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A comparative study of deformation in hexagonal and star-shaped implant screwdriver heads

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Abstract

Background Dental implants are a popular and effective solution for replacing missing teeth. However, there are challenges such as screw loosening and component failure. This deformation can impact torque application and screw retention. While research has focused on implant system longevity, there is limited investigation into how different screwdriver head designs, particularly hexagonal and star-shaped, perform under repeated opening and closing cycles, which are crucial for long-term implant stability. The study compared the deformation characteristics of hexagonal and star-shaped implant screwdriver heads after multiple opening and closing cycles.

Methods In this in vitro experimental study, abutments were placed on two implant systems mounted in die stone and torqued to 25 N/cm according to the manufacturer's recommendations, using 12 screwdrivers (n = six for each implant). The screwdriver heads underwent examination under a stereomicroscope at 50x magnification. Subsequently, the outline and deformation of the screwdriver head after 0, 50, 100, 200, and 300 opening and closing cycles were analyzed using AutoCAD software. The changes in the surface area of hexagonal and star-shaped driver heads after different cycles were statistically evaluated using SPSS 24 ($\alpha = 0.05$).

Results The investigation revealed a reduction in the surface area of both hexagonal and star-shaped driver heads with an increase in the frequency of cycles. Notably, following all cycles, except 0–50 and 50–100, the alterations in the surface area of the star-shaped driver head were significantly greater than those observed in the hexagonal driver head ($P < 0.001$).

Conclusion The study shows that the star-shaped driver head deformed more than the hexagonal one, especially in cycles exceeding 100.

Keywords Dental implants, Dental implant-abutment design, Screw driver

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Background

Dental implants are one of the most effective treatment modalities for replacing missing teeth in both partially and completely edentulous ridges [1]. The increased popularity of dental implants is due to improved chewing function, preserved adjacent teeth, enhanced esthetics, and better overall functionality, especially with recent advances in prosthodontic treatments [1, 2]. The use of dental implants is increasing due to their high success rate, with longitudinal studies reporting success rates as high as 89–95.3% for dental implant treatment [2, 3].

Dental implants offer numerous advantages for both clinicians and patients, but they also come with certain limitations. The issues include biomechanical problems such as loosening or fracture of implant components due to failed osseointegration, cement failure, or abutment screw loosening, as well as inflammation, infection, and damage to adjacent structures such as the vitality of adjacent teeth. Additionally, aspiration of implant components is among the possible complications [4–6].

The available evidence indicates that biological issues exhibit comparable incidence rates in both tooth- and implant-supported restorations. Conversely, technical issues manifest with greater frequency in implant-supported prostheses. These technical difficulties encompass ceramic veneering fracture, loosening of screws or abutments, and compromised prosthesis retention [3]. One issue that has been receiving more attention is the loosening of abutment screws, which can lead to the subsequent fracture of the screw [7–9]. The prevalence of abutment screw loosening is 6–38% [4, 10, 11]. Loose abutment screws can usually be retorqued or replaced. However, abutment screw fracture may occur, posing a challenge for the clinician and potentially requiring implant restoration replacement to access the screw [12].

Factors such as the design of the implant-abutment interface, surface adaptation, occlusal loads, method of closure of implant components, and tightening of screws can all affect the implant-abutment connection [13]. Preload, which is the pressure created when tightening the abutment screw, is a crucial factor in preventing loosening and fracture of the abutment screw [14]. The amount of preload depends on the torque applied to tighten the screw, the materials, screw head design, threads, and surface roughness [15]. Therefore, it is important to apply the correct amount of torque to prevent abutment screw loosening [8, 9, 12, 16, 17]. Increasing the torque results in higher preload, but accuracy in applying torque is often lacking [18]. Insufficient torque may result in the disengagement of components, leading to screw fatigue, loosening, or fracture. In contrast, excessive torque can cause the stripping of screw threads [7]. The torque applied depends on the force by the clinician, with risks of under-tightening and over-tightening [19].

Considering the abovementioned problems, some authors suggest the use of mechanical torque control devices that enable the application of controlled torque [19, 20]. When tightening the abutment screw, incomplete matching of the screw threads with the internal implant threads leads to uneven contact along the interface, causing areas of concentrated stress. Over time, cyclic loading and micromovement result in wear at these contact points, which can lead to a 2–10% reduction in the initial preload, contributing to screw loosening and torque loss [21, 22].

It should be noted that although increasing the torque is beneficial for implant-abutment stability, the application of excessive torque causes tensile stresses, decreases the proportional limit of the screw against the application of functional loads, and generates stresses exceeding the yield strength of the abutment screw, leading to stripping and permanent deformation of the screw [23]. Screw loosening inevitably occurs following permanent deformation of the screw [16, 19, 20].

Excessive torque application not only hurts the abutment screw threads and screw head, it also affects the geometrical form of the screwdriver head as well. The hexagonal form is the most common selection for the screw head socket because it can optimize torque transfer conditions [24]. This study aimed to compare the deformation of hexagonal and star-shaped implant screwdriver heads following repeated opening and closing cycles. The null hypothesis posited that the design of the screwdriver head would not have a significant impact on its deformation after repeated opening and closing cycles.

Methods

This in vitro study was conducted in 2022 at the Faculty of Dentistry, Tabriz University of Medical Sciences, Tabriz, Iran. The study protocol was approved by the ethics committee of the university (Institutional Review Board: IR.TBZMED.VCR.REC.1398.222).

In this in vitro, experimental study, the sample size was calculated to be 12 according to a study by Chae-Heon et al., [25] assuming $\alpha = 0.05$ and a power of 80%, with an initial sample size of 100, using Power and Sample Software.

The study used two dental implants from the brand DIO: the DIO-UF (Universal Fixture) implant system with a length of 11.5 mm and diameter of 4.3 mm with a 4.5 mm diameter abutment, and the DIO-SM (Slimline Mini) implant system with the same dimensions. Each implant system included a control group (0 cycles) and four experimental groups exposed to 50, 100, 200, and 300 cycles of opening and closing.

The dental implants were mounted vertically in die stone blocks (GC; FUJIROCK EP Corporation, Tokyo, Japan) with a standard placement depth of 3 mm from the implant collar to the die stone surface, measured precisely using calipers. Standard metal molds measuring 50 × 20 × 20 mm were used to create the blocks, and a surveyor ensured proper alignment during embedding. Each block was fixed on a table, and the respective abutments were attached to the implants and tightened to 25 N/cm using the manufacturer-recommended screwdrivers (DIO-UF and DIO-SM). For each dental implant system, six screwdrivers from the respective manufacturer were used, totaling 12 screwdrivers. The DIO-UF screwdriver was hexagonal, while the DIO-SM screwdriver was star-shaped. The implant-abutment interface design was also considered in selecting the DIO-UF and DIO-SM systems. The DIO-UF used a hexagonal internal connection, while the DIO-SM used a star-shaped internal connection. These differing interface designs may influence the force transfer and stability of the screwdriver heads, which can impact torque retention and the degree of deformation during cyclic loading. The screwdrivers were examined under a stereomicroscope (CDS, Nikon, Tokyo, Japan) at x50 magnification. Figure 1 illustrates the samples used in this study, showing the die stone blocks and the two distinct screwdriver head designs (hexagonal and star-shaped) evaluated for surface area changes after repeated loading cycles.

Each set of six screwdriver heads was photographed using a stereomicroscope (CDS; Nikon, Tokyo, Japan) before any intervention and then after 50, 100, 200, and 300 cycles of opening and closing with 25 N/cm torque. A custom mechanical testing device was employed to standardize the cycles for consistent torque and movement. Each cycle was defined as one complete engagement and disengagement of the screwdriver, conducted by the same operator, with 10-second intervals between cycles to simulate typical clinical use.

To measure deformation, the outlines of the screwdriver heads were traced manually using AutoCAD software. The traced outlines were then processed in AutoCAD to calculate the two-dimensional surface area of the screwdriver head profiles by summing the enclosed pixel area. This method allowed for consistent

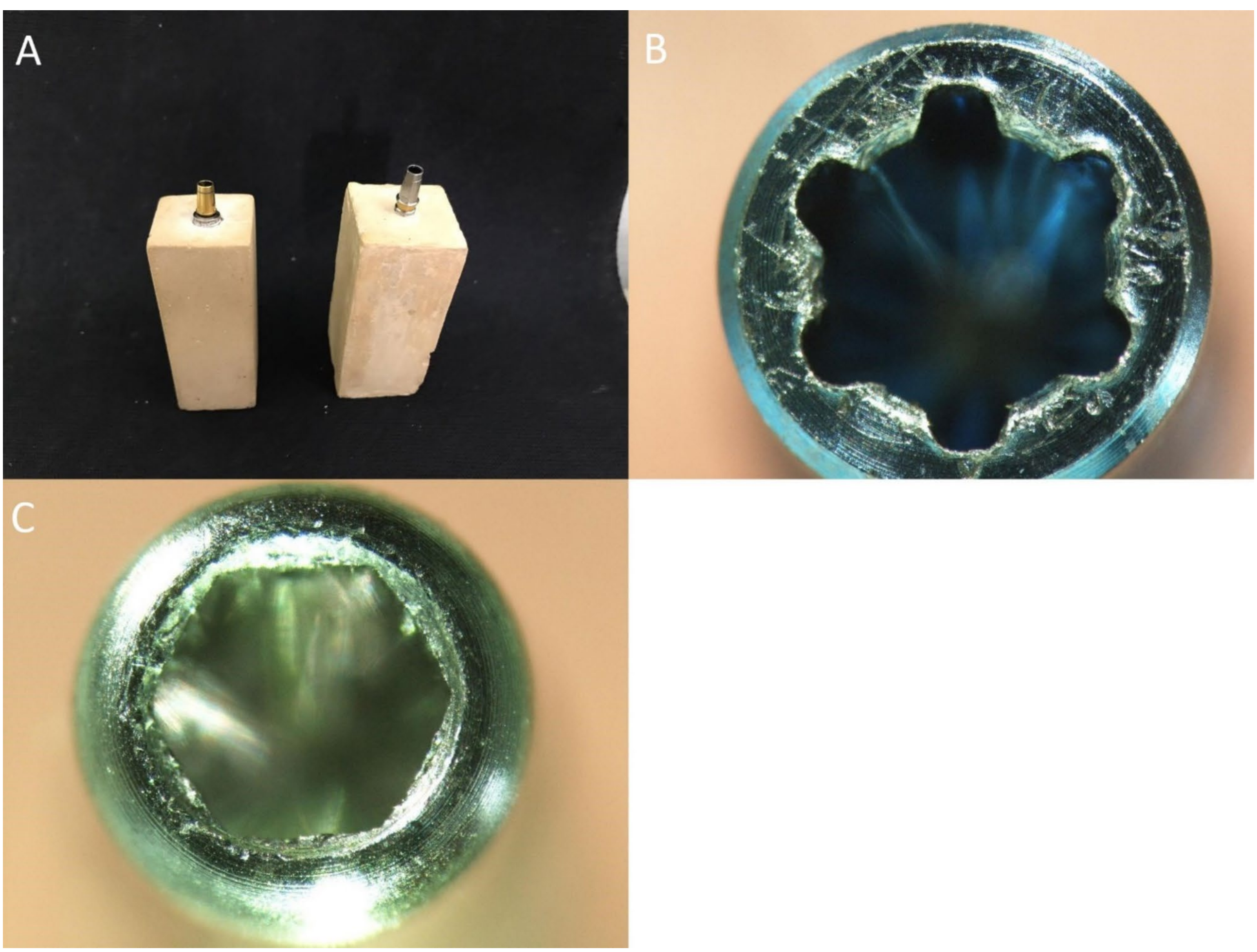

Fig. 1 Sample images used in the study. (**A**) Die stone blocks. (**B**) Star-shaped screwdriver head. (**C**) Hexagonal screwdriver head

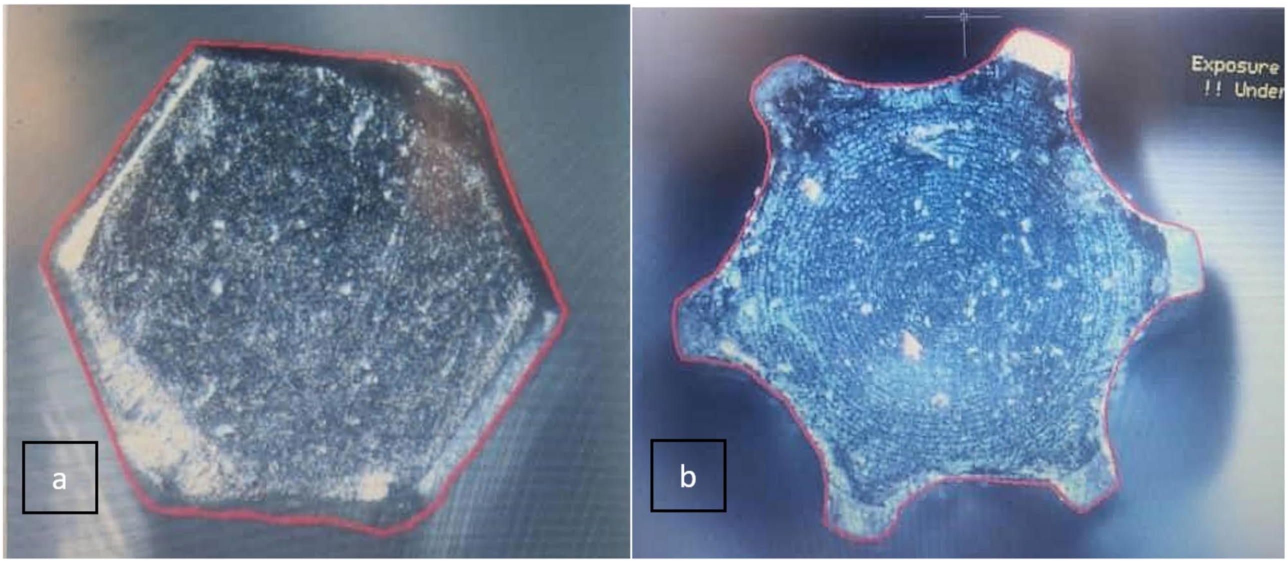

Fig. 2 Outlining the hexagonal (**a**) and star-shaped (**b**) screwdriver heads using AutoCAD software

Table 1 Mean change in surface area (measured in square millimeters, mm^2) of the driver heads in star-shaped and hexagonal designs after different cycles of opening and closing

Cycles	Std. deviation ± Mean	
	Hexagonal	Star-shaped
0	0.00 ± 228.17	0.0 ± 264.85
50	0.36 ± 227.49	0.21 ± 264.32
100	0.33 ± 226.87	0.33 ± 263.59
200	0.42 ± 226.14	0.42 ± 261.99
300	0.37 ± 225.37	0.31 ± 260.7
Total	0.082 ± 226.809	0.082 ± 263.088

Table 2 Comparison of the change in surface area (measured in square millimeters, mm^2) of the hexagonal and star-shaped driver heads after different cycles of opening and closing by independent t-test

Cycles	Mean and std. deviation		
	Hexagonal	Star-shaped	*P*-value (T-test)
0–50	0.36 ± 0.69	0.21 ± 0.54	0.393
50–100	0.23 ± 0.61	0.29 ± 0.73	0.457
100–200	0.24 ± 0.73	0.47 ± 1.59	0.002
200–300	0.22 ± 0.77	0.36 ± 1.29	0.013

comparisons of surface area changes across different cycles (see Fig. 2). Any change in the surface area after 0, 50, 100, 200, and 300 cycles was recorded. After each set of cycles, the screwdriver heads were rinsed with distilled water to remove any debris or residue from the testing process, then allowed to air dry before evaluation. Each cycle of opening and closing involved a standardized movement of engaging and disengaging the screwdriver with a torque of 25 N/cm, performed by the same operator to ensure consistency. The time interval between each cycle was set at 10 s to simulate typical clinical use. Changes in surface area were then compared between the two groups of drivers with hexagonal and star-shaped head designs. Drivers that showed deformations due to extraneous factors, such as accidental drops or excessive pressure unrelated to the cycling procedure, were excluded and replaced.

We assessed the data's normal distribution using the Kolmogorov-Smirnov test. Subsequently, we utilized repeated measures ANOVA, the Bonferroni test, and independent t-tests to compare the groups. All statistical analyses were performed using SPSS 24 at a significance level of 0.05.

Results

The Kolmogorov-Smirnov test indicated a normal distribution for all data ($P > 0.05$), except for surface area data at 0 cycles in both groups and 200 cycles in the hexagonal group ($P < 0.05$).

Table 1 shows the surface area of the driver's heads in both star-shaped and hexagonal designs after different cycles of opening and closing. With an increase in the number of cycles, the surface area of both driver head designs decreased. Specifically, during 0-300 cycles, the surface area was reduced by 2.81 units in the hexagonal design and 4.15 units in the star-shaped design. Furthermore, after all cycles, the surface area of the hexagonal design was consistently lower than that of the star-shaped design.

Table 2 compares the change in surface area of the hexagonal and star-shaped driver head designs after different cycles of opening and closing by using an independent t-test. The results showed that by an increase in the frequency of cycles, the change in surface area of both driver head designs increased, such that maximum change occurred by an increase in cycles from 200 to 300. In general, maximum change was noted in star-shaped head design by an increase in cycles from 100 to 200, and minimum change was noted also in star-shaped head design by an increase in cycles from 0 to 50. In all phases except for 0–50 cycles, the changes in surface area of the star-shaped driver head design were greater than those in the hexagonal driver head design. After 0–50 cycles, the change in surface area of the star-shaped head design was 0.15 units lower than that in the hexagonal head design ($P = 0.393$). The difference in surface area change between the two designs was significant after 100–200 ($P = 0.002$) and 200–300 ($P = 0.013$) cycles.

Within-group comparison of the surface area of the two driver head designs after different cycles:

Repeated measures ANOVA showed a significant difference in the surface area of driver's heads after different cycles in both hexagonal ($P < 0.001$) and star-shaped ($P < 0.001$) groups. Pairwise comparisons of the surface areas after each pair of cycles by the Bonferroni test revealed significant differences in all comparisons in both groups ($P < 0.001$).

Discussion

This study compared the deformation of hexagonal and star-shaped implant screwdriver head designs after repeated opening and closing cycles. The null hypothesis posited that the design of the screwdriver head would not have a significant impact on its deformation after repeated opening and closing cycles. The results showed a reduction in the surface area of both driver's head designs by an increase in opening and closing cycles, suggesting a progressive wear mechanism over time. Pairwise comparisons showed significant differences within each group after different cycles. This finding is probably because the outer layer of metal in driver's heads is more resistant to wear [26].

In a study by Ghaffari et al. [27], the deformation of implant abutment screw heads in both hexagonal and star-shaped designs was evaluated after multiple rounds of tightening and loosening. The results showed that the surface area of the screw heads increased with each round of tightening and loosening, regardless of the design. Furthermore, it was observed that the extent of area changes was greater in star-shaped screw heads compared to hexagonal screw heads at all stages. This aligns with our findings, where the surface area changes in the star-shaped design were significantly greater than in the hexagonal design after the 100–200 and 200–300 cycles, indicating that the star-shaped design may experience higher wear over prolonged use.

De Paiva et al. [28] evaluated the resistance of square-shaped and hexagonal screwdriver head designs against deformation and showed that the square-shaped head design required greater torque due to a larger contact area compared with the hexagonal type. They also indicated that all screwdrivers were resistant to elastic deformation after 10 consecutive tightening cycles of the abutment screw with 32 N/cm torque and experienced no significant change. They concluded that the geometrical form of screwdriver heads had no significant effect on their deformation. However, our study suggests that the deformation of screwdriver heads is more complex and that design differences affected wear over repeated cycles, particularly when subjected to higher numbers of cycles. This may be because repeated use, as applied in our study with up to 300 cycles, increases the effects of contact stresses in ways that 10 cycles may not.

Kim et al. [29] reported an increase in scratches following the use of screwdrivers with square-shaped heads, compared with hex-slotted type. They added that drivers with square-shaped heads had higher wear resistance. In contrast, our results showed that the star-shaped driver, with its smaller contact area and greater number of edges, experienced more significant wear over time, especially after 100 cycles. This highlights the potential disadvantage of a more complex design in terms of wear resistance. Deformation and stripping of the abutment screw and screwdriver head can complicate abutment screw replacement.

The changes in surface area in star-shaped head design were greater than those in hexagonal design in all cycles except for 0–50. The difference between the two groups regarding surface area in 0–50, and 50–100 cycles was not significant, but the change in surface area in 100–200 and 200–300 cycles in star-shaped driver design was significantly greater than that in hexagonal driver. Thus, the null hypothesis of the study was rejected. Since the contact area of the hexagonal driver is larger than that of the star-shaped driver, the load is distributed in a larger surface area, and a lower load is applied per surface area unit in the use of the hexagonal driver. Since the number of external angles in the star-shaped driver ($n = 12$) is twice the rate in the hexagonal driver ($n = 6$), the possibility of rounding corners in the star-shaped driver is higher. This geometry-based difference likely accelerated wear in the star-shaped design. Also, it appears that the degradation of star-shaped drivers is accelerated with use.

Studies on the changes in the surface area of driver's heads are minimal, and a search of the literature by the authors yielded only one study regarding the deformation of the driver's head. De Paiva et al. [28]Evaluated the resistance of square-shaped and hexagonal driver heads against deformation and concluded that the geometric design of the driver's heads had no significant effect on their deformation. Their results were different from the present findings, which may be due to their different methodology since they had 10 cycles of opening and closing while in this study, up to 300 cycles were applied. Due to repeated use of drivers, they are often fabricated from alloys with very high wear resistance, and 10 cycles are too low to assess and compare the wear of different driver head designs.

Our findings highlighted the importance of screwdriver head design in implant dentistry, particularly regarding tool wear over repeated use. The star-shaped screwdriver heads exhibited greater deformation, suggesting they may be less durable in high-volume clinical settings, potentially compromising screw tightening and seating accuracy. In contrast, hexagonal screwdriver heads showed better wear resistance, making them a more reliable option for prolonged use. These insights emphasize the need for clinicians to choose screwdriver designs based on their expected frequency of use to ensure consistent tool performance and long-term implant success. Understanding wear patterns can lead to more informed decisions, optimizing both clinical efficiency and patient outcomes.

One limitation of this study was the requirement to replace the screw corresponding to each driver at each phase of the opening and closing cycles. This replacement was necessary to ensure that any wear observed on the screwdriver head resulted from interaction with a non-worn screw in each phase, thereby isolating the wear effect on the screwdriver itself. Consequently, a new screw was used at each phase for each driver, resulting in a high number of screws ($n = 12$) being used overall. Further studies are required on the wear of other screwdriver head designs. Moreover, the nature of this in vitro study may be considered as a limitation for clinical interpretation and results should be interpreted with care given the nature of this study.

Conclusion

The present results showed that the surface area of the screwdriver heads decreased as the frequency of cycles increased for both head designs, indicating progressive wear. The reduction in surface area of the star-shaped driver head was greater than that of the hexagonal driver head across all cycles except 0–50. At cycle 100, the star-shaped driver head exhibited a more pronounced reduction in surface area compared to the hexagonal head, reflecting a higher degree of wear under cyclic loading conditions.

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Author contributions
All authors contribute to the conception and design of the work and the acquisition, analysis, and interpretation of data.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
This in vitro study was conducted in 2022 at the Faculty of Dentistry, Tabriz University of Medical Sciences, Tabriz, Iran after obtaining ethical permission from the Research Council (Ethics Code: IR.TBZMED.VCR.REC.1398.222).

Human ethics and consent to participate declarations
Not applicable.

Consent for publication
all authors All authors are satisfied with the publication of this article.

Competing interests
The authors declare no competing interests.

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References

1. Karoussis IK, Salvi GE, Heitz-Mayfield LJ, Brägger U, Hämmerle CH, Lang NP. Long-term implant prognosis in patients with and without a history of chronic periodontitis: a 10-year prospective cohort study of the ITI® dental implant system. Clin Oral Implants Res. 2003;14(3):329–39.
2. Romeo E, Lops D, Margutti E, Ghisolfi M, Chiapasco M, Vogel G. Long-term survival and success of oral implants in the treatment of full and partial arches: a 7-year prospective study with the ITI dental implant system. Int J Oral Maxillofacial Implants. 2004;19(2).
3. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res. 2007;18:97–113.
4. Binon PP. The evolution and evaluation of two interference-fit implant interfaces. Postgrad Dent. 1996;3(1):3–13.
5. Liaw K, Delfini RH, Abrahams JJ, editors. Dental implant complications. Seminars in ultrasound, CT and MRI. Elsevier; 2015.
6. Sun M, Shui Y, Zhang Y, Ma R, Zhao Y, Chen H, et al. Influence of abutment screw-Tightening methods on the screw joint: immediate and Long-Term stability. Int J Dent. 2024;2024:5768318.
7. Siamos G, Winkler S, Boberick KG. The relationship between implant preload and screw loosening on implant-supported prostheses. J Oral Implantology. 2002;28(2):67–73.
8. Butkevica A, Nathanson D, Pober R, Strating H. Measurements of repeated tightening and loosening torque of seven different implant/abutment connection designs and their modifications: an in vitro study. J Prosthodont. 2018;27(2):153–61.
9. Bakaeen LG, Winkler S, Neff PA. The effect of implant diameter, restoration design, and occlusal table variations on screw loosening of posterior single-tooth implant restorations. J Oral Implantology. 2001;27(2):63–72.
10. Haas R, Mensdorff-Pouilly N, Mailath G, Watzek G. Brånemark single tooth implants: a preliminary report of 76 implants. J Prosthet Dent. 1995;73(3):274–9.
11. Naert I, Quirynen M, Hooghe M, van Steenberghe D. A comparative prospective study of splinted and unsplinted Brånemark implants in mandibular overdenture therapy: a preliminary report. J Prosthet Dent. 1994;71(5):486–92.
12. Tsuge T, Hagiwara Y. Influence of lateral-oblique Cyclic loading on abutment screw loosening of internal and external hexagon implants. Dent Mater J. 2009;28(4):373–81.
13. Huang Y, Wang J. Mechanism of and factors associated with the loosening of the implant abutment screw: A review. J Esthetic Restor Dentistry. 2019;31(4):338–45.

14. Szajek K, Wierszycki M. Screw preload loss under occlusal load as a predictor of loosening risk in varying dental implant designs. J Mech Behav Biomed Mater. 2023;148:106165.
15. Yan X, Liu Z, Zheng M, Li Y, Wang Y, Chen W. Preload control method of threaded fasteners: A review. Chin J Mech Eng. 2024;37(1):97.
16. Jaarda MJ, Razzoog ME, Gratton DG. Effect of preload torque on the ultimate tensile strength of implant prosthetic retaining screws. Implant Dent. 1994;3(1):17–23.
17. Williamson RT, Robinson FG. Retrieval technique for fractured implant screws. J Prosthet Dent. 2001;86(5):549–50.
18. Guda T, Ross TA, Lang LA, Millwater HR. Probabilistic analysis of preload in the abutment screw of a dental implant complex. J Prosthet Dent. 2008;100(3):183–93.
19. Goheen KL, Vermilyea SG, Vossoughi J, Agar JR. Torque generated by handheld screwdrivers and mechanical torquing devices for osseointegrated implants. Int J Oral Maxillofacial Implants. 1994;9(2).
20. Maalhagh-Fard A, Jacobs LC. Retrieval of a stripped abutment screw: a clinical report. J Prosthet Dent. 2010;104(4):212–5.
21. Sakaguchi RL, Borgersen SE. Nonlinear contact analysis of preload in dental implant screws. Int J Oral Maxillofacial Implants. 1995;10(3).
22. Dixon DL, Breeding LC, Sadler JP, McKay ML. Comparison of screw loosening, rotation, and Deflection among three implant designs. J Prosthet Dent. 1995;74(3):270–8.
23. Honório Tonin BS, He Y, Ye N, Chew HP, Fok A. Effects of tightening torque on screw stress and formation of implant-abutment microgaps: A finite element analysis. J Prosthet Dent. 2022;127(6):882–9.
24. Khalaf K, Azhang A, Cheng C-H, Nikkhoo M. Biomechanical investigation of bone screw head design for extracting stripped screw heads: integration of mechanical tests and finite element analyses. Materials. 2023;16(15):5470.
25. Chae-Heon C. Changes of abutment screw after repeated closing and opening. J Korean Acad Prosthodont. 2004;42(6):628–40.
26. Moghadasi K, Mohd Isa MS, Ariffin MA, Mohd jamil MZ, Raja S, Wu B, et al. A review on biomedical implant materials and the effect of friction stir based techniques on their mechanical and tribological properties. J Mater Res Technol. 2022;17:1054–121.
27. Ghaffari T, Nourizadeh A, Shafiei E, Ghasemi S, Mahmoudzadeh M, Ataei K. Evaluation of implant abutment screw head deformation in hexagonal and star designs after successive tightening and loosening. J Adv Periodontol Implant Dent. 2023;15(1):60–3.
28. de Paiva MSM, de Oliveira SN, Dias JVA, da Trindade Neto CG, de Queiroz JRC, de Oliveira EA, et al. Influence of two types of connections in driver-retention screw assembly. J Craniofac Surg. 2017;28(2):e145–6.
29. Kim HJ, Choe HC, Chung CH, Brantley WA. Deformation of dental abutment screw after tightening and loosening. Key Eng Mater. 2007;345:13–6.

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