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Fracture Resistance of Single-Unit Implant-Supported Crowns: Effects of Prosthetic Design and Restorative Material

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Abstract

Purpose: To evaluate the fracture resistance and fracture patterns of single implant-supported crowns with different prosthetic designs and materials.
Materials and Methods: One hundred and forty-four identical crowns were fabricated from zirconia-reinforced lithium silicate (ZLS), leucite-based (LGC), and lithium disilicate (LDS) glass-ceramics, reinforced composite (RC), translucent zirconia (ZR), and ceramic-reinforced polyetheretherketone (P). These crowns were divided into 3 subgroups according to restoration design: cementable crowns on a prefabricated titanium abutment, cement-retained crown on a zirconia-titanium base abutment, and screw-cement crown ($n = 8$). After adhesive cementation, restorations were subjected to thermal-cycling and loaded until fracture. The fracture patterns were evaluated under a stereomicroscope. Statistical analysis was performed by using 2-way ANOVA/Bonferroni multiple comparison post hoc test ($\alpha = 0.05$).
Results: For each prosthetic design, ZR presented the highest fracture resistance ($p \leq 0.005$). Other than the differences with ZLS and RC for screw-cement crowns ($p > 0.05$) and RC for crowns on zirconia-titanium base abutments ($p > 0.05$), LGC showed the lowest fracture resistance. P endured higher loads than LDS ($p < 0.001$), except for the crowns on zirconia-titanium base abutments ($p > 0.05$). Cementable crowns presented the highest fracture resistance ($p < 0.001$), other than LGC and LDS. The differences between LGC crowns ($p > 0.05$) or LDS crowns on prefabricated titanium and zirconia-titanium abutments were nonsignificant ($p = 0.133$). Fragmented crown fracture was predominant in most of the restorations. Screw and abutment fractures were observed in ZR screw-cement crowns, and all P crowns were separated from the abutments.
Conclusions: Restorative material and restoration design affect the fracture resistance and fracture pattern of implant-supported single-unit restorations. Clinicians may restore single-unit implants in premolar sites with the materials and prosthetic designs tested in the present study.

In implant dentistry, the aim is to restore function and esthetics by rehabilitating the relevant area with a successful implant surgery and restoration.[1,2] Single implant-supported crowns stand out as the preferred treatment option for replacing posterior teeth due to their high survival rates.[1,3–6] However, the duration of healing period required for osseointegration is the main disadvantage.[7] Therefore, it is crucial for clinicians to combine suitable restorative materials and techniques that reduce the time required to treat the patient.

Correct selection of prosthetic components is one of the key elements to achieve a successful and long-lasting implant-supported restoration.[7] This selection is influenced by several factors including cost, ease of manufacturing, esthetics, occlusion, and the clinical performance of the restorative material to be used.[8] Advancements in computer aided design and computer aided manufacturing (CAD/CAM) technologies have enabled clinicians to design implant-supported restorations that are case-specific and highly esthetic[9,10] using a wide range of restorative materials with different mechanical properties.[11–13] Among these materials, zirconia, which has superior mechanical properties compared with other all-ceramic systems,[14,15] can be used as an abutment material due to its esthetic properties[1,3,16] and long-term survival.[17] However, complications have been reported while using single-unit zirconia abutments due to the fragile nature of this material.[3] Previous studies have shown that two-piece or zirconia-titanium base abutments, which consist of a transmucosal zirconia part and a titanium base,[10] presented higher fracture resistance compared to single-unit zirconia abutments.[2,18–20] Polyetheretherketone (PEEK) is a thermoplastic polymeric that has drawn attention as an alternative restorative material[21] due to its excellent mechanical properties, temperature resistance, chemical stability, and high biocompatibility.[22] Recently, this high-performance polymer has been modified with ceramic reinforcements to improve its mechanical and esthetic properties.[22–25] Modified PEEK behaves like cortical bone due to its modulus of elasticity (4 GPa), thereby reducing the stress transmitted to the bone.[26] Several reports are available on the clinical aspect of ceramic reinforced PEEK.[1,27] However, the information on the use of this material as an implant-supported crown material is limited.[21,28,29]

Besides the properties of the restorative material, the nature of the superstructure also affects clinical success.[30,31] Cement-retained restorations are easier to fabricate, have superior esthetic properties, present a higher potential of passivity, and are more resistant to ceramic fractures. In addition, cement acts as a barrier that prevents contamination and it is easier to arrange occlusion to direct the forces to the longitudinal axis of the implant with a restoration that has no screw access opening.[7,8,32] However, failure of these restorations is directly related to the excess cement present in inaccessible areas, which may cause an inflammatory response from the surrounding peri-implant soft tissue.[11,21] The main advantages of screw-retained restorations are retrievability and exceptional marginal integrity. Nevertheless, requirements of complex laboratory and clinical procedures as well as an optimal implant position, a higher rate of screw loosening, and disruption of occlusal anatomy due to the screw access opening are major drawbacks.[7,8] Advantages of these two connection types are combined in the screw-cement technique, in which crowns with screw access openings are cemented on a zirconia-titanium base abutment separately or on a titanium base abutment as a screw-cement crown in laboratory and subsequently screwed intraorally.[3,12,28,30,33]

A recent study reported that restorative material selection when manufacturing an implant-supported crown significantly affects the fracture pattern and load of the restoration.[29] However, the literature regarding the comparison of prosthetic design and selection of the restorative material on the fractural behavior of restorations is scarce. Thus, the present study aimed to compare the fracture resistance and fracture patterns of single-unit implant-supported crowns with different prosthetic designs and crown materials. The null hypothesis was that fracture resistance would not be affected by prosthetic design or crown material.

Materials and methods

Prior to beginning the study, a power analysis was performed (G*Power v.3.1.10; Heinrich-Heine-Universität Düsseldorf, Germany) to predict the sample size required for eighteen groups according to results of a previous study.[12] Eight samples per test group were determined to meet requirements (power = 80%, $f = 0.4$, $\alpha = 0.05$).

One hundred and forty-four dental implants (Trias Implants; Servo-Dental GmbH & Co. KG, Hagen, Germany) with a diameter of 3.8 mm and height of 12 mm were embedded in acrylic resin with a 3-mm gap between implant neck and resin surface[4,34] to simulate the posterior implants replacing maxillary first premolar. Stainless-steel plates were employed to ensure standardization while the samples were embedded. These implants were divided into three main groups according to the prosthetic design as cement-retained crowns on prefabricated titanium abutments (cementable), cement-retained crowns on zirconia-titanium base abutments, and screw-retained crowns cemented on titanium base abutments (screw-cement). These 3 main restoration groups were further divided into 6 subgroups according to the restorative materials used, which were zirconia-reinforced lithium silicate glass-ceramic (ZLS, Celtra Duo; Dentsply Sirona, PA), leucite-based glass ceramic (LGC, G Ceram; Gülsa, İzmir, Turkey), reinforced composite (RC, BRILLIANT Crios; Coltène AG, Altstätten, Switzerland), lithium disilicate glass-ceramic (LDS, IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein), translucent zirconia (ZR, Ceramill Zolid HT+; Amann Girrbach, Koblach, Austria), and ceramic-reinforced PEEK (P, BioHPP; Bredent, Senden, Germany). An overview of the groups is presented in Table 1.

One titanium base abutment (Grade 5, 3 mm in height; Trias Implants; Servo-Dental GmbH & Co. KG, Hagen, Germany) and one prefabricated titanium abutment (Grade 5, 7 mm in height; Trias Implants; Servo-Dental GmbH & Co. KG, Hagen, Germany) were fixed to their respective implants. After inserting a scan body on the titanium base abutment and coating the prefabricated titanium abutment with an anti-reflecting spray (CEREC Optispray; Dentsply Sirona, Bensheim, Germany), they were digitized by using a laboratory scanner (inEos X5; Dentsply Sirona, Bensheim, Germany). A single unit premolar shaped crown (11.5 mm length, 8.5 mm width) was designed using CAD software (CEREC inLab v 18; Dentsply Sirona, Bensheim, Germany) in standard tessellation language (STL) format. Fig 1 represents the overall design of the crowns as well as the design parameters, which were determined according to previous studies.[3,35]

Forty-eight full contour crowns were milled to restore prefabricated abutments, while another 48 crowns with screw access channels were milled to restore titanium base abutments as screw-cement crowns. Afterwards, the computer file was split and 48 zirconia substructures (Ceramill ZI; Amann Girrbach, Koblach, Austria) with their respective crowns were milled. LDS and ZLS crowns were crystallized as per manufacturers' recommendations, while ZR crowns and zirconia substructures were sintered in a zirconia furnace. Thereafter, all restorations were treated as indicated by their manufacturers (Table 2). Intaglio surfaces of zirconia substructures and titanium base abutments were sandblasted with 50 μm Al_2O_3 at 2.0 bar, while prefabricated titanium abutments were pretreated with 110 μm Al_2O_3 at 1.5 bar. Prior to cementation, all crowns were polished with a low-speed handpiece and a diamond polishing paste (Diamond Polish Mint; Ultradent, South Jordan, UT) to standardize the polishing procedure and eliminate the possible effects of polishing on fracture resistance.

Prefabricated titanium abutments were tightened to their respective implants with a torque wrench driver at 30 N/cm and the screws were retightened 10 min later to prevent

Table 1 Prosthetic designs and group abbreviations

				Restorative material					
				ZLS	LGC	RC	LDS	ZR	P
Prosthetic design	-	Prefabricated titanium abutment	Crown (Cement retained)	n = 8	n = 8	n = 8	n = 8	n = 8	n = 8
	Ti base	Zirconia substructure	Crown (Cement retained)	n = 8	n = 8	n = 8	n = 8	n = 8	n = 8
	Ti base	-	Full crown (Screw retained)	n = 8	n = 8	n = 8	n = 8	n = 8	n = 8

* ZLS: Zirconia-reinforced lithium silicate glass-ceramic; LGC: Leucite-based glass ceramic; RC: Reinforced composite; LDS: Lithium disilicate glass-ceramic; ZR: Translucent zirconia; P: Ceramic-reinforced PEEK.

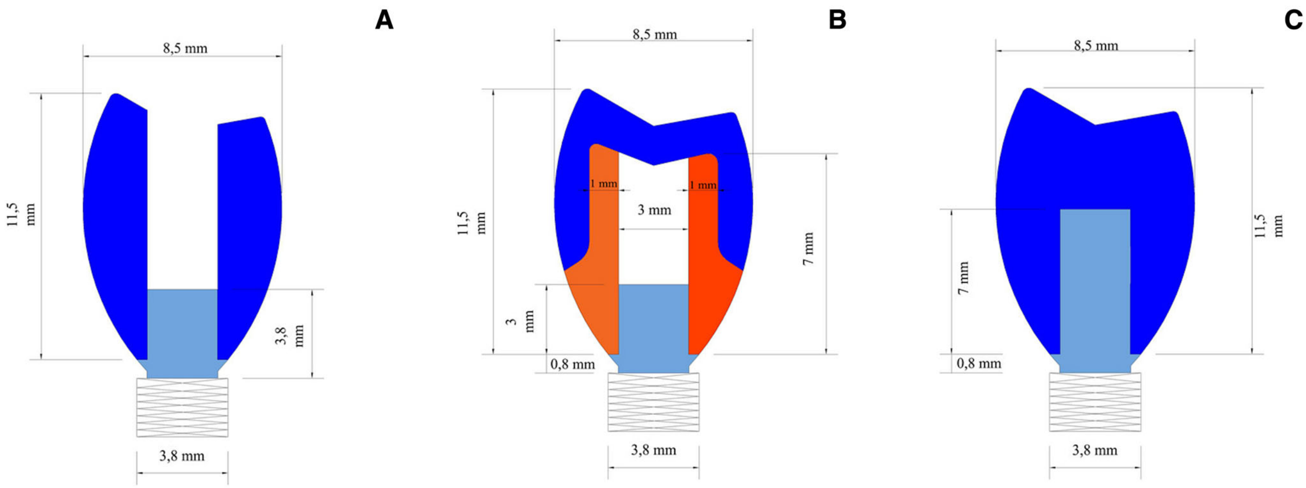

Figure 1 Schematic design of the restoration parameters showing the height and the buccolingual width of the crowns, the dimensions of the titanium base abutment, zirconia substructure, and the prefabricated titanium abutment. (A) Screw-cement crown, (B) Crown on zirconia-titanium base abutment, and (C) Cementable crown.

screw loosening.[2,3,28] Subsequently, screw access openings were sealed with a Teflon tape and a light-cure composite resin (Filtek Z250; 3M ESPE, St. Paul, MN). Full contour crowns were then adhesively seated on these abutments using a self-adhesive resin cement (G-CEM LinkAce; GC Corporation, Tokyo, Japan). After removing excess cement, an LED-curing unit (Bluephase; Ivoclar Vivadent, Schaan, Liechtenstein) was applied from all surfaces for 60 s.

Screw-cement crowns and zirconia substructures were cemented to titanium base abutments using a self-curing dental luting composite (Multilink Hybrid Abutment; Ivoclar Vivadent, Schaan, Liechtenstein). Preparation surfaces of the zirconia substructures were treated similar to intaglio surfaces. Screw-cement crowns and zirconia-titanium base abutments were tightened to the implants and sealed similar to prefabricated titanium abutments. Thereafter, separate crowns were bonded to zirconia-titanium base abutments in the same way as full contour crowns. All samples were then stored in distilled water at 37°C for 24 hours before thermal-cycling.

Samples were subjected to thermal-cycling for 5000 cycles between 5 and 55 °C with a dwell time of 30 s.[9] The maximum load at fracture (N) was measured by loading the samples statically with a universal testing machine (Shimadzu Corporation, Kyoto, Japan) with a 6-mm stainless steel sphere resting on buccal and palatal cusps (1 mm/min). Even distribution of forces was ensured by placing a tin foil with a thickness of 0.5 mm between indenter and samples.[1,29] After load to failure test, the restorations were visually examined under a stereomicroscope (Euromex Nexius Zoom Range, Arnhem, Netherlands) with a magnification of x12.5. Fracture patterns were categorized as: Score 1: Crown failure, Score 2: Screw or abutment failure, Score 3: Crown separation from the substructure (with deformation), Score 4: Crown separation from the substructure (without deformation).

Data were analyzed using a statistical analysis software (SPSS V23; SPSS Inc, Chicago, IL) at a significance level of $\alpha = 0.05$. The Shapiro-Wilk test was executed to analyze the distribution of the data. Two-way analysis of variance (ANOVA) was used to examine the effects of prosthetic design and restorative material on fracture resistance, followed by Bonferroni multiple comparison post hoc test. The fracture patterns were further evaluated by using Chi-square test ($\alpha = 0.05$).

Table 2 Surface treatments of the restorative materials used

Restorative Material	Surface Treatment
ZLS	5% hydrofluoric acid for 30 s + 60 s of silane (Monobond Plus; Ivolcar Vivadent, Schaan, Liechtenstein) application
LGC	5% hydrofluoric acid for 60 s + 60 s of silane (Monobond Plus; Ivolcar Vivadent, Schaan, Liechtenstein) application
RC	Airborne particle abrasion using 50 µm Al_2O_3 particles at 1.5 bar for 5 s
LDS	5% hydrofluoric acid for 20 s + 60 s of silane (Monobond Plus; Ivolcar Vivadent, Schaan, Liechtenstein) application
ZR	Airborne particle abrasion using 50 µm Al_2O_3 particles at 2 bar for 20 s
P	Airborne particle abrasion using 110 µm Al_2O_3 particles at 2 bar for 10 s from a distance of 15 mm + 10 s of Visio.link (Bredent, Senden, Germany) application followed by 90 s of LED curing

*ZLS: Zirconia-reinforced lithium silicate glass-ceramic; LGC: Leucite-based glass ceramic; RC: Reinforced composite; LDS: Lithium disilicate glass-ceramic; ZR: Translucent zirconia; P: Ceramic-reinforced PEEK.

Table 3 Fracture resistance values of different materials: mean ± standard deviation (N)

	Screw-Cement Crown	Crown on Zirconia-Titanium Base Abutment	Cementable
ZLS	850.6 ± 124.4^{Cd}	1435.3 ± 143^{Bc}	1873.2 ± 284.8^{Ad}
LGC	584.9 ± 89.3^{Ad}	788.1 ± 153.5^{Ad}	870.9 ± 204.6^{Af}
RC	725.7 ± 157.2^{Bd}	1019.2 ± 174.2^{Bd}	1434.1 ± 261.5^{Ae}
LDS	1412.7 ± 206.2^{Bc}	1961.1 ± 153^{Ab}	2342.8 ± 157.2^{Ac}
ZR	2452.8 ± 265.6^{Ca}	3109.1 ± 221.7^{Ba}	3751.4 ± 335.2^{Aa}
P	1978.6 ± 210.6^{Bb}	1942.1 ± 440.1^{Bb}	2896.5 ± 453^{Ab}

*Different lowercase letters represent significant differences among columns, while uppercase letters represent differences in rows ($p < 0.05$). ZLS: Zirconia-reinforced lithium silicate glass-ceramic; LGC: Leucite-based glass ceramic; RC: Reinforced composite; LDS: Lithium disilicate glass-ceramic; ZR: Translucent zirconia; P: Ceramic-reinforced PEEK.

Results

The effects of prosthetic design ($F = 338.762$, $df = 2$, $p < 0.001$), material ($F = 1707.513$, $df = 5$, $p < 0.001$), and their interaction ($F = 69{,}387$, $df = 10$, $p < 0.001$) were found to be statistically significant. Table 3 summarizes the descriptive statistics of each prosthetic design and restorative material. Cementable crowns presented significantly higher fracture resistance values than screw-cement crowns ($p < 0.001$) and crowns on zirconia-titanium base abutments ($p \leq 0.045$). However, no significant differences were observed for LGC restorations ($p > 0.05$), while similar values were observed when LDS was fabricated as cementable crowns and crowns on zirconia-titanium base abutments ($p = 0.133$). ZLS, LDS, and ZR crowns on zirconia-titanium base abutments showed higher fracture resistance values than screw-cement crowns of the same materials ($p < 0.001$), whereas LGC, RC, and P showed similar values while comparing these prosthetic designs ($p > 0.05$).

The fracture resistance values among cementable crowns were ranked as ZR, P, LDS, ZLS, RC, and LGC in decreasing order ($p \leq 0.02$). While comparing the fracture resistance values of the crowns on zirconia-titanium base abutments, ZR showed the highest values ($p < 0.001$), while LGC and RC showed the lowest values ($p < 0.001$). As for the other materials, LDS and P showed similar values ($p > 0.05$) that were higher than ZLS ($p \leq 0.002$). The differences among ZLS, LGC, and RC screw-cement crowns were nonsignificant ($p > 0.05$) and these materials showed the lowest fracture resistance values ($p < 0.001$). The highest fracture resistance values were observed in ZR screw-cement crowns ($p \leq 0.005$), while P showed statistically higher values than LDS ($p < 0.001$).

The fracture resistance values among ZLS and ZR were ranked as cementable crowns, crowns on zirconia-titanium base abutments, and screw-cement crowns in decreasing order ($p < 0.001$). RC ($p \leq 0.045$) and P ($p < 0.001$) showed the highest fracture resistance values when fabricated as cementable crowns, while other designs of these materials showed similar values ($p > 0.05$). Screw-cement LDS crowns showed the lowest values within this material ($p < 0.001$).

Fracture patterns are presented in Table 4. Chi-square test presented significant differences within each prosthetic design ($p < 0.001$) and for ZR as screw-cement crown, and P as cementable crown ($p = 0.032$). In general, a similar fracture pattern of fragmented crown fracture was observed in all restorative material-prosthetic design pairs except for P and ZR. Three ZR screw-cement crowns presented screw fractures, while all of the P restorations were separated from their abutments with only 3 cementable P crowns showing deformation while separating (Fig 2).

Discussion

The present study evaluated the fracture resistance of 3 prosthetic designs using 6 different restorative materials for single-unit implant-supported crowns. The null hypothesis was rejected as prosthetic design and restorative material affected the fracture resistance of implant-supported crowns.

Maximum masticatory forces in the molar region were reported to reach up to 900 N[36] and among the materials tested in the present study, LGC could not endure such forces regardless of the prosthetic design. Moreover, similar to the finding of previous studies,[1,4,21,29] ZR presented the highest fracture resistance values compared to other restorative materials for each prosthetic design. This result may be associated with the properties of the material.[3] Previous studies have concluded that LDS[3] and P[28] screw-cement crowns are not suitable for treating implant-supported molar restorations as reported fracture resistance values were inferior to 900 N. The crown design of the study by Nouh et al[3] is similar to the present study, yet the absence of repeated mechanical loading in the present study might be the reason for the higher fracture resistance values obtained. However, fracture resistance values in the present study are superior to the documented maximum masticatory forces

Table 4 Fracture patterns (n and %) of the restorations

	Screw-Cement Crown				Crown on Zirconia-Titanium Base Abutments				Cementable				
	Score 1	Score 2	Score 3	Score 4	Score 1	Score 2	Score 3	Score 4	Score 1	Score 2	Score 3	Score 4	
ZLS	8 (100 %)	-	-	-	8 (100 %)	-	-	-	8 (100 %)	-	-	-	
LGC	8 (100 %)	-	-	-	8 (100 %)	-	-	-	8 (100 %)	-	-	-	
RC	8 (100 %)	-	-	-	8 (100 %)	-	-	-	8 (100 %)	-	-	-	
LDS	8 (100 %)	-	-	-	8 (100 %)	-	-	-	8 (100 %)	-	-	-	
ZR	5[a] (62.5 %)	3[ab] (37.5 %)	-	-	8 (100 %)	-	-	-	8 (100 %)	-	-	-	$p = 0.032$
P	-	-	-	8[a] (100 %)	-	-	-	8[a] (100 %)	-	-	3[ab] (37.5 %)	5[a] (62.5 %)	$p = 0.032$
	$P<.001^a$				$P<.001^a$				$P<.001^a$				

*Score 1: Crown failure, Score 2: Screw or abutment failure, Score 3: Crown separation from the substructure (with deformation), Score 4: Crown separation from the substructure (without deformation). [a] $p < 0.05$ presents significant differences among materials within each prosthetic design. [b] $p < 0.05$ presents significant differences among prosthetic designs within each material. ZLS: Zirconia-reinforced lithium silicate glass-ceramic; LGC: Leucite-based glass ceramic; RC: Reinforced composite; LDS: Lithium disilicate glass-ceramic; ZR: Translucent zirconia; P: Ceramic-reinforced PEEK.

in the premolar region that were in the range of 200-445 N.[37] Therefore, all the restorative material-prosthetic design pairs tested in the present study might be clinically acceptable to restore missing teeth in the premolar region.

Restorative materials with low modulus of elasticity, such as RC and P, might be preferred in load-bearing areas as these materials absorb more energy than ceramics, which have a brittle nature.[21] This shock absorbing effect might be particularly favorable for implant-supported restorations as occlusal loads are directly transmitted to the peri-implant bone.[4,11] Additionally, previous studies showed that P-titanium base abutments can endure similar occlusal loads as zirconia-titanium base abutments.[1] In the present study, P withstood comparable occlusal forces with LDS and even surpassed it when fabricated as a screw-cement crown. These findings are in agreement with previous studies.[21,28,29] In addition, P restorations exhibited statistically lower fracture resistance values than ZR restorations in the present study, which supports the findings of previous studies.[28,29] Al-Zordk et al[28] evaluated the fracture resistance of screw-cement maxillary first premolar P crowns after thermal-cycling, and reported lower values (556.76 N) than the present study, which may be related to the longer thermal-cycling (7000 cycles at 5-55°C) performed. However, in another study investigating the fracture resistance of different CAD/CAM materials as screw-cement crowns after thermomechanical aging (49 N for 1.2×10^6 cycles at 2 Hz), P crowns showed higher values (2030 N) than the present study, which were also comparable with zirconia screw-cement crowns (2645 N).[21] The fracture resistance of mandibular first molar shaped P crowns on prefabricated titanium and zirconia-titanium base abutments after thermomechanical aging (100 N for 1.2×10^6 cycles at 2.4 Hz) has also been studied.[29] Elsayed et al[29] presented similar fracture resistance values for both types of restorations (3877.8 N on prefabricated titanium abutment and 3967 N on zirconia-titanium base abutment) that were higher than the findings of the present study. These contradicting results may be attributed to the differences in aging processes,[21,28,29] shapes of the tested crowns,[29] and materials used.[21] Furthermore, P crowns are generally veneered with composite for esthetically pleasing final restorations. However, monolithic restorations were fabricated in the present study to eliminate possible failures in the composite P interface or veneering material.[29] P substructures cemented on titanium abutments were shown to achieve mean fracture values of 1920.9 N when veneered with milled composite and 921.3 N when veneered with paste composite,[12] which are considerably lower than findings of the present study (2896.5 N). Moreover, P crowns veneered with paste composite did not survive thermomechanical aging when fabricated as crowns with screw access channels. The difference between the present study and the study by Preis et al[12] might be related to the thermomechanical aging performed as well as the possibility of composite-P interface acting as a weak point during the fracture test.

RC used in the present study has an elastic modulus around 10 GPa,[13] yet compared to P (4 GPa) it still has higher modulus of elasticity and presented with significantly lower fracture resistance values compared to those of LDS or ZR; this is in accordance with the study of Yazigi et al.[21] Moreover, in a previous study, a composite resin material with an elastic modulus

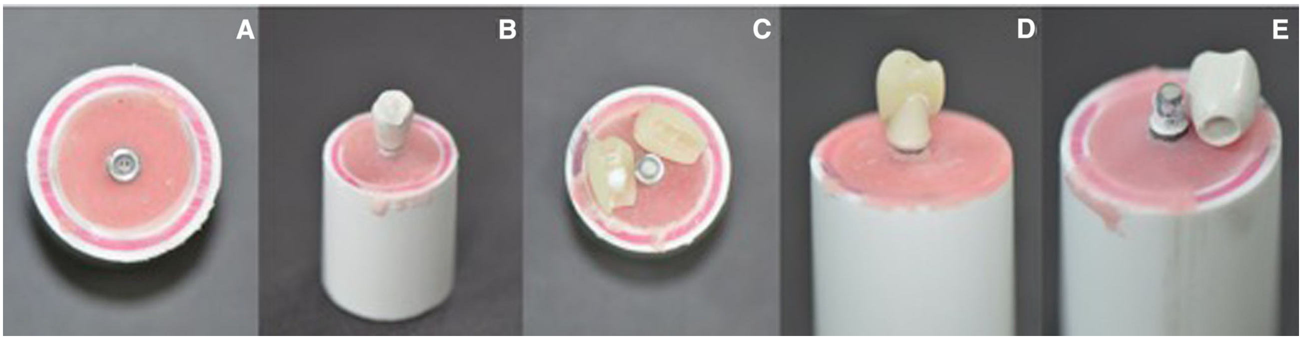

Figure 2 Fracture patterns observed. (A) Screw fracture, (B) Deformed P crown, (C) Crown failure of a screw-cement crown, (D) Crown failure of a crown on a zirconia-titanium base abutment, and (E) Separated P crown.

of 1.7 GPa showed equivalent fracture resistance values with LDS.[4] These findings might indicate the durability of materials with low elastic modulus to high occlusal loads. However, this interpretation needs further in vivo support.

In the present study screw-cement crowns presented statistically lower values than crowns on zirconia-titanium base abutments for ZR and LDS, while similar values were observed for other restorative materials. Interestingly, in a previous study no significant difference was found between screw-cement crowns and crowns on zirconia-titanium base abutments while using ZR or LDS.[3] These diverse results indicate the necessity of further studies in which screw-cement crowns are investigated.

The present study is believed to be the first on the fracture resistance of LGC, ZLS, and RC when fabricated as screw-cement crowns. These materials demonstrated statistically lower fracture resistance values compared to ZR, LDS, and P when manufactured as screw-cement crowns, with the difference between each other being nonsignificant (Table 3). Furthermore, ZLS (1435.3 ± 143 N) survived higher fracture resistance values than RC (1019.2 ± 174.2 N) and LGC (788.1 ± 153.5 N) while restoring zirconia-titanium base abutments. LGC was shown to obtain comparable fracture resistance values with LDS in a previous study when cemented on solid abutments.[7] However, in the present study the difference between cementable LGC (870.9 ± 204.6 N) and LDS (2342.8 ± 157.2 N) was significant. In the present study, the prefabricated titanium abutment (7 mm) and the crown (11.5 mm) were higher than in the study from Stona et al[7] (4 mm of solid abutment height and 1.6 mm of occlusal ceramic thickness), which may be the reason behind these differences. Weyhrauch et al[9] investigated the fracture resistance of premolar crowns fabricated from several CAD/CAM ceramics cemented on titanium abutments and similar to the findings of the present study, LDS presented with higher fracture resistance values than LGC and ZLS. This was further supported by another study[11] and the superiority of LDS over ZLS might be explained by the fact that the latter is milled in a crystallized state, which may have weakened the prosthetic structure.[9] This may also explain the low values of ZLS screw-cement crowns.

The fracture resistance values of crowns on zirconia-titanium abutments and screw-cement crowns were lower than cementable crowns, regardless of the restorative material. These results comply with previous studies, in which all-ceramic crowns presented higher fracture resistance values when titanium abutments and zirconia-titanium abutments were restored.[1,38] Moreover, the screw access channel of the screw-cement crowns might have caused the lower fracture resistance values compared with cementable crowns as the continuity of the crowns was disrupted. In addition, the high modulus of elasticity and brittle structure of zirconia may have negatively affected the fracture resistance of the restorations.[9,39] These properties of zirconia might have also affected the fracture patterns as screw fracture was only seen in ZR screw-cement crowns. These catastrophic fractures may be due to the high stress accumulation created by the high elasticity modulus of zirconia on the screw head and abutment. On the contrary, rather than fracture, separation of the restoration from substructure was observed when P was used and this may be due to the low elastic modulus of the material. Clinically, this type of failure can be classified as favorable, as both the substructure material and the non-deformed crown can be reused if necessary. Both of these findings are substantiated by the statistically significant distribution of fracture patterns for ZR and P. As for the other test groups, crown fractures were observed regardless of the restoration design, which were in line with previous studies.[9,10]

Static loading was applied during fracture testing. This test method does not simulate the masticatory function that may result in screw loosening or screw fracture,[17,21,29] which is a limitation of this study. Elshiyab et al[16] showed that chewing simulation of zirconia hybrid-abutments restored with zirconia or lithium disilicate crowns significantly reduces the fracture resistance of the restorations. This finding is consistent with the study of Bankoglu Gungor et al.[10] Future in vitro studies where these prosthetic designs and materials are tested after thermomechanical loading or in vivo studies may be beneficial to comprehend the outcomes of these two parameters on the survival of single-unit implant-supported crowns.

Conclusions

Regardless of the prosthetic design, translucent zirconia presented the highest fracture resistance values, while leucite-based glass ceramic presented lower fracture resistance values than other materials. Other than leucite-based glass ceramic and lithium disilicate glass ceramic, prefabricated titanium abutments restored with cement-retained crowns showed the highest fracture resistance, whereas the screw-cement crown design endured the lowest fracture loads for zirconia-reinforced lithium silicate and translucent zirconia. Nevertheless, all restorative material-prosthetic design pairs demonstrated resistance to tolerate the maximum chewing forces in the premolar area.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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