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Effect of Different Supporting Die Materials and Crown Thicknesses on the Fracture Load of Monolithic 3Y-TZP Zirconia and Lithium Disilicate Crowns

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EFFECT OF DIFFERENT SUPPORTING DIE MATERIALS AND CROWN THICKNESSES ON THE FRACTURE LOAD OF MONOLITHIC 3Y-TZP ZIRCONIA AND LITHIUM DISILICATE CROWNS

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A THESIS

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ABSTRACT

Background: Conventionally, the strength of dental materials used for fixed restorations is measured using specimens of simplified geometry (i.e bars or discs). There is value in measuring the strength of these materials in their anatomic geometry (i.e crowns) under clinically relevant loading conditions. One advantage of performing the so-called crown fracture test is that the material may benefit from its ability to be strengthened by its bond to a tooth-mimicking die. When performing a crown fracture test, the ideal die material is natural tooth structure. However, the variability in natural tooth anatomy and microstructure makes the use of a standardized, synthetic die material advantageous. Milled resin-based composites may be used to fabricate the synthetic dies as they have a similar modulus of elasticity as dentin. Newer 3D printed resins may be an alternative material choice as they are easier and less expensive to fabricate than milled resin-based composite. Additionally, Zirconia and lithium disilicate have been often utilized as materials for tooth-supported complete-coverage restorations. Different categories of cements have been recommended for the cementation of these restorations. Nevertheless, there is limited evidence regarding the influence of the type of cement and the material thickness used on the clinical outcomes of teeth restored with zirconia or lithium disilicate restorations.

Objective: The aim of the present study is to evaluate the effect of using different supporting die materials with different mechanical characteristics on the fracture strength

of 3 mol% yttria-stabilized tetragonal zirconia polycrystals (3Y-TZP). Furthermore, we seek to investigate the fracture resistance of different thicknesses of 3Y-TZP and lithium disilicate crowns using different luting cements.

Methods: A standardized premolar crown preparation was performed on a typodont tooth and scanned. The preparation was fabricated into resin dies (n=10) by 3D printing or milling. .8 mm thick zirconia crowns were designed and milled to fit on the dies. The crowns were bonded to the resin dies. The fracture load of the crowns was tested against a 3.5 mm diameter steel indenter in a universal testing machine. Ten extracted human premolars were prepared to a standardized crown preparation using a fixed handpiece on a rotating base. The preparations were then scanned, and duplicates of the prepared teeth were 3D printed out of a resin. 1 mm thick zirconia crowns were fabricated for each preparation. The crowns were bonded to the dies and natural teeth then loaded until fracture. Data were compared with a t-test or a 1-way ANOVA and Tukey post-hoc analysis. For the second part of the study, three experimental crown groups made from 3 mol% yttria-stabilized zirconia polycrystalline ceramic material of 0.8mm, 1.0mm, and 1.25mm uniform thickness were fabricated. Moreover, three experimental crown groups were made from lithium disilicate material of 1 mm, 1.25 mm, and 1.5 mm uniform thickness. The crowns were then luted to one of the 3D printed die materials selected from the first part of the study (NextDent C&B) with either resin cement or RMGI cement. Then all specimens will be loaded at the universal testing machine until fracture, Data were compared with a 1-way ANOVA and Tukey post-hoc analysis.

Results: In part one, A one-way ANOVA revealed no significant differences between the fracture force of the zirconia crowns on the three die materials. A t-test revealed that there was no significant difference in the crown fracture force of zirconia crowns on natural tooth dies (1313.792 N) and a 3D printed resin die (1156.293 N) (p=.618). Regarding the second part of this study, a one-way ANOVA showed that increasing the thickness of 3Y-TZP zirconia and lithium disilicate crowns as well as using resin cements significantly increased the fracture load of these indirect restorations (p<0.001).

Conclusion: Despite having a low modulus of elasticity and flexural strength values, 3D-printed die materials appear to provide sufficient support for high-strength zirconia restorations and offer comparable results of crown fracture tests. For Part 2, increasing the thickness of 3Y-TZP zirconia and lithium disilicate crowns with resin cements considerably increases the fracture load of both materials.

Keywords: Zirconia, Lithium Disilicate, Crown Fracture, 3D Printing

DEDICATION

This thesis is dedicated to my family. Everything I have accomplished so far has been because of you. Your endless prayers and kind wishes have saved me countless times along the road. From the deepest spot in my heart, I appreciate everything you did and still doing for me.

To Dr. Lawson, my sincere gratitude for your unique personality. I will always be proud to have you as my mentor. You have added something precious to my character. Since my first day In the United States, you always have been there for me.

To my Biomaterials family here at UAB, thank you for giving me some of the best years of my life.

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LIST OF ABBREVIATIONS

IFU – Instructions for use

Li DS – Lithium Disilicate

RMGI – Resin-modified glass ionomer

STL – **ST**ereo**L**ithography

10-MDP – 10-methacryloxydecyl dihydrogen phosphate

3Y-TZP – 3 mol% Yttria-Stabilized Tetragonal Zirconia Polycrystals

1. INTRODUCTION

With the rapid increase in the utilization of ceramic restorations, it is critical to measure their clinically relevant mechanical properties to predict their intraoral performance (1). There is no specific mechanical property that can conclusively predict the longevity of ceramic indirect restorations, however, understanding their strength will help to prevent fractures during function (2). Although not common, complete fracture and chipping of both metal-ceramic and all ceramic crowns are reported technical failures for single-unit crowns. The 5-year cumulative fracture rate ranges from 0.05% for metal-ceramic crowns to 0.4% for zirconia crowns to 2.3% for lithium disilicate crowns. The 5-year cumulative chipping rate ranges from 3.1% for zirconia to 2.6% for metal ceramic to 1.5% for lithium disilicate (3). When new variations of restorative materials or surface treatments are developed, laboratory testing of their effect on the strength must be performed to ensure they do not increase the clinical incidence of crown fracture or chipping.

Regarding the first part of this study, the International Standards Organization (ISO) standard for dental ceramic materials (ISO 6872:2015) describes three methods for the calculation of strength: three-point flexural, four-point flexure, and biaxial flexure (piston-on-three-ball). Three- and four-point tests utilize a bar supported on two ends and loaded across its center at one or two points respectively. Biaxial flexural testing employs a disc specimen supported near its periphery and loaded in the center. Ceramics fail when the weakest flaw within the material propagates a critical crack. For this reason, four-point flexural testing leads to lower strength values than three-point flexural testing because there is a greater area subjected to the maximum bending moment (between the loading points) and there is a higher probability that a critical flaw will be present in this area. Biaxial flexural testing will provide higher strength than three- or four-point flexural testing as the specimens are not loaded on their edges, where they are susceptible to failure due to flaws introduced in their fabrication process. The advantage of using a standardized geometry for specimens when testing the strength of materials is that specimens are consistent between testing sites and loading may be applied such that stresses are determined by known calculations (4).

Despite the standardization offered by ISO testing, the ISO standard is not specified in the methods required to polish flexural strength specimens which has led to different laboratories reporting 50% lower strength values of the same dental ceramic in round-robin testing (5).

Another method of testing strength is the use of the crown fracture test which utilizes a crown form cemented to a tooth preparation die that is loaded on its occlusal/lingual surface to failure. The advantages of crown fracture tests include the following. First, flaws or stress risers introduced into the crowns that result from their fabrication process can be factored into their measured strength. The method of fabrication of different ceramics may lead to specimens with different surface flaws that are more representative of actual clinical conditions than a flat bar (6).

On one hand, a crown fracture test can measure the effects of bonding the crown material to a tooth die or the effects of varying the thickness of the crown at certain anatomical locations. On the other hand, there is no standard methodology used for this test, and there are many aspects of the protocol that may be varied, including the geometry and material properties of the crown specimens, dies, and loading indenter (7).

As in this part of the study we address the influence of using different die materials on the fracture load of 3 mol% yttria-stabilized tetragonal zirconia polycrystals (3Y-TZP), the presence of a supporting structure may affect the strength of one material more than another. Some materials may bond better to their substructure die which more efficiently allows stress transfer (8). Also, the different mismatch in elastic modulus between the crown and the substructure die may allow some materials to fare better than others. Previous studies have reported that rankings of materials with crown fracture load testing do not correlate with flexural strength testing (9).

When comparing different die materials, extracted teeth as a die material may be expected to be the best solution to mimic oral situations, but the wide range of variations in the morphology of the teeth, dentin composition, pulp size, and even complications that happen after tooth extraction such as demineralization, desiccation, and degradation could lead to deviation in test conditions and in turn, inconsistent data (10). An example of the studies in which natural teeth were used as die materials was the one done by Abdulazeez et al. He used sound extracted premolars for orthodontic purposes with comparable sizes and characteristics to study the influence of various finish line designs on the fracture strength and failure modes of monolithic zirconia crowns (11).

To overcome the disadvantages of using natural extracted teeth as a die material, substitute die materials have been used in previous studies, including resins (filled and unfilled) and metals. Ideally, a die material would have similar bonding strength and modulus as dentin.

Other investigators have used different materials which can be easily controlled and standardized. AL-Makramani et al. used a nonprecious metal alloy (Wiron 99, BEGO, Bremen, Germany) to evaluate the effect of using different luting cement on the fracture resistance of all ceramic coping (12). Ruizhi YIN et al. utilized stainless steel dies to test the impact of surface finishing and polishing on the fracture strength of monolithic zirconia crowns (13). The drawback of using metal dies to support zirconia restorations is that their high modulus of elasticity enables the dies to deform less than the tooth structure would during the loading of the restorations. As a result, there is a reduction in the shear stress between the die material and ceramic crowns and higher values for the fracture strength of the zirconia restorations than what would happen with natural tooth structure (14).

Another type of die material that is commonly used to evaluate the fracture strength of the zirconia is milled resin composite. Resin composite has a lower modulus of elasticity than metal which can match the modulus of natural dentin. A study by Jian et al., however, compared the influence of using milled resin and titanium dies on the fracture strength of monolithic molar zirconia crowns, and reported that using resin composite dies may underestimate the fracture strength of these restorations due to premature fracture of the dies. Additionally, the surface texture differences between the smooth surface of resin dies and natural dentin remain controversial when it comes to their effect to form the restoration-adhesive-dentin complex, which will affect the outcomes of fracture strength of zirconia restorations (15, 16).

The introduction of a higher content of filler particle in 3D printed resins may give these materials sufficient mechanical properties to be used as a tooth-mimicking die material for crown fracture testing. 3D printing allows the fabrication of multiple specimens faster and more economically than milling which in turn would simplify the laboratory procedure for this test (17).

With regards to the second portion of the research, Recently, All-ceramic dental restorations have become more popular because of their appealing appearance, biocompatibility, and ability to create a natural-looking result (18). However, During mastication, dental restorations are subjected to various stresses of different kinds and intensities which renders them susceptible to breaking under complicated states of stress, especially ceramics because they are brittle materials (3). While monolithic ceramics do not have issues such as chipping, delamination, or fracture that are associated with veneers, other clinical concerns can still arise. These may include the capacity to endure the forces of chewing, the wear on opposing teeth, and the ability to achieve an acceptable appearance (19). To reduce the risk of clinical failure, it's important to take into account the properties of the materials used when creating restorations. Based on these values, clinicians may consider the amount of tooth structure they remove during preparations for indirect restorations.

To the best of our knowledge, there is currently no established minimum recommended thickness for 3Y-TZP monolithic zirconia supported by scientific data, and there is no consensus on how thin these crowns can be fabricated (20, 21).

In 2015, Nakamura et al. reported that monolithic zirconia crowns can be used with a chamfer width of 0.5 mm and occlusal thickness of 0.5 mm for properly restoring molar teeth with regard to their fracture resistance. He stated that the extent of occlusal reduction is a more significant factor in determining the fracture resistance of monolithic zirconia crowns, compared to the amount of axial reduction (22). Paul Weigl et al.

supported these findings in their study and concluded that monolithic zirconia crowns with a thickness of 0.5 mm are strong enough and perform well in laboratory testings, regardless of the type of cement used. On the other hand, zirconia crowns below 0.5 thickness were found to have inadequate strength and therefore unsuitable for use in clinical practice. However, using an adhesive bonding method improved the stability and performance of these thinner crowns (23). Prott et al. proposed that a minimum occlusal thickness of 1 mm. for 3Y-TZP monolithic zirconia crowns would result in high fracture resistance, allowing the indirect restorations to withstand the demanding oral environment. This conclusion was based on the results of their study in which the crowns were subjected to a number of fatigue cycles equivalent to 5 years of clinical use (24).

Regarding the cementation of 3Y-TZP monolithic zirconia crowns, however, bonding these indirect restorations with resin cements would significantly enhance their fracture resistance (25). The vast majority of dental professionals prefer to use RMGI cement while luting 3Y-TZP monolithic zirconia crowns especially if they have adequate retention form in their preparations (26). The popularity of using RMGI cements when luting zirconia crowns can be attributed to their ease of manipulation and reduced susceptibility to technical errors as well as moisture tolerance.

To conclude, several studies have reported that the strength of 3Y-PSZ is not affected by luting with RMGI cement even at a 0.5 mm thickness, so both resin cement and RMGI cement can be used according to the clinician's judgment and considerations (27, 28).

Despite the existence of numerous all-ceramic and metal-ceramic systems, there is no universal material that can be used for all single-tooth restorations. The appropriate choice of restorative system for individual teeth must take into account the characteristics of the available materials and requires careful evaluation. Lithium disilicate glass ceramics, for instance, are a suitable choice in situations where esthetics is crucial due to their exceptional translucency and optical properties. However, their mechanical properties are weaker compared to other metal-based ceramics, so a thicker material is necessary to meet high aesthetic standards and prevent fractures during function (29).

Regarding the optimal thickness of lithium disilicate crowns, there are different and contradictory results from various studies, and it is important to refer to that because one of the major challenges in conducting crown fracture tests is standardizing the conditions and variables involved in the experiment. In his study, D. Edelhoff et al. reported the data analyzed over a period of 11 years and he found that the use of monolithic occlusal onlays made from lithium disilicate ceramic of 1 mm. thickness can be deemed a trustworthy solution for full-mouth rehabilitation in patients with significant tooth wear (30). other studies support the same recommendations for the thickness of monolithic lithium disilicate crowns.(31-33) So, 1 mm. seems to be the minimum thickness required to achieve acceptable fracture resistance of monolithic lithium disilicate crowns.

Based on what we know, adhesive resin cementation significantly increased the retention of lithium disilicate crowns (34). Furthermore, De Kok et al. in his study suggested that using adhesive resin cements significantly improved the fracture resistance of lithium disilicate crowns (35). On the other hand, two clinical studies that were conducted using the same group of participants analyzed the rates of failure and complications associated with short-span lithium disilicate fixed partial dentures that were either conventionally or adhesive cemented. After 8 and 10 years, the studies reported that there was no significant difference between the two methods (36, 37).

2. OBJECTIVES

The main objective of this study is to evaluate the effect of different supporting die materials and crown thicknesses on the fracture load of 3Y-TZP monolithic zirconia and lithium disilicate crowns using different dental cements. In order to address the objective of the thesis successfully, the thesis is composed of the following sections.

2.1 Evaluating The Effect of Die Material on Crown Fracture Test.

The first objective of this part of the study is to measure and compare the fracture load of zirconia crowns cemented to several resin-based die materials with a standardized geometry.

The second objective of this part study is to compare the fracture load of zirconia crowns bonded to dies of one resin-based die material and natural teeth of the same geometry.

2.2 Evaluating The Effect of Different Thicknesses and Cement Types on The Fracture Load of Monolithic 3Y-TZP Zirconia and Lithium Disilicate Crowns.

The purpose of this in vitro study was to investigate the thickness of the restoration and the type of cementation, which are required to guarantee sufficient fracture strength of monolithic CAD/CAM fabricated zirconia and lithium disilicate crowns.

3. HYPOTHESES

1. Die materials with a lower modulus would result in a lower fracture load of monolithic 3Y-TZP zirconia - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary.

2. The fracture load of monolithic 3Y-TZP zirconia bonded to natural teeth dies would exceed the fracture load of monolithic 3Y-TZP zirconia bonded to resin-based dies - This will be determined by T-test for equality of means.

3. Increasing the thickness of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations would improve their fracture load - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary.

4. Bonding of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations with a resin cement would achieve higher fracture load than cementing them with Resin Modified Glass Ionomer (RMGI) - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary.

4. MATERIALS AND METHODS

4.1 Effect of Using Different Die Materials on The Fracture Strength of 3Y-TZP Monolithic Zirconia Crowns.

4.1.1 Specimen Preparation

An artificial maxillary premolar tooth made of acrylic material was utilized to create a tooth preparation that adhered to specific standards. These standards included a minimum height of 4mm, no sharp angles, and a 1mm incisal-cervical marginal curvature (Figure 1 and Figure 2). To achieve a uniform angle of convergence, a high-speed handpiece was utilized to secure a coarse diamond tapered rotary cutting bur (6856.31.016 FG, Brasseler, Savannah, GA USA). This bur was then positioned at a 6°-10° angle from the tooth's vertical axis. The process involved reducing the occlusal and axial walls by 1mm and creating a modified chamfer finish line.

Figure 1. Occlusal view of tooth preparation

Figure 2. Lateral view of tooth preparation.

Afterwards, a die scan was conducted at the Clinical Laboratory of the University of Alabama's School of Dentistry. This was carried out with the assistance of a 3Shape E3 benchtop scanner (manufactured by 3Shape Inc. in Copenhagen, Denmark), as depicted in (Figure 3). This scanner was employed to capture images which were then utilized in designing and constructing models through the use of the Dental Restorative System 2020 computer-aided design software (manufactured by 3Shape Inc.). The digital scan produced would be utilized through stl file in both the fabrication of the die and the coping (Figure 4).

Figure 3. A Benchtop scanner was used to digitize the tooth preparation for the design of dies and copings

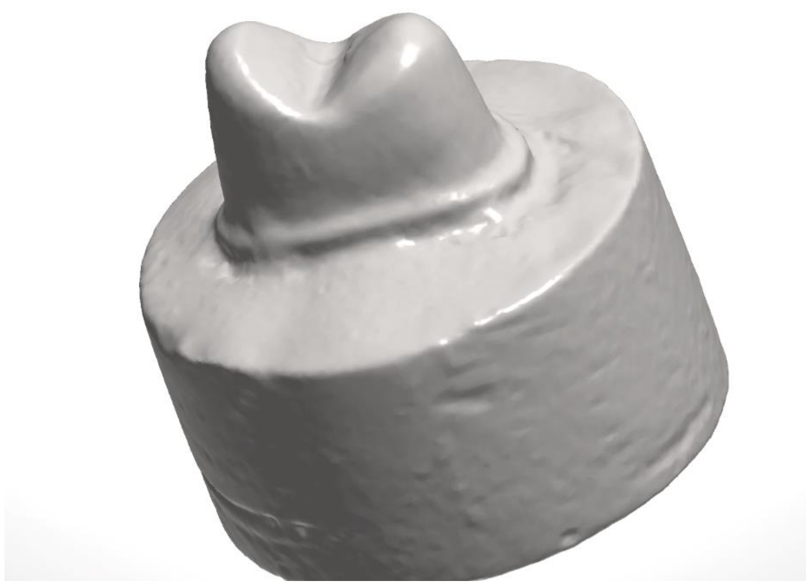

Figure 4. Scan, lateral view, of tooth preparation used for designing

The STL. file was used to 3D-print dies from two resin composite materials (NextDent C&B, NextDent BV, Soesterberg, Netherlands) (Figure 5), and (OnX A1, SprintRay, Los Angeles, CA), Figure 6, in a 3D printer (Pro95 S, SprintRay) (Figure 7).

The dies were cleaned in 91% isopropyl alcohol and post-cured according to the manufacturer's recommendations with Procure 2 (SprintRay) (Figure 8).

Dies were also milled from blocks of heat-cured resin composite (Lava Ultimate, 3M, St. Paul, MN) using the inLab MC X5 milling machine (Dentsply Sirona, Charlotte, NC, USA) (Figure 9).

Figure 5. NextDent C&B used to 3D print dies

Figure 6. OnX A1 used to 3D print dies

Figure 7. Pro95 S 3D printer from SprintRay

Figure 8. Procure 2 from Sprintray

Figure 9. Lava Ultimate for resin milled dies

A crown was designed to fit on the standardized preparation using a uniform 0.8 mm. thickness and 0.02 mm. cement space with Computer Aided Design software (Dental Restorative System 2020, 3Shape Inc) (Figure 10).

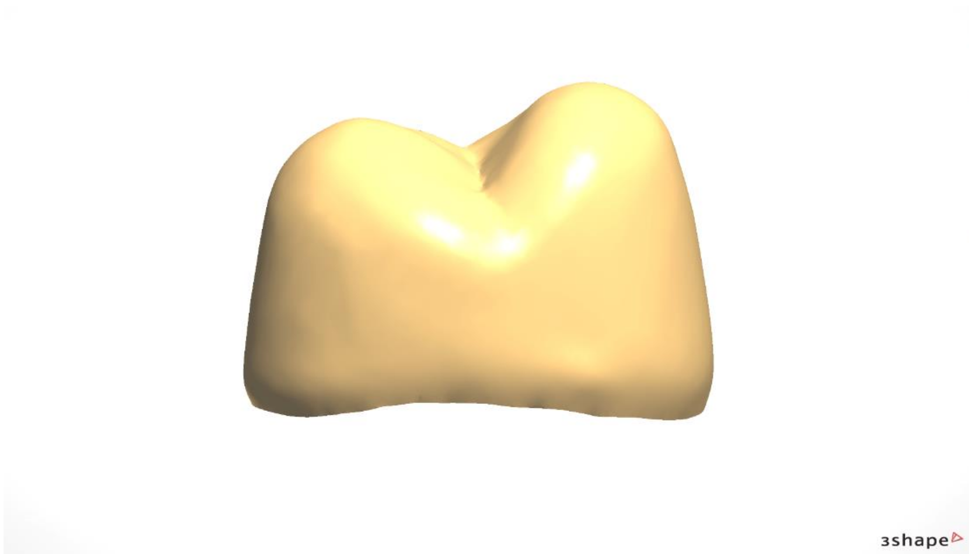

Figure 10. Standardized crown design

Crowns were milled from 3 mol% Yttria-Stabilized Tetragonal Zirconia Polycrystals, 3Y-TZP (Cercon HT, Dentsply Sirona) using the inLab MC X5 milling Machine (Dentsply Sirona). A total of thirty were milled with a standardized cement space of 0.02 mm for all experimental groups. After the milling procedure the copings will be removed from the CAM machine and final sintering will be performed in a zirconia sintering furnace. The copings were examined for deformation and debris, corrected as necessary, and cleaned with steam. Crowns were seated on a definitive die and assigned to groups for cementation (Figure 11).

Figure 11. assessment of the designed crowns on dies

To prepare the intaglio surface of 3Y-TZP crowns, 50 µm particles of Al_2O_3 were used to air-abrade at a pressure of 0.2 MPa for 15 seconds on one surface at a 45-degree angle, using a sandblaster (Basic Eco, Renfert), as shown in Figure 12. Afterward, all specimens underwent ultrasonic cleaning in a distilled water-bath for 10 minutes and were dried using air that was free of oil.

Figure 12. Sandblasting Machine (Basic Eco, Renfert)

4.1.2 Cementation

Regarding Cementation, the crowns (n=10/group) were bonded to the three different types of dies with an MDP-containing, dual-cure, self-adhesive resin cement (Panavia SA Cement Universal, Kuraray America, New York, NY) According to manufacturer's instructions (Figure 13).

Figure 13. Panavia SA Cement Universal

- Clean the resin tooth die with fine pumice and water.
- Make sure the intaglio surface of zirconia restoration decontaminated by sandblasting with alumina, then ultrasonically cleaned and dried.
- Apply thin, even layer of cement to all internal aspects of the crown.
- Seat crown, a standardized load of 10 N for 5 min duration of the cement-setting reaction by means of a universal loading machine. (Figure 14 and Figure 15).
- Partially light-polymerize excess for 2-3 seconds and remove excess material.

- Clean margins of any remaining excess.
- Store specimens in 24° C H_2O for 24 hours prior to testing.

Figure 14. Using a standardized load to confirm proper seating of the crowns

Figure 15. Force during cementation is directed through the long axis of the die

4.1.3 Crown Fracture Test

Specimens were placed into a fixture in a universal testing machine (Instron 5583, Instron Inc., Norwood, MA) (Figure 16 and Figure 17) which oriented the long axis of the tooth at 30° from the vertical direction of the loading indenter. A stainless-steel in-denter with an end curvature of 3.5mm diameter was centered on the central groove of the crown such that it contacted both the buccal and palatal cusps (Figure 18 and Figure 19). Compressive loading was applied at 0.5 mm/min crosshead speed until fracture on the buccal cusp. Fracture load was recorded once a 20% drop in load occurred. Crowns were visually observed to ensure that fracture occurred. The highest load before fracture was recorded as the fracture load. Fracture loads were compared using a 1-way ANOVA and Tukey post-hoc.

Figure 16. Specimens mounted on the Universal Testing Machine

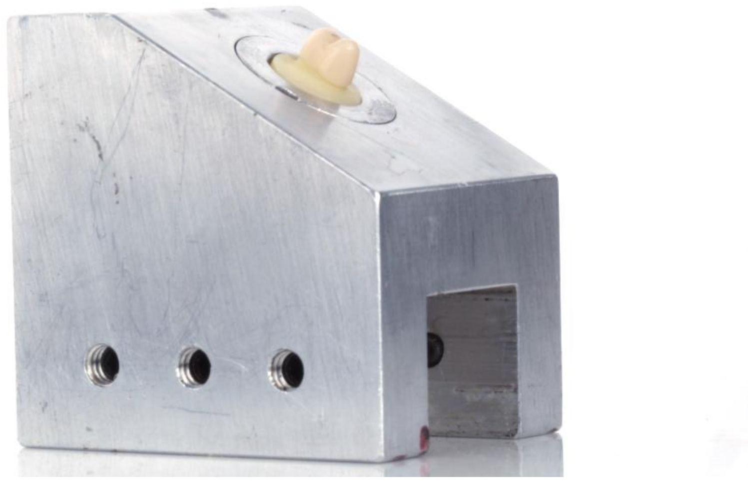

Figure 17. A custom fixture oriented at 30° from the vertical direction of the loading indenter.

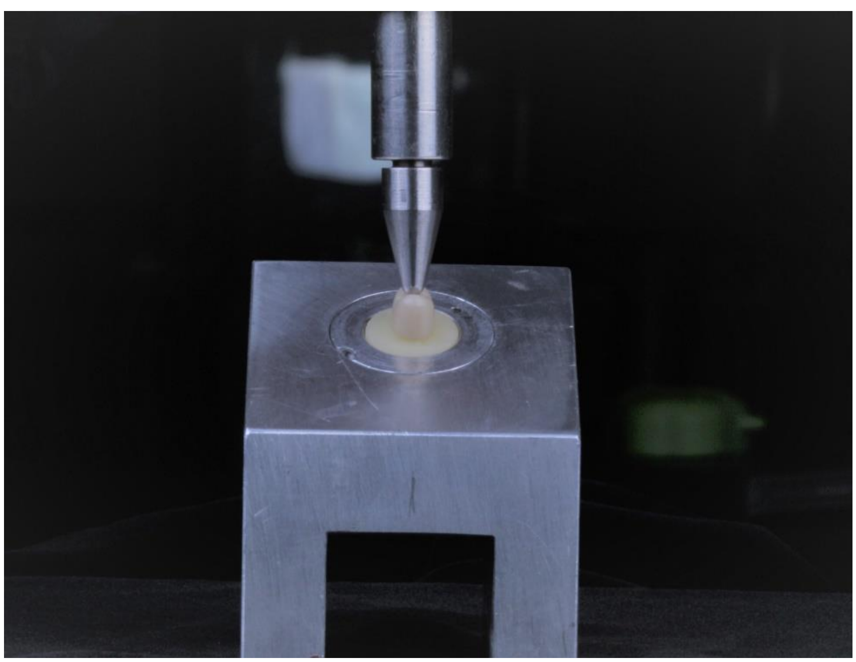

Figure 18. Loading crowns at 30° off axis to introduce complicated stresses (frontal view)

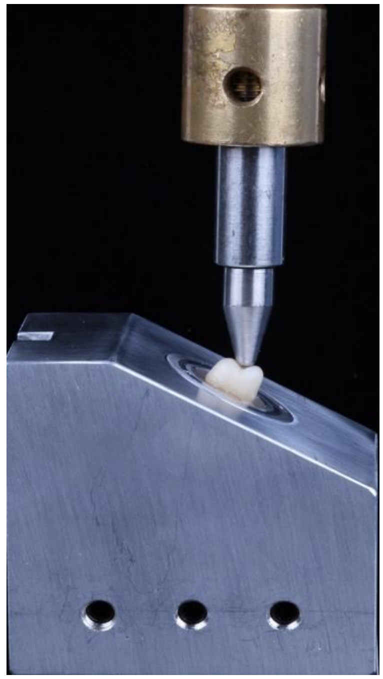

Figure 19. Loading crowns at 30° off axis to introduce complicated stresses (lateral view)

4.1.4 Flexural Strength Test

The three-point bend flexural strength bars (2 x 2 x 25 mm) of the 3D-printed materials were produced using the same fabrication process as described in the previous section. Flexural strength bars of the heat-cured resin composite were fabricated by sectioning the composite into 2 x 2 x 17 mm bars with a circular sectioning saw (IsoMet Slow Speed Saw, Buehler, Lake Bluff, IL, USA). The length of the bars was limited by the maximum length of the blocks. Specimens were polished on all sides with 600 grits SiC paper and stored in water for 24 hours at 37 °C.

The height and width of the specimens were measured with digital calipers and placed on a testing fixture which contained 2 mm. diameter rod supports with 20 mm. (3D-printed resins) or 12mm (heat-cured resin composite) span length. The specimens were loaded in their center at 1mm/min with a 2 mm. diameter steel indenter until fracture (Figure 20).

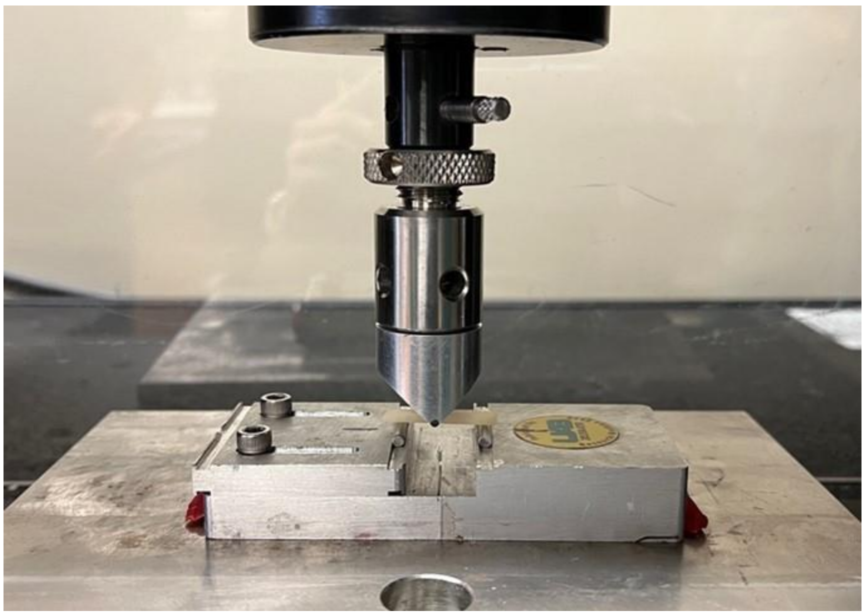

Figure 20. The Three-Point Bending Flexural Strength Test

4.1.5 Comparison of a Natural Tooth to a Resin-Based Die Material

Afterward, Following IRB approval, human-extracted premolars with comparable sizes were selected and mounted in acrylic. The teeth (n=10) were prepared with 4 mm, 10° taper, and modified chamfer finish line using a coarse diamond tapered rotary cutting bur. An electric handpiece mounted to a surveyor was used to ensure a standard taper (Figure 21, Figure 22 and Figure 23).

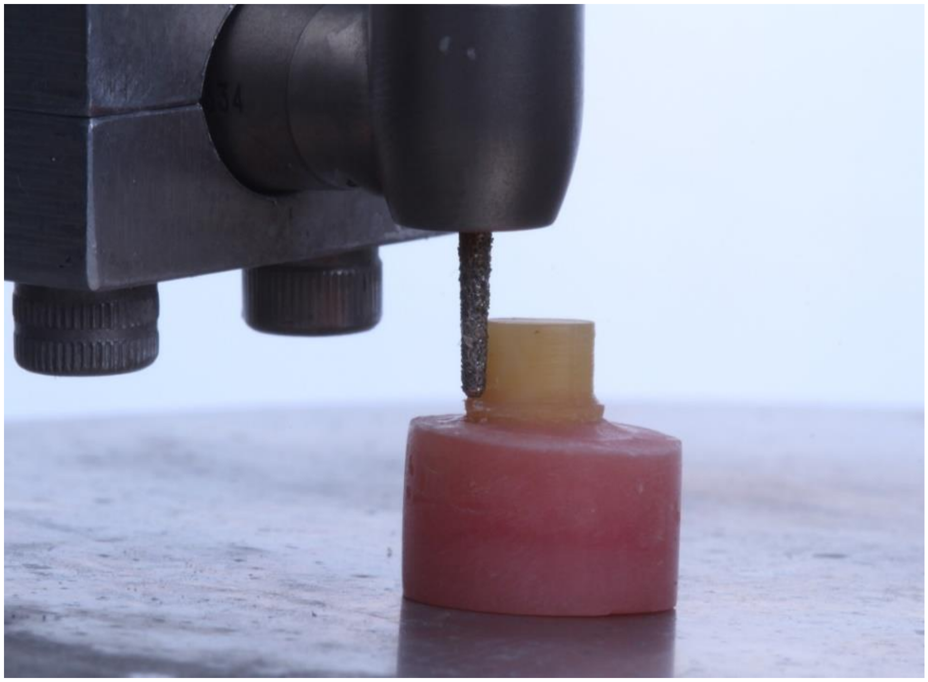

Figure 21. Standardized axial wall preparation

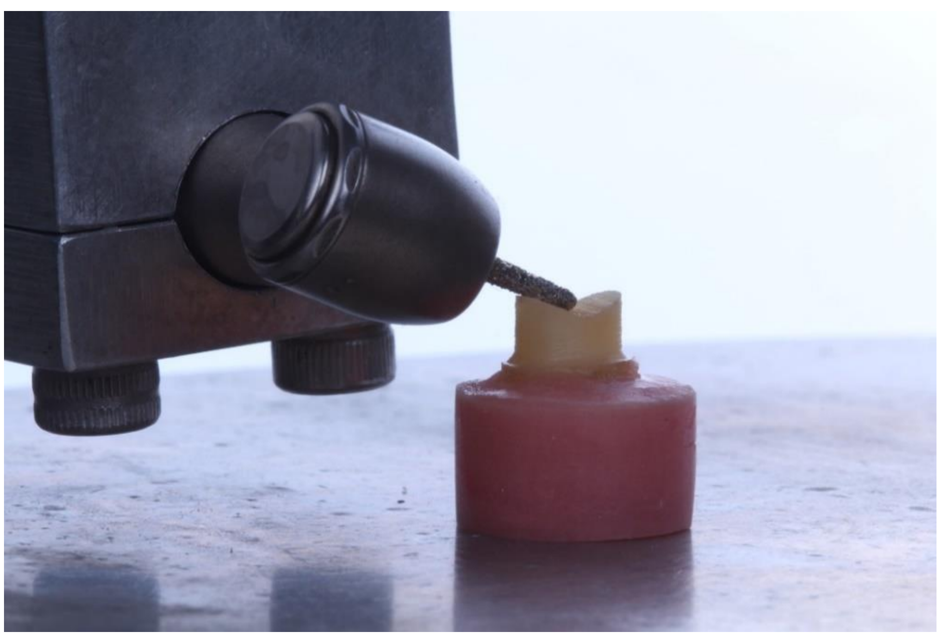

Figure 22. Standardized occlusal reduction

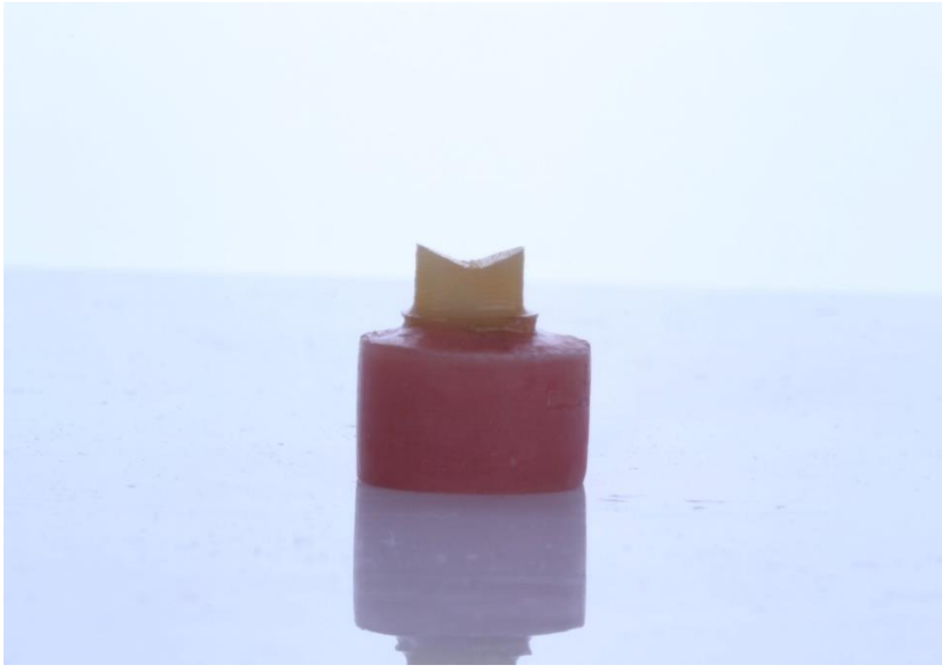

Figure 23. Natural tooth after standardized axial and occlusal reduction.

The prepared teeth were scanned in a benchtop scanner (3Shape E3) to produce an STL. file for each toot preparation. The. stl was used to 3D-print dies from a resin composite material (NextDent C&B) using the same fabrication process as described in the previous section.

Crowns were designed to fit on each preparation using a uniform 0.8 mm. thickness and 0.02 mm. cement space. The crowns were milled from 3 mol% yttria-stabilized zirconia and sintered using the same fabrication process as described in the previous section. Afterword, crowns were bonded and fractured in the same process as described previously.

4.1.6 Mode of Fracture Analysis

The examination of fractured samples was carried out visually to determine the type of fracture that occurred, whether it was Type 1 (caused by the ceramic breaking only), Type 2 (involving both the coping and resin die), or Type 3 (Fracture of the die without fracture of the crown). Examples of typical samples can be seen in Figure 24, Figure 25 and Figure 26.

Figure 24. Type 1 fracture (fracture of the crown only)

Figure 25. Type 2 fracture (fracture of the crown and die)

Figure 26. Type 3 fracture (fracture of the die without fracture of the crown)

4.2 Effect of Different Crown Thicknesses on The Fracture Load Of 3Y-TZP Monolithic Zirconia and Lithium Disilicate Crowns Using Two Different Types of Dental Cements

4.2.1 Specimen Preparation

The Same STL. file that has been used to design and create the 3D printed dies in the first part of the project was used again to 3D print 120 dies from a resin composite material (NextDent C&B, NextDent BV, Soesterberg, Netherlands) which were washed, cleaned and the post cured according to the manufacturer's instructions (Figure 27).

Figure 27. NextDent C&B resin die.

The standard STL that had been used previously was used again to design crowns of three different mean axial thicknesses of 0.6, 0.8, and 1 mm. of 3Y-TZP Monolithic Zirconia (Cercon HT, Dentsply Sirona) using the inLab MC X5 milling Machine (Dentsply Sirona). Furthermore, 1, 1.2, and 1.5 mm. of Lithium Disilicate Crowns were milled from HT IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) using the 3Shape design software.

The experimental design consisted of six groups with varying material thickness. Each group was then further divided into 2 sub-groups according to the cement used (Figure 28). Subgroups (A) were bonded using adhesive monomer cement (Panavia SA Cement Universal, Kuraray America, New York, NY) with built in MDP primer. On the other hand, subgroups (B). crowns were luted using self-curing resin modified glass ion-omer luting cement (Rely X Luting Plus Cement, 3M-ESPE, Minneapolis, MN) Table 1. All cements were used in accordance with manufacturer’s instructions.

Figure 28. Different Cements used in this part of the study

Table 1 Part 2 Study Design

	3Y-TZP (0.6 mm)	***3Y-TZP (0.8 mm)***	***3Y-TZP (1 mm)***	***Li DS (1 mm)***	***Li DS (1.2 mm)***	***Li DS (1.5 mm)***
(A) Panavia SA & surface treatment	*n=10* Group 1	*n=10* Group 3	*n=10* Group 5	*n=10* Group 7	*n=10* Group 9	*n=10* Group 11
(B) Rely X Luting Plus & surface treatment	*n=10* Group 2	*n=10* Group 4	*n=10* Group 6	*n=10* Group 8	*n=10* Group 10	*n=10* Group 12

For all the 3Y-TZP crowns, the intaglio surface was air-abraded with 50 µm particles of Al2O3 at 0.2 MPa for 15 s at a distance of 10 mm on one surface at 45-degree incidence using a sandblaster (Basic Eco, Renfert).

The process of bonding lithium disilicate copings is different from the method used for adhesively cemented Zirconia crowns. The internal surfaces of the copings were treated differently, by being etched with 5% hydrofluoric acid (C Max 5 Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds. Following this, the etched ceramic surface was rinsed thoroughly with water for 60 seconds. Finally, a silane coupling agent (Calibra Silane, Dentsply Sirona) was applied to the intaglio surface of each crown and allowed to air dry for 60 seconds (Figure 29 and Figure 30).

Figure 29. Hydrofluoric acid used to etch e.max crowns

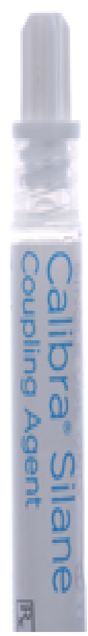

Figure 30. Calibra silane, Dentsply Sirona

4.2.2 Cementation

3Y-TZP Zirconia and Lithium Disilicate crowns that were cemented using Rely-X Luting Plus Cement according to manufacturer's instructions as following:

- Clean resin tooth dies with fine oil-free pumice and water.
- Rinse and lightly dry. Leave tooth surface moist.
- Squeeze out and discard a peppercorn-sized amount of cement prior to attaching the mixing tip.
- Apply thin, even layer of cement to all internal aspects of coping.
- Seat coping, apply a standardized load of 10 N for 5 min duration of the cement-setting reaction by with a universal loading machine as shown previously in the first part.
- Excess cement can be removed.
- Store specimens in 24° C H_2O for 24 hours prior to testing.

4.2.3 Crown Fracture Test

The Crown fracture test was conducted following the same parameters and methodology mentioned in the first part of the study.

4.2.4 Mode of Fracture Analysis

Fractured specimens were evaluated for fracture mode by visual examination to determine the failure type as mentioned before.

5. RESULTS

5.1 Effect of Using Different Die Materials on The Fracture Strength of 3Y-TZP Monolithic Zirconia Crowns.

5.1.1 Fracture Load of Monolithic 3Y-TZP Zirconia Crowns Using Standardized Dies Fabricated From Different Resin-Based Materials.

The average fracture load of 3Y-TZP monolithic zirconia crowns using standardized dies fabricated from different resin-based materials (and standard deviation) is presented in Table 2 and Figure 31.

Table 2 Fracture load of 3Y-TZP crowns using different resin-based die materials

Die Materials	Fracture Load (N)
Lava Ultimate	1137.5±88.7a
OnX	1112.7 ±109.8a
NextDent C&B	1084.5 ±134.2a

*The same lowercase letter in the same vertical column indicates no significant difference ($p>0.05$).

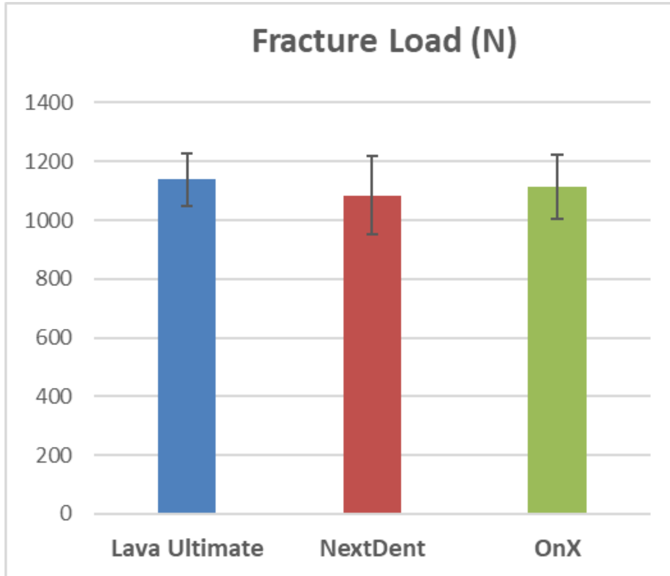

Figure 31. Fracture load of 3Y-TZP crowns using different resin-based die materials

5.1.2 Statistical Analysis of Fracture Load of Monolithic 3Y-TZP Crowns Data Using Different Resin-Based Die Materials

A 1-way ANOVA was performed and the difference between the groups was found to be not statistically significant (p>0.05) (Figure 32).

ANOVA

Load

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14055.408	2	7027.704	.556	.580
Within Groups	341250.820	27	12638.919		
Total	355306.228	29			

Figure 32. One-way ANOVA table for fracture load of 3Y-TZP crowns data using different resin-based die materials

5.1.3 Flexural Strength and Modulus of Elasticity of Different Resin-Based Die Materials

The average flexural strength of different resin-based die materials (and standard deviation) is presented in Table 3 and Figure 33.

Table 3 The average flexural strength of different resin-based die materials

Die Materials	Flexural Strength (MPa)
Lava Ultimate	134.425 ± 15.210a
OnX	115.960 ± 14.654b
NextDent C&B	90.241 ± 8.84c

*The same lowercase letter in the same vertical column indicates no significant difference (p>0.05).

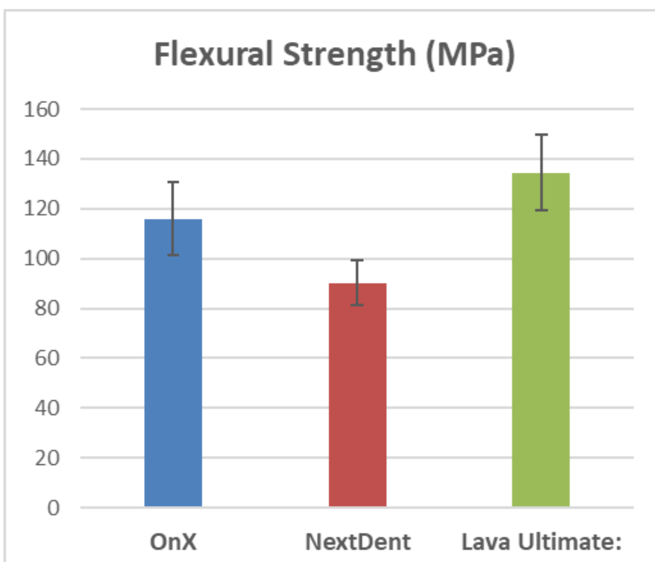

Figure 33. The average flexural strength of different resin-based die materials

The average modulus of elasticity of different resin-based die materials (and standard deviation) is presented in Table 4 and Figure 34.

Table 4 The average modulus of elasticity of different resin-based die materials

Die Materials	Modulus of Elasticity (MPa)
Lava Ultimate	7905.094 ± 1152.531a
OnX	5063.027± 591.388b
NextDent C&B	1950.989± 129.19c

*The different lowercase letters in the same vertical column indicate a significant difference (p<0.001).

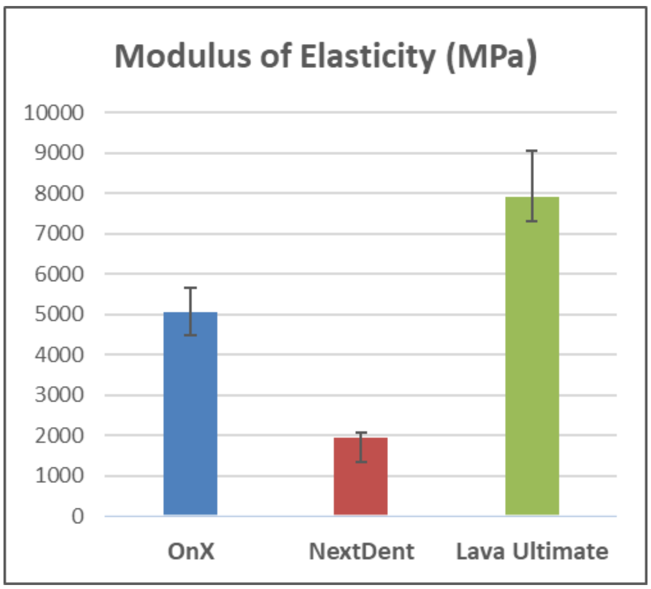

Figure 34. The average modulus of elasticity of different resin-based die materials

5.1.4 Statistical Analysis of Flexural Strength and Modulus of Elasticity of Different Resin-Based Die Materials

Regarding Flexural Strength, a 1-way ANOVA was performed, and groups were determined to be significantly different (p<0.001) (Figure 35). Tukey post-hoc analysis separated groups into 3 significantly different groups (Figure 36).

ANOVA

Strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11719.574	2	5859.787	31.204	<.001
Within Groups	6948.188	37	187.789		
Total	18667.763	39			

Figure 35. One-way ANOVA table for flexural strength results.

Strength

Tukey HSD[a,b]

Material	N	Subset for alpha = 0.05		
		1	2	3
NextDent	10	90.2408		
OnX	15		115.9602	
Lava Ultimate	15			134.4254
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.857.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Figure 36. Tukey's post-hoc analysis for flexural strength results

For the Modulus of Elasticity, a 1-way ANOVA was performed, and groups were determined to be significantly different ($p<0.001$) (Figure 37). Tukey post-hoc analysis separated groups into 3 significantly different groups (Figure 38).

ANOVA

Modulus

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	214695597.6	2	107347798.8	167.992	<.001
Within Groups	23643156.89	37	639004.240		
Total	238338754.5	39			

Figure 37. One-way ANOVA table for modulus of elasticity results.

Modulus

Tukey HSD[a,b]

		Subset for alpha = 0.05		
Material	N	1	2	3
NextDent	10	1950.9888		
OnX	15		5063.0266	
Lava Ultimate	15			7905.0935
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.857.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Figure 38. Tukey's post-hoc analysis for modulus of elasticity results

5.1.5 Fracture Load Evaluation of Monolithic 3Y-TZP Zirconia Bonded to Natural Teeth Dies Versus Resin-Based Dies.

The average fracture load of monolithic 3Y-TZP zirconia crowns bonded to natural teeth dies versus resin-based dies. (and standard deviation) is presented in Table 5 and Figure 39.

Table 5 Fracture load of 3Y-TZP crowns using Natural Teeth and Resin-Based Die Materials

Die Material	Fracture Load (N)
Natural Teeth Dies	1313.792 ± 240.311a
NextDent C&B Dies	1156.292 ± 163.611a

*The same lowercase letter in the same vertical column indicates no significant difference (p>0.05).

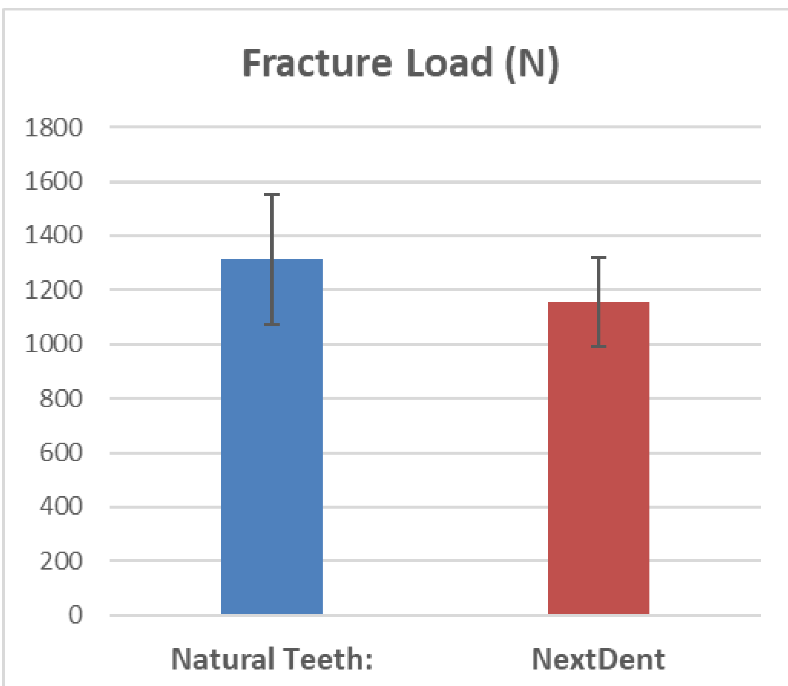

Figure 39. Fracture load of 3Y-TZP crowns using natural teeth and resin-based die materials

5.1.6 Statistical Analysis of The Fracture Load of Monolithic 3Y-TZP Zirconia Bonded to Natural Teeth Dies Versus Resin-Based Dies.

A T-test was performed and the difference between the groups was found to be not statistically significant ($p>0.05$) (Figure 40)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Load	Equal variances assumed	.257	.618	1.713	18	.052	.104	157.49899	91.93372	-35.64659	350.64457
	Equal variances not assumed			1.713	15.868	.053	.106	157.49899	91.93372	-37.52376	352.52175

Figure 40. T-test for evaluation of fracture load of 3Y-TZP zirconia bonded to natural teeth versus resin-based dies

5.1.7 Mode of Fracture Analysis

Most of the specimens in this part of the study showed Type 2 Fracture which includes both the ceramic crown and the die, mainly in the direction of the buccal cusp which may be related to the tilting of the custom fixture and the angle through which the load is applied. (Figure 41 and Figure 42)

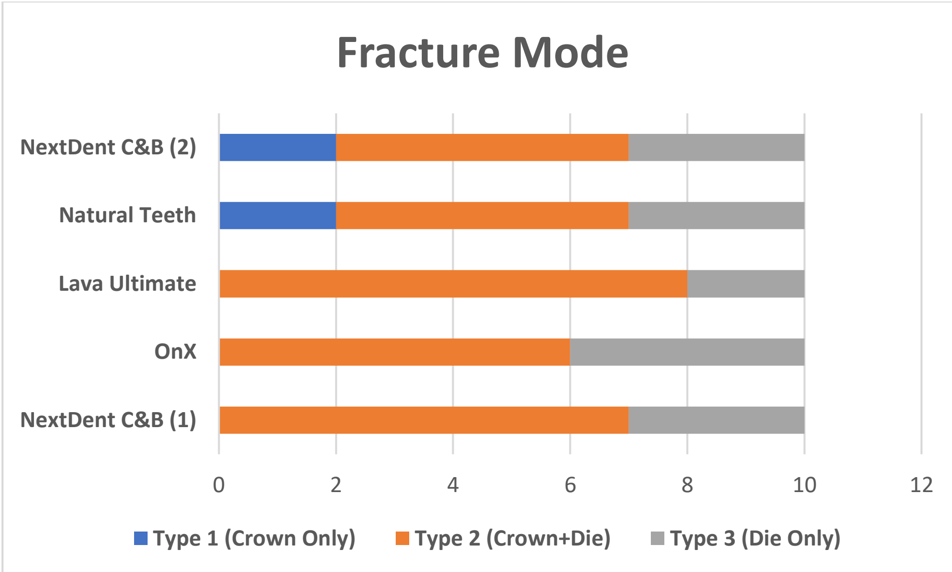

Figure 41. The fracture mode of crowns and dies in the first part of the study

Figure 42. The direction of the fracture is through the crown and die.

5.2 Effect of Different Crown Thicknesses on The Fracture Load Of 3Y-TZP Monolithic Zirconia and Lithium Disilicate Crowns Using Two Different Types of Dental Cements.

5.2.1 Fracture Load of 3Y-TZP Monolithic Zirconia Crowns with Different Thicknesses Using Two Different Types of Dental Cements.

The average fracture load of 3Y-TZP monolithic zirconia crowns with different thicknesses using two different types of dental cement is presented in Table 6 and Figure 43.

Table 6 Fracture Load of 3Y-TZP Monolithic Zirconia Crowns with Different Thicknesses Using Two Different Types of Dental Cements.

	Fracture Load when Using Panavia SA Universal Cement (N)	Fracture Load when Using RelyX Luting Plus Cement (N)
3Y-TZP Crowns with 0.6 mm.	793.130 ± 64.469a	639.002 ± 111.770d
3Y-TZP Crowns with 0.8 mm.	1147.065± 97.155b	989.865 ± 116.224e
3Y-TZP Crowns with 1 mm.	1535.462 ± 101.461c	1378.100 ± 143.224f

*The different lowercase letters in the table indicate significant statistical differences ($p < 0.001$).

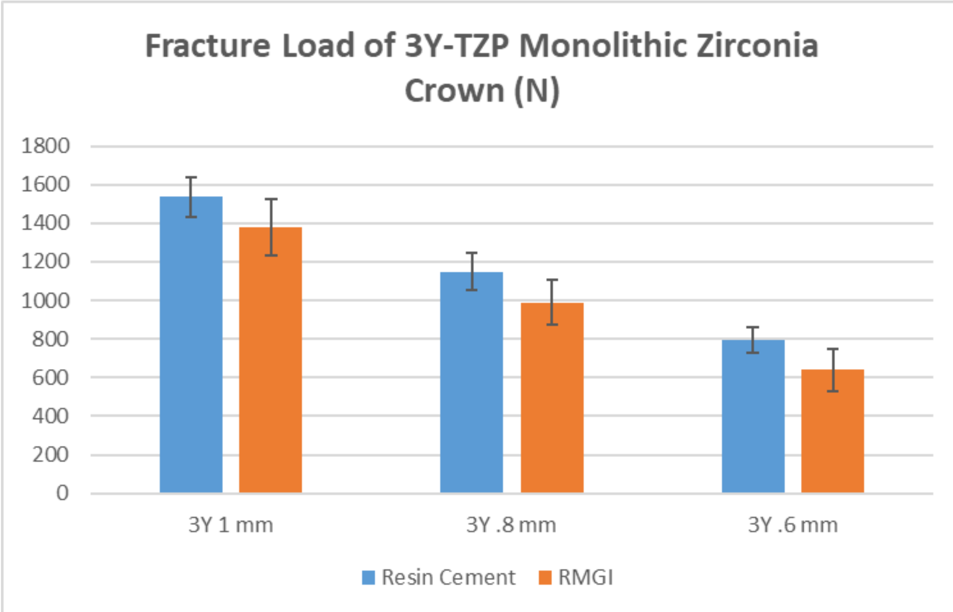

Figure 43. Fracture load of 3Y-TZP zirconia crowns with different thicknesses using two different types of dental cement

5.2.2 Statistical Analysis of Fracture Load of 3Y-TZP Monolithic Zirconia Crowns with Different Thicknesses Using Two Different Types of Dental Cements.

A One-way ANOVA was performed, and groups were determined to be significantly different ($p<0.001$) (Figure 44). Tukey post-hoc analysis separated groups into 6 significantly different groups (Figure 45).

ANOVA

Cement

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5857040.030	5	1171408.006	99.831	<.001
Within Groups	633630.266	54	11733.894		
Total	6490670.296	59			

Figure 44. One-way ANOVA to evaluate the fracture loads of different groups

Fracture Load

Tukey HSD[a]

Material	N	Subset for alpha = 0.05					
		1	2	3	4	5	6
3Y .6 mm + RMGI Cement	10	639.0019					
3Y .6 mm + Resin Cement	10		793.1296				
3Y .8 mm. + RMGI Cement	10			989.8648			
3Y .8 mm. + Resin Cement	10				1147.0653		
3Y 1 mm. + RMGI Cement	10					1378.0999	
3Y 1 mm. + Resin Cement	10						1535.4619
Sig.		1.000	1.000	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Figure 45. Tukey post-hoc analysis separated groups into 6 significantly different groups

5.2.3 Fracture Analysis of 3Y-TZP Monolithic Zirconia Crowns with Different Thicknesses Using Two Different Types of Dental Cements. (Figure 46)

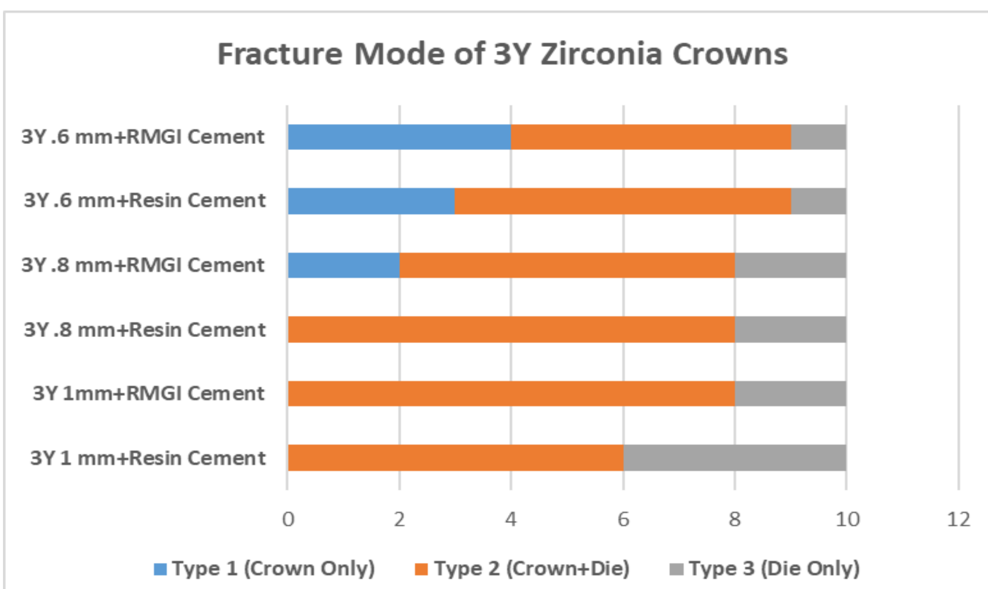

Figure 46. Fracture mode analysis of 3Y zirconia crowns

5.2.4 Fracture Load of Lithium Disilicate Crowns with Different Thicknesses Using Two Different Types of Dental Cements.

The average fracture load of lithium disilicate crowns with different thicknesses using two different types of dental cement is presented in Table 7 and Figure 47

Table 7 Fracture Load of Emax Crowns with Different Thicknesses Using Two Different Types of Dental Cements

	Fracture Load when Using Panavia SA Universal Cement (N)	Fracture Load when Using RelyX Luting Plus Cement (N)
Emax Crowns with 1.5 mm.	794.389 ± 104.856c	687.800 ± 62.913b, c
Emax Crowns with 1.2 mm.	777.355 ± 111.980c	584.407 ± 77.430b
Emax Crowns with 1 mm.	575.258 ± 69.962a, b	464.546 ± 77.765a

*Only different lowercase letters in the table indicate significant statistical differences ($p<0.001$).

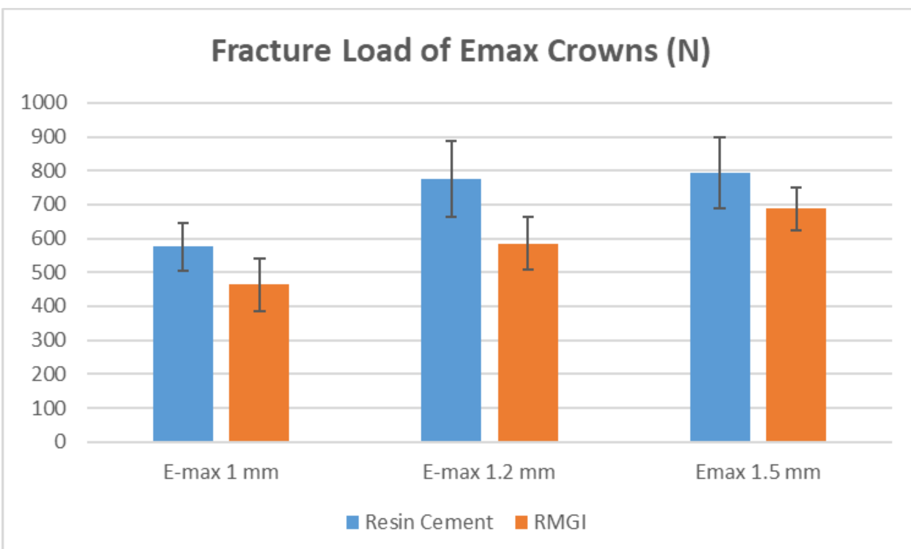

Figure 47. Fracture load of E.max crowns with different thicknesses using two different types of dental cement

5.2.5 Statistical Analysis of Fracture Load of Lithium Disilicate Crowns with Different Thicknesses Using Two Different Types of Dental Cements.

A One-way ANOVA was performed, and groups were determined to be significantly different ($p<0.001$) (Figure 48). Tukey post-hoc analysis separated groups into 3 significantly different groups (Figure 49).

ANOVA

Cement

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	827344.082	5	165468.816	22.346	<.001
Within Groups	399867.075	54	7404.946		
Total	1227211.157	59			

Figure 48. One-way ANOVA to evaluate the fracture loads of different groups

Fracture Load

Tukey HSD[a]

		Subset for alpha = 0.05		
Thickness	N	1	2	3
Emax 1 mm + Rely X Luting Plus	10	464.5455		
Emax 1 mm + Panavia SA Universal	10	575.2583	575.2583	
Emax 1.2 mm + Rely X Luting Plus	10		584.4067	
Emax 1.5 mm + Rely X Luting Plus	10		687.8001	687.8001
Emax 1.2 mm + Panavia SA Universal	10			777.3547
Emax 1.5 mm + Panavia SA Univesal	10			794.3889
Sig.		.061	.054	.078

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Figure 49. Tukey post-hoc analysis separated groups into 3 significantly different groups.

5.2.6 Fracture Analysis of Monolithic E.max Crowns with Different Thicknesses Using Two Different Types of Dental Cements. (Figure 50)

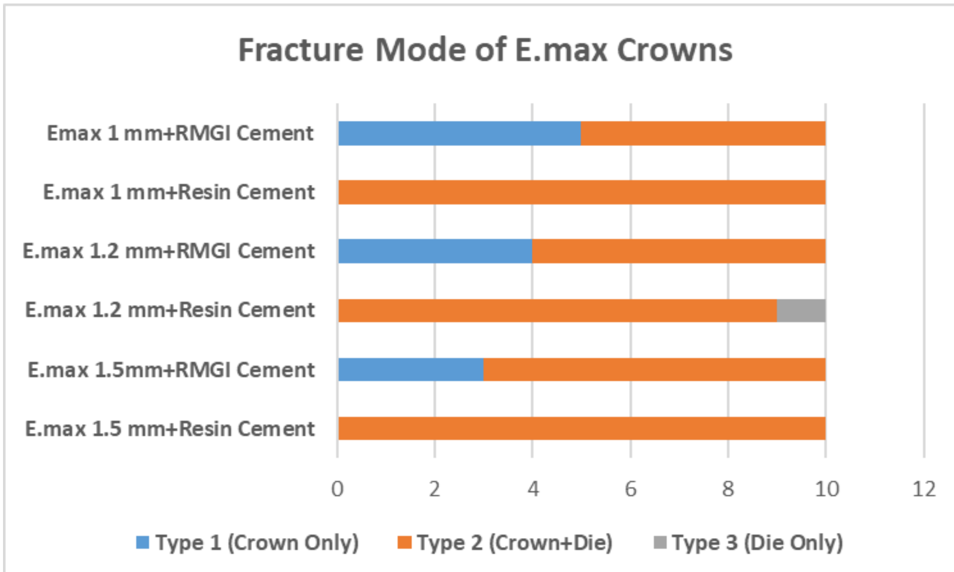

Figure 50. Fracture mode analysis of E.max crowns

6. DISCUSSION

Regarding the first part of this study which evaluates the fracture load of 3Y-TZP monolithic zirconia crowns using standardized dies fabricated from different resin-based materials, The assumption that zirconia crowns bonded to stiffer resin-based die materials would achieve higher fracture loads was not proved to be true. The elastic modulus of the stiffer resins was 2.5-4 x more than the least stiff resin. Despite this difference, there was no statistical difference in the fracture load of the zirconia crowns on any of the resin dies.

The results of the study are similar to a previous study. A study by Machry et al. (38) bonded 0.7mm and 1.0mm 3 mol% yttria-stabilized zirconia discs to 2mm discs of epoxy resin (modulus = 14.9 GPa) and composite resin (11 GPa). The discs were cyclically step-loaded against a stainless-steel spherical piston. The zirconia specimens bonded to the different substrate discs demonstrated similar fatigue fracture load (maximum fatigue load to cause fracture). In the study, flat specimens of zirconia were loaded perpendicular to their surface by a round ball. In this configuration, the mismatch in elastic modulus between the zirconia and substructure resins indicates that the substructure may undergo more strain than the zirconia under a given load (5). As a result, tensile forces accumulate in the undersurface of the zirconia opposite the loading ball. The loading configuration used in the current study employs a rounded sphere loading a single cusp at 30° off the axis of the tooth. Likely load was transferred to the occlusal groove as evidenced by the observation of the fracture surfaces of the crowns involving the occlusal groove. A previous finite element analysis of crowns indented by a sphere reported that loading on steeper cusps transfers stress to the occlusal groove whereas loading a flatter cusp concentrates stress below the indenter.

Furthermore, the hypothesis that zirconia crowns bonded to a resin-based die material would achieve a similar fracture load as those bonded to natural dentin was proven to be correct. The least stiff resin (elastic modulus = 1.9 GPa) was chosen to be compared to dentin (elastic modulus = 19.3 GPa) (39). The zirconia crowns fractured on the resin dies produced a statistically similar fracture load as those on natural dentin dies.

A previous study by Yucel et al.(14) produced conical dies of epoxy resin (elastic modulus = 11.8 GPa) and dentin (elastic modulus = 18.6). Uniform 0.6 mm thickness zirconia crowns were bonded to the dies. A vertical load was applied with a metal 2 mm. diameter indenter until failure. There was no statistically different fracture strength of the zirconia crowns on either the epoxy resin or dentin dies. A study by Jian et al.(15) examined zirconia crowns bonded to dentin, porous titanium (elastic modulus = 18.5 GPa), and resin composite (elastic modulus = 17.3). Crowns were loaded to failure by a 6 mm. diameter steel ball. Despite the similar elastic modulus of porous titanium and resin composite, the zirconia crowns fractured on porous titanium were significantly stronger. The crowns fractured at a similar load using porous titanium and dentin dies. The possible explanation is that the porous titanium and dentin dies was stronger and did not fracture during their use, whereas the resin composite dies fractured during testing.

The elastic modulus of zirconia has been reported to be around 200 GPa. The the difference in the elastic modulus between zirconia and the die materials is much greater than the difference between the different die materials. This relative difference may account for the similar fracture load of zirconia crowns on the different die materials. A previous study examined the fracture of a resin-based crown material (polymer-infiltrated ceramic network material, Enamic) on dies with different elastic moduli (40). The elastic modulus of the resin-based crown material (37 GPa) was closer to that of the die materials. In that study, crowns fractured at the highest load on dentin (elastic modulus = 18 GPa) followed by a dentin analog (G10, elastic modulus = 15 GPa) and then resin composite (elastic modulus = 10 GPa).

Aside from the research implication of the study, the clinical relevance of the study is that the modulus of different resin core materials under zirconia crowns may not affect their fracture load. Therefore, a core build-up performed from a low-modulus resin may be acceptable under a zirconia crown. Previous studies have shown that metal-based dies allow a higher fracture strength of zirconia crowns,(14) suggesting that crowns cemented on cast cores or titanium abutments would be expected to withstand a higher load before failure.

The methodology used in this study has several major limitations, and therefore this study serves only as a piece of the puzzle to better elucidate a test methodology for crown fracture testing. A blatant disadvantage of this test is that static loading was performed rather than cyclic loading. High static loads applied by blunt spherical indenters produce Hertzian cone cracks located at the contact surface just outside the contact area. When lower stresses are applied cyclically, a single crack may be initiated on the cement surface which is driven towards the contact surface until a fracture occurs. The latter form of fracture is more representative of clinical failures. An additional disadvantage of this test is that all testing was performed dry (14). Water present at crack tips may potentiate fracture. This moisture may be present from saliva on the external surface of the crown or from pulpal fluid on the cement surface of the crown. Therefore, modeling of crown fracture testing should be performed in a water chamber and possibly include a wet, porous die material.

Future testing should examine the use of different dies when tested under wet cyclical loading. Additionally, other ceramic and resin crown materials should be tested as the results of this study will not translate to other crown materials.

For the second part of the study, the use of a monolithic material without the need for layering porcelain while preserving tooth structure is highly clinically desirable. Therefore, the primary aim of this study was to investigate the fracture strength of monolithic 3Y-TZP and Lithium disilicate crowns when using different material thicknesses and cement types.

Although there is no agreement on tooth preparation standards for such restorations, the thickness of the zirconia and Lithium disilicate material is a crucial factor in their resistance to fracture. In this study, the coping thickness was determined based on the manufacturer's advice, which suggested a minimum reduction of 0.7 mm. for 3Y-TZP zirconia and 1-1.5 mm. e.max full contour restorations.

Regarding 3Y-TZP monolithic zirconia crowns, this study results indicated that all of the crowns that were tested could bear failure loads that exceeded the normal physiological forces of chewing, which range from 50 to 250 N (41). This comes to an agreement with the fact that 3Y-TZP has the highest amount of tetragonal phase and the lowest amount of cubic phase which makes it more resistant to fracture and significantly increases its fracture resistance due to transformation toughening (42).

However, significant consideration should be given when planning to utilize 3Y-TZP crowns with a thickness below 1mm. because in this study none of our crowns underwent any type of mouth motion fatigue which would have probably affected the final results especially of 0.6 mm 3Y-TZP groups. That’s why from the literature we can conclude that 1 mm 3Y-TZP crown thickness seems to be the most ideal situation for the long-term success of these materials. Based on that, most of the manufacturers do not suggest using monolithic zirconia crowns with a thickness of less than 1 mm. in the posterior area where there are a lot of complicated stresses applied.

Some studies, on the other hand, propose that using 3Y-TZP crowns with a minimum thickness of 0.5 mm. to 1 mm. may be enough to withstand normal masticatory forces especially if these restorations were bonded using resin-based dental cement (43, 44).

Concerning the influence of the type of cement on the fracture load of 3Y-TZP crowns, this study shows that using resin-based cement significantly increases the fracture load of the 3Y-TZP when compared to the application of a resin-modified glass ionomer cement (RMGI) for the final cementation procedure. However, many clinicians opt to lute zirconia crowns using resin-modified glass ionomer cement (RMGI), and a considerable amount of research indicates that the durability of 3Y-TPZ remains acceptable even when luting with RMGI cement up to a thickness of 0.5 mm (27, 28).

On one hand, Due to the ability of the resin cement to generate a strong bond between the die material and the crown, this results in preventing cracks from the growth within the zirconia crowns. Finally makes these crowns show improved fracture performance when compared to RMGI cement. Furthermore, resin cements have better mechanical properties and a higher modulus than RMGI cements, allowing for a better foundation for these restorations. Accordingly, resin-based cements are preferred in cases when there is any compromised or questionable tooth preparation or when we choose to use minimal thicknesses of the 3Y-TZP crowns.

On the other hand, we found that using RMGI cement with 3Y-TZP crowns of thickness 0.8 mm or higher, resulted in a high fracture load of these crowns which is clinically acceptable in normal conditions. These findings may allow us to consider using RMGI cement with 3Y-TZP crowns after sandblasting the intaglio surface of the crowns especially if there is enough tooth structure after preparation and ideal retention and resistance forms. Using resin-modified glass ionomer cements with zirconia restorations has several benefits, such as reduced technique sensitivity, ease of excess cement removal, ability to tolerate moisture, and time efficiency.

Regarding the e.max crown fracture test, lithium disilicate restoration thickness requirements are always recommended based on the material's mechanical properties and traditional laboratory testing to optimize the restoration strength. However, the restoration fracture is a multifactorial issue influenced by a combination of variables including tooth preparation and restoration geometry, restoration mechanical properties, cementation material, and progressive damage caused by occlusal function.

In our study, we only investigated the combined influence of the material thickness and the type of cement used on the fracture load of monolithic lithium disilicate material. Generally, using resin-based cement in combination with 1.2-1.5 mm. seems to improve the fracture load of e.max crowns.

When using 1 mm. thickness of e.max crowns, there was no statistical difference between groups in which we used either RMGI or resin-based cements. However, on the other hand, bonding 1.2 mm. and 1.5 mm. of e.max crowns with resin-based cement achieved a statistically significant difference over the 1 mm. thickness groups.

According to the findings of this study, using e.max crowns with at least 1.2 mm. thickness coupled with the use of resin-based cement seems to be an ideal requirement for the long-term success of these indirect restorations. And when we compare these results with the study of the 3Y-TZP crown fracture test, we can assume that using 1.2 -1.5 mm of e.max crowns would have the same fracture resistance as using 0.6 mm. of 3Y-TZP when both bonded with a resin-based cement and this is consistent with the findings of the study by Baladhandayutham B et al (45).

Despite that, we should deal carefully with the results of the crown fracture tests as it is not a standardized test with a lot of variations between the studies. Some studies reported similar values for e.max crown fracture loads (46). Other studies reported higher values of fracture loads for the same materials (22, 47). Consequently, it is fundamental to give appropriate attention to the methodology used for the crown fracture test.

For instance, bonding of e.max crowns to resin-based printed dies appears to be less reliable than bonding to natural dentin which needs more extensive testing in the future.

Furthermore, the lack of thermocycling and fatigue loading of the e.max crowns may have a direct effect on the fracture resistance values. Additionally, tilting the crowns by 30° from their long axis and the application of load mainly on the buccal cusps as mentioned before in the materials and methods section until fracture happened may be the reason why the final fracture load values of e.max crowns are lower than what was mentioned before in other different studies (41, 45, 48).

7. CONCLUSION

7.1 Hypotheses

1. Die materials with a lower modulus would result in a lower fracture load of monolithic 3Y-TZP zirconia - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary. - ***REJECT***

2. The fracture load of monolithic 3Y-TZP zirconia bonded to natural teeth dies would exceed the fracture load of 3Y-TZP monolithic zirconia bonded to resin-based dies - This will be determined by T-test for equality of means - ***REJECT.***

3. Increasing the thickness of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations will improve their fracture load - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary - ***ACCEPT.***

4. Bonding of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations with a resin cement would achieve higher fracture load than cementing them with Resin Modified Glass Ionomer (RMGI) - This will be determined by completing a 1-way ANOVA and Tukey post-hoc analysis if necessary - ***ACCEPT.***

7.2 Limitations of the Study

1. The use of aging and fatigue cycling may have been employed to improve the clinical prediction of crown performance.
2. All testing was performed dry. Water present at crack tips may potentiate fracture. This moisture may be present from saliva on the external surface of the crown.
3. A blatant disadvantage of this test is that static loading was performed rather than cyclic loading.
4. These results are specific to the materials tested in this study, and differences in the composition of other brands of the material may have significant effects on the conclusions of this study.

7.3 Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. There was no difference in the static fracture load of zirconia crowns bonded to 3D-printed or milled resin dies with modulus ranging from 1.9-7.9 GPa.
2. There was no difference in the static fracture load of zirconia crowns bonded to a 3D printed resin die (elastic modulus = 1.9 GPa) or to natural dentin.
3. Increasing the thickness of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations will improve their fracture load.

4. Bonding of the CAD/CAM monolithic 3Y-TZP zirconia and lithium disilicate indirect restorations with a resin cement would achieve higher fracture load than cementing them with Resin Modified Glass Ionomer (RMGI).

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APPENDIX

INSTIUTIONAL REVIEW BOARD APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

NHSR DETERMINATION

TO: Lawson, Nathaniel

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)
IORG Registration # IRB00012550 (IRB 03)

DATE: 17-Nov-2022 (Revised 12/19/22 to include student's name)

RE: IRB-300010037
Evaluation of die materials

The Office of the IRB has reviewed your Application for Not Human Subjects Research Designation for the above referenced project.

The reviewer has determined this project is not subject to FDA regulations and is not Human Subjects Research. Note that any changes to the project should be resubmitted to the Office of the IRB for determination.

if you have questions or concerns, please contact the Office of the IRB at 205-934-3789.

Additional Comments:

Lab testing of dental materials.

Student's Name: Akram Sayed Ahmed

Student's Project Title: Evaluation of die materials