

# Fracture resistance of different implant supported ceramic abutment/crown systems

## Purpose

The purpose of this study was to investigate the fracture resistance and failure modes of different non-aged and aged abutment/crown systems.

## Materials and Methods

One hundred dental implants (diameter 4.3 mm and length 11.5 mm) were restored with five abutment/crown systems: G1: a lithium disilicate hybrid abutment crown, G2: a lithium disilicate crown cemented on a lithium disilicate hybrid abutment, G3: a lithium disilicate crown cemented on a zirconia hybrid abutment, G4: a direct veneer porcelain layering on a zirconia hybrid abutment, and G5: a lithium disilicate crown cemented on a prefabricated all-zirconia abutment. Each group was divided into two groups (n=10) as control (non-aged) and thermomechanically aged. The fracture resistance test was performed. Failures during the aging process and after the fracture resistance test were examined.

## Results

Both of the factors (restoration type and aging) affected the fracture resistance values and there was not an interaction between the factors ( $p>0.05$ ). When fracture resistance values were compared regardless of aging, the highest values were observed in G3 and G4, respectively ( $p<0.05$ ). When comparing the fracture resistance values, regardless of the restoration type, the aged group showed a significant lower fracture resistance value than control group ( $p<0.05$ ).





## Conclusion

A titanium base enhanced the fracture resistance of zirconia abutments. Thermomechanical aging decreased the fracture resistance of the tested ceramic abutment/crown systems. The major failure mode was the abutment fracture.

**Keywords:** Dental implant-abutment design; Yttria-stabilized tetragonal zirconia polycrystals ceramic

## Introduction

The ultimate goal in implant dentistry is not only to achieve a functional result, but also to create pleasing esthetics that consider the proper proportions and natural relationships among the peri-implant soft tissue, bone, and restorative material (1,2). Abutment, which is an intermediate component between implant and restoration, is important for mechanical stability and the esthetic result of an implant restoration. In this context, the present study has focused on the abutment material, abutment design, and crown material to provide reliable and esthetic implant-supported restorations (2). Biocompatibility, mechanical properties, and clinical success of implant abutments fabricated from commercially pure titanium have been well-documented (3-5). However, the metallic color of the titanium may reflect through soft tissue and impair the esthetics.

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To achieve optimal esthetics, especially in the anterior region, all-ceramic abutments have been introduced due to their tooth-like color and possible biological advantages (6). Furthermore, developments in Computer Aided Design-Computer Aided Manufacturing (CAD-CAM) technology have led clinicians to design case-specific, esthetic implant-restorations and to fabricate these restorations from various materials (7). Zirconia and lithium disilicate ceramics have been used recently as high strength implant supported superstructure materials.

Zirconia abutments can be fabricated as an one-piece which is entirely made of zirconia and as a two-piece consisting of a titanium base and a transmucosal zirconia part. This zirconia part connects to the dental implant via the titanium base. The connection element of the one-piece zirconia abutments has been reported to be prone to fracture (8). Moreover, the precise fit of the connection interface is questionable (9) and wear has been reported at the titanium implant (10). The two-piece zirconia abutments, which provide a titanium-titanium interface at the implant abutment connection, revealed a higher fracture strength compared with one-piece zirconia abutments and reduced the risk of implant platform damage under occlusal forces (11). Therefore, the two-piece zirconia abutments have currently attracted significant interest with high fracture resistance, good esthetics, providing a precise fit with the implant, and biocompatibility (1,6,12). However, the high optical opacity and white appearance of the zirconia ceramic are well known (13). To mimic the translucent appearance of natural dentition, conventional zirconia is veneered with glass ceramics in dental restorations (14). Veneering zirconia abutments can be achieved by cementing a ceramic crown on the zirconia abutment bonded on a titanium base or direct ceramic processing on the abutment bonded on a titanium base. Nevertheless, zirconia may fail to provide optimal esthetics because of its opacity in some clinical situations.

Lithium disilicate (LDS), the strongest glass ceramic, has a higher translucency and can provide better shade matching with natural dentition compared with zirconia (9,15). Recently, prefabricated LDS has been considered as an esthetic abutment material while the material has been widely used in fixed prosthodontics. LDS abutments are used with titanium bases. There are two restorative possibilities using LDS abutments including cementing a ceramic crown on the LDS abutment and fabricating the abutment and crown in one-piece and bonded to a titanium base (9). LDS abutments, especially one-piece restorations which are a combination of abutment and crown, can provide some advantages over zirconia abutments including less interocclusal space requirement, higher translucency, and elimination of layered structure and its interfacial bond problems.

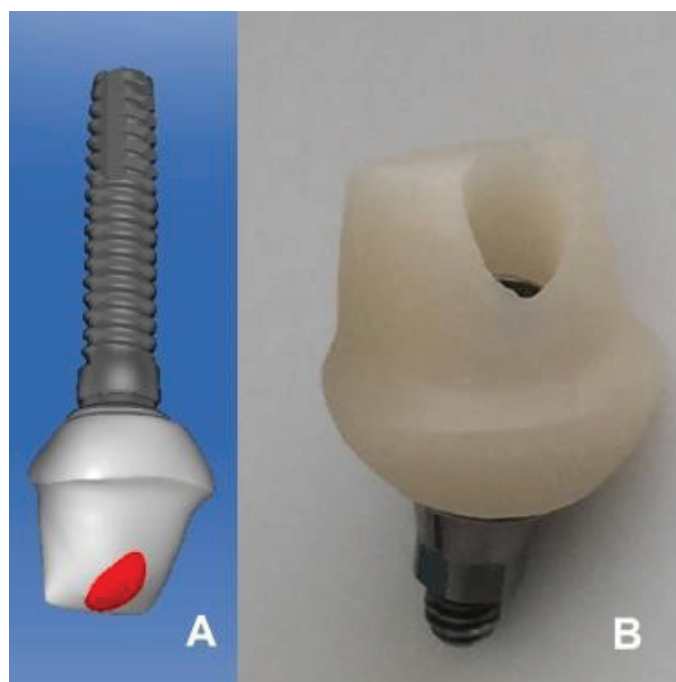
Literature research revealed that several studies were conducted on the mechanical performance of zirconia abutments with different designs. However, limited research has been conducted on mechanical performance of differently designed two-piece ceramic abutments including lithium disilicate implant abutments (2,9). The purpose of this study was to investigate the fracture resistance and failure modes of non-aged and aged zirconia and LDS ceramic abutments with different crown designs. The null hypotheses of the study were that there would be no difference between the fracture

resistance of the different ceramic abutment/crown systems and thermomechanical aging would not affect the fracture resistance of these abutments.

## Materials and Methods

### Sample characteristics and preparation

One hundred dental implants (diameter 4.3 mm and length 11.5 mm) (NobelReplace, Nobel Biocare, Gothenburg, Sweden) were restored with five ceramic implant abutment/crown systems simulating the restoration of a maxillary right central incisor. The groups were as follows: Group 1 (G1): A Lithium disilicate hybrid abutment crown, Group 2 (G2): A Lithium disilicate crown cemented on a lithium disilicate hybrid abutment, Group 3 (G3): A Lithium disilicate crown cemented on a zirconia hybrid abutment, Group 4 (G4): A direct veneer porcelain layering on a zirconia hybrid abutment, Group 5 (G5): A Lithium disilicate crown cemented on a prefabricated all-zirconia abutment. Ceramic implant abutment/crown systems were designed and manufactured using a CAD-CAM system (Cerec, Sirona Dental Systems, Bensheim, Germany) (Figure 1).



**Figure 1.** Custom ceramic abutment A: Design of abutment B: Milled and crystallized lithium disilicate abutment.

G1 (which consisted of a monoblock abutment and crown combination bonded to the titanium base) was milled from lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). For G2, G3, and G4, abutments were bonded to the titanium base. Using this abutment design, identical abutment parts were fabricated from lithium disilicate for G2, and from a presintered Y-TZP material (incorisZI mesoblocks, Sirona Dental Systems) for G3 and G4. After the milling process, the lithium disilicate abutments were fully crystallized in a porcelain furnace (Programat P300, Ivoclar Vivadent) and zirconia abutments were dried and sintered in a calibrated sintering furnace (inFire HTC, Sirona Dental Systems). CAD-CAM fabricated parts were produced in a milling unit

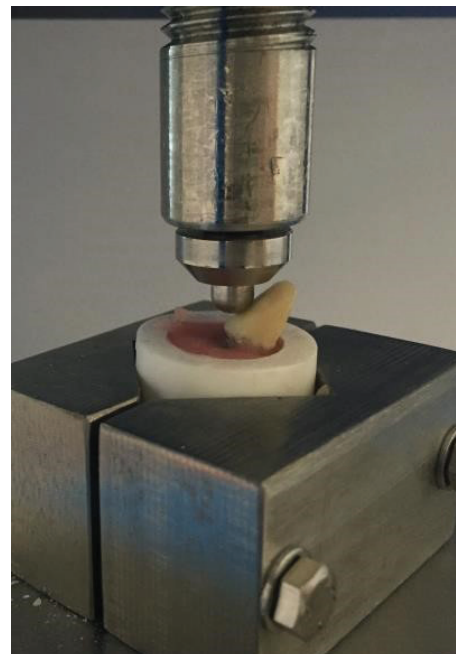
(Cerec MC XL, Sirona Dental Systems). After the fabrication process of the ceramic parts (lithium disilicate or zirconia), the hybrid abutments, ceramic part and titanium base of the abutments were bonded using a resin cement (Multilink Hybrid Abutment, Ivoclar Vivadent). Luting space was directly determined by the software. Prior to cementation, the titanium bases were screwed to the implants with a torque of 35 Ncm and appropriate manufacturer recommended surface treatments were applied to the bonding surfaces. The screw holes in the titanium bases were sealed with heavy body impression material (Hydrorise Maxi Heavy, Zhermack Spa, Badia Polesine, Italy). The bonding surfaces of the titanium bases were air-borne particle abraded with 50 microns aluminum-oxide particles at 2 bars pressure for 20 seconds. The bonding surfaces of the lithium disilicate ceramics were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) followed by applying silane (Monobond Plus, Ivoclar Vivadent). Bonding surfaces of zirconia ceramics were air abraded with 50 microns aluminum-oxide particles at 2 bars pressure for 20 seconds. Both titanium bases and ceramic parts were cleaned in an ultrasonic bath of distilled water and dried prior to the cementation. After cleaning, the bonding surfaces were protected from contamination. A self curing resin cement (Multilink Hybrid Abutment, Ivoclar Vivadent) was used to bond titanium bases and ceramic parts of the restorations. Careful insertion of the ceramic part was provided considering the rotation and position stops. Two components were seated and pressed together by hand, using a constant pressure. Excess cements were removed. Then, as recommended by the cement manufacturer, the specimens were left to self-cure for 7 minutes. The specimens were stored in a humidifier at room temperature for 24 hours. Twenty specimens were prepared for each abutment group, 10 of which were assigned to the control (non-aged) group and thermomechanical aging group.

To prepare the crown part of the restorations, digital impressions of G2, G3, and G5 abutments were taken with the intraoral camera. The crown design of the G1 restoration was copied to each restoration design to prepare standardized crowns. The crowns were milled from lithium disilicate and full crystallization was provided. Crowns were seated on the abutment under finger pressure and cemented with dual cure self-adhesive resin (Multilink Automix, Ivoclar Vivadent) according to the manufacturer's instructions. Any excess cement was removed. The restorations were cured for 20 s from each side and all margins were finished and polished with abrasive disks. In G4 (the direct veneer porcelain layering on a zirconia hybrid abutment group), feldspathic ceramic (Vita VM9, Vita Zahnfabrick, Bad Sackingen, Germany) was processed directly on to the abutment. After specimen fabrication, the ceramic abutment/crown system-implant assemblies were embedded into autopolymerizing acrylic resin in a 30-degree off-axis loading platform by using a custom-made positioning device (2).

#### *Aging and fracture resistance protocols*

Ten specimens from each group were exposed to thermomechanical aging in an artificial chewing simulator (Mastication Simulator, Esetron Smart Robototechnologies, Ankara, Turkey). The aging process included 500000 loading

cycles under a dynamic loading force of 100 N load which was vertically applied on the cingulum of the crowns with a 6-mm-diameter steel ball and at a 0.5 mm/min crosshead speed and simultaneous thermocycling performed for 2000 cycles (1 minute each cycle) in 5°C and 55°C water. The specimens that survived at the end of the aging were tested for fracture resistance. The remaining 10 specimens in each of the five groups did not undergo the aging process, however, they underwent the fracture resistance test. The fracture resistance test was performed with a universal testing machine (Compression/Tension Device, Esetron Smart Robototechnologies) (Figure 2). The load was vertically applied below the incisal edge on the lingual aspect of the crown with a 6-mm-diameter steel ball and at a crosshead speed of 0.5 mm/min. The load at fracture (N) was recorded, and fractures during the simulation process and after the fracture resistance test were examined and analyzed under magnification (Loupe opt-on; Orange Dental, Biberach, Germany).



**Figure 2.** Specimen positioned in universal testing machine.

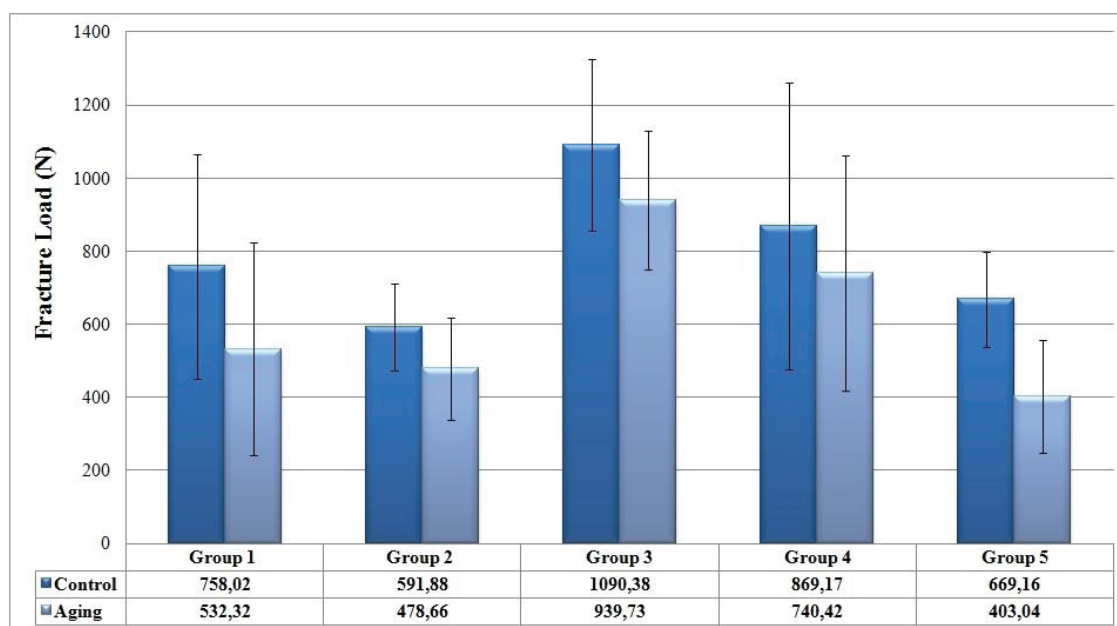
#### *Statistical analysis*

The data was analyzed with statistical software (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM). The fracture resistance values were statistically analyzed using two-way analysis of variance (ANOVA), with the restoration type and thermomechanical aging as the independent variables followed by the Tukey HSD test.

All p values less than 0.05 were considered to be statistically significant.

#### **Results**

One specimen from Group 5 (thermomechanically aged lithium disilicate crown cemented on prefabricated all-zirconia abutment) was fractured (abutment fracture) during the aging process and this specimen was excluded from the statistical analysis. The fracture resistance values of both



**Figure 3.** Fracture resistance values of the tested groups

\*Group 1: Lithium disilicate hybrid abutment crown, Group 2: Lithium disilicate crown cemented on lithium disilicate hybrid abutment, Group 3: Lithium disilicate crown cemented on zirconia hybrid abutment, Group 4: Direct veneer porcelain layering on zirconia hybrid abutment, Group 5: Lithium disilicate crown cemented on prefabricated all-zirconia abutment.

**Table 1.** Fracture resistance values of the restoration types

Restoration type	Mean ( $\pm$ SD)*
Group 1 (n=20) Lithium disilicate hybrid abutment crown	645.17 ( $\pm$ 313.88) C
Group 2 (n=20) Lithium disilicate crown cemented on a lithium disilicate hybrid abutment	535.28 ( $\pm$ 139.21) C
Group 3 (n=20) Lithium disilicate crown cemented on a zirconia hybrid abutment	1015.05 ( $\pm$ 221.83) A
Group 4 (n=20) Direct veneer porcelain layering on a zirconia hybrid abutment	804.80 ( $\pm$ 355.90) B
Group 5 (n=19) Lithium disilicate crown cemented on a prefabricated all-zirconia abutment	543.10 ( $\pm$ 193.97) C

\*SD: Standard deviation

Same capital letters indicate that the values were not statistically different among the restoration type groups.

control and aging groups in all restoration type groups are shown in Figure 3.

It was observed that the control group of Group 3 had the highest fracture resistance value among the groups and fracture resistance values were lower in all thermomechanically aged groups than the control groups. According to the two-way ANOVA, both of the factors (restoration type and aging) affected the fracture resistance values of the specimens and there was no interaction between the factors ( $p=0.844$ ). The fracture resistance values of the groups by restoration type are shown in Table 1.

When fracture resistance values were compared according to the restoration type, the highest values were observed in Group 3 and Group 4, respectively ( $p<0.05$ ). The lowest value was observed in Group 2, however, the results were not statistically different among Groups 1, 2, and 5. When comparing the fracture resistance values of the groups

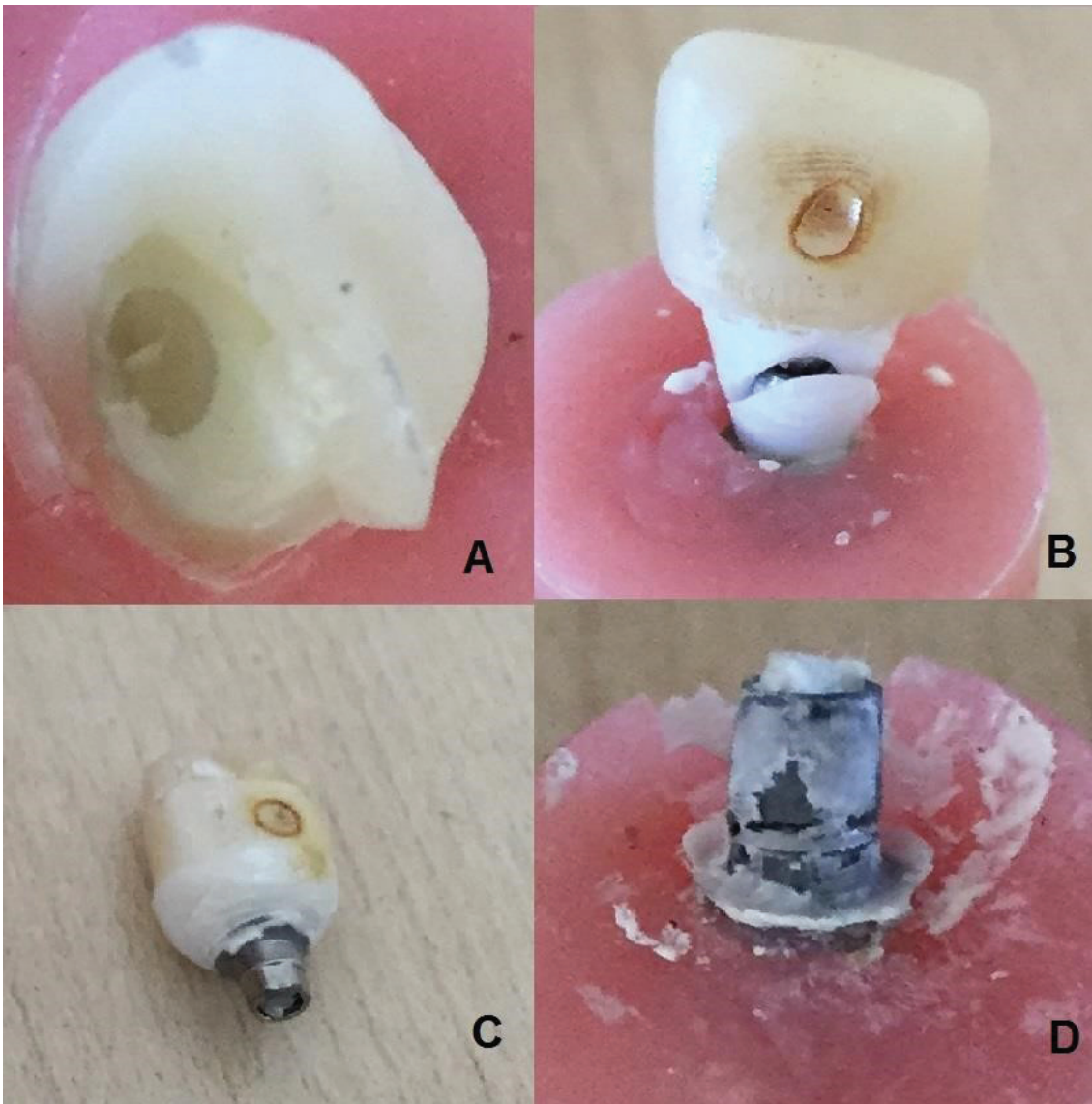
**Table 2.** Fracture resistance values of control and aging groups

Aging	Mean ( $\pm$ SD)*
Control (Non-aged) Group (n=50)	795.72 ( $\pm$ 304.32) a
Aging Group (n=49)	623.24 ( $\pm$ 297.55) b

\*SD: Standard deviation

Same small letters indicate that the values were not statistically different between the restoration type groups.

regardless of the restoration type, the aged group showed a significant lower fracture resistance value than the control group ( $p<0.05$ ) (Table 2). The failure modes of the specimens were examined after the load at fracture test (Figure 4). The failure modes of non-aged and aged specimens are shown in Table 3 and 4, respectively.



**Figure 4.** Failure modes A: Crown fracture B: Abutment fracture C: Fracture of screw of titanium base D: Deformation of titanium base .

**Table 3.** Failure modes of non-aged specimens

	Crown fracture	Abutment fracture	Fracture of screw of titanium base	Deformation of titanium base
Group 1	1	9	-	-
Group 2	6	3	1	-
Group 3	5	2	1	2
Group 4	3	3	4	-
Group 5	2	8	-	-

**Table 4.** Failure modes of the aged specimens

	Crown fracture	Abutment fracture	Fracture of screw of titanium base	Deformation of titanium base
Group 1	2	7	1	-
Group 2	6	4	-	-
Group 3	3	6	1	-
Group 4	3	5	2	-
Group 5	-	9	-	-

In both non-aged and aged specimens, the most observed failure was abutment fracture followed by crown fracture. Six non-aged specimens (one in G2, one in G3, and four in G4) showed a fracture of the screw in the titanium base. Four aged specimens (one in G1, one in G3, and two in G4) showed a fracture of screw in the titanium base. Deformation of the titanium base was seen in only two specimens in the non-aged Group 3.

## Discussion

The null hypotheses of the present study were rejected as significant differences were found between the fracture resistances of the different ceramic abutment/crown systems and thermomechanical aging resulted in significantly lower fracture resistance compared with non-aged restorations. The fracture resistance values found in the present study revealed that one-piece zirconia abutments showed lower fracture resistance than zirconia abutments with titanium bases. This finding is in agreement with previous studies (1,8,12). The implant abutment connection area has been reported as the weakest part of an internal connection in the one-piece zirconia abutment (8). The titanium base of the hybrid ceramic abutments functioned as a substitute for the weakest part of these abutments. Therefore, the titanium base can reinforce the fracture strength of a zirconia abutment. Furthermore, Stimmelmayer et al. (12) reported similar mechanical behavior for zirconia abutments with a titanium base and titanium abutments. Another reported problem with one-piece zirconia abutments was the greater wear that was generated on the implant platform in one-piece zirconia abutments compared with titanium abutments (10,16). Therefore, the two-piece zirconia abutment design provides significant advantages over one-piece zirconia abutments by generating a titanium-titanium interface at the implant-abutment connection which has been shown to reduce the risk of implant platform damage in use and to enhance fracture resistance.

The mechanical behavior of one-piece, two-piece, and differently designed zirconia abutments have been extensively studied. However, limited information exists on the more recently introduced lithium disilicate implant abutments (2,9). In the present study, the mean fracture resistance of both groups (Group 1 and Group 2) of lithium disilicate abutments was found to be lower than the two-piece zirconia abutment groups and no statistical difference was found between Group 1 and Group 2 - similarly with previous researches (2,9). However, a seemingly positive difference between Group 1 and Group 2 was observed with regard to failure mode. In Group 1, generally catastrophic bulk fractures were observed while a fracture of the ceramic crown and an intact abutment was observed in Group 2. These results of the lithium disilicate abutment groups may reveal an advantage of the restoration type using a lithium disilicate abutment and cemented crown. The crown failure on an intact abutment can be easily reconstructed. Furthermore, in this design, the optimal implant angulation to position the screw hole in the palatal site of the restoration is less critical while it is important for lithium disilicate hybrid abutment crown restoration type.

Maximum bite forces in humans range from approximately

100 N to 300 N in the anterior region and 200 N to 900 N in the posterior region (17,18). Furthermore, bruxism and other parafunction can cause higher bite forces (19). The mean fracture resistances found in this study showed that zirconia abutments with titanium bases can withstand maximum bite forces in both anterior and posterior region. However, one-piece zirconia abutments and lithium disilicate abutment/crown systems which showed lower fracture resistance may not withstand higher levels of force in the posterior region, and so the use of these restorations should be limited in the anterior region.

In the present study, implant-supported anterior restorations with different designs and materials were tested under artificially aged and non-aged conditions. In-vitro testing of restorations under static load without artificial aging can provide information on indication and clinical limitations of a treatment modality. However, artificial aging has been considered as a reliable tool to predict clinical durability of restorations before recommending for clinical use (14,20). In the present study, all specimens were subjected to cyclic loading and thermal cycling to the mechanical behavior of different restorations under clinically approximated conditions. The parameters of mastication simulation were chosen taking previous studies into consideration (1,8,21). There are, however, no accepted standards of loading parameters for testing implant restorations in a mastication simulator. The thermomechanical aging performed in the study which simulated an approximately 2.5 years of clinical service period for a fixed prosthesis (22,23). The results of this study revealed a significant decrease in the fracture resistance of restorations tested as well as previous studies (2,8). This fatigue behavior of ceramic abutments might be attributed to the presence of micro defects and the slow growth of subcritical cracks within the material (24). In addition to the effects of mechanical loading, zirconia ceramics are sensitive to thermal aging in the presence of moisture in the oral environment (25).

Restorations with a titanium base showed high fracture resistance ranging from 740-1090 N in the universal testing machine. However, comparing the fracture resistance values of this study can not be possible because the test parameters including implant design, implant-abutment connection, abutment dimensions, restorative material, and loading conditions may affect the magnitude of the load that causes a fracture of an implant-supported crown (4,9).

Considering the failures during the study, one specimen in Group 5 failed during thermomechanical aging and the remaining specimens survived. However, deterioration related to aging generally occurs without any evidence of failure (26). The fracture resistance values and failure modes after a static fracture test may indicate weak points and deformed parts. In the present study, abutment fracture was generally observed in the one-piece zirconia abutment group especially at the implant-abutment connection in accordance with previous studies (8,27,28). Thin ceramic parts can be prone to fracture. In the two-piece zirconia abutment groups, the fracture of the crown part was prominent while fracturing in the zirconia abutment part generally occurred in aged specimens. This may be attributed to the negative effects of aging on zirconia.

The results of the present study may provide clinically relevant data for different implant-supported ceramic abutment/crown systems in anterior applications. However, invitro conditions do not simulate the clinical situation. Well-designed long-term randomized controlled clinical studies are required to evaluate survival and complication rates of these restorations in clinical use.

## Conclusion

Zirconia abutments with a titanium base enhance the fracture resistance of zirconia abutments. Prefabricated zirconia abutments showed a lower fracture resistance than other zirconia abutments. Thermomechanical aging decreased the fracture resistance of the tested ceramic abutment/crown systems. All specimens withstood the thermomechanical aging except one specimen in the prefabricated zirconia abutment group. The major failure mode was the abutment fracture.

**Türkçe Öz:** Farklı implant destekli seramik abutment/kron sistemlerinin kırılma dayanıklılığı. Amaç: Bu çalışmanın amacı yaşlandırılmayan ve yaşlandırılan farklı abutment/kron sistemlerinin kırılma dayanıklılığını ve başarısızlık tiplerini belirlemektir. Gereç ve yöntem: Yüz adet dental implant (4.3 mm çapında ve 11.5 mm uzunluğunda), beş farklı abutment/kron sistemi ile restore edildi. Bu sistemler G1: lityum disilikat hibrit abutment kron, G2: lityum disilikat hibrit abutment üzerine simante edilen lityum disilikat kron, G3: zirkonya hibrit abutment üzerine simante edilen lityum disilikat kron, G4: veneer porseleni uygulanan zirkonya hibrit abutment ve G5: prefabrike zirkonya abutment üzerine simante edilen lityum disilikat kron grubudur. Her grup, kontrol (yaşlandırmasız) ve termomekanik yaşlandırma olmak üzere iki gruba (n=10) ayrıldı. Kırılma dayanıklılığı testi yapıldı. Yaşlandırma süreci boyunca ve kırılma dayanıklılığı testinden sonra başarısızlık tipleri belirlendi. Bulgular: Her iki faktöründe (restorasyon tipi ve yaşlandırma) kırılma dayanıklılığı değerlerini etkilediği fakat faktörler arasında interaksiyon olmadığı belirlendi ( $p>0.05$ ). Yaşlandırma faktörü olmadan kırılma dayanıklılıkları karşılaştırıldığında, en yüksek değerler sırasıyla G3 ve G4'te belirlendi ( $p<0.05$ ). Restorasyon tipi olmadan kırılma dayanıklılıkları karşılaştırıldığında, yaşlandırma grubunda kontrol grubuna kıyasla daha düşük kırılma dayanıklılığı tespit edildi ( $p<0.05$ ). Sonuç: Titanium kaide zirkonya abutmentlerin kırılma dayanıklılığını arttırmaktadır. Termomekanik yaşlandırma, test edilen seramik abutment/kron sistemlerinin kırılma dayanıklılığını azaltmaktadır. En sık görülen başarısızlık tipi abutment kırığıdır. Anahtar kelimeler: Dental implant-kaide tasarımı; Yitria-dengeli tetragonal zirkonyum polikristali seramiği.

**Ethics Committee Approval:** Not required.

**Informed Consent:** Not required.

**Peer-review:** Externally peer-reviewed.

**Author contributions:** MBG and CA participated in designing the study. MBG and CA participated in generating the data for the study. MBG and CA participated in gathering the data for the study. MBG, SKN, HY and CA participated in the analysis of the data. MBG and SKN wrote the majority of the original draft of the paper. HY and CA participated in writing the paper. All authors approved the final version of this paper.

**Conflict of Interest:** The authors have no conflicts of interest to declare.

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