Original Article

In-Vitro Comparison of Screw Loosening, Fracture Strength and Failure Mode of Implant-Supported Hybrid-Abutment Crowns and Screwmentable Crowns Manufactured with Different Materials

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ABSTRACT

Background: Hybrid-abutment crowns and screwmentable crowns offer a fusion of the benefits from both screw and cement-retained restorations, potentially enhancing the overall performance of the restoration. **Aim:** This study aimed to evaluate the screw loosening and fracture strength of hybrid-abutment crowns and screwmentable crowns made with two different materials. **Methods:** Forty single-crown were made on titanium implants and divided into four groups (n = 10) [SM-Ti: Screwmentable titanium-porcelain crowns on stock titanium abutment; SM-Zr: Screwmentable zirconia-porcelain crowns on stock zirconia abutment; AC-Ti: Titanium-porcelain abutment crowns; AC-Zr: Zirconia-porcelain abutment crowns.] Specimens were torqued with 30 NCm and thermocycled between 5°C and 55°C in 20-second cycles for 5000 cycles. Removal torque values (RTV) were measured. Following the RTV measurement, the screws were changed with fresh screws and torqued again. Afterwards, specimens were loaded to fracture and fracture strengths were recorded, failure modes were examined. **Statistical Analysis Used:** Analysis of variance and Bonferroni test was performed. **Results:** The AC-Ti group displayed the highest mean torque loss (%20.09 ± 6.49) and the SM-Ti group displayed the lowest (%9.59 ± 8.84). Only the difference between AC-Ti and SM-Ti groups was found statistically significant, there are no significant differences between other groups. The fracture strengths are 385.84 ± 27.68 N, 313.18 ± 39.97 N, 272.69 ± 35.03 N, and 156.71 ± 19.83 N for AC-Ti, AC-Zr, SM-Ti, and SM-Zr groups, respectively and all differences were found to be statistically significant. Failures occurred as deformation in titanium components, whereas fractures were observed in zirconia components. **Conclusion:** Screw loosening was observed only in the AC-Ti group. No significant difference was observed among the torque loss values in the remaining groups. Titanium and zirconia materials do not exert any influence on screw loosening after thermal aging for hybrid-abutment crowns. Moreover, when assessing fracture strength, hybrid-abutment crowns exhibit superior strength and durability compared to screwmentable crowns.

KEYWORDS: *Abutment, dental implant, fracture strength, hybrid-abutment crown, screwmentable crown, screw loosening*

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INTRODUCTION

Implant-supported prostheses have emerged as a treatment approach for addressing both functional and aesthetic concerns associated with single-tooth deficiencies.[1-6] With the advancements in dental

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implant technology and the increase in the variety of prosthetic components, selecting the most suitable abutment for a particular clinical scenario becomes increasingly challenging.[2,3] Various types of titanium and zirconia abutments are used for implant-supported fixed prostheses and can be manufactured either in one or two pieces.[7,8] The base part of the abutment that connects with the implant is made of titanium (Ti-base), and the part that supports the restoration is made of zirconia in a two-piece system.[8,9] The presence of a titanium-titanium interface within the implant-abutment connection zone serves to enhance the fracture resistance of the restoration and offers protection against damage to the implant platform when subjected to occlusal forces in contrast to one-piece zirconia abutments.[8,10] Abutments can either be stock (prefabricated) abutments or manufactured individually (custom) for the patient. Custom abutments are manufactured by casting, copy milling, or CAD/CAM (Computer-Aided Design/Computer-Aided Manufacture) systems.[11-13] Custom abutments are deemed necessary in specific clinical scenarios, particularly when there is a need for a superstructure collar to achieve an optimal emergence profile or interocclusal space is limited.[9] A crucial determinant for achieving success is the consideration of the retention type of the superstructure. It can be provided either with cement or screw retention or with a combination of these two types.

The performance of screw and cement-retained restorations regarding survival rate, biological and technical complications, or esthetics were evaluated. Studies comparing cement and screw-retained restorations have not found any obvious advantage over each other for these two retention types.[14-17] The cement-retained technique has the disadvantage of residual cement may lead to periimplantitis and/or mucositis. Additionally, cemented crowns pose challenges for removal in the event of complications, such as screw loosening. The screw-retention technique increases the time required for delivery, as each adjustment before final placement necessitates screw insertion and removal, along with radiographic verification of proper seating. These hazards could be eliminated with the use of modified hybrid designs. Modified hybrid designs aimed to combine the advantages associated with cement and screw retentions, effectively establishing a third retention type.[14] These kinds of crowns are cemented extra orally to the abutment and screwed to implant as a single unit named "segmentable" in the reviewed literature.[18]

Recently, a new iteration of hybrid restorations has emerged, where the abutment and superstructure crown are conjoined as a single unit and connected to the implant via screw retention, commonly known as "hybrid-abutment crowns".[14,19,20] They are also mentioned as "non-segmented crowns" by some authors.[21] Hybrid-abutment crowns can either be manufactured from single blank milling or by baking veneer porcelain onto the abutment or representative abutment, manufactured by CAD-CAM to resemble abutment morphology. Consequently, directly veneered restoration was screwed to implant as one piece.[6,22-25] One-piece designs can be used with both titanium and zirconium abutments.[22,26-28] Fracture strength or load-bearing capacity is an important mechanical property for implant abutments and is considered an indicator of long-term clinical success.[29] Another factor to be considered in the selection of abutment is screw loosening. One of the prevalent complications in implant-supported fixed prosthetic restorations is the loosening of the abutment screw, which frequently occurs in implant-supported single crowns.[30,31]

While the screw loosening rate in implant-supported fixed partial restorations was 5.6% following a clinical follow-up period of 5 years, this rate was 12.7% in implant-supported single crowns.[32-34]

Various methods exist for assessing the percentage of screw loosening; including evaluating screw elongation, gauging preload, and measuring the screw removal torque.[35] Measuring the removal torque is the method currently in use to measure the screw loosening. Devices for measuring the removal torque can be manual and electronic. Electronic devices are better than manual devices in terms of clarity and ease of use.[11] Kim *et al*.[35] and Cardoso *et al*.[36] demonstrated that the ratio of the removal torque value after thermocycling to the initial tightening torque indicates the extent of loosening following thermocycling.

Thermocycling is a method used to simulate the temperature fluctuations experienced in the oral cavity, exposing dental materials and teeth to similar conditions that may lead to adverse effects. It enables the estimation of clinical performance by replicating oral environment temperatures.[37]

In the present study, it was aimed to compare the fracture strength and torque loss of implant-supported single crown restorations manufactured with different materials and techniques after thermal cycling. Only a limited number of studies have assessed the difference between hybrid-abutment crowns and screwmentable crowns regarding fracture strength[14,18-20] and screw loosening,[9,21] highlighting the need for further research to ascertain the efficacy of hybrid-abutment crowns. Laboratory tests offer a time-efficient and reproducible method for evaluation, with the advantage of standardized test parameters. When carefully designed, these tests can serve as valuable predictors of material performance and clinical applicability, providing insights into their potential success before broader clinical adoption. The present study aims to compare the screw loosening and fracture strengths of implant-supported hybrid-abutment crowns and screwmentable crowns manufactured with two different materials.

The two null hypotheses of the present study were conducted as: (1) there is no difference in torque loss of screwmentable crowns and hybrid-abutment crowns after thermocycling, and (2) there is no difference in fracture strength and failure mode of screwmentable crowns and hybrid-abutment crowns after thermocycling.

Methods

Forty dental implants in 3.8 mm diameter, 11.5 mm length, and with an internal hexagonal connection were used (Ratioplant, HumanTech Germany GmbH, Steinenbronn, Germany). The implants were positioned into the acrylic resin cylinder blocks vertically. For this purpose; each implant was mounted to a pin fixator (Degussa, Rosbach, Germany) by using the implant carrying pin (Ratioplant, HumanTech Germany GmbH, Steinenbronn, Germany). A plastic tube was filled with autopolymerizing acrylic resin that was mixed according to the manufacturer's recommendations. The vertical arm of the pin fixator was lowered using the loosening of the screw. The implant specimen fixed at the end of the vertical arm of the pin fixator was embedded in the autopolymerizing resin, up to a depth of 1 mm apical to the implant platform. The position of the implant specimen in the acrylic cylinder was fixed by tightening the screw of the pin fixator.[14] The implant specimen was held in the aforementioned position until the completion of polymerization [Figure 1]. Implant-supported single-crown restorations were planned in complying with the upper 1st premolar morphology (incisogingival 9 mm, buccopalatinal 9.5 mm, and mesiodistal 7 mm). A putty elastomeric index was used to standardize the porcelain thicknesses and dimensions of the restoration. Implants were randomized by simple randomization into four groups (n = 10) according to the abutment material and superstructure design as demonstrated in Table 1.

Stock titanium abutments (Ratioplant, HumanTech Germany GmbH) (0° angle, gingival height of 1 mm, and platform width of 4.5 mm) were used for the SM-Ti group. The substructures have a 2.5 mm diameter screw access hole on the occlusal side[18] and were designed with dental modeling software (Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany) and manufactured from titanium (Starbond Ti4, Scheftner Dental Alloys GmbH, Mainz, Germany) with CAD-CAM (HSC 20 Linear, DMG Mori, Stuttgart, Germany).

For the SM-Zr group, stock zirconia abutments (Ratioplant, HumanTech Germany GmbH) with the same dimensions as the abutments in the previous group were used, and zirconia substructures were designed (Exocad DentalCAD, Exocad GmbH) and milled (DentMILL 2013, Delcam, Birmingham, England) from green zirconia blanks (Upcera ST, Shenzhen Upcera Dental Technology Co., Liaoning, China) with CAD-CAM. After the fit-checking and fine-adjustment of the internal and marginal fitting accuracy of the abutments and substructures in both groups, veneer porcelain (Cerabien ZR, Kuraray Noritake Dental Inc., Tokyo, Japan) was baked on the substructures and glazed conventionally.[18]

For the AC-Ti group, representative Ti abutments with a substructure morphology and a 2.5 mm diameter screw access hole on the occlusal side were designed (Exocad DentalCAD, Exocad GmbH) and manufactured (HSC 20 Linear, DMG Mori, Stuttgart, Germany) from Ti blanks (Starbond Ti4, Scheftner Dental Alloys GmbH, Mainz, Germany) by using CAD-CAM. After checking the internal and marginal fitting accuracy of representative abutments to the implants, veneer porcelain (CCC-Bond, Alphadent NV, Waregem, Belgium; Ti-Ceram, Nobelpharma, Chicago IL, USA) was baked directly on the Ti representative abutments[21-23] with the same dimensions as the crowns in the previous groups and glazed conventionally [Figure 2]. For the last group, AC-Zr, representative Zr abutments with the same dimensional properties as the previous group were designed (Exocad DentalCAD, Exocad GmbH) and milled (DentMILL 2013, Delcam, Birmingham, England) from green zirconia blanks (Upcera ST, Shenzhen Upcera Dental Technology Co.,) by employing CAD-CAM. For the connection of the representative abutments with the implants, Ti-bases with a height of 5 mm and a platform width of 4.5 mm[14] were designed (Exocad DentalCAD, Exocad GmbH) with dental modeling software and milled (HSC 20 Linear, DMG Mori, Stuttgart, Germany) from titanium blanks (Starbond Ti4, Scheftner Dental Alloys GmbH) with CAD-CAM and fit of Ti-bases was checked according to the rotation and positioning parameters [Figure 3]. The restoration was completed with veneer porcelain directly baked on the representative abutment.[21,25-27] The screw access holes of the abutment and representative abutments were sealed with wax to prevent cement overflow. Then, the abutment surfaces and crown intaglio of the SM-Ti group and the adhesive interfaces of the Ti-bases of the AC-Zr group were sandblasted with 50 µm aluminum oxide (Al_2O_3) particles under 2 bar pressure for 20 seconds. Washed 5 minutes in detergent solution, rinsed 5 minutes in distilled water by using ultrasonic cleaner (Sonorex, Bandelin, Germany), and dried with an oil-free air syringe.[9] Afterward, silane (Silane, Ultradent Products, South Jordan, UT, USA) was applied and bench-dried to permit the evaporation of the solvent of the silane agent. The abutments of the SM-Zr group and the bonding surfaces of the representative abutments in the AC-Zr group were not sandblasted to avoid tetragonal-monoclinic phase transformation, only silane was applied. After surface treatment, crowns manufactured with screw access holes on the occlusal surfaces of the SM-Ti and SM-Zr groups were cemented to the abutments with a chemically polymerized adhesive resin cement (Multilink Hybrid-Abutment, Ivoclar-Vivadent, Schaan, Liechtenstein).[18] Abutment crowns were also assembled with their Ti-bases with the same protocol as the AC-Zr group.[14] The single crown specimens were torqued to the implants using a torque of 30 NCm, as per the manufacturer's guidelines with a calibrated digital torque meter (PCE-TM80, PCE Instruments, Meschede, Germany). The screw access holes were closed with Teflon tape and temporary filling material (Coltosol F, Coltene-Whaledent Inc., Altstätten, Switzerland), after being kept in distilled water at 37°C for 24 hours before the thermal cycle.[24] Then specimens were thermocycled between 5°C and 55°C with 20-seconds dwell-time, 5-seconds transfer time for a total of 5000 cycles as adhering to the studies aiming to measure the bond strengths of the adhesively luted restorations after thermocycling.[38] After thermal cycling, the removal torque values of specimens were measured by using a digital torque measuring device[35] (PCE-TM80, PCE Instruments, Meschede, Germany). The following equation[35] is used for the standardization of this measure and the intergroup comparison:

Torque loss rate after thermocycle (%)

$$= \frac{\text{Tightening torque} - \text{Removal Torque Value after thermocycle}}{\text{Tightening torque}} \times 100$$

The counter-clockwise force was applied to screws with the torque wrench attached to the sensor part of the digital torque meter. The maximum torque value obtained upon screw release was recorded as the removal torque value.[35] After measuring and recording the removal torque values, the screws were replaced with fresh ones. Fresh screws were tightened to 30 Ncm as described, by using a digital torque meter (PCE-TM80, PCE Instruments). Afterward, screw access holes were sealed using Teflon tape and restored with restorative resin composite (Tetric N-Ceram Bulk Fill, Ivoclar, Vivadent) conventionally. Specimens were subjected to fracture loading using a universal testing machine (KgN-50, Shimadzu, Osaka, Japan) using a specially manufactured steel specimen holder. Each specimen was positioned within the specimen holder housing, secured in the suitable position by tightening the screw, with an established angle of 30° between the force and the long axis of the implants and crowns [Figure 4].[35] Force was directed to the occlusal inclination of the buccal cusp to simulate the worst clinical scenario that could occur.[14] The specimens were subjected to a continuously increasing force and 2 mm/min crosshead speed.[20] The forces at the moment of fracture were recorded in Newtons (N). After failures, all specimens were analyzed with a digital microscope (Leica S8 APO, Ernst-Leitz GmbH, Wetzlar, Germany) at magnifications ranging from 10× to 50×, and failure modes were photographed (Leica DFC 295, Ernst-Leitz GmbH). Radiographic examination was applied to the specimens in which plastic deformation of the metal components or mobility in the abutment–crown complex was observed to determine whether there was a screw or abutment fracture. The microscopic and radiographic evaluation was performed to visual assessment of the failure modes. The data were analyzed by using the SPSS Statistics For Windows Software (IBM Corp. Released 2017, IBM SPSS Statistics For Windows, Version 25.0., IBM Corp., Armonk, NY, USA) at $a = 0.05$ significance level.

Results

Screw loosening

The torque loss of the groups was calculated according to the removal torque values and shown in Table 2. Accordingly, the highest screw loosening was

Table 1: Summary of study and group identification

Group	Abutment	Manufacture	Superstructure
SM-Ti	Ti abutment	Stock	Screwmentable titanium-porcelain crown
SM-Zr	Zr abutment	Stock	Screwmentable zirconia-porcelain crown
AC-Ti	Ti representative abutment	CAD-CAM	Veneer porcelain baked directly on the representative abutment
AC-Zr	Zr representative abutment with Ti-base	CAD-CAM	Veneer porcelain baked directly on the representative abutment

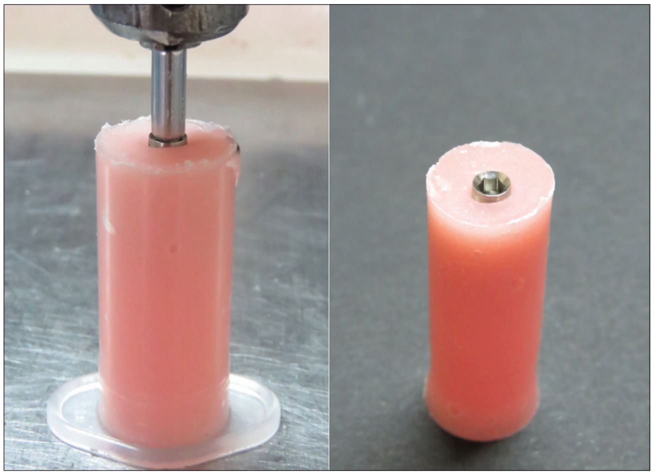

Figure 1: Positioning the implant in acrylic resin cylinder blocks

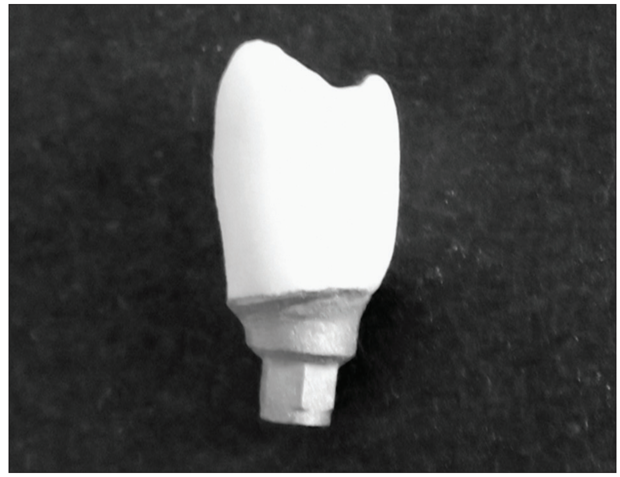

Figure 2: Overview of a sample of AC-Ti group. Abutment crown obtained by baking veneer porcelain directly on titanium representative abutment manufactured by CAD-CAM

Figure 3: Overview of some samples of the AC-Zr group. Abutment crown obtained by baking veneer porcelain directly on a zirconia representative abutment manufactured by CAD-CAM and supported with Ti-base

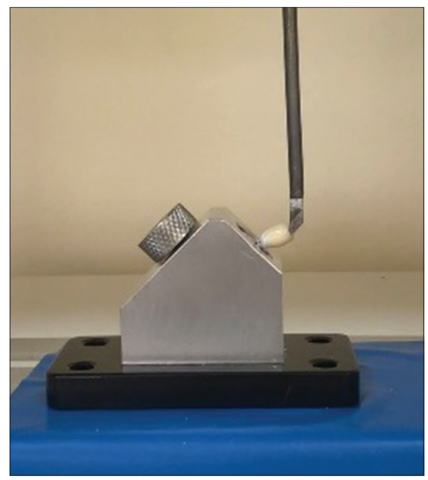

Figure 4: Specially manufactured steel specimen holder

Table 2: Descriptive statistics for screw loosening

RTV (%)	*n*	Mean	Std. Deviation	Minimum	Maximum
SM-Ti	10	9.59	8.84	0.00	22.66
SM-Zr	10	15.23	6.07	3.33	24.66
AC-Ti	10	20.09	6.49	7.33	28.33
AC-Zr	10	11.63	7.48	0.00	24.33

RTV: removal torque value

Table 3: One-way ANOVA for screw loosening

RTV (%)	Sum of squares	df	Mean square	*F*	Sig.
Between groups	636.10	3	212.03	3.97	0.015*
Within groups	1919.58	36	53.32		
Total	2555.69	39			

RTV: removal torque value. *Significant value (P<0.05)

Table 4: Multiple comparisons with the bonferroni correction test for RTV

	SM-Ti	SM-Zr	AC-Ti	AC-Zr
SM-Ti	-	0.55	0.01*	1.00
SM-Zr	0.55	-	0.86	1.00
AC-Ti	0.01*	0.86	-	0.08
AC-Zr	1.00	1.00	0.08	-

*Significant value (P<0.05)

observed in the AC-Ti group. This group is followed by SM-Zr, AC-Zr, and SM-Ti groups, respectively. One-way ANOVA revealed a significant difference in the overall means of the groups [Table 3]. Analysis of variance (ANOVA) was conducted, followed by post-hoc comparisons using the Bonferroni method for statistical analysis [Table 4]. Following the Bonferroni test, statistical significance ($P < 0.05$) was observed only between the SM-Ti and AC-Ti groups, with no significant differences noted between the remaining groups ($P > 0.05$).

Fracture strength

Table 5 presents the mean fracture strengths of the specimen groups. Accordingly, the group with the highest fracture strength was determined as AC-Ti, followed by AC-Zr, SM-Ti, and SM-Zr groups, respectively. Analysis of variance and Bonferroni correction showed that all pairwise comparisons were statistically significant [Tables 6 and 7].

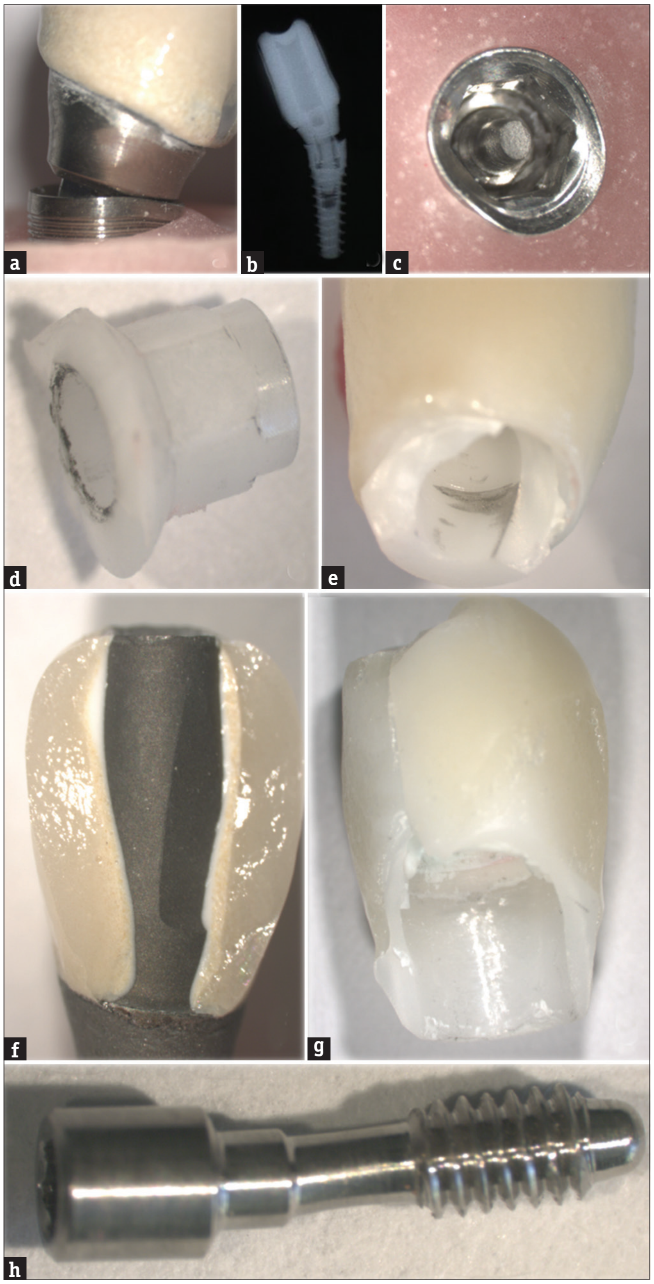

Figure 5: Failure modes. (a) Plastic deformation of the implant and hex of group SM-Ti, (b) Radiograph of the plastic deformation of group SM-Ti, (c) Screw fracture of a sample of group SM-Ti, (d and e) Internal hex level fracture of group SM-Zr, (f) Restoration fracture at titanium-porcelain level of group AC-Ti, (g) Separation of the abutment–crown complex from ti-base and fracture of group AC-Zr, (h) Plastic deformation of the screw

Failure modes

Table 8 and Figure 5 provide an overview of the failure modes observed in the test groups. The predominant failure mode identified in the SM-Ti groups involved screw, hex, and implant. Other failure modes observed in the mentioned group are restoration and screw fracture. In all of the samples in the SM-Zr group, zirconia fracture was determined at the level of the internal hexagon and no other failures occurred. Restoration fracture occurred only in 1 of the specimens in the AC-Ti group whereas the restoration fracture was accompanied by deformation of the abutment screw, internal hexagon, and implant in the remaining specimens. It was observed that all of the restoration fractures occurred at the titanium-porcelain level. In the AC-Zr group, restoration fractures, adhesive separation of the restoration from Ti-base, and deformation of screw, hex, and implant were observed.

Table 5: Descriptive statistics for fracture strength in Newton

Fracture strength (*n*)	*n*	Mean	Std. Dev.	Min.	Max.
SM-Ti	10	272.69	35.03	213.12	331.52
SM-Zr	10	156.71	19.83	127.05	178.85
AC-Ti	10	385.84	27.68	344.47	434.95
AC-Zr	10	313.18	39.97	258.85	374.80

Table 6: One-way ANOVA for fracture strength

Fracture strength	Sum of squares	df	Mean square	*F*	Sig.
Between groups	275395.78	3	91798.59	92.14	0.00*
Within groups	35866.57	36	996.29		
Total	311262.36	39			

*Significant value ($P<0.05$)

Table 7: Multiple comparisons with bonferroni correction test for fracture strength

	SM-Ti	SM-Zr	AC-Ti	AC-Zr
SM-Ti	-	0.00*	0.00*	0.04*
SM-Zr	0.00*	-	0.00*	0.00*
AC-Ti	0.00*	0.00*	-	0.00*
AC-Zr	0.04*	0.00*	0.00*	-

*Significant value ($P<0.05$)

Table 8: Failure modes of samples

	SM-Ti	SM-Zr	AC-Ti	AC-Zr
Screw fracture	1	-	-	
Restoration fracture	2	-	1	1
Screw, hex and implant deformation	6	-	-	2
Screw, hex and implant deformation and restoration fracture	1	-	9	3
Internal hex level fracture	-	10	-	-
Separation of the abutment–crown complex from ti-base, accompanied by fracture	-	-	-	4

Discussion

The data of the current study rejected the first hypothesis stating that there is no difference in torque loss of screwmentable crowns and hybrid-abutment crowns after thermocycling. This result contradicts those found by Al-Zordk *et al*.,[9] who stated that screw loosening is not related to the material of the abutment crown. This may be because the implant-abutment connection areas of all 3 groups in Al-Zordk's study were titanium bases. The present study demonstrated that the difference between the zirconia abutment crowns, titanium screwmentable crowns, and zirconia screwmentable crowns was not found significant regarding screw loosening but a statistically significant screw loosening occurred in titanium abutment crowns compared to other test groups. Also, some previous prospective clinical follow-up studies confirmed that the difference between screw-loosening percentages of zirconia abutment crowns and zirconia cement-retained crowns was not significant.[25,26] This can be explained by screw loosening is a late-stage complication.[39] The present study subjected the specimens to 5000 cycles of thermocycling, alternating between temperatures of 5°C and 55°C within 20-second intervals. According to the International Organization for Standardization (ISO) standards; 500 thermal cycles applied at a temperature between 5°C and 55°C is suitable for simulating short-term clinical use of dental materials.[40] Twenty thermal cycles were found equivalent to one day of clinical use.[41] In this context, the thermal cycling process used for artificial aging in the present study simulates approximately 1 year of clinical use, which was considered a short-term clinical duration for the implant prosthesis; therefore, the findings of the present study are limited to the short term.

Different superstructure retention types have different stress distribution patterns. Also, it is known that the similarity of the friction coefficient of the materials in the implant-abutment interface is a factor to be considered in terms of screw loosening.[33,35,42,43] Despite these facts, a significant difference was not observed among the groups except for titanium abutment crowns and screwmentable crowns. A statistically significant screw loosening occurred only in titanium abutment crowns after cyclic loading compared to other test groups. Both the prefabricated titanium abutments and abutment screws were supplied by the same manufacturer in the present study. Therefore there is an optimal match between the abutment, abutment screw, and the implant fixture. Unfortunately, the titanium blocks used for CAD-CAMing of the titanium representative abutments in the present study are not special blanks for the manufacture of abutments. In special blanks, the connection is prefabricated. Therefore, the adjustment between the internal hexagon and the abutment is better. Since the screw hole has already been drilled in these blanks, there is no need to drill screw holes and machine the hexagon surfaces. Given that the screw hole and hexagon are prepared, the abutment screw from the relevant implant company can be considered to fit perfectly, resulting in minimal anticipated torque loss.[11] Also, prefabricated abutments and connection surfaces pass quality control phases so differences between surfaces are less but CAD-CAMed surfaces differ depending on the method or machine used. The joint accuracy of CAD-CAM abutments has been criticized to be poorer than stock abutments. For this reason, blocks consisting of pre-made joint zones are recommended and require to be investigated further.[11]

The removal torque is generally reported to be 85–90% of the tightening torque.[36] From this perspective, torque loss of other groups was within the acceptable limits except for titanium abutment crowns with a 20.09% ± 6.49% torque loss.

The findings of this study are not in agreement with the results of Jemt[23] and Aalaei *et al*.,[21] who stated that crowns manufactured separately from the abutment are more prone to screw loosening. This variation could be ascribed to differences in the methodologies employed. As mentioned previously, the titanium blocks with pre-made joint zones were used in Jemt's[23] study and this may have reduced the risk of screw loosening observed in restorations manufactured as one piece. Furthermore, the differences between the results may be attributed to Jemt's[23] study being clinical research and Aalaei *et al*.[21] utilized a finite element analysis (FEA). FEA studies assume that all materials are homogenous, isotropic, and exhibit linear elasticity, which may restrict the applicability of the results to clinical scenarios.

The second null hypothesis was rejected because the fracture strength of abutment crowns was found higher than screwmentable crowns in both titanium and zirconia groups. This result is in agreement with those found by Roberts *et al*.,[18] who also noted that manufacturing the system in one piece without an intermediate cement phase strengthens the overall prosthetic restoration. However, the findings of this study were not in agreement with the results of Jemt[22] and Henriksson *et al*.,[27] who found abutment crowns and separate crowns clinical performances equally successful. Their results may be explained by the investigated restorations located within the incisor and canine regions, known to typically experience lower maximum chewing forces compared to posterior dentition and this may affect the results. Evaluating crowns within the posterior regions might have yielded different results. Some in-vitro studies stated that there is no significant difference between the fracture strength of abutment crowns and separate crowns.[14,19,20] However, their methodology and the hybrid-abutment crown material differed from those used in this study. Nouh *et al*.,[14] Elsayed *et al*.[19] and Elsayed *et al*.[20] evaluated lithium disilicate hybrid-abutment crowns. Furthermore, these studies utilized titanium bases in both hybrid-abutment crowns and abutments with separate crowns. This may have positively impacted the fracture strength of abutments with separate crowns because it's known that abutments combined with titanium bases have much higher fracture strengths.[44]

It has been remarked in some previous studies that abutment crowns are suitable for clinical use in the posterior region.[9,23,25] This result can be considered consistent with the findings of the present study. The peak force of mastication recorded in the premolar teeth ranged from 245-491 N during normal chewing function.[45] The restorations of all groups except the screwmentable zirconia group endured and exceeded masticatory forces within these ranges. Therefore, it's not recommended to use screwmentable zirconia restorations in the premolar region. Drawing from the findings of the present investigation, fracture patterns occurring on the abutment crowns are more destructive. Some related studies confirmed that fracture patterns of abutment crowns were more catastrophic than separate crowns and this may be attributed to enhanced force dispersion owing to the presence of assorted interfaces of separate crowns while abutment crowns have only a small interface area and limited absorption of the forces.[10,14]

Deformation of the various titanium components (screw, hex, and implant neck) was observed in SM-Ti and AC-Ti groups at 70% and 90%, respectively. An important observation for the AC-Ti group, exhibits the highest deformation rate in titanium components and also the group displaying the highest fracture strength. As loads exceed the yield limit of titanium, the components deform and bend. This may cause to fracture of the weakest part; the abutment screw.[46] In the entire zirconia abutments without titanium base (group SM-Zr), fractures were consistently observed at the internal hexagonal connection. This outcome aligns with findings from previous research.[20] The failure modes in AC-Zr group showed homogeneous character. The most common failure modes are the deformation of the titanium components and adhesive failure of the abutment crown combination from the ti-base. Zirconia ceramics exhibit notable resistance to compressive stresses, yet they demonstrate limited durability when subjected to tensile stresses. This gives friable character to the ceramic materials and tends to fracture under tensile stresses.[47] Under applied loads, metallic materials typically undergo both elastic and plastic deformations before eventual failure. In contrast, zirconia does not exhibit a plastic deformation phase. A brittle fracture occurs immediately after elastic deformation with almost zero elongation in the material. This is because the modulus of elasticity of zirconia (200 MPa) is higher than titanium (114-120 GPa).[5] Consequently, it's evident that specimens within the SM-Zr group, lacking titanium components, experienced immediate fracture without exhibiting any preceding deformations. The mentioned fracture modes are consistent with some other studies.[14,19,20,48]

When abutments with an internal connection are used and subjected to forces applied at a 30° angle to the implant axis, second-class levering effects are induced. Consequently, the load is concentrated in the area of the abutment's internal hexagon. As a result, the internal hex of the abutment becomes a highly stressed component, experiencing torque and stress concentrations. This may explain why most of the abutments failed at this connection area, observed as either zirconia fractures in the SM-Zr group or plastic metal deformation in the other groups.[20] Adhesive failures of the abutment crown combination in the AC-Zr group might be attributed to the area of bonding for the titanium bases used. Nouh *et al*.[14] referred to 3 mm height titanium bases as "short titanium bases". Based on this information, 5 mm height titanium bases were used in the present study. Despite this adjustment, adhesive failures were observed in the AC-Zr group. Therefore, it's recommended to investigate the effect of the titanium base height. The lack of dynamic loading can be thought of as a limitation of this study. However, thermocycling equivalent to one year of clinical use can cause short-term complications. However, thermal aging equivalent to a longer period of clinical use under cyclic loading may help to improve the knowledge regarding implant-retained single crowns.

Conclusion

Considering the constraints of our current study, the hybrid-abutment crown material does not impact torque loss following thermal aging, however, the superstructure design does. Titanium hybrid-abutment crowns are more prone to screw loosening than titanium screwmentable crowns while there is no difference for zirconia. Based on fracture resistance, hybrid-abutment crowns have higher fracture strength than screwmentable crowns for both materials. Using hybrid-abutment crowns may offer clinical benefits by enhancing the durability of the implant- supported restorations against excessive chewing forces.

Author contributions

All authors contributed to the study equally.

Ethics approval

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Declaration of patient consent

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Conflict of interest

The authors declare that they have no conflict of interest.

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