Concilio LR, Brandt WC, Claro Neves AC. Stability of external and internal implant connections after a fatigue test. *Eur J Dent*. 2013;7:267–271.

5. Jörnéus L, Jemt T, Carlsson L. Loads and designs of screw joints for single crowns supported by osseointegrated implants. *Int J Oral Maxillofac Implants*. 1992;7:353–359.

6. Burguete RL, Johns RB, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. *J Prosthet Dent*. 1994;71:592–599.

7. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. *Int J Oral Maxillofac Implants.* 1995;10:529–536.

8. Vinhas AS, Aroso C, Salazar F, et al. In vitro study of preload loss in different implant abutment connection designs. *Mater*. 2022;15:1392.

9. Tzenakis GK, Nagy WW, Fournelle RA, Dhuru VB. The effect of repeated torque and salivary contamination on the preload of slotted gold implant prosthetic screws. *J Prosthet Dent*. 2002;88:183–191.

10. Khraisat A, Abu-Hammad O, Dar-Odeh N, Al-Kayed AM. Abutment screw loosening and bending resistance of external hexagon implant system after lateral cyclic loading. *Clin Implant Dent Relat Res*. 2004;6:157–164.

11. Weiss EI, Kozak D, Gross MD. Effect of repeated closures on opening torque values in seven abutment-implant systems. *J Prosthet Dent*. 2000;84: 194–199.

12. Cardoso M, Torres MF, Lourenço EJV, Telles DDM, Rodrigues RCS, Ribeiro RF. Torque removal evaluation of prosthetic screws after tightening and loosening cycles: an in vitro study. *Clin Oral Implants Res*. 2012; 23:475–480.

13. Örtorp A, Jemt T, Wennerberg A, Berggren C, Brycke M. Screw preloads and measurements of surface roughness in screw joints: an in vitro study on implant framework. *Clin Implant Dent Relat Res*. 2005;7:141–149.

14. Byrne D, Jacobs S, O'Connell B, Houston F, Claffey N. Preloads generated with repeated tightening in three types of screws used in dental implant assemblies. *J Prosthodont*. 2006;15:164–171.

15. Coppede AR, Mattos MDGCD, Rodrigues RCS, Ribeiro RF. Effect of repeated torque/mechanical loading cycles on two different abutment types in implants with internal tapered connections: an in vitro study. *Clin Oral Impl Res.* 2009;20:624–632.

16. Kavitha G, Sonkesriya S, Kumar KA, et al. Outcome of implant diameter and length on the distribution of stress with immediate loaded implants: a 3D finite element analysis. *J Pharm Bioallied Sci*. 2023;15(Suppl 2):S1329–S1331.

17. Goheen KL, Vermilyea SG, Vossoughi J, Agar JR. Torque generated by handheld screwdrivers and mechanical torquing devices for osseointegrated implants. *Int J Oral Maxillofac Implants*. 1994;9:149–155.

18. Tolman DE, Laney WR. Tissue-integrated prosthesis complications. *Int J Oral Maxillofac Implants*. 1992;7:477–484.

19. Neto HT, Tuzita AS, Gehrke SA, Moura RDV, Casati MZ, Mesquita AMM. A comparative analysis of implants presenting different diameters: extra-narrow, narrow and conventional. *Mater*. 2020;13:1888.

20. Moris ICM, Faria ACL, Ribeiro RF, Rodrigues RCS. Torque loss of different abutment sizes before and after cyclic loading. *Int J Oral Maxillofac Implants*. 2015;30:1256–1261.

21. Quek CE, Tan KB, Nicholls JI. Load fatigue performance of a single--tooth implant abutment system: effect of diameter. *Int J Oral Maxillofac Implants.* 2006;21.

22. Gross M, Kozak D, Laufer BZ, Weiss EI. Manual closing torque in five implant abutment systems: an in vitro comparative study. *J Prosthet Dent*. 1999;81:574–578.

23. Hein D, Joly JC, Napimoga MH, Peruzzo DC, Martinez EF. Influence of abutment angulation on loss of prosthetic abutment torque under mechanical cycling. *J Prosthet Dent*. 2021;125:349e1–349e6.

24. Velez J, Pelaez J, Lopez-Suarez C, Agustin-Panadero R, Tobar C, Suarez MJ. Influence of implant connection, abutment design and screw insertion torque on implant-abutment misfit. *J Clin Med*. 2020;9:2365.

25. Srimurugan-Thayanithi N, Abou-Ayash S, Yilmaz B, Schimmel M, Bragger U. Effect of abutment cooling on reverse torque values of abutment screws: an in vitro study. *Int J Oral Maxillofac Implants.* 2023;38:94–100.

26. Fernando FL, Michell M, Rocio O, et al. Machined abutment screw loosening on external hexagonal-connection implant system: a preliminary in vitro study. *Clin Oral Implants Res*. 2023;28:99.

27. Martin WC, Woody RD, Miller BH, et al. Implant abutment screw rotations and preloads for four different screw materials and surfaces. *J Prosthet Dent*. 2001,86:24–32.

28. Guzaitis KL, Knoernschild KL, Viana MAG. Effect of repeated screw joint closing and opening cycles on implant prosthetic screw reverse torque and implant and screw thread morphology. *J Prosthet Dent*. 2011; 106:159–169.

29. Sammour SR, El-Sheikh MM, El-Gendy AA. Effect of implant abutment connection designs, and implant diameters on screw loosening before and after cyclic loading: in-vitro study. *Dent Mater*. 2019;35:265–271.