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ORIGINAL RESEARCH ARTICLE

Fracture Strength and Stress Distribution Analyses of CAD/CAM Titanium and Zirconia Abutments Restored with Resin-Based Ceramic and Monolithic Zirconia Crowns

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Abstract

Purpose: The aim of this study was to evaluate the effect of two different crown and abutment types produced with CAD/CAM systems on the biomechanical behavior of implant-supported fixed restorations.
Materials and Methods: Thirty-six titanium implants received either custom-made zirconia abutments cemented on a Ti-base (Zi) or single-piece custom titanium abutments (Ti). Then, resin-based ceramic crowns (RBC) were manufactured for half of each abutment type, and monolithic zirconia crowns (MZ) were manufactured for the other half. Thus, 4 study groups were formed as follows: Zi-RBC, Zi-MZ, Ti-RBC, and Ti-MZ. The fracture resistance of the groups was tested using a universal testing machine, and the failure types were determined. The stress distribution on abutments and crowns was evaluated with finite element analysis (FEA).
Results: As the abutment type, zirconia showed higher fracture strength (1377.2 ± 185.7 N for Group Zi-RBC and 2333.9 ± 149.5 N for Group Zi-MZ) than titanium (1181 ± 119.6 for Group Ti-RBC and 1810.6 ± 315.2 for Group Ti-MZ) for both crown types. Considering the crown material, monolithic zirconia showed higher fracture strength for both abutment types. None of the groups showed screw or implant deformation. Ti-RBC and Ti-MZ groups showed only crown failures, while 22% of Group Zi-RBC and 44% of Group Zi-MZ showed abutment fractures in addition to crown fractures. FEA analysis did not show significant differences for crowns, while differences were observed for abutments.
Conclusions: Zirconia abutments cemented on titanium bases can be considered an acceptable alternative to titanium abutments. Monolithic zirconia may provide longer intraoral service than resin-based ceramic as a crown material, considering its higher resistance to fracture.

Keywords: Dental crown; Dental stress analysis; Flexural strength; Single-tooth dental implant; Zirconium oxide

Introduction

Replacing missing teeth with implant-supported fixed prostheses (ISFP) is a valid treatment option, yet implant failure can be a displeasing complication for both the dentist and the patient. The biological and mechanical properties of prosthetic superstructures play a crucial role in the survival rate of ISFP.[1] As the implants lack the damping effect that occurs owing to the periodontal ligament natural teeth have, excessive stresses transferred from the ISFP through the implant body may result in resorption at the crestal bone, screw loosening, and fractures in prosthesis components.[2,3] Therefore, the implant superstructure should be made considering the mechanical disadvantage that implants possess.

The abutment that is directly screwed on the implant body and a restorative crown placed on the abutment compose the implant superstructure.[4] Abutments can be stock or custom-made.[5] Technological developments have enabled the design of prosthetic appliances with digital systems and their custom production.[2] Custom abutments can be directly produced from titanium discs in one piece or from aesthetic materials that are cemented on stock

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titanium bases (Ti-base) to maintain the titanium-titanium connection at the implant-abutment interface.[6] The latter is called a hybrid abutment, which is a two-piece compound: a Ti-base and a computer-aided design and computer-aided manufacturing (CAD/CAM) custom-made aesthetic abutment part.[7] Hybrid abutments can be fabricated either as a screw-retained single-piece abutment-crown compound or as a separate abutment and crown that are cemented on ti-bases in a row.[8] Different material combinations of abutment and restorative crowns have been investigated in the literature, considering aesthetic, mechanical, and physical properties.[1,3,9]

As an abutment material, titanium is frequently used and can be considered the gold standard with favorable properties such as sufficient stability, optimal resistance, and biocompatibility with the adjacent tissues.[3,10] However, an important drawback of titanium abutments is their aesthetic disadvantage due to the grey reflection they cause at the gingival margin when the gingival biotype is thin or the depth of the emergence profile is inadequate.[3,11,12] Hybrid abutment systems composed of zirconia CAD/CAM abutments cemented on Ti-bases have overcome the aesthetic disadvantage of titanium abutments.[8] Zirconia is an outstanding material when it comes to restorative crowns for ISFPs, thanks to its biocompatibility, aesthetic properties, and high resistance to fracture.[13,14] However, zirconia has a low elastic modulus and is thus too stiff, which may transmit unfavorable stresses to the ISFP, resulting in mechanical complications.[3,15]

Recent articles focused on proposing new restorative crown materials for ISFP, such as resin-based hybrid ceramics (RBCs) with low elastic modulus to create a shock-absorbing mechanism and decrease the masticatory forces transmitted into the bone.[2,3,9,15] However, as these materials have a low elasticity modulus, the material hardness decreases as well.[16] Therefore, resistance to fracture in resin-based ceramic ISFP may not be as high as that of zirconia.[3] Considering that the fracture strength of prosthetic material is an important parameter for long-term implant success, different combinations of implant superstructures should be investigated. Yet, there is not enough supporting scientific data to declare a safer combination choice for ISFP as abutment and restorative material.

Considering these subjects, this study aimed to evaluate the biomechanical behavior of different combinations of implant superstructures with three-dimensional (3D) finite element analysis (FEA) and fracture strength evaluation. Different combinations of implant superstructures included two abutments (single-piece custom titanium abutment and custom zirconia abutment cemented on a Ti-base) and crown types (CAD/CAM zirconia and resin-based ceramic (RBC) crowns). The null hypothesis was that implant-supported restorations employed with different abutments and crowns would exhibit similar stress distribution with no significant difference in fracture resistance.

Material and Methods

This study was conducted in two parts. The first part included a fracture strength test using a universal testing machine. In the second part, an in vitro study simulation was performed through FEA to evaluate stress distribution on different sections of the prosthetic restoration. Two different types of abutments (Ti: single-piece custom titanium abutment and Zi: custom zirconia abutment cemented on a Ti-base) and two different types of CAD/CAM crowns (MZ: monolithic zirconia and RBC: resin-based ceramic crowns) were evaluated. Detailed information regarding the materials used and the study groups that were formed according to the abutment and crown types is shown in Table 1. The minimum sample size required for this study was calculated as n=9 per group for a 4-group variable with a 0.50 effect size, 80% power, and α=0.05.

Thirty-six titanium implants (Zimmer Dental Inc., Carlsbad, CA, USA) with a diameter of 4.1 mm and lengths of 11.5 mm were embedded in auto-polymerizing acrylic resin blocks (Meliodent; Heraeus Kulzer GmbH, Hanau, Germany) perpendicularly. The implants were divided into two groups: the implants that receive custom zirconia abutments cemented on a Ti-base and the implants that receive single-piece custom titanium abutments. Scan bodies were screwed on Ti-bases for the groups that were determined to receive zirconia abutments and scanned using the CEREC AC Bluecam system (Sirona Dental System Gmbh, Bensheim, Germany). An anatomical zirconia abutment was designed with a chamfer finish line and with a 1 mm marginal width to fit on the Ti-base (CEREC SW 4.2 software). The height of the custom abutment was determined according to the height of the Ti-base, which was 4.5 mm. Zirconia abutments were produced from semi-sintered zirconia blocks (inCoris ZI meso L, Sirona Dental System Gmbh, Bensheim, Germany) with a milling machine (inLab MC XL Sirona Dental System Gmbh, Bensheim, Germany) and sintered in a furnace (inFire HTC Speed Sirona Dental System Gmbh, Bensheim, Germany) according to the manufacturer's recommendations. The zirconia abutments were cemented on ti-bases using resin cement (Panavia F2.0, Kuraray, Osaka, Japan) according to the manufacturer's recommendations. The same stereolithography (STL) data from the designed zirconia abutments were used to produce titanium abutments (Kera Ti 5 titanium discs, Eisenbacher Dentalwaren ED GmbH, Wörth am Main, Germany) using a five-axis milling machine (Avamill Chrome, Lansing, MI, USA).

A mandibular second premolar crown with 80 μm cement space was designed by the same software that the zirconia abutment design was made with the 'multilayer' mode. The cement space was set according to a study that reported increased repeatability with the least variation for CAD/CAM crowns designed with 80 μm cement space via CEREC SW 4.2 software.[17] Custom crowns were produced from either monolithic zirconia (inCoris TZI Mono S blocks, Sirona Dental System Gmbh, Bensheim, Germany) or RBC blocks (Lava Ultimate, 3M ESPE, Dental Products, St. Paul, MN, USA) using a CEREC milling machine (inLab MC XL Sirona Dental System Gmbh, Bensheim, Germany) according to the study group (Table 1) (n=9). The monolithic zirconia crowns were then sintered in a furnace (inFire HTC Speed Sirona Dental System Gmbh, Bensheim, Germany) according to the manufacturer's recommendations. All produced abutments and crowns were sandblasted with 50 μm aluminum oxide particles at 0.1 MPa and cleaned in an ultrasonic cleaner.

The produced abutments were screwed onto the corresponding implants with a 30 N placement torque as recommended by the manufacturer, and the screw holes were filled with polytetrafluoroethylene (PTFE) straps. Monolithic zirconia and resin nanoceramic crowns were cemented on the corresponding abutments with light finger pressure using resin cement (Panavia F2.0, Kuraray Noritake, Osaka, Japan). The remaining space over screw holes was filled with flowable composite resin (Clearfil Majesty ES Flow, Kuraray Noritake, Osaka, Japan) and polymerized. Full seating of the crowns was confirmed with a stereomicroscope (M3Z, Leica Microsystems, Wetzlar, Germany).

Fracture Strength Test

Fracture resistance tests were conducted using a universal testing machine (Lloyd-LRX, Lloyd Instruments, Fareham, Hampshire, UK) with a round-end 4 mm diameter stainless cylinder that was directed towards the central fossa of each crown at a speed of 1 mm/min. The samples were loaded until the first fracture occurred, and the maximum values at which the crowns were fractured were recorded in Newton (N).

Table 1. Abutment and restorative crown materials used, manufacturers and group abbreviations of the study

Group abbreviations	Abutment type	Manufacturer	Restorative crown material	Brand name and manufacturer
Zi-RBC	Zirconia abutment cemented on a Ti-base	inCoris ZI meso L, Sirona Dental System GmBh, Bensheim, Germany	Resin-based hybrid ceramic	Lava Ultimate, 3M ESPE Dental Products, St. Paul, MN, USA
Zi-MZ	Zirconia abutment cemented on a Ti-base	inCoris ZI meso L, Sirona Dental System Gmbh, Bensheim, Germany	Monolithic zirconia	inCoris TZI Mono S, Sirona Dental System Gmbh, Bensheim, Germany
Ti-RBC	Custom titanium abutment	Kera Ti 5, Eisenbacher Dentalwaren ED GmbH, Wörth am Main, Germany	Resin-based hybrid ceramic	Lava Ultimate, 3M ESPE Dental Products, St. Paul, MN, USA
Ti-MZ	Custom titanium abutment	Kera Ti 5, Eisenbacher Dentalwaren ED GmbH, Wörth am Main, Germany	Monolithic zirconia	inCoris TZI Mono S, Sirona Dental System Gmbh, Bensheim, Germany

(Zi-RBC: Ti-base abutment-Resin based hybrid ceramic crown, Zi-MZ: Ti-base abutment-Monolithic zirconia crown, Ti-RBC: Titanium abutment-Resin based hybrid ceramic crown, Ti-MZ: Titanium abutment-Resin based hybrid ceramic crown)

Table 2. Modulus of elasticity (GPa) and Poisson's ratios of the materials used in the study

Material	Elastic Modulus (GPa)	Poisson ratio
Acrylic resin	2,5	0,3
Titanium	110	0,35
InCoris TZI	144	0,35
InCoris ZI	70	0,21
Lava Ultimate	12,8	0,3
Panavia	18,6	0,28

Finite Element Analysis

In this study, stress and fracture resistance values were obtained for each material and compared with each other. 3D models were created for groups Zi-RBC, Zi-MZ, Ti-RBC, and Ti-MZ, as in mandibular second premolar crowns screwed on implants embedded in acrylic resin. Then, the stress values, distribution, and concentration regions of two different abutment materials and two different crown materials were investigated by a 3D FEA.

To replicate the conditions of the in vitro fracture resistance test, the 3D models of implants and Ti-bases were made based on the optical scans of these parts obtained using a scanner (Smartoptics, Sensortechnik GmbH, Sinterstrasse 8, D-44795 Bochum, Germany). The designs obtained from the Cerec CAD/CAM system (Sirona Dental System Gmbh, Bensheim, Germany) were converted into STL format for the 3D abutment and crown models. To mimic the models used in the fracture strength test, an 80 μm cement space was created.

To form geometric models, all 3D models were transferred to the Rhinoceros software (Rhinoceros 4.0, NURBS Modeling for Windows, Seattle, WA, USA). Particular features of the relationship between the abutment and crown and the combination of the implant and the acrylic base were taken as a reference to create finite element models with suitable surface characterizations. After the formation of geometric models, coordinate information for the STL data was transferred to the FEA software (Algor Fempro, ALGOR Inc., Pittsburgh, PA, USA) to create 3D mesh designs. The 3D mesh models on mesh software mostly consisted of eight-node bricks to create the most appropriate mesh model possible. The number of nodes and elements were 161,563 and 821,498, respectively. The mechanical properties of all materials used in the study (elastic modulus and Poisson ratios) were defined based on published data (Table 2) and introduced into the Algor Fempro 3D FEA program.[18–21] The mechanical properties of all structures were assumed to be linearly elastic, isotropic, and homogeneously distributed.

The fracture resistance test was simulated using the same procedure for finite element analysis. The selected model's maximum fracture strength was set at 2448.684 N, which was applied to the implant superstructure perpendicularly to replicate the load application in the fracture resistance test. According to this analysis, Von Mises stress (VMS) values in MPa were obtained for the abutment and restorative crown parts individually.

After the fracture resistance test, the failure type for each sample was examined according to a classification by Elsayed et al.[1] The classification was made as follows: Type 1, crown fracture only (without abutment fracture) (Figure 1); Type 2, both crown and abutment fracture (Figure 2); and Type 3, screw and implant deformation.

Statistical Analysis

The distribution of the data was tested according to the Shapiro-Wilk test, and the homogeneity of the variance was controlled with the Levene test. An independent sample t-test was used to compare two independent groups when the normality assumption was met (α=0.05). Statistical analysis of the fracture test results was conducted using the IBM SPSS 25 package program.

Results

Statistical comparison of the fracture strength values of the study groups is presented in Table 3. As the abutment material, Zi showed higher fracture strength values than Ti for both crown materials ($p<0.001$). Considering crown types, MZ showed higher mean fracture strength than RBC for both abutment types ($p<0.05$). Group Zi-MZ showed the highest fracture strength value [2333.9 (149.5) N], while Group Ti-RBC showed the lowest [1181 (119.693) N] (Table 3).

Table 3. Comparison of fracture strength values

Abutment type	Crown type		p
	RBC	MZ	
Zi	1377.2 ± 185.7^{Aa}	2333.9 ± 149.5^{Ab}	**0.017**
Ti	1181 ± 119.6^{Ba}	1810.6 ± 315.2^{Bb}	**0.001**
p	**<0.001**	**<0.001**	

(Zi: Custom zirconia abutment cemented on a ti-base, Ti: Single-piece custom titanium abutment, RBC: Resin-based ceramic crowns, MZ: Monolithic zirconia) Different superscript uppercase letters within column and lowercase letters within row indicate statistically significant difference ($p<0.05$).

The failure types in the study groups are shown in Figure 2, and the distribution of failure types is displayed in Figure 3. Groups Zi-RBC and Zi-MZ showed 22% and 44% Type 2 failure, respectively.

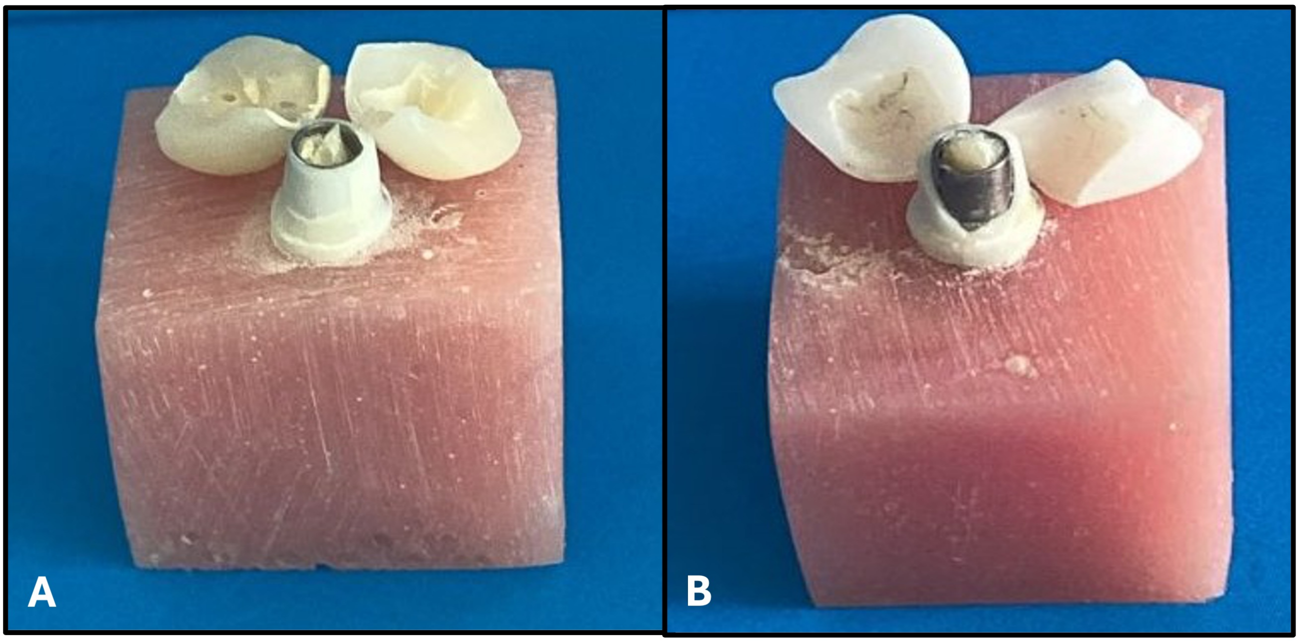

Figure 1. A representative image of failure A: Type 1. A crown fracture only, the abutment is intact. B: Type 2. Crown and abutment fracture is seen together

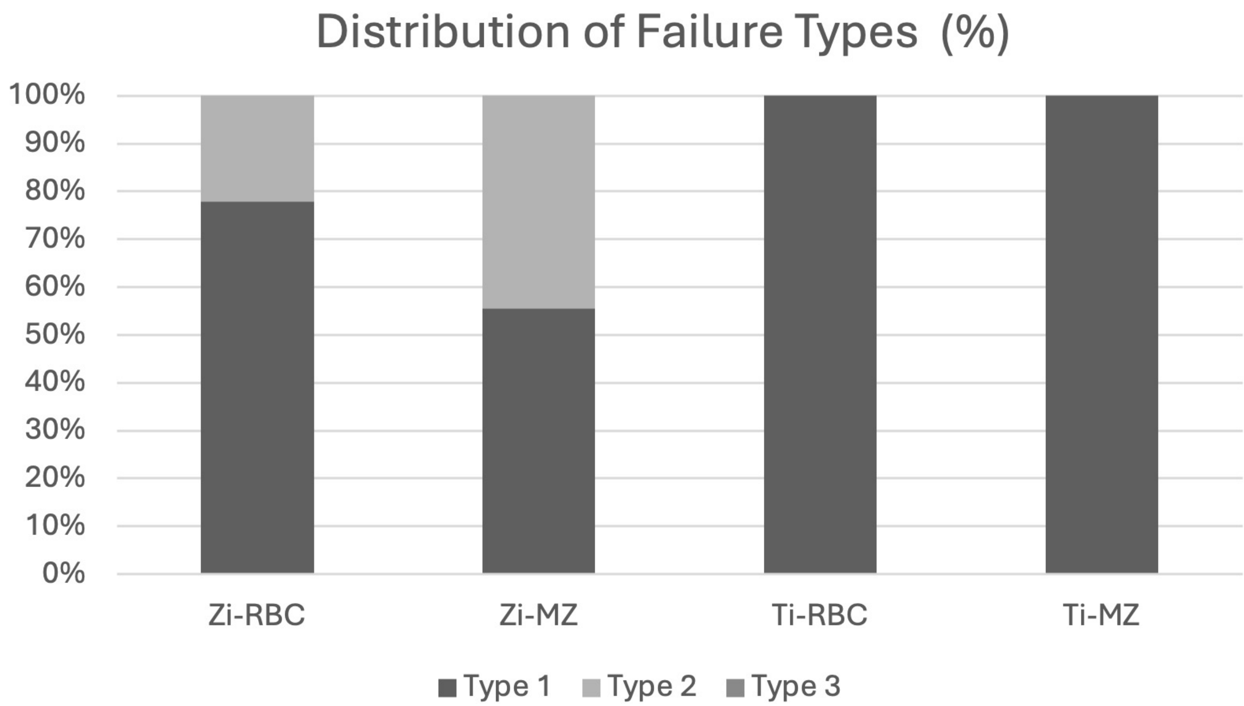

Figure 2. Distribution of failure types in percentages. Type 1. Crown fracture only (without abutment fracture) Type 2. Both crown and abutment fracture Type 3. Screw and implant deformation

(Zi-RBC: Ti-base abutment-Resin based hybrid ceramic crown, Zi-MZ: Ti-base abutment-Monolithic zirconia crown, Ti-RBC: Titanium abutment-Resin based hybrid ceramic crown, Ti-MZ: Titanium abutment-Resin based hybrid ceramic crown)

Other groups did not show Type 2 failure, and none of the groups showed Type 3 failure.

Maximum VMS values of crowns and abutments obtained for each group (MPa) are given in Table 4. Changes in force distribution on both abutment and crown restoration surfaces were observed depending on varied materials. The highest force for abutments was calculated for Group Zi-RBC as 1264.3 MPa, and the lowest force for abutments was calculated for Group Zi-MZ as 434.4 MPa. The RBC crowns caused higher VMS stress values on abutments compared to monolithic zirconia crowns. Overall, the values varied as Zi-RBC > Ti-RBC > Ti-MZ > Zi-MZ. On the other hand, the highest and the lowest VMS values obtained from the crowns were for Group Zi-MZ with 1295.51 MPa and for Group Ti-RBC with 789.17 MPa, respectively. The VMS values for crowns followed the pattern of Zi-

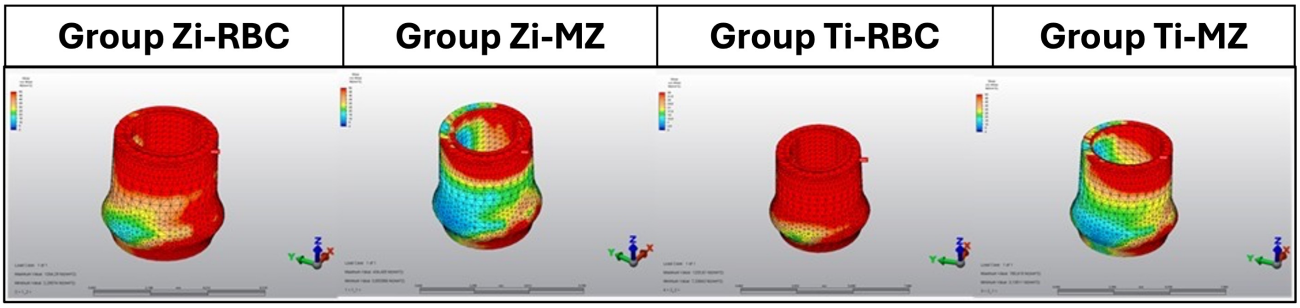

Figure 3. 3D stress distribution images of abutments

(Zi-RBC: Ti-base abutment-Resin based hybrid ceramic crown, Zi-MZ: Ti-base abutment-Monolithic zirconia crown, Ti-RBC: Titanium abutment-Resin based hybrid ceramic crown, Ti-MZ: Titanium abutment-Resin based hybrid ceramic crown)

MZ > Ti-MZ > Zi-RBC > Zi-RBC in all models (Table 4). Monolithic zirconia crowns had higher VMS values compared to RBC crowns.

Table 4. Maximum Von Mises Stress values (MPa) of crowns and abutments obtained for each group

Model	Abutment	Restorative crown
Zi-RBC	1264.3	789.6
Zi-MZ	434.4	1295.5
Ti-RBC	1233.8	789.2
Ti-MZ	780.6	1127.7

Zi-RBC: Ti-base abutment–Resin-based hybrid ceramic crown; Zi-MZ: Ti-base abutment–Monolithic zirconia crown; Ti-RBC: Titanium abutment–Resin-based hybrid ceramic crown; Ti-MZ: Titanium abutment–Monolithic zirconia crown.

Stress distribution images in 3D of the abutments and crowns are presented in Figure 3 and Figure 4, respectively. For all abutment types, loaded forces were concentrated at the occlusal-lingual regions (Figure 3). Additionally, the RBC crown type caused more stress on both Zi and Ti abutments compared to monolithic zirconia crowns. However, stress distribution on crowns did not show significant differences. Overall, stress areas were focused on the occlusal contact points for all crown restorations (Figure 4).

Discussion

This in vitro study evaluated the fracture strength and stress distribution of two abutment and crown types fabricated from different CAD/CAM materials. The null hypothesis of the study was rejected because different combinations of implant superstructures differed in fracture strength and FEA stress distribution analysis according to the CAD/CAM material type.

Since performing stress analysis and fracture tests in vivo is not feasible, the fracture strength of the materials was evaluated with an in vitro load-to-fracture test with a universal testing machine. Additionally, the stress distribution of the applied load on the specimens was analyzed by a 3D FEA analysis. Baiamonte et al.[22] compared in vitro test results of loading strain occurring on implants with the results obtained by means of the FEA and observed that the two results were in perfect agreement with each other, concluding that FEA is applicable to dental systems. The FEA models can simulate complex geometric shapes and reflect the tested tissue, restorative material, and forces received by these to imitate intraoral conditions.[10] This structural analysis enabled the evaluation of stress distributions of a given force in complex designs, such as implant-abutment-restoration interfaces, and the material's behavior in response.[23,24] The 3D FEA tests are used in various studies to predict the effects of occlusal forces on implants and to figure out how materials respond to these forces.[10,24] However, all the materials tested in FEA models are assumed homogenous and isotropic with linear elastic characteristics for this type of analysis, yet this may not always be the case for dental materials.[10,25] Besides, 3D FEA tests do not provide a range of possible calculations and conclude in a single Von Mises stress value for stress concentration areas; as a consequence, performing statistical analysis with significant comparisons is not applicable. Therefore, in this in vitro study, FEA analysis was applied complementary to the mechanical fracture strength test to better understand the materials' behavior and limits under applied forces.

Independent from the crown and abutment material, all implant superstructure combinations showed higher fracture strength than 900 N, which is the maximal physiological masticatory force recorded in the molar region.[26–28] Likewise, Gutiérrez Robledo et al. reported higher fracture strength than occlusal forces occurring on the molar area for different types of zirconia and RBC crowns tested for implant restorations.[26] On the other hand, both crown types supported with zirconia abutments showed higher resistance to fracture than crowns supported with titanium abutments. This finding can be supported by a previous study by Elsayed et al.,[1] who reported that zirconia as the abutment material showed higher fracture strength than that of titanium and PEEK materials. On the other hand, Akan et al.[10] reported higher fracture strength for custom titanium abutments than zirconia abutments restored with monolithic zirconia crowns. The difference in these results could be explained by the test method, considering that Akan et al. tested anterior implant-supported abutments and crowns while other studies conducted fracture strength tests for the molar region.[1] Oblique forces on the anterior crowns might have caused excessive bending at the Ti-base zirconia interface and earlier cracks or fractures.[1,29] Another finding of our study was that monolithic zirconia crowns showed higher resistance to fracture than resin-based ceramic crowns, regardless of the abutment type. This finding is in line with the previous findings, which reported lower fracture strength for resin-based composite crowns than for zirconia when used for implant-supported restorations.[10,30] According to the findings of the present study, both abutment and crown materials used in our study affected the fracture resistance of the restoration complex as the implant superstructure. However, Elsayed et al.[1] found no difference in fracture strength between resin-based composite and lithium disilicate composite crowns, irrespective of the abutment material. Based on these findings, it can be assumed that different abutment and crown materials influence the fracture strength of the implant-supported restoration complex and that zirconia is a more resistant material for implant superstructures than resin-based composite and titanium.

This study ensured the standardization of the production process of study specimens. The same STL data was used to manufacture zirconia and custom-made titanium abutments. Additionally,

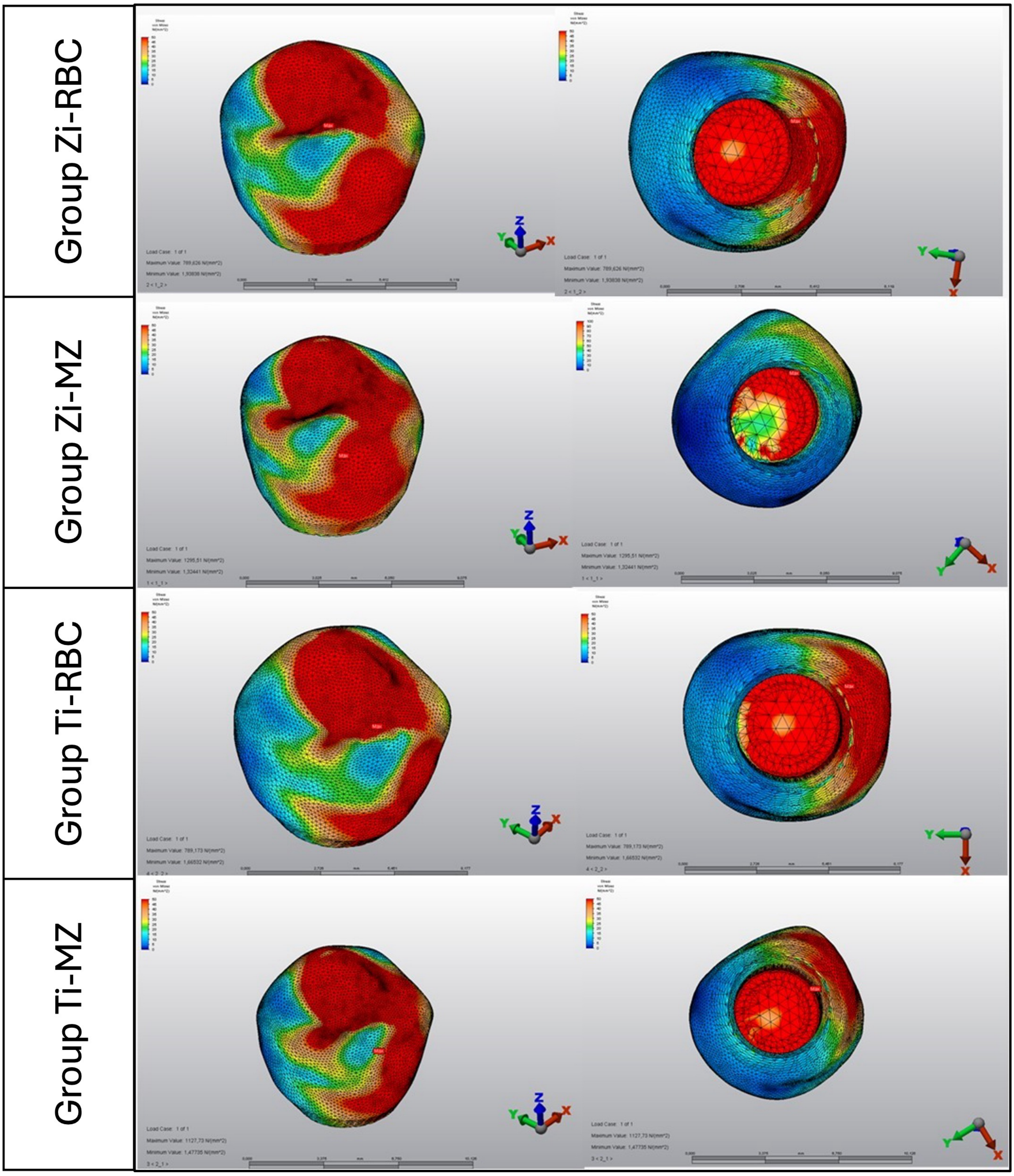

Figure 4. 3D stress distribution images of the crowns occlusally and cervically

(Zi-RBC: Ti-base abutment-Resin based hybrid ceramic crown, Zi-MZ: Ti-base abutment-Monolithic zirconia crown, Ti-RBC: Titanium abutment-Resin based hybrid ceramic crown, Ti-MZ: Titanium abutment-Resin based hybrid ceramic crown)

monolithic zirconia and resin-based ceramic crowns were produced using the same STL. Therefore, the specimens to be tested for fracture strength had the exact same outline, allowing these STL data to be used in the FEA test. A major drawback of such a design is that the fit of custom-made titanium abutments cannot be guaranteed at the implant interface area even when the original implant configuration in the digital library is used, which may cause screw fracture or implant deformation.[10] However, no such complications were observed for the custom-made titanium abutment groups in our study.

Failure types were classified as crown fracture (Type 1), crown-abutment fracture (Type 2), and screw or implant deformation (Type 3). A recent study stated that fractures in implant superstructure areas may be due to stress concentrations caused by geometrical design factors.[12] However, there was no such pattern for our study, and since all crowns failed catastrophically, no additional classification was made for crown fractures. All classifications for fractures were irreparable, but in Type 1 failure, reuse of the abutment was feasible, while for Type 2, it was not possible. On the other hand, Type 3 failure would cause more complicated complications that can end up with implant loss, unlike the other 2 failure types. However, none of the groups showed Type 3 failure in our study. It can be concluded that the damping effect of crowns used in our study prevented further implant and screw deformation.[1] Both types of crowns supported with single-piece titanium abutments showed only Type 1 failure, while RBC and monolithic zirconia crowns supported by zirconia abutments showed 22% and 44% Type 2 failures, respectively. Materials with a higher modulus of elasticity or rigidity may produce high-stress concentrations in critical areas, leading to catastrophic failures.[31] Type 2 failures observed in crowns supported by zirconia abutments can be explained by the rigid support that the zirconia abutment presented, considering that zirconia's elasticity modulus was reported almost twice that of titanium (200 GPa for Zi vs. 110 GPa for Ti).[14,32] This finding is in line with a recent study in which higher catastrophic failure was reported for monolithic zirconia implant-supported crowns because of their stiffness.[33]

3D images of FEA analysis on abutments revealed that the RBC crown type caused more homogenous and intensive stresses on all aspects of both abutment types compared to monolithic zirconia crowns (Figure 3). In accordance with this finding, Von Mises stress values on abutments of RBC crown groups were higher than MZ crowns (Table 4). However, monolithic zirconia crowns showed concentrated stress on the occlusal-lingual aspect of the abutments (Figure 3). On the other hand, stress distribution on crowns did not show significant differences (Figure 4), while Von Mises Stress values of MZ crowns were higher than RBC crowns, similar to fracture resistance tests. According to FEA and VMS analyses, it can be assumed that stresses on both abutments and crowns were more affected by restorative crown type than abutment type. This finding can be supported by a recent study that reported similar stress distribution for zirconia crowns with different geometric features. The authors stated that small differences found in the FEA analysis can be attributed to the geometric variables of the test specimens.[34] On the other hand, a recent study on different abutment types reported concentrated stresses on screw channels for titanium abutments.[10] This study reported screw or implant neck fractures for these abutments where the stresses are concentrated. Yet, no such failures were reported in our study. Therefore, the FEA analysis in our study is complementary to fracture strength tests.

The damping behavior of RBC crowns on abutments can be seen in FEA analysis. However, the stresses transferred to the supporting crestal bone were not evaluated with the present FEA analysis. Therefore, according to this study, the stresses occurring in accordance with the effect of different implant superstructure types on the crystal bone interpretation are not applicable. Another limitation of our study was the absence of thermo-mechanical cycling, which better simulates intraoral conditions.[33] Future studies may focus on the effects that different abutment and restorative crown materials have on the peri-implant bone in accordance with "thermomechanical" cycling.

Conclusion

The following conclusions were drawn within the limitations of the present study:

- For implant-supported restorations, monolithic zirconia crowns may serve longer than resin-based ceramic crowns intraorally, considering their higher fracture strength.
- Zirconia abutments, cemented on titanium bases can be considered a reasonable alternative to titanium abutments as they provide higher resistance to fracture. However, clinicians should be cautious about abutment fractures under excessive loads.
- Monolithic zirconia and resin-based ceramic crowns demonstrate similar stress distribution on crowns but cause variable stress distribution on abutments.

Ethical Approval

Since resources obtained from humans or animals were not used in this study, ethics committee approval was not obtained.

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Author Contributions

Study Design : All Authors
Data Collection : N.E.O.
Analysis and Interpretation : All Authors
Literature Review : N.E.O. , E.I.O.
Writing : N.E.O. , E.I.O.

Conflict of Interest

There is no conflict of interest in this study.

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