ORIGINAL RESEARCH

Effect of Restoration Design on the Removal Torque Loss of Implant-supported Crowns after Cyclic Loading

Suppanut Jongsiri[1], Mansuang Arksornnukit[2], Woraporn Homsiang[3], Krid Kamonkhantikul[4]

Abstract

Aim: To compare the removal torque loss (RTL) percentage of screw-retained, cement-retained, and combined screw- and cement-retained implant-supported crowns after cyclic loading and measure the impact of cyclic loading on removal torque.

Materials and methods: Thirty-two dental implants (4.0 × 10 mm) in resin blocks and abutments were divided into four groups ($n = 8$) based on restoration design: combined screw- and cement-retained group (SC), two cement-retained groups: cemented with adhesive resin cement (AR) (Panavia V5) or provisional cement (PR) (RelyX Temp NE), and screw-retained one-piece titanium group (TI). Removal torques were measured in Newton-centimeter (Ncm) before and after 500,000-cycle cyclic loading with forces ranging from 20 to 200 N at 15 Hz. The RTL percentage in each group was calculated. The paired *t*-test was used to detect the difference between pre-loading (RT1) and post-loading removal torque (RT2) in each group and 1-way ANOVA was used to detect the difference of RTL percentage between groups.

Results: The post-loading removal torques in all groups were significantly lower than their pre-loading removal torques ($p < 0.001$). The 1-way ANOVA test found no significant difference in the RTL% between the study groups. The PR group exhibited the lower RTL% (30.74 ± 7.3%), followed by the TI (30.78 ± 5.6%), AR (32.12 ± 2.5%), and SC (35.71 ± 5.1%) groups.

Conclusion: Combined screw- and cement-retained restorations exhibited similar RTL compared with other restoration designs, and cyclic loading significantly affected the removal torque.

Clinical significance: Combined screw- and cement-retained restorations can be utilized in single-tooth situations, offering a comparable impact on screw joint stability while providing benefit of retrievability. Cyclic loading significantly influences joint stability, periodic checkup for screw loosening is recommended.

Keywords: Abutment screw loosening, Cyclic loading, Dental implant, Restoration design, Removal torque.

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Introduction

Dental implants have been excellent treatment options with a high and predictable success rate in restoring single-tooth areas.[1] An implant-supported single crown can be retained using either a screw or cement. A screw-retained crown, connected to an abutment with a screw or connected directly to a dental implant as a one-piece restoration, is typically used in cases presenting with a limited occluso-gingival space. This design offers retrievability and reduces the incidence of peri-implantitis caused by excess cement. However, a cement-retained crown, connected to an abutment using a luting cement, provides better occlusal integrity and esthetics because there is no screw access channel on the occlusal surface.[2] A cement space allows the crown to achieve a passive fit, resulting in reduced strain at the implant–bone interface.[3] Cement-retained crowns are also cost-effective and easy to fabricate.[4] Another retention type is a combination of screw-retained and cement-retained crowns, also known as a combination implant crown,[5] cement-retained crown with a screw channel,[6] or screwmentable crown,[7] that offer passiveness and retrievability. This restoration design can be cemented extraorally to eliminate the risk of excess cement remnants.[6]

Cement selection is crucial for successful treatment. Cement can be categorized as either permanent or provisional cement (PR). Permanent cements, such as resin modified glass ionomer or adhesive resin (AR), have been widely used in implant-supported crowns.[8] In contrast, using PRs has been suggested to ensure retrievability without causing damage to the abutments or implants.[9,10] However, these PRs exhibit poor physical properties, such as low tensile strength and high solubility.[11] Cement types can further influence the damping effect of the implant-supported crown that contributes to the stability of the abutment screw joint.[12]

Customizing the abutment using computer-aided design-computer-aided manufacturing (CAD-CAM) technology eliminates the intrinsic dimensional inaccuracies during the waxing, investing, and casting processes. A customized abutment, including a crown, can be made as a one-piece restoration. Single implant-supported crowns fabricated with CAD-CAM technology have a

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better marginal fit compared with the conventional fabrication method.[13] Monolithic zirconia produced by CAD-CAM technology is a commonly used material for implant-supported crowns due to its esthetic appeal and high fracture strength.[14] Furthermore, crown materials with a higher modulus of elasticity, such as ceramic or titanium, are less shock-absorbing compared with resin-based materials.[12]

A screw joint is a combined assembly between an abutment and a dental implant connected with an abutment screw. Screw pre-load or clamping force is influenced by the screw[15] and abutment material.[16] This force is proportional to the applied torque and the tensile strength of the screw. The joint separating force is the force that tends to separate the screw joint. Screw loosening occurs when the separating forces exceed the clamping force.[17] Another crucial factor that affects screw loosening is the settling effect or embedment relaxation that occurs when the external thread of the abutment screw encounters the internal thread of the dental implant by touching only the roughest spots.[17] These spots can be flattened, without an external force, resulting in an increased contact surface and a decreased pre-load. A 10-year retrospective study found that screw loosening was the most commonly encountered technical complication in dental implants, followed by ceramic chipping and loss of retention.[18] If the screw loosening occurs in a cement-retained crown, it might be necessary to remove the crown from the abutment to reach the screw and remake the crown. Furthermore, screw loosening could lead to crestal bone loss as bacteria can accumulate in the open interface, potentially impacting the long-term prognosis of implant restorations.

Several investigations compared the incidence of abutment screw loosening between screw-retained and cement-retained prostheses in *in vivo*[19] and *in vitro* studies.[20,21] To the best of our knowledge, there were few studies comparing the mechanical integrity of combined screw- and cement-retained prostheses to other restoration designs in terms of fracture resistance.[22,23] However, there were no studies comparing combined screw- and cement-retained restorations with other restoration designs in terms of abutment screw loosening in single implant-supported crowns. Therefore, the aim of this study was to compare the RTL percentage of screw-retained, cement-retained, and combined screw- and cement-retained implant-supported crowns after cyclic loading, and to measure the impact of cyclic loading on removal torque. The null hypotheses of this study were that (1) there was no significant difference in the removal torque of each study group between before and after cyclic loading, and (2) there was no significant difference in the RTL percentage between screw-retained, cement-retained, and combined screw- and cement-retained implant-supported crowns.

Materials and Methods

Study Design and Sample Size Calculation

Statistical software was used to calculate the sample size (G*Power 3.1, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). According to the data in a previous study,[20] each group needed a minimum of 6 specimens for an alpha of 0.05 and a power of 80%. To account for a 20% error, eight specimens per group were used in the present study ($n = 8$). The present *in vitro* study was conducted in the Dental Materials research and development center, Chulalongkorn University, Bangkok, Thailand during September 2022 to January 2023.

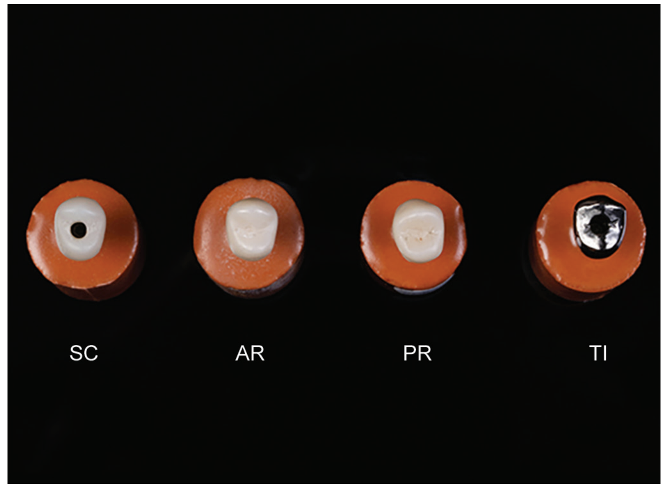


Fig. 1: Representative specimen in each restoration design group: combined screw- and cement-retained crown (SC), cement-retained crown cemented with adhesive resin cement (AR), cement-retained crown cemented with provisional cement (PR), and screw-retained one-piece titanium crown (TI) group

Specimen Grouping

There were four study group in this study: combined screw- and cement-retained group (SC), two cement-retained groups cemented with an AR or a PR, and screw-retained one-piece titanium group (TI) (Fig. 1).

Specimen Preparation

Thirty-two 4-mm-diameter and 10-mm-long dental implants (Superline, Dentium Co., Ltd, Seoul, South Korea) were embedded individually in 16-mm-diameter and 25-mm-long cylindrical epoxy resin blocks (Chockfast orange, ITW Performance Polymers, Shannon, Ireland) using customized aluminum blocks. The details of the implant components and materials used in this study are presented in Table 1. The implant shoulder was placed 3 mm above the top surface of the block to comply with ISO 14801:2016 specifications.[24]

The prepared blocks were randomly divided into the aforementioned four groups. A stock abutment with a diameter of 4.5 mm, height of 5.5 mm, and gingival height of 2.5 mm (Dual abutment, Dentium Co., Ltd, Seoul, South Korea) was scanned using an intraoral scanner (CEREC Omnicam, Dentsply Sirona, NC, USA). Subsequently, a permanent maxillary first premolar crown was designed using design software (SW4.6.1, Dentsply Sirona, NC, USA).

In the SC, AR, and PR groups, monolithic zirconia crowns (Ceramill Zolid HT, Amann Girrbach AG, Koblach, Austria) were milled by a milling machine (Ceramill Motion 2, Amann Girrbach AG, Koblach, Austria) and sintered in a furnace (Ceramill Therm 3, Amann Girrbach AG, Koblach, Austria) according to the manufacturer's recommendations. In the SC group, a screw access channel was drilled in each zirconia crown using round diamond rotary burs (801.314.014, Komet Dental, Lemgo, Germany) before sintering.

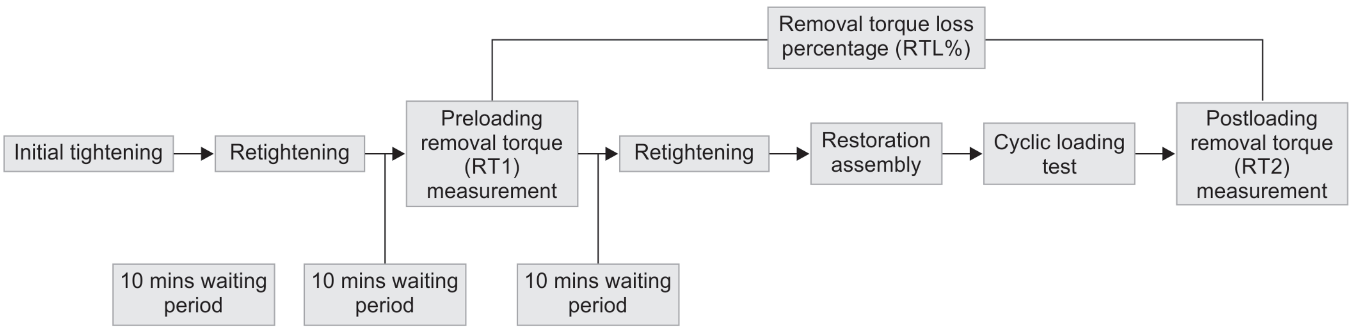
In the TI group, premolar crowns were digitally designed (HyperDENT V 8.2, FOLLOW-ME! Technology Group, Munich, Germany) with the same dimensions as the other groups and milled from titanium blanks (Dentium Ti blank, Dentium Co., Ltd, Seoul, South Korea) using a milling machine (Dentium rainbow Mill-metal, Dentium Co., Ltd, Seoul, South Korea).

Table 1: Materials used and their compositions

Material	*Manufacturer*	*Composition*	*Lot no.*
SuperLine implant	Dentium Co., Ltd, Seoul, South Korea	Commercially pure titanium grade IV	202108270037
Dual abutment			202105120210
Dentium Ti-blank			202002050143
Ceramill Zolid HT+	Amann Girrbach AG, Koblach, Austria	ZrO_2, 6–7% Y_2O_3, HfO_2, Al_2O_3	1905000
Panavia V5	Kuraray Noritake Dental Inc., Tokyo, Japan	Bis-GMA, TEGDMA, aromatic multifunctional monomer, aliphatic multifunctional monomer, new chemical polymerization accelerator, dl-camphorquinone, photopolymerization, accelerator, surface treated barium glass, fluoroaluminosilicate glass, fine particulate filler	5R0161
RelyX Temp NE	3M ESPE, MN, USA	ZnO, white mineral oil, petrolatum	6351810

Bis-GMA, bisphenol diglycidylether methacrylate; TEGDMA, triethylene glycol dimethacrylate

Flowchart 1: Diagram showing the process in this study



Preloading Removal Torque (RT1) Measurement

The abutments were attached to the dental implants with a torque of 30 Newton-centimeter (Ncm) using the manufacturer's screwdriver connected to a digital torque gauge (Tohnichi BTGE50CN-G, Tohnichi Mfg Co., Ltd, Tokyo, Japan). The tightening protocol was modified from a previous study.[25] Retightening was done after 10 minutes to compensate for the settling effect. After 10 minutes, the pre-loading removal torques (RT1) were measured with the digital torque gauge. Tightening and retightening were performed with the same protocol. The process of this study is illustrated in Flowchart 1.

Restoration Assembly

The inner surface of each crown in the SC, AR, and PA groups was airborne-particle abraded with 50-µm aluminum oxide at 0.2 MPa of pressure, 10 mm away from the nozzle for 10 seconds, and steam-cleaned. The abutment screw channel was filled with polytetrafluoroethylene (PTFE) tape.

In the SC and AR groups, crowns were cemented onto the implant abutments with AR (Panavia V5, Kuraray Noritake Dental Inc., Tokyo, Japan) using finger pressure and light-activated by a light-curing unit with an irradiance of 1000 mW/cm^2 for 20 seconds per surface (SmartLite Focus, Dentsply Sirona, NC, USA). In the PR group, PR (RelyX Temp NE, 3M ESPE, MN, USA) was used according to the manufacturer's instructions. The excess cement was completely removed.

Only in the SC and TI groups, the screw channels were filled with PTFE tape, followed by composite resin (Filtek Z350 XT, 3M ESPE, MN, USA), and light-activated for 40 seconds.

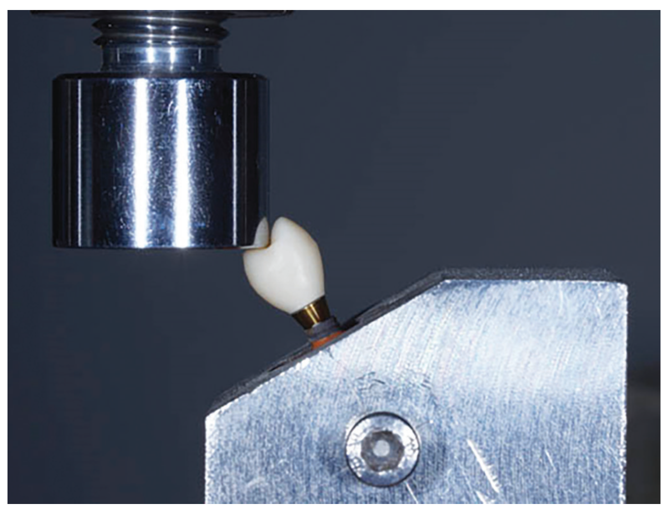


Fig. 2: Implant crown specimen fixed in a holding device under cyclic loading

Cyclic Loading Test

Each specimen was securely fixed into a customized stainless steel holding device attached to a dynamic testing machine (ElectroPuls E1000, Instron Corp, MA, USA). The holding device was positioned at 30° to the vertical plane (Fig. 2). The specimens were subjected to 500,000-cycles cyclic loading, using a 25-mm-diameter loading head contacting the crowns at the palatal cusp. The loading force ranged from 20 to 200 N, applied at a frequency of 15 Hz, and the testing was conducted at room temperature.

Table 2: Mean and standard deviation of preloading removal torque (Ncm), postloading removal torque (Ncm), and removal torque loss percentage

Group	*RT1*	*RT2*	*RTL%*
SC	$28.07^{A} \pm 1.3$	$18.06^{B} \pm 1.8$	$35.71^{a} \pm 5.1$
AR	$28.36^{A} \pm 1.4$	$19.23^{B} \pm 0.6$	$32.12^{a} \pm 2.5$
PR	$28.68^{A} \pm 0.6$	$19.84^{B} \pm 2.0$	$30.74^{a} \pm 7.3$
TI	$27.93^{A} \pm 0.6$	$19.31^{B} \pm 1.3$	$30.78^{a} \pm 5.6$

Different superscript uppercase letters indicate significant differences between before and after cyclic loading in each group ($p < 0.05$). Different superscript lowercase letters indicate significant differences between groups ($p < 0.05$)

Postloading Removal Torque (RT2) Measurement

After cyclic loading, the crowns in the AR and PR groups were removed, and the crowns in the SC and TI groups were drilled to access the screw channel, and the PTFE tape was removed. The RT2 of each group was measured with a screwdriver connected to the digital torque gauge. The RTL% were calculated as follows: RTL% = [(RT2–RT1)/RT1] *100.

Statistical Analysis

The data were collected and statistically analyzed using IBM SPSS statistics v22.0 software (IBM Corp, NY, USA) ($\alpha = 0.05$). The results were expressed as mean and standard deviation (SD). In this study, the screw loosening was studied in terms of removal torque loss (RTL).

The Shapiro–Wilk test and the Levene test were used to verify the normal distribution and homogeneity of the variance. The paired *t*-test was used to compare the RT1 and RT2 within each group in Ncm, determining the effect of cyclic loading on the removal torque change. One-way ANOVA, followed by the Tukey test, was used to identify the difference of RTL% between study groups.

Results

The descriptive and statistical analyses of the present study are presented in Table 2. Notably, every specimen survived the 500,000-cycles cyclic loading without any bending or deformation. The Shapiro–Wilk test indicated that the data followed a normal distribution. The paired *t*-test indicated a significant difference between RT1 and RT2 in each group ($p < 0.001$).

Although the 1-way ANOVA result found no significant difference ($p = 0.28$) in the RTL% between the study groups, the lowest RTL% was in the PR group (30.74 ± 7.3%), followed by the TI (30.78 ± 5.6%), AR (32.12 ± 2.5%), and SC (35.71 ± 5.1%) groups.

Discussion

The present study compared the RTL of combined screw- and cement-retained crowns with that of other restoration designs featuring the same implant-abutment connection after cyclic loading. The first hypothesis was rejected because RT2 was significantly lower than RT1 in each group. In contrast, the second hypothesis was accepted because no significant difference was found in the RTL% between study groups. These findings indicated that combined screw- and cement-retained restorations maintained similar screw joint stability compared with other restoration designs.

The load cycle was set at 500,000 cycles, which is equivalent to 6 months of *in vivo* mastication.[26] The load was set from 20 to 200 N because the average occlusal force on the premolar area ranges from 54 to 234 N.[27] The crowns in this study were designed using the reported mesiodistal and buccolingual width of the maxillary first premolar (7.1 and 9.2 mm, respectively).[28]

The RT1 in the present study, ranged from 0.17 to 16.17%, is in line with previous studies that reported that the RTL before cyclic loading ranged from 2 to 19%.[21,25,29–31] The reduction in removal torque without an external force applied to the implant-abutment connection is caused by the settling effect. Retightening is strongly recommended to maintain the screw joint preload. The RT2 in the present study ranged from 30.74 to 35.71%, which is consistent with previous studies that reported a RTL of 26–36%.[20,21] The RT2 in all groups were significantly lower compared with their RT1. Similar results have been reported in previous studies.[21,31,32] The cyclic loading was confirmed to markedly affect the removal torque values. Evaluating the joint stability during maintenance appointments is recommended to prevent further technical complications.

Although the differences in RTL in each study group were not significant, the RTL% in the TI group was slightly lower than that in the SC, AR, and PR groups compared between the crown materials. This might be because the elastic modulus of the crown made of commercially pure titanium grade IV in the TI group (110 GPa) is lower than that of the zirconia crowns in the SC, AR, and PR groups (200 GPa), resulting in more deformation and lower force transmission through the titanium crown.[12] Previous studies also reported similar RTL means between prefabricated- and customized abutments after cyclic loading.[33,34] In contrast, a study reported that the RTL means in the customized group was significantly greater than that in the prefabricated group.[32] Different restoration designs and the number of cyclic loading cycles may contribute to this disparate finding.

Comparing the cement types, the RTL% in the AR group was higher than that in the PR group. The different elastic modulus of the cement material in the AR group (6.3 GPa) and in the PR group (0.2 GPa)[35] can influence the damping effect.[12] These results suggest that when using provisional cementation, the applied force was transferred to the cement, which acts as an absorbing layer before reaching the screw joint. This might be attributed to better shock-absorbing ability in the PR group. Using a PR may mitigate the risk of abutment screw loosening by reducing the loading force transmitted to the screw joint.

Within the same crown material, the RTL% in the SC group was comparable to that in the AR and PR groups, indicating that the presence of a screw channel does not influence screw joint stability. Another crucial aspect to consider when selecting a restoration design is fracture resistance. A previous study reported no significant difference in fracture resistance between the group with and without a screw channel in monolithic zirconia restorations.[22] These restorations combine the benefits of screw-retained and cement-retained restorations. They offer retrievability, allowing for repairs or servicing without extensive damage to the implant components. Additionally, they provide ease in removing excess cement, reducing the risk of peri-implantitis. They also maintain the advantages of cement-retained restorations, such as better passive fit, lower cost, and ease of fabrication.

With the limitation of the testing machine is available, the specimens were evaluated without being immersed in fluid, which may not entirely represent the clinical situation. In the present study, the specimens were subjected to cyclic loading for 500,000 cycles; however, a significant RTL may be discovered if the specimens were cyclically loaded for an extended period. Further research is suggested to verify the findings and impacts concerning the screw loosening in clinical setting.

Conclusion

After a 500,000-cycle cyclic loading, the removal torques in all restoration design groups significantly decreased. However, the RTL% of combined screw- and cement-retained restorations was similar compared with other restoration designs.

Clinical Significance

Combined screw- and cement-retained restorations can be utilized in single-tooth situations, offering a comparable impact on screw joint stability while providing benefit of retrievability. Cyclic loading significantly influences joint stability, periodic checkup for screw loosening is recommended.

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References

1. Jung RE, Pjetursson BE, Glauser R, et al. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 2008;19(2):119–130. DOI: 10.1111/j.1600-0501.2007.01453.x.
2. Wittneben JG, Joda T, Weber HP, et al. Screw retained vs. cement retained implant-supported fixed dental prosthesis. Periodontol 2000. 2017;73(1):141–151. DOI: 10.1111/prd.12168.
3. Chee W, Felton DA, Johnson PF, et al. Cemented versus screw-retained implant prostheses: which is better? Int J Oral Maxillofac Implants 1999;14(1):137–141. PMID: 10074764.
4. Michalakis KX, Hirayama H, Garefis PD. Cement-retained versus screw-retained implant restorations: A critical review. Int J Oral Maxillofac Implants 2003;18(5):719–728. PMID: 4579961.
5. McGlumphy EA, Papazoglou E, Riley RL. The combination implant crown: A cement- and screw-retained restoration. Compendium 1992;13(1):34, 36, 38 passim. PMID: 1521259.
6. Milin KN. Extraoral cementation of implant crowns. Dent Today 2010;29(10):130,132–133. PMID: 21086801.
7. Sarafidou K, Vasileiadi G, Louvrou MK, et al. Screwmentable implant-supported prostheses: A systematic review. J Prosthet Dent 2023;130(1):35–47. DOI: 10.1016/j.prosdent.2021.08.027.
8. Wadhwani CPK, Schwedhelm ER, Tarica DY, et al. Implant luting cements. In: Wadhwani CPK, editor. Cementation in Dental Implantology: An Evidence-Based Guide. Berlin, Heidelberg: Springer; 2015. pp. 50–51.
9. Breeding LC, Dixon DL, Bogacki MT, et al. Use of luting agents with an implant system: Part I. J Prosthet Dent 1992;68(5):737–741. PMID: 1432793.
10. Nematollahi F, Beyabanaki E, Alikhasi M. Cement selection for cement-retained implant-supported prostheses: A literature review. J Prosthodont 2016;25(7):599–606. DOI: 10.1111/jopr.12361.
11. Mehl C, Harder S, Wolfart M, et al. Retrievability of implant-retained crowns following cementation. Clin Oral Implants Res 2008;19(12):1304–1311. DOI: 10.1111/j.1600-0501.2008.01587.x.
12. Rosentritt M, Schneider-Feyrer S, Behr M, et al. In vitro shock absorption tests on implant-supported crowns: Influence of crown materials and luting agents. Int J Oral Maxillofac Implants 2018;33(1):116–122. DOI: 10.11607/jomi.5463.
13. Nejatidanesh F, Shakibamehr AH, Savabi O. Comparison of marginal and internal adaptation of CAD/CAM and conventional cement retained implant-supported single crowns. Implant Dent 2016;25(1):103–108. DOI: 10.1097/ID.0000000000000346.
14. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008;24(3):299–307. PMID: 17659331.
15. McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. Dent Clin North Am 1998;42(1):71–89. PMID: 9421671.
16. Jo JY, Yang DS, Huh JB, et al. Influence of abutment materials on the implant-abutment joint stability in internal conical connection type implant systems. J Adv Prosthodont 2014;6(6):491–497. DOI: 10.4047/jap.2014.6.6.491.
17. Winkler S, Ring K, Ring JD, et al. Implant screw mechanics and the settling effect: Overview. J Oral Implantol 2003;29(5):242–245. PMID: 14620687.
18. Wittneben JG, Buser D, Salvi GE, et al. Complication and failure rates with implant-supported fixed dental prostheses and single crowns: a 10-year retrospective study. Clin Implant Dent Relat Res 2014;16(3):356–364. DOI: 10.1111/cid.12066.
19. Sailer I, Mühlemann S, Zwahlen M, et al. Cemented and screw-retained implant reconstructions: A systematic review of the survival and complication rates. Clin Oral Implants Res 2012;23(Suppl 6):163–201. DOI: 10.1111/j.1600-0501.2012.02538.x.
20. Moris IC, Faria AC, Ribeiro RF, et al. Torque loss of different abutment sizes before and after cyclic loading. Int J Oral Maxillofac Implants 2015;30(6):1256–1261. DOI: 10.11607/jomi.3868.
21. Vahey BR, Sordi MB, Stanley K, et al. Mechanical integrity of cement- and screw-retained zirconium-lithium silicate glass-ceramic crowns to Morse taper implants. J Prosthet Dent 2018;120(5):721–731. DOI: 10.1016/j.prosdent.2018.01.028.
22. Hussien AN, Rayyan MM, Sayed NM, et al. Effect of screw-access channels on the fracture resistance of 3 types of ceramic implant-supported crowns. J Prosthet Dent 2016;116(2):214–220. DOI: 10.1016/j.prosdent.2015.12.016.
23. Rosa L, Borba M, Mallmann F, et al. Influences of screw access hole and mechanical cycling on the fracture load of implant-supported crowns. Int J Prosthodont 2019;32(5):423–429. DOI: 10.11607/ijp.6286.
24. ISO 14801. Dentistry-Implants-Dynamic Fatigue Test for Endosseous Dental Implants. Geneva, Switzerland: International Organization for Standardization; 2016.
25. Siamos G, Winkler S, Boberick KG. Relationship between implant preload and screw loosening on implant-supported prostheses. J Oral Implantol 2002;28(2):67–73. PMID: 12498448.
26. Graf H. Bruxism. Dent Clin North Am 1969;13(3):659–665. PMID: 5256151.
27. Mericske-Stern R, Zarb GA. In vivo measurements of some functional aspects with mandibular fixed prostheses supported by implants. Clin Oral Implants Res 1996;7(2):153–161. DOI: 10.1034/j.1600-0501.1996.070209.x.
28. Scheid RC. Morphology of Premolars. In: Scheid RC, editor. Woelfel's Dental Anatomy. 8th ed. Philadelphia, PA: Lippincott Williams and Wilkins; 2012. pp. 85–119.
29. Benjaboonyazit K, Chaijareenont P, Khongkhunthian P. Removal torque pattern of a combined cone and octalobule index implant-abutment connection at different cyclic loading: An in-vitro experimental study. Int J Implant Dent 2019;5(1):1. DOI: 10.1186/s40729-018-0154-2.
30. Huang Y, Wang J. Mechanism of and factors associated with the loosening of the implant abutment screw: A review. J Esthet Restor Dent 2019;31(4):338–345. DOI: 10.1111/jerd.12494.
31. Sammour SR, Maamoun El-Sheikh M, Aly El-Gendy A. Effect of implant abutment connection designs, and implant diameters on screw loosening before and after cyclic loading: In-vitro study. Dent Mater 2019;35(11):e265–e271. DOI: 10.1016/j.dental.2019.07.026.

32. Yi Y, Heo SJ, Koak JY, et al. Comparison of CAD/CAM abutment and prefabricated abutment in Morse taper internal type implant after cyclic loading: Axial displacement, removal torque, and tensile removal force. J Adv Prosthodont 2019;11(6):305–312. DOI: 10.4047/jap.2019.11.6.305.
33. Klongbunjit D, Aunmeungtong W, Khongkhunthian P. Implant-abutment screw removal torque values between customized titanium abutment, straight titanium abutment, and hybrid zirconia abutment after a million cyclic loading: an in vitro comparative study. Int J Implant Dent 2021;7(1):98. DOI: 10.1186/s40729-021-00378-z.
34. Paek J, Woo YH, Kim HS, et al. Comparative analysis of screw loosening with prefabricated abutments and customized CAD/CAM abutments. Implant Dent 2016;25(6):770–774. DOI: 10.1097/ID.0000000000000481.
35. Taha D, Sabet A. In vitro evaluation of material dependent force damping behavior of implant-supported restorations using different CAD-CAM materials and luting conditions. J Prosthet Dent 2021;126(1):93.e1–93.e9. DOI: 10.1016/j.prosdent.2021.03.016.