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FRACTURE RESISTANCE OF GLASS-CERAMIC AND ZIRCONIA CROWNS AFTER ENDODONTIC ACCESS

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CERTIFICATE OF APPROVAL

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LIST OF ABBREVIATIONS

C	(degrees) Centigrade
CAD/CAM	Computer Aided Design/Computer-aided Manufacturing
MLI	monolithic lithium disilicate intact
MLR	monolithic lithium disilicate endodontically accessed and repaired
µm	micrometers
min	minute
mm	millimeter
MZI	monolithic zirconia intact
MZR	monolithic zirconia endodontically accessed and repaired
N	Newtons
NEMA	National Electrical Manufacturers Association
rpm	revolutions per minute

TITLE

Fracture Resistance of Glass-Ceramic and Zirconia Crowns After Endodontic Access

RUNNING (SHORT) TITLE

Fracture Resistance of All Ceramic Crowns

CLINICAL IMPLICATIONS

Endodontic access through a glass-ceramic or zirconia crown can introduce surface and subsurface cracks that may cause failure of the restoration. Whether to repair or replace a crown with an endodontic access should be discussed with the patient.

ABSTRACT

Statement of Problem: Fracture resistance of monolithic glass-ceramic and zirconia crowns may be compromised following endodontic access preparation.

Purpose: The purpose of this *in vitro* study is to assess the effect of endodontic access preparation and repair on the fracture resistance of monolithic glass-ceramic and zirconia crowns on a mandibular first molar model.

Materials and Methods: Twenty monolithic mandibular first molar zirconia crowns and 20 monolithic mandibular first molar lithium disilicate crowns were designed, milled, and crystallized or sintered. The crowns were divided into four groups (n=10): monolithic lithium disilicate intact (MLI), monolithic lithium disilicate endodontically accessed and repaired (MLR), monolithic zirconia intact (MZI), and monolithic zirconia endodontically accessed and repaired (MZR). All crowns were adhesively cemented to duplicate mandibular first molar dies fabricated from a continuous filamentous woven fiberglass bonded epoxy resin. Cemented crowns were stored in deionized water for 24 hours at 37°C. The crowns from the MLR and MZR groups were endodontically accessed, and the access restored with a resin-based nanocomposite. Crowns were positioned onto a universal testing machine and a compressive load applied to the mesial marginal ridge until catastrophic fracture. Maximum compressive forces between groups was compared using a T test or Wilcoxon test ($\alpha=0.05$).

Results: Fracture resistance of adhesively cemented lithium disilicate and zirconia crowns were not significantly reduced due to endodontic access.

Conclusions: Within the limitations of this *in vitro* study, endodontic access does not significantly affect the fracture resistance of adhesively cemented lithium disilicate and

zirconia crowns. To provide conclusive clinical recommendations, further studies need to be conducted on restoration aging, marginal seal integrity, and endodontic access shape and size.

INTRODUCTION

It was estimated in 2012 that about one indirect restorative unit was fabricated and delivered for every 2.3 US adults. This equates to 54.5 million indirect units delivered based on the population in 2012.[1] Taking this same ratio and applying it to the 2019 US adult population from the US Census Bureau, the amount of indirect units would be 110.96 million, over a two-fold increase.[2] Indications for placement of full coverage restorations include large defective restorations, symptomatic cracked tooth syndrome, large carious lesions, asymptomatic cracks, endodontically treated teeth, and teeth with multiple broken cusps.[3]

Removal of tooth structure for a full coverage restoration depends on multiple factors with restorative material of choice being one of these factors. An *in vitro* study in 2002 using typodont molars showed all-ceramic crown preparations with mean tooth structure removal ranging from 67% to 72%.[4] Schwindling et al in 2019 had mean tooth structure removal for lithium disilicate crowns at 35% and zirconia crowns at 21%.[5] During crown preparation, all enamel is usually removed and the remaining tooth dentinal structure thickness from the pulp chamber can vary from 0.5 mm to 2 mm. This amount of remaining tooth structure must prevent thermal, chemical, osmotic and microbial irritation from the vital pulp.[6-8]

Complications can arise with vital teeth after cementation of full coverage restorations. Overall, studies have shown these teeth experience a 3-25% pulpal necrosis rate.[9] For all-ceramic restorations, the need for endodontic treatment was previously calculated to have a mean incidence of 1% with a range of 0-5%.[10] A more recent systematic review by Gorman, et al. in 2016 reported on a 5, 7, and 8.5-year study with pulpal necrosis complication mean incidence rates of 4%, 8.6%, and 2.5%, respectively.[11]

Endodontic access through a ceramic crown can also present multiple clinical challenges. Surface and subsurface cracks can be introduced by abrasive particles when preparing the endodontic access opening. These cracks can propagate and cause a catastrophic failure of the ceramic crown.[12-13] Modern dental ceramics have been developed to mitigate crack propagation. Stress-generated flaws on zirconia induces a tetragonal to monoclinic transformation.[14] Transformation toughening induces an increase in volume and compressive stresses. In turn, strengthening the zirconia and halting crack progression.[15-16] Also, the lack of clinical landmarks for detecting the pulp chamber can lead to a more aggressive opening and a weaker foundation due to the loss of underlying dentin.[17] Strengths of current dental ceramics such as lithium disilicate and zirconia have made endodontic access challenging.

Reportedly, the most efficient instrument for accessing ceramic restorations with no evidence of dulling of the bur or charring of the restoration was a 126 µm grit, coarse diamond bur.[18] Furthermore, outcome success of endodontic treatment is influenced by the maintenance and quality of a coronal seal.[19-21] Based on a systematic review, there was no consensus in the literature with regards to accessing the crown and repair protocols for ceramic restorations with an endodontic access.[11]

As a result, the aim of this *in vitro* study is to assess the effect of endodontic access preparation and repair on the fracture resistance of monolithic glass-ceramic and zirconia crowns on a mandibular first molar model. The null hypothesis is that there is no difference in fracture resistance between an intact monolithic restoration and an endodontically accessed and repaired monolithic restoration.

MATERIALS AND METHODS

Master Die Fabrication

Mandibular first molar analog dies were designed by scanning (Freedom HD; DOF Inc.; Seongdong-gu, Seoul, South Korea) a mandibular first molar typodont tooth (T-1560 #19; Columbia Dentoform; Lancaster, PA) and using digital reduction through DentalCAD (Exocad GmbH; Darmstadt, Hesse, Germany). Dies were milled (CORiTEC 350i Loader; imes-icore GmbH; Eiterfeld, Germany) from NEMA Grade G-10 continuous filament woven fiberglass bonded epoxy resin (The Gund Company, St. Louis, MO).

The dies were digitally prepared with set parameters in DentalCAD. A chamfer margin was reduced by 1.0 mm and at an angle of 30 degrees. The occlusal reduction was 1.5 mm. The buccal and lingual areas were reduced by 1.5 mm. 4.0 mm of preparation height was ensured.

Through the DentalCAD software, a digital base was added to the die design to ensure consistent orientation of the die on the jig mounted on the universal testing machine (MTS Insight 5; MTS Systems Corporation; Eden Prairie, MN) (Figure 1).

Crown Design and Milling

All milled crowns, both lithium disilicate (IPS e.maxCAD LT; Ivoclar Vivadent Inc.; Amherst, NY) and zirconia (IPS e.max ZirCAD LT; Ivoclar Vivadent), were standardized and designed based on the digital preparation for a mandibular first molar. The crown was designed to fit the previously fabricated mandibular first molar analog dies. Crown occlusal thickness was set at 1.5 mm, margin thickness at 1.0 mm, and axial crown thickness at 1.0 mm. Twenty identical mandibular first molar crowns were fabricated (inLab MC X5; Dentslply Sirona; Charlotte, NC) from lithium disilicate CAD blocks of low translucency, shade A3. Twenty identical mandibular first molar crowns were milled (Zenotec Select Hybrid; Wieland Dental+Technik GmbH & Co. KG; Pforzheim, Germany) from zirconium CAD discs of low translucency, shade A3.

Each of the 20 monolithic lithium disilicate crowns were polished (K0240 Dialite LD Extra-Oral Finishing and Polishing System; Brasseler USA Dental; Savannah, GA) and put through one crystallization firing cycle in a dental laboratory oven at temperature of 850°C for 13 mintues and 10 seconds (Programmat P510, Ivoclar Vivadent). Afterwards, 20 monolithic zirconium crowns were each put through one sintering cycle in a dental laboratory furnace at a temperature of 1600°C for 4 hours and 30 minutes (Programmat S1 1600, Ivoclar Vivadent) and polished (K0238 Dialite ZR Extra-Oral Finishing and Polishing System; Brasseler USA Dental).

Crown Bonding

All crowns were bonded to their respective dies using a dual-cure adhesive luting cement per manufacturer's instructions and as described below.[23]

Monolithic lithium disilicate crown cementation – Pretreatment of the 20 lithium disilicate restorations was initiated with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent Inc.) applied to the intaglio surface for 20 seconds, then rinsed with tap water and gently air dried with an air/water syringe tip. Next, a silane coupling agent (Monobond Plus; Ivoclar Vivadent Inc.) was placed on the intaglio surface for 60 seconds and gently air dried. All 20 dies to receive IPS e.max lithium disilicate CAD crowns were rinsed with water and air dried prior to cementation. Finally, a primer adhesive (Multilink Primer A/B; Ivoclar Vivadent Inc.) was placed on the 20 dies for 30 seconds and air dried.

With completion of pretreatment, the lithium disilicate restorations were adhesively bonded to the dies following manufacturer's instructions. Seating of the restoration onto the die was completed with digital pressure and verified through stereomicroscopy (SMZ645; Nikon; Tokyo Japan). Margins were light cured (Epilar S10, 3M) in quarter segments (mesio-lingual, disto-lingual, mesio-buccal, and disto-buccal) for 3 seconds each. Excess cement was removed with a scaler and margins were covered with a glycerine gel/air block (Liquid Strip; Ivoclar Vivadent Inc.) to ensure full polymerization of the surface layer. All margins were light cured again for 20 seconds. The glycerine gel/air block was rinsed off with water.

IPS e.max zirconia CAD crown cementation – Pretreatment of the 20 zirconium CAD restorations started by air abrading the intaglio surface with 100 μm aluminum oxide (Al_2O_3) at a maximum 1 bar of pressure. All subsequent steps followed the same cementation process for lithium disilicate restorations detailed above (Figure 2).

Endodontic Access and Repair

Endodontic Access – Mesial, distal, buccal, and lingual dimensions were measured on a mandibular first molar typodont tooth (T-1560 #19; Columbia Dentoform). Referring to previous studies on endodontic access outlines for mandibular first molars, the access outline measurements on the typodont tooth were determined to be 5 mm mesial to distal on both the buccal and lingual borders, 3 mm on the mesial border and 2 mm on the distal border.[24-26] This access outline was marked. A stencil of the typodont tooth was created from a clear vacuform matrix material (Copyplast 1.5mm/125mm – Round; Great Lakes Dental Technologies; Tonawanda, NY) with the access outline removed to serve as the transfer template. 10 lithium disilicate and 10 zirconia crowns were randomly selected and access outlines marked using the transfer template (Figure 3).

Based on the study by Qeblawi et al in 2011, a new 126 μm coarse-grit round end tapered diamond bur (ZR6850; Komet USA LLC, Rock Hill, SC) was selected for each endodontic access.[11] An electric handpiece (GENTLEpower LUX 25 LPA; KaVo Dental; Brea, CA) at 200,000 rpm was used with copious water spray to access marked specimens to a depth of 4 mm.[18]

Endodontic Access Repair - Accessed restorations were repaired with a light cured resin-based composite (Filtek Supreme Ultra; 3M USA; St. Paul, MN). The anatomy of the repaired occlusal surfaces was adjusted to be flush with the adjacent lithium disilicate or zirconia material with a football white stone bur (Dura-White Stones; Shofu Incorporated; Kyoto, Japan). Finishing (Enhance Tip System Kit; Dentsply Sirona) and polishing (Enhance PoGo Complete Kit; Dentsply Sirona) of the occlusal surface was completed (Figure 4).

Failure Load Testing and Data Collection

Specimens were placed on a custom 3D printed titanium jig that allowed consistent orientation with a custom 3D printed titanium (Ti-6Al-4V; AP&C – A General Electric Additive Company; Boisbraind, Canada) 3 mm round tip piston. Static, blunt loading was conducted parallel to the long axis of the specimen. The tip was placed with a crosshead speed of 0.5 mm/min on the mesial marginal ridges of both the intact and repaired crowns (Figure 5). Using MTS Testworks 4 software, increases in the fracture loads were continuously recorded in Newtons (N) starting at 100 N. Progressive force was applied until complete fracture of the crown. Stress-strain curves were analyzed for the first discontinuity representing a drop in the load and called "failure load." Complete failure load was designated by the peak load prior to a greater than 5% drop in load (Figure 6).

Statistical Analysis

The fracture resistance within each group (i.e., combinations of material/access) was summarized using means and standard deviations. To assess the significant impact of material or access type on failure load, a linear model that included an interaction term was used. Planned comparisons by access were evaluated in both materials.

Statistical analysis was performed in R (R Core Team, Vienna, Austria). The significance of all analyses was evaluated using an alpha of 0.05.

RESULTS

Figure 7 shows the mean failure loads for each material for both intact and restored crowns. The force required to fracture intact crowns (2310N ± 557N) was statistically equivalent (p=.98) to the force required to fracture repaired crowns (2307N ± 683N). However, there was a large and statistically significant difference (p<.0001) between the force required to fracture monolithic zirconia (2814N ± 398N) and monolithic lithium disilicate (1802N ± 281N). There was no significant interaction between material and access type (p=.19).

Planned comparisons between the fracture resistance of intact vs. restored crowns for each material revealed no significant difference for either monolithic lithium disilicate (p=.35) or monolithic zirconia (p=.36).

DISCUSSION

There was no difference in fracture resistance between an intact monolithic restoration and an endodontically accessed and repaired monolithic restoration in either of the two tested materials. However, there were large differences in fracture resistance due to the material used.

The results for lithium disilicate were similar to recent studies by Bompolaki et al,[17] Oğuz et al,[30] and Mallya et al.[31] but contrary to the findings from Lund et al.[32] This can be attributed to the varying testing protocols and materials utilized for each study. Findings for zirconia were comparable to studies by Scioscia et al[33] and Mallya et al[31]. Like lithium disilicate, both mean failure loads for intact and repaired zirconia crowns were above the maximum natural bite forces produced. Although these *in vitro* results cannot be directly compared to a clinical environment, it would suggest both materials, whether intact or repaired, can withstand maximum masticatory forces at extreme conditions.[27-29]

National Electrical Manufacturers Association (NEMA) Grade G-10 is a continuous filament woven fiberglass bonded epoxy resin utilized in previous studies.[17-18] Stress-strain curves of NEMA G-10 were comparable to stress-strain curves of hydrated dentin. Also, resin cement bond strengths, in both wet and dry NEMA G-10, were similar to dentin.[22] These properties along with the ability to create uniform milled dies made NEMA G-10 an ideal dentin substitute for this study.

The use of NEMA G-10 as a dentinal substrate, instead of natural extracted teeth, allowed for greater control of material uniformity in an *in vitro* setting, while still maintaining similar properties to natural dentin.[22] Previous studies showed the use of either natural teeth or a dentinal substrate yielded similar results for both intact and repaired conditions.[17, 31, 34]

Endodontic access preparations in this study were standardized using a transfer template. This negated any significant variability in the dimensions of the access size and allowed a conservative access approach. Since there are no definitive repair protocols for endodontically accessed ceramic restorations,[11] a simple, straightforward approach was adopted to try and ensure an adequate coronal seal. Although the margins of the coronal seal were not inspected, it deserves a closer investigation to determine its effect on failure load. Overall, further studies on repair protocols are needed to determine an appropriate methodology for restoring coronal seal.

Within the confines of this study, there are limitations. Thermocycling in combination with cyclic loading would have closely simulated ceramic aging in the oral environment.[35] Furthermore, load testing under wet conditions might extend surface and subsurface flaws causing a decrease in the mean failure loads[22] and would have increased clinical translatability for this investigation. Future studies are needed to incorporate these additional parameters.

This study adds to the current body of literature and shows monolithic ceramic crowns with repaired endodontic accesses show no statistical difference in strength compared to intact crowns. Although, in this “best case” scenario, it should be noted the thickness used for the lithium disilicate and zirconia crowns were above the minimum recommendations set by the manufacturer. It is possible, that lower mean failure loads might be encountered with material thicknesses lower than the ones utilized in this study. Granted, clinicians might encounter varying all-ceramic crown thicknesses due to changes in manufacturer recommendations, previous loss of tooth structure extent caused either by trauma or carious lesions, previous defective full coverage restorations (i.e. metal-ceramic restorations), and variation in tooth reduction. Once the all-ceramic crown is accessed, providers should examine the thickness of the material along the access outline to help determine susceptibility to fracture. Future studies should consider assessing varying material thicknesses

CONCLUSION

Based on the conditions of this *in vitro* study, endodontic access did not significantly affect the fracture resistance of monolithic lithium disilicate and monolithic zirconia crowns. Conclusive clinical recommendations can be made with future studies on ceramic aging, marginal seal integrity, varying material thickness, and endodontic access shape and size.

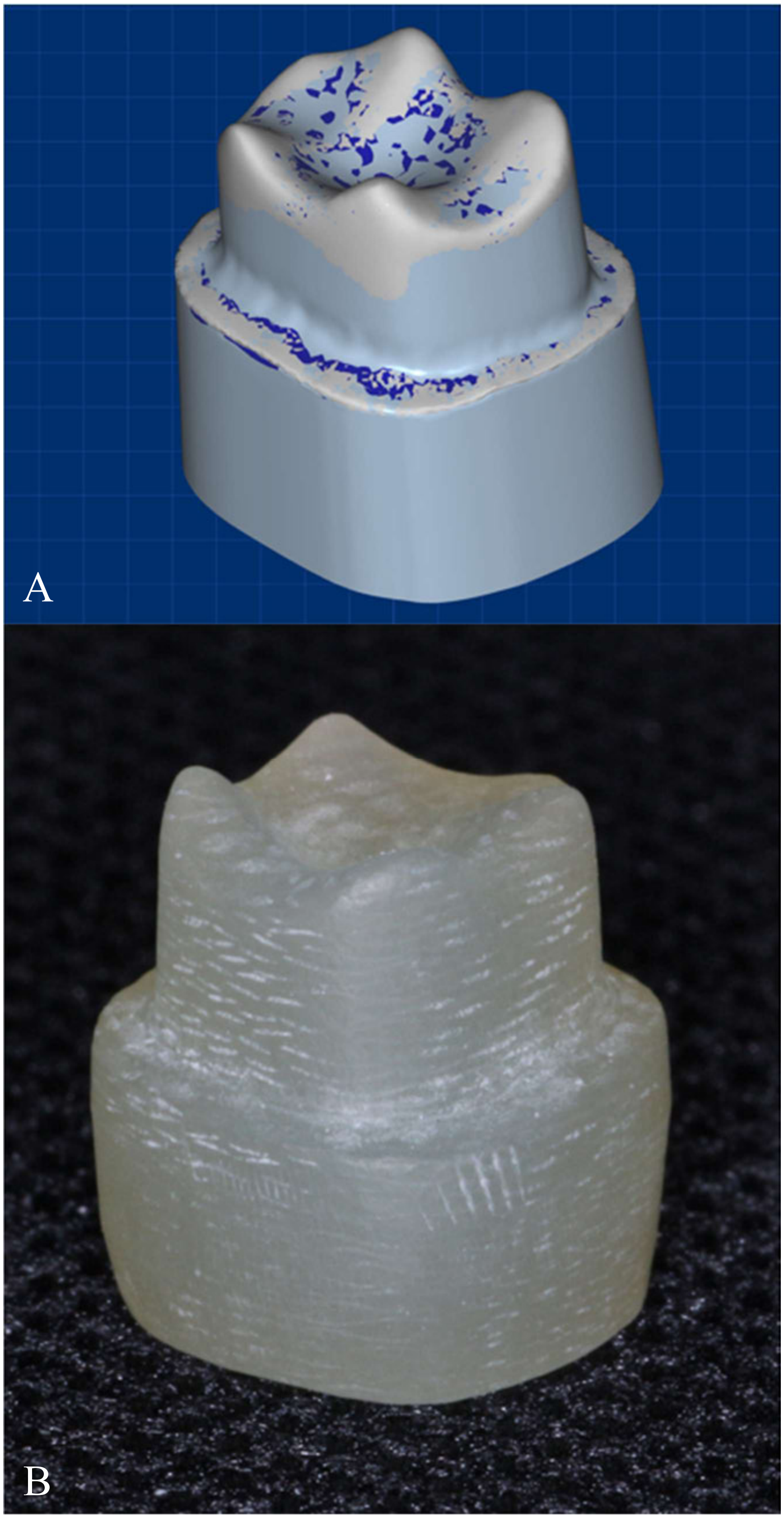

Figure 1: DentalCAD master die design (A) and NEMA Grade G10 master die (B).

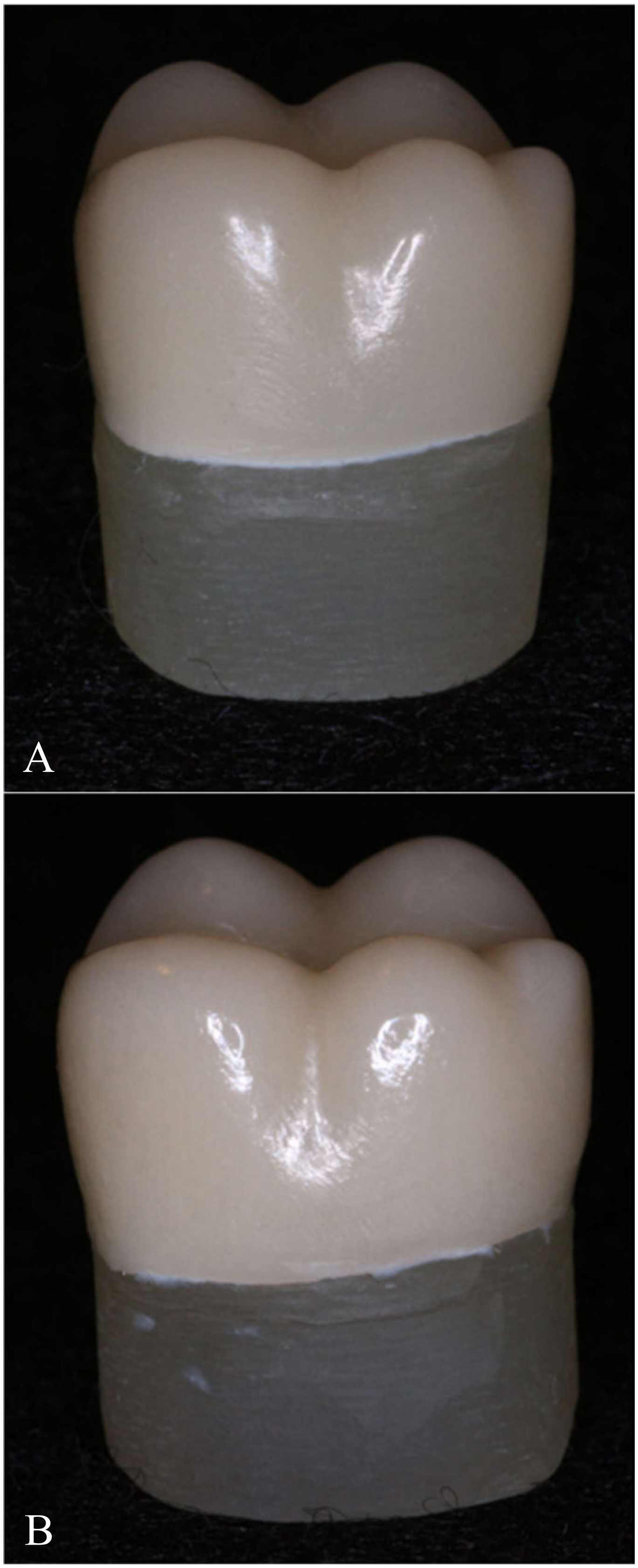

Figure 2: Lithium disilicate (A) and zirconia (B) crowns cemented on NEMA Grade G10 dies.

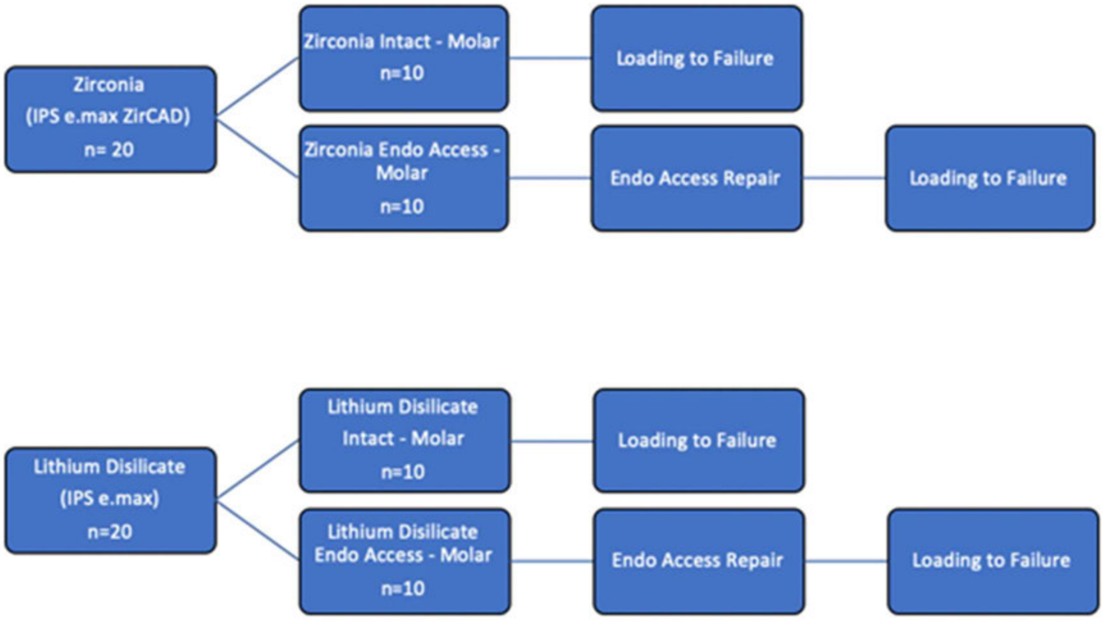

Figure 3: Study Design - crowns for each material cemented on NEMA Grade G10 dies (n=20) and divided into two groups: intact (n=10) and accessed (n=10).

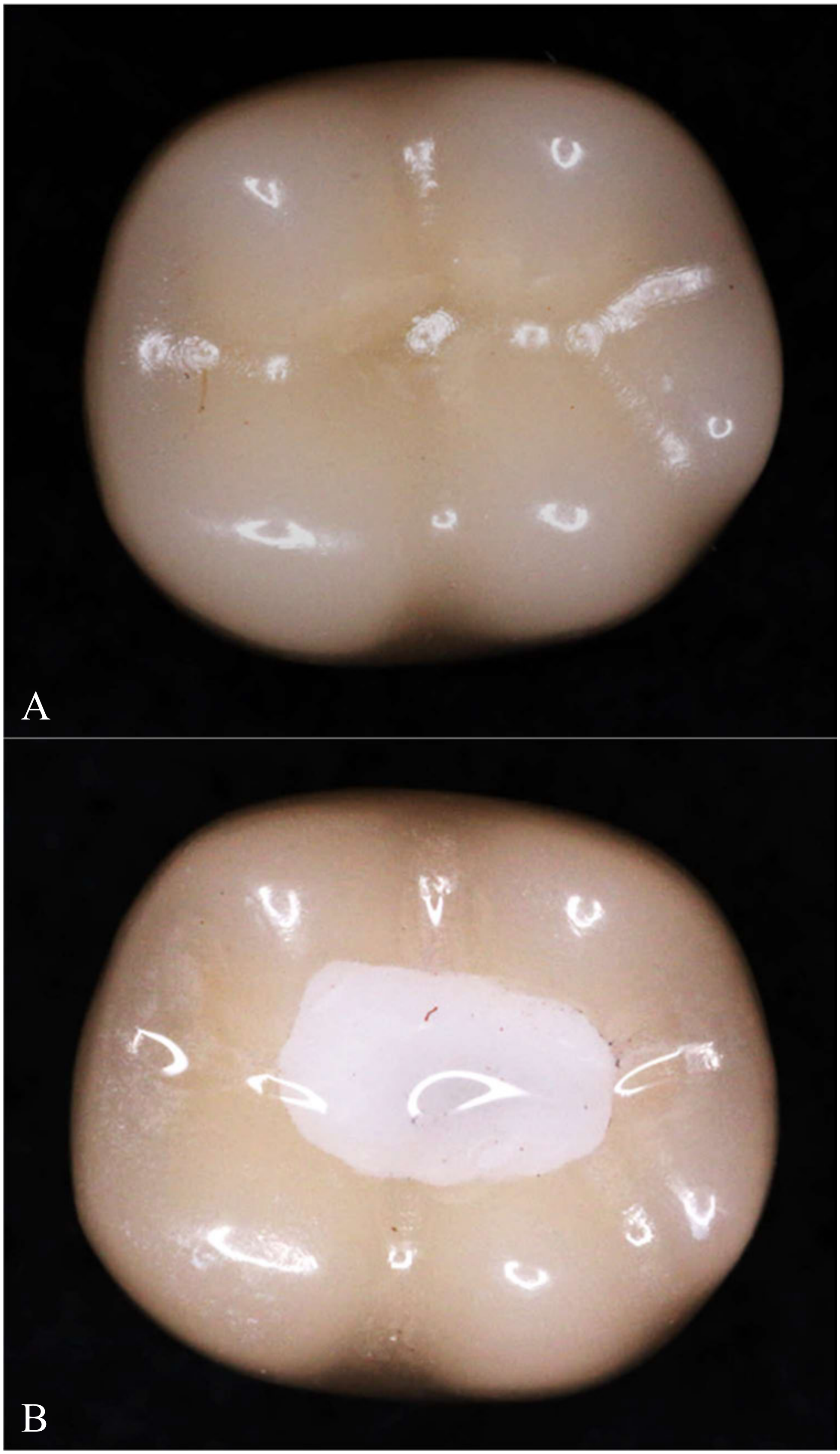

Figure 4: Intact lithium disilicate crown (A) and accessed/repaired lithium disilicate crown (B).

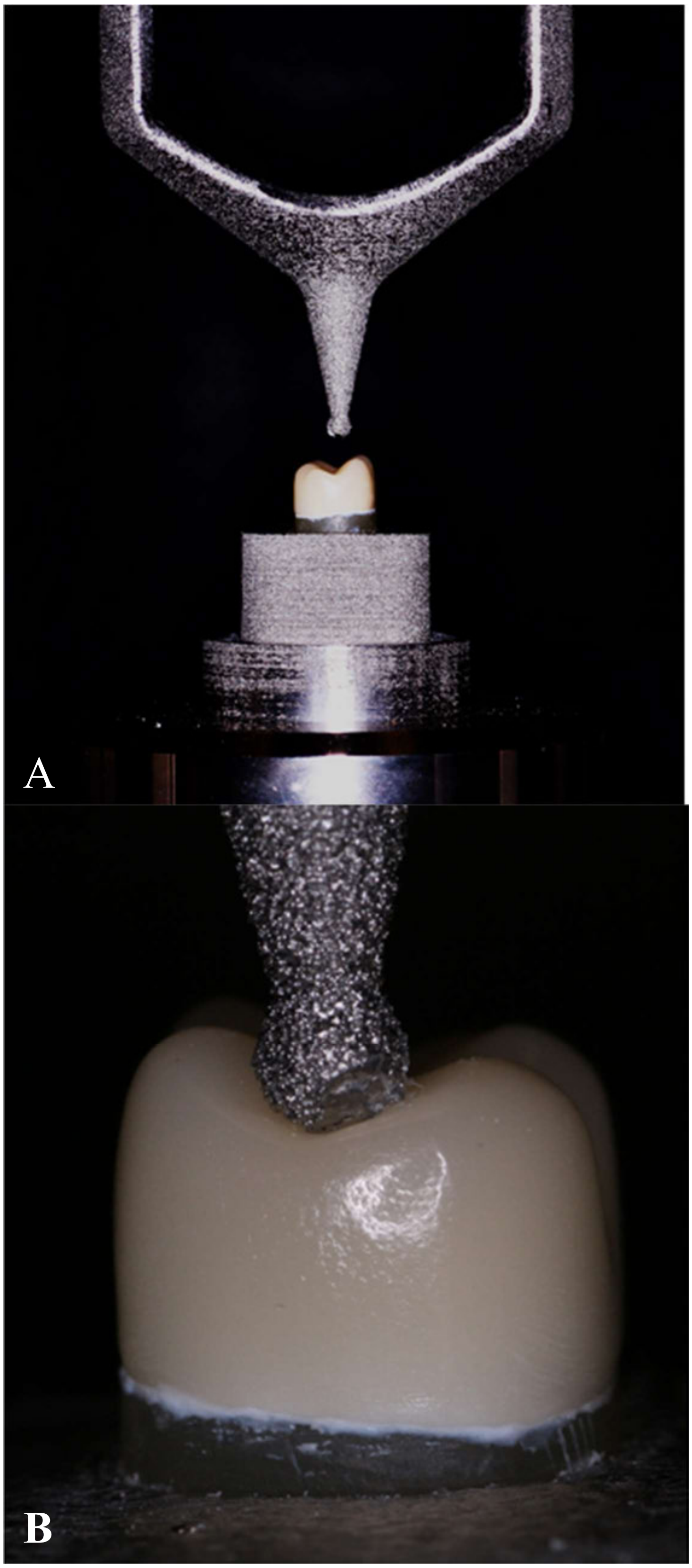

Figure 5: Static load test setup with MTS Insight 5 (A). Lithium disilicate crown loaded parallel to the long access of the specimen on the mesial marginal ridge (B).

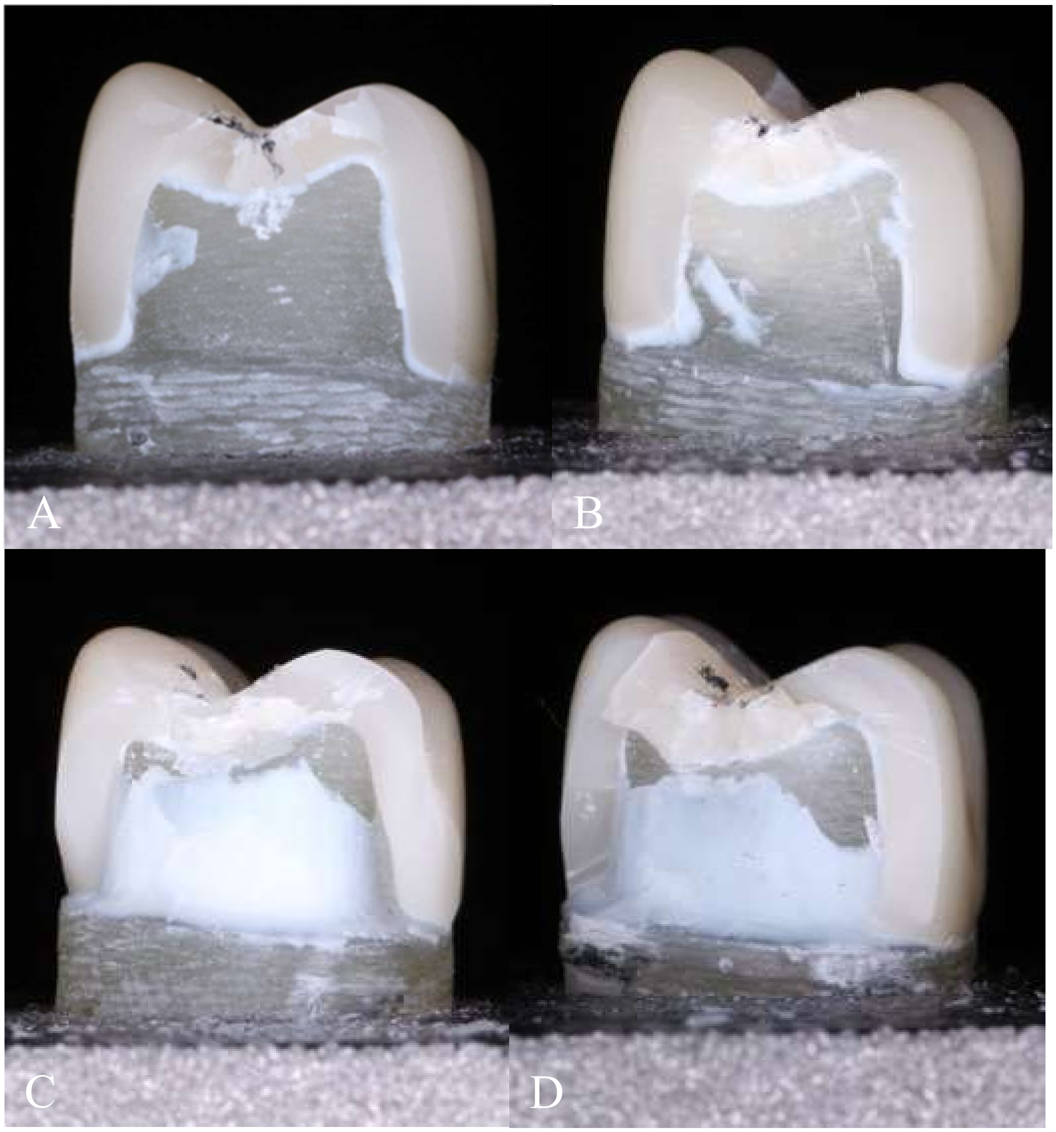

Figure 6: Failed intact (A) and accessed/repaired (B) lithium disilicate crowns. Failed intact (C) and accessed/repaired (D) zirconia crowns

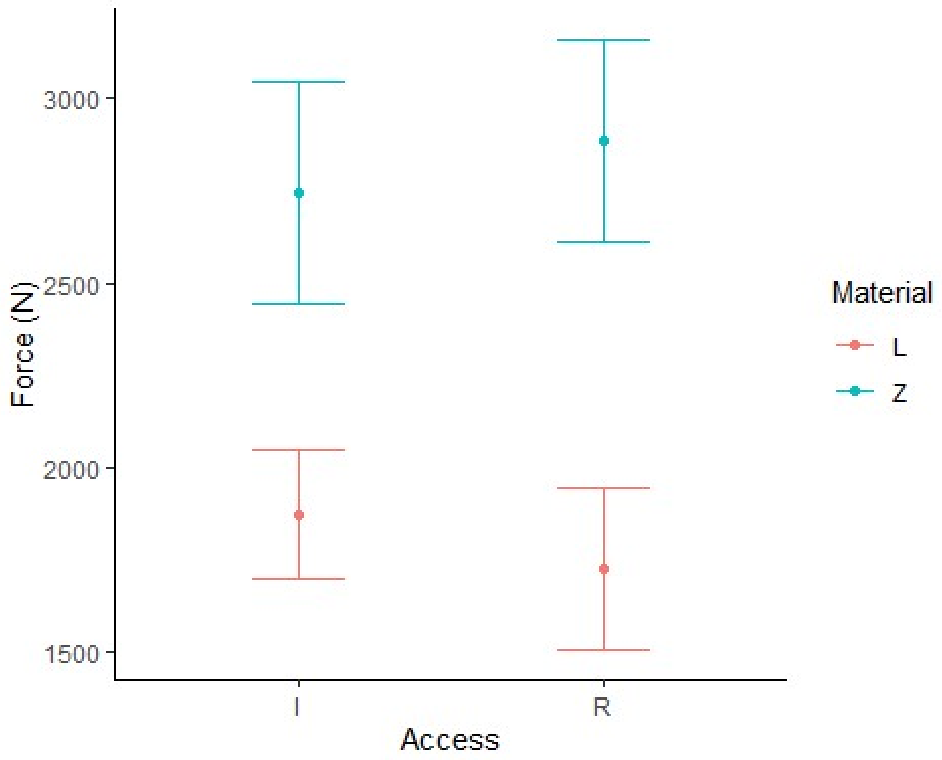

Figure 7: Mean force loads with standard deviations (N=Newtons) for intact (I) and repaired (R) lithium disilicate (L) or zirconia (Z) crowns.

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