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THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Fracture resistance of endodontically accessed minimal thickness all ceramic crowns

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Master of Science Degree
June 01, 2021

THESIS/MANUSCRIPT APPROVED: DATE:

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FRACTURE RESISTANCE OF ENDODONTICALLY ACCESSED MINIMAL THICKNESS ALL-CERAMIC RESTORATIONS

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A thesis submitted to the Faculty of the
Comprehensive Dentistry Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology
June 2021

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ABSTRACT

Fracture Resistance of Endodontically Accessed Minimal Thickness All-Ceramic Restorations

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Abstract:

Advances in material science and bonding chemistry allows for fabrication of thinner all-ceramic restorations. Questions remain regarding their strength after endodontic access and repair. **Objective:** This study will compare the fracture resistance of three types of ceramic crowns that have been endodontically accessed and repaired. **Methods:** Sixty minimal thickness crowns will be digitally designed. Twenty crowns will be milled from lithium disilicate (LiS2), twenty from medium translucency zirconia (ZMT), and twenty from low translucency zirconia (ZLT). The crowns will be crystallized or sintered and adhesively bonded with a dual-cured resin cement to dies milled from a continuous filament woven fiberglass bonded epoxy resin. Ten samples of each crown type will undergo endodontic access and repair with nanohybrid composite resin. All specimens will undergo static load testing on a universal testing machine with a compressive force applied until failure. **Results:** Study ongoing. **Conclusions:** To be determined.

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LIST OF ABBREVIATONS

Al_2O_3	aluminum oxide
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
IQR	interquartile range
LiS2	lithium disilicate
LiS2I	lithium disilicate intact crown
LiS2R	lithium disilicate endodontically accessed and resin-repaired crown
LT	Low Translucency
µm	micrometer
mm	millimeter
MT	Medium Translucency
N	Newtons
NEMA	National Electrical Manufacturers Association
PMMA	Polymethyl methacrylate
RPM	Revolutions per minute
ZLT	zirconia Low Translucency
ZLTI	zirconia Low Translucency intact crown
ZLTR	zirconia Low Translucency endodontically accessed and resin-repaired crown
ZMT	zirconia Medium Translucency
ZMTI	zirconia Medium Translucency intact crown

ZMTR	zirconia Medium Translucency endodontically accessed and resin-repaired crown
3D	three dimensional

CHAPTER 1: Introduction

BACKGROUND

All-ceramic based indirect dental restorations are becoming an increasingly large portion of the dental armamentarium. Due to their strength, esthetic properties and the speed and ease of fabrication through computer aided design and computer aided manufacturing (CAD/CAM), all-ceramic restorations are well received by practitioners and patients alike. In 2017, within the US Navy alone, all-ceramic restorations (both CAD/CAM and traditional analog fabrication pathways) accounted for over 66% of indirect restorations vice full metal or porcelain fused to metal based restorations.[1] Additionally, the advancement in ceramic material properties and adhesive bonding chemistry has allowed for more conservative tooth preparation—less tooth reduction and hence thinner restoration material thickness.

A recent analysis of a dental insurance database over a 10-year period (2008-2017) involving 88,409 teeth with crowns, reported a 3% incidence rate of all-ceramic crowns requiring endodontic treatment after crown placement.[2] Other studies have reported the need for endodontic treatment following all-ceramic crown placement at anywhere from 2.1%-8.6% over a 5 to 8.5 year period.[3] While removal and replacement of an indirect restoration following endodontic therapy is an ideal treatment, endodontic access through existing indirect restorations with subsequent direct restoration of access opening is not uncommon. One survey of 543 dentists revealed that 72% of practitioners tend to access through existing crowns and restore access openings as the final restoration.[4] Currently, there is no consensus as to the effect of endodontic access and repair on all-ceramic crowns. Studies by Lund et al. and Scioscia et al. indicate that endodontic access may have a statistically significant negative effect on crown fracture resistance, while studies by Mallya et al., Gerogianni et al., and Bompolaki et al. found no significant effect.[5-9]

Recently, a study conducted by Lares found no significant difference in fracture resistance between adhesively cemented milled lithium disilicate and zirconium crowns within their respective groups, regardless of endodontic access.[10] It is possible however, that no difference was noted because the occlusal crown thickness was 1.5 mm, which might provide an adequate amount of bulk to resist fracture forces.

The aforementioned literature tested restorations with an occlusal crown thickness that ranged from 1.34 to 2 mm. To the author's knowledge, no such studies have been performed using the manufacturer's minimum recommended guidelines for restoration thickness in relation to adhesive bonding. The purpose of this *in vitro* study is to investigate the relationship between fracture strength and restoration thickness of endodontically accessed and repaired milled lithium disilicate, medium translucency zirconia and low translucency zirconia full coverage indirect restorations on a first mandibular molar model, using the minimal thickness parameters set by the manufacturer. The null hypothesis is that there will be no difference in fracture resistance between intact and endodontically accessed and repaired restorations within their respective groups.

CHAPTER 2: Materials and methods

The basis of this protocol is adapted from the master's thesis of Christian Lares, Uniformed Services University of the Health Sciences, 2020.

MASTER DIE FABRICATION

Mandibular first molar analog dies will be 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 will be milled (CORiTEC 350i Loader; imes-icore GmbH; Eiterfeld, Germany) from National Electrical Manufacturers Association (NEMA) Grade G-10 continuous filament woven fiberglass bonded epoxy resin (The Gund Company, St. Louis, MO). The dies will be digitally prepared with set parameters in DentalCAD. For the lithium disilicate (LiS2) and zirconia medium translucency (ZMT) groups, the dies are planned as follows: a 1.0 mm chamfer margin at an angle of 30 degrees with an axial taper of 6% and occlusal, buccal and lingual reductions of 1.0 mm with a preparation height of 4 mm. For the zirconia low translucency (ZLT) group, the die will be modified to have a 0.6 mm rounded shoulder margin and occlusal, buccal and lingual reductions of 0.6 mm instead of 1.0 mm, while maintaining the same margin angle and taper. Through the DentalCAD software, a digital base will be added to the die designs 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).

CROWN DESIGN AND MILLING

All lithium disilicate (IPS e.maxCAD LT; Ivoclar Vivadent Inc.; Amherst, NY), zirconia medium (IPS e.max ZirCAD MT; Ivoclar Vivadent) and zirconia low translucency (IPS e.max Zircad LT; Ivoclar Vivadent) crowns will be standardized and designed based on clinical recommendations from the manufacturer.[11, 12] For the LiS2 and ZMT designs, the crown occlusal thickness parameters will be set at 1 mm, margin thickness at 1.0 mm, and axial crown thickness at 1.0 mm. For the ZLT design, the crown occlusal thickness will be modified to 0.6 mm, margin thickness at 0.6 mm and axial crown thickness of 0.6 mm. The crowns will be based on the same mandibular first molar typodont tooth as above. Twenty crowns will be fabricated (inLab MC X5; Dentslply Sirona; Charlotte, NC) from lithium disilicate CAD blocks, shade A3. Each of the 20 LiS2 crowns will then be 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 850º C for 13 minutes and 10 seconds (Programmat P510, Ivoclar Vivadent). Forty zirconia crowns will be milled (Zenotec Select Hybrid; Wieland Dental+Technik GmbH & Co. KG; Pforzheim, Germany) and divided into twenty restorations from zirconia CAD discs MT, shade A3 and twenty from zirconia CAD discs LT, shade A3. The 40 zirconia crowns will be put through one sintering cycle in a dental laboratory furnace at a temperature of 1600ºC 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 will be bonded to their respective dies using a dual-cure adhesive luting cement per manufacturer's instructions and as described below. Lithium disilicate crown cementation – Pretreatment: 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent Inc.) is applied to the intaglio surfaces of the lithium disilicate restorations for 20 seconds, then rinsed with tap water and gently air dried with an air/water syringe tip. A silane coupling agent (Monobond Plus; Ivoclar Vivadent Inc.) will be subsequently applied to the intaglio surface for 60 seconds and air dried. All the NEMA G10 dies for the LiS2 CAD crowns are to be rinsed with water and air dried. A primer adhesive (Multilink Primer A/B; Ivoclar Vivadent Inc.) will be applied on the dies for 30 seconds and air dried. The lithium disilicate restorations will then adhesively bonded to the dies following manufacturer's instructions. Cementation of the restorations will be achieved with digital pressure and verified through stereomicroscopy (SMZ645; Nikon; Tokyo Japan). The margins will then be light-cured (Epilar S10, 3M) in quarter segments (mesio-lingual, disto-lingual, mesio-buccal, and distobuccal) for 3 seconds each. Excess cement will be removed with a hand scaler and all margins covered with a glycerine gel/air block (Liquid Strip; Ivoclar Vivadent Inc.) to ensure full polymerization of the surface layer. All margins will then again be light-cured again for 20 seconds and the glycerine gel/air block rinsed off with water.

Zirconia crown cementation – Pretreatment of the 40 zirconia CAD restorations will be accomplished by air abrasion of the intaglio surface with 100 µm aluminum oxide (Al2O3) at a maximum 1 bar of pressure vice hydrofluoric acid etching. All subsequent steps will follow the same cementation process for lithium disilicate restorations detailed above.

ENDODONTIC ACCESS AND REPAIR

The most common root anatomy for a mandibular first molar is two roots, with three canals (two mesial and one distal).[13] Based on measurements of the typodont model tooth and following previous studies on endodontic access outline for mandibular first molars, a simulated idealized access outline was created.

The outline shape is trapezoidal andthe border measurements for 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 (**Figure 1**).[14-16] A clear vacuform matrix material (Copyplast 1.5mm/125mm – Round; Great Lakes Dental Technologies; Tonawanda, NY) stencil was fabricated with the endodontic access outline template. 10 LiS2, 10 ZMT and 10 ZLT crowns will be randomly selected and marked with the template.

Endodontic access of crowns will be performed with a 126-µm grit zirconia removal diamond bur (ZR850 Komet USA LLC, Rock Hill, SC) based on recommendations from Qeblawi.[17] Specimens are to be accessed to a depth of 4 mm using an electric handpiece (GENTLEpower LUX 25 LPA; KaVo Dental; Brea, CA) at 200,000 revolutions per minute (rpm) with water spray.

Models that will undergo endodontic access will be repaired with a light-cured nanohybrid composite resin (Filtek Supreme Ultra; 3M USA; St. Paul, MN), placed in 2 mm increments as per the manufacturer's instructions. The anatomy of the repaired occlusal surfaces will be adjusted to be flush with the margins of the ceramic restorations using a football white stone bur (Dura-White Stones; Shofu Incorporated; Kyoto, Japan), finished (Enhance Tip System Kit; Dentsply Sirona) then polished (Enhance PoGo Complete Kit; Dentsply Sirona).

In total, there will be six different groupings of restorations: LiS2 intact crowns (LiS2I), LiS2 endodontically accessed and resin-repaired crowns (LiS2R), ZMT intact crowns (ZMTI), ZMT endodontically accessed and resin-repaired crowns (ZMTR), ZLT intact crowns (ZLTI), and ZLT endodontically accessed and resin-repaired crowns (ZLTR) (**Figure 2**).

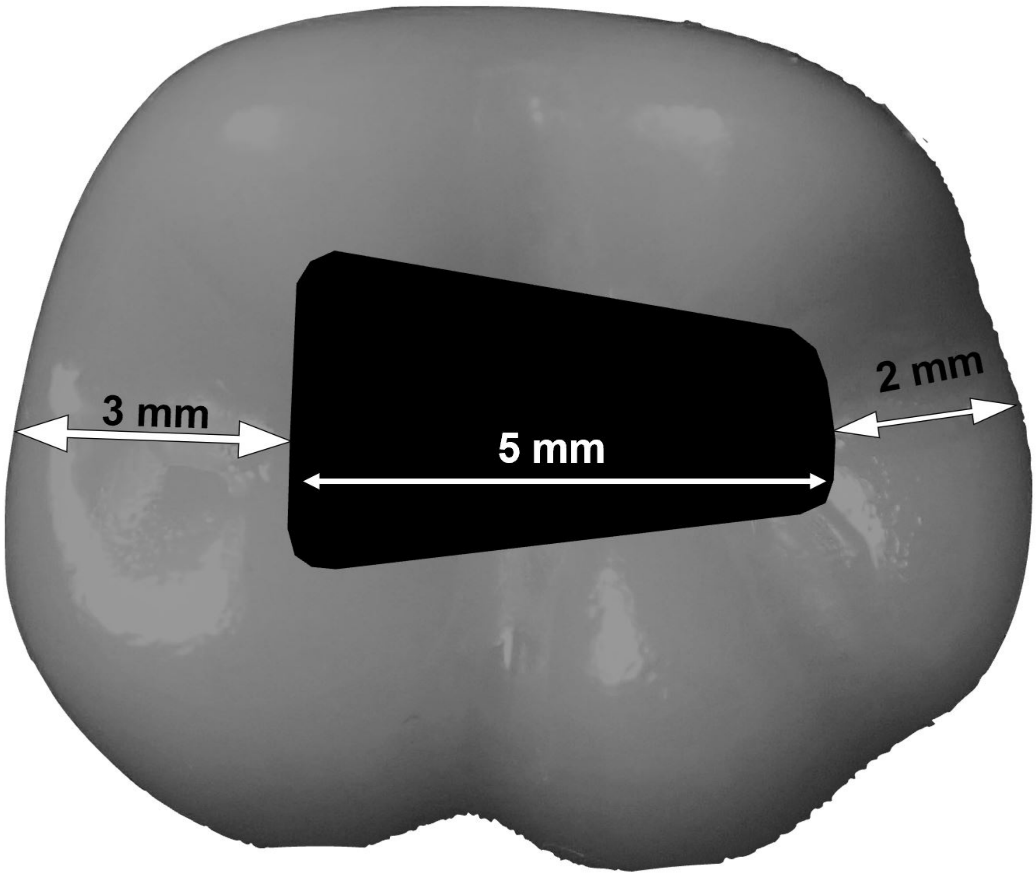

Figure 1. Diagram of endodontic access

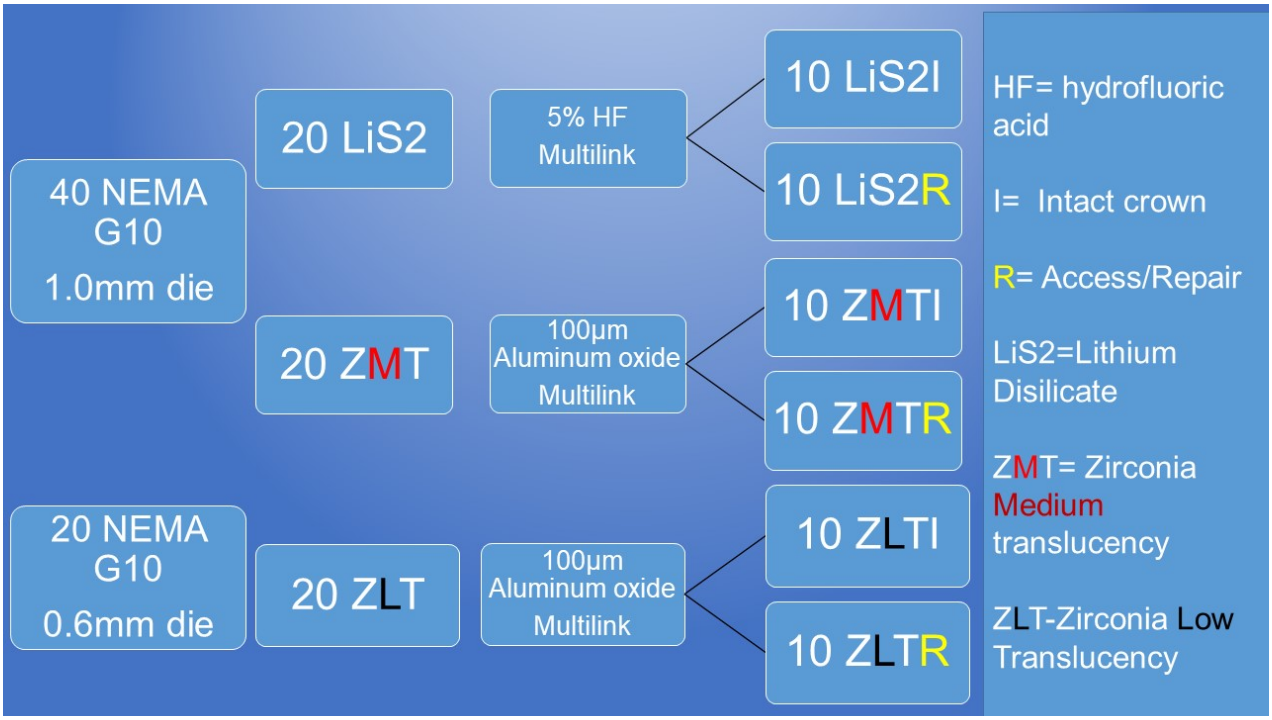

Figure 2. Schematic of test groups

FAILURE LOAD TESTING AND DATA COLLECTION

Specimens will be placed on a custom 3D printed titanium jig to maintain a consistent orientation to the custom 3D printed titanium (Ti-6Al-4V; AP&C – A General Electric Additive Company; Boisbraind, Canada) 3 mm round tip piston. Static, blunt loading will be conducted parallel to the long axis of the specimen at a crosshead speed of 0.5 mm per minute on the mesial marginal ridges of all cemented crowns. Progressive load will be applied until complete fracture of the crown (**Figure 3**). Increases in the fracture loads will be continuously recorded in Newtons (N) starting at 100 N using MTS Testworks 4 software. Stress-strain curves will be analyzed for the first discontinuity representing a drop in the load, which is designated as "failure load." Complete failure load is defined as the peak load prior to a greater than 5% drop in load.


Figure 3. Mounting jig and setup for load testing

Data Analysis Plan

All analyses will use an alpha level of 0.05. The fracture resistance within each group (i.e., combinations of material/access) will be described, using means and standard deviations or medians with the interquartile range (IQR) as appropriate. To address the primary objective, we will compare the fracture resistance between endodontically accessed restorations and intact full coverage all-ceramic restorations. Here, we will use a T-Test or Wilcoxon test to test fracture resistance between the two groups. As a secondary objective, using a similar method as above, we will compare the fracture resistance between the two material types. As an additional secondary objective, we will compare the fracture resistance for each of the material types independently. Here, we will also test the differences among the groups by including an interaction term in a linear model to identify if there is a difference in the degree to which endodontic access affects these materials.

CHAPTER 3: Results

Existing design files were loaded for modifications within Exocad software, however technical challenges prevented altering the CAD designs to fit the proposed design parameters for this study. To overcome this challenge, similar, but not exact, CAD replicas were designed using Exocad software's virtual library. Three prototype crowns were fabricated along with two prototype polymethyl methacrylate (PMMA) resin bases. While examining the fit, marginal discrepancies between the die and crowns were noted. While seating the LiS2 crown onto the die, a lingual fracture occurred which fragmented the crown. Measuring with an Iwason gauge, crown material thickness was found to be below desired parameters in the area of fracture. All prototypes were noted to have wide variance in material thicknesses that ranged from 0.4 mm to 1.6 mm along both axial and occlusal surfaces. The PMMA resin die was found to fit poorly within the titanium mounting jig (**Figure 3**). The original typodont tooth #19 and an original NEMA G-10 resin base from the previous study by Lares were digitally re-scanned. Three additional variations in die and crown design were initiated using DentalCAD workflows. These new die and crown designs will be manufactured and prototypes will be evaluated for accurate form and intimate fit.

CHAPTER 4: Discussion

This study design was intended to be a follow-on exploration of fracture resistance as researched by Lares. As such, the parameters were set to be as close to the original study to reduce heterogeneity and allow for better comparison of data. Several of the previous studies used a variety of materials for the die/substructure ranging from composite resin, extracted teeth, epoxy resin, or PMMA. The rationale was not always discussed. NEMA G-10 was chosen here because previous research has indicated that its mechanical properties in regards to resin bonding and elasticity are comparable to that of hydrated dentin,[18] and it allows for a standardized model with less variation as one might find in an extracted teeth study design. The use of two different zirconia types (MT and LT) was added because the manufacturer indicated a difference in minimal thickness requirements. This is due to difference in composition. Medium translucency zirconia has higher yttria content with higher cubic phase zirconia. Cubic phase zirconia is more translucent and has better optical and esthetic properties but is not as strong as tetragonal phase, due to a loss in the ability to undergo transformation toughening. Because of its higher tetragonal phase content, ZLT is expected to exhibit better strength properties than ZMT, and this is reflected in the difference between the minimum thickness requirements.

Since the genesis of the experiment, further research regarding differing occlusal thickness and endodontic access was conducted, specifically comparing 3 mol% yttria (3Y) and 5 mol% yttria zirconia (5Y) at 0.5-, 1.0-, 1.5- and 2.0-mm thicknesses. These are analogous to low and high translucency zirconia, respectively. Nejat et al. found that mean fracture load was significantly reduced in both types of zirconia after endodontic access if the occlusal thickness was ≤1.0 mm for 3Y and ≤1.5 mm for 5Y zirconia crowns.[19] One main difference in that experimental design included the use of a resin modified glass ionomer luting cement on a PMMA die as opposed to an adhesive resin cement to NEMA G-10 dies as we have proposed. It should also be noted that the 0.5 mm tested occlusal thickness for the 5Y zirconia is also less than the 0.7 mm thickness recommended for single crowns as stated by that manufacturer.[20]

Challenges were encountered within the digital design phase. Some of these may be due in part to limitations, both technical and knowledge-based, of the 3D scanning and CAD/CAM systems. As the primary aim of the study was to investigate the material strength at a minimum thickness, special emphasis was placed on designing a crown restoration that matched the typodont model externally, and yet maintained the minimal thickness in all dimensions and then fabricating the die to "retrofit" and match the crown. The decision to attempt fabrication of the dies through digital reduction was made in consideration to maintain the most idealized preparation design with exact degree of margin angle and taper. Additionally, both die and crown models were designed with the intent to fit the titanium jig and load testing set up previously used. While awaiting necessary supplies, with the assistance of the Naval Postgraduate Dental School Prosthodontic Laboratory, prototype designs were fabricated but the fit of dies and crowns were found to be inaccurate and overall crown thickness found to be highly variable and compromised. The software available has specific workflows and steps and our attempts to "work backwards," starting with our desired crown design and then creating a preparation to fit the intaglio were overall, unsuccessful. The variances in prototype material thickness found may possibly be explained by drill compensation and machining limitations.

To expedite die fabrication, considerations to manually prepare typodont teeth and scan the preparations for use as master dies should be examined. This will also serve to aid in the proper sequencing for the software. Recommendations are to also re-visit the material thickness parameters selected and allow for a wider range while maintaining the minimal thickness at the chosen point of impact (mesial marginal ridge).

Other areas that may require further consideration include the use of thermocycling, wet storage, and fatigue cycling to better simulate any effects of wear over time. Bur selection for endodontic access may also affect the crown integrity post endodontic access and repair. Kim et al. found coarse-grit or fine-grit conventional diamond burs exhibited greater areas of fracture and more extensive surface defects as compared to specialized zirconia removal fine-grit diamond burs, which created smooth furrows of plastic deformation and less surface defects on zirconia blocks.[21] Those may be indicative of a more intact compressive layer of zirconia and may lead to better flexural strength comparatively.[21]

CHAPTER 5: Conclusions

While still a topic worth investigating, this experiment would benefit from some design changes as mentioned previously. From a clinical standpoint, good judgment is necessary for decision-making when considering repair or replacement of a lithium disilicate or zirconia crown after endodontic access. Examination of the restoration's occlusal thickness at the site of endodontic access may give some indication of the risk of restoration failure. Further research and clinical trials may provide more conclusive recommendations.

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