EFFECTS OF VARIOUS THICKNESSES ON LOAD TO FRACTURE OF POSTERIOR CAD/CAM LITHIUM DISILICATE GLASS CERAMIC CROWNS SUBJECTED TO CYCLIC FATIGUE

by

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DEDICATION

This thesis is dedicated to my beloved family, my husband, Dr. Yasir Alsenaidi, my children, Ibrahim and Sultan, and my parents, Dr. Sultan Alangari and Khairiah Alqahtani.

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INTRODUCTION

Patients’ awareness of new esthetic treatment modalities, such as all-ceramic restorations, challenges the dentist to use new technologies to meet patient desires. Single visit treatment for CAD/CAM all ceramic crowns versus multiple appointments for pressed ceramics, in terms of impression making, wax up and laboratory work, is one of the preferences of patients in the dental clinic. Their goal is to achieve dental restorative treatment in a short time. Throughout the years, introduction of new materials and techniques has occurred rapidly, and research to test those materials has increased in an attempt to shift towards evidence- based dentistry (Kelly et al, 1989).[1]

High leucite-containing ceramic and optimal pressable glasses were introduced in the late 1980’s as the first pressable ceramic materials (Table I). A glass ceramic based on a SiO_2–Li_2O system was developed in 2004 (Empress II, Ivoclar-Vivadent®). Crystalline filler particles were added to increase the strength, thermal expansion and contraction behavior of ceramics. Other types of filler additions include particles of high-melting glasses that are stable at the firing temperature of the ceramic. The crystalline phase that forms is a lithium disilicate ($Li_2Si_2O_5$) and makes up about 70% of the volume of the glass ceramic. Lithium disilicate has an unusual microstructure that consists of randomly oriented small interlocking plate-like crystals. This may improve the material strength since the needle-like crystals may deflect, branch or blunt the cracks. Arrested crack propagation through the material provides a substantial increase in the flexural strength. Despite the increase in strength of the leucite-reinforced pressed material, fracture is still possible when used in the posterior region.[2]

Lithium disilicate re-emerged in 2006 as a partially crystallized milling block. The flexural strength of the material was found to be more than 170 percent than any currently used leucite-reinforced ceramics. The use of CAD/CAM milling for different restorative treatments such as zirconium dioxide or metal frameworks for full-contoured crowns (lithium disilicate at chairside or in the laboratory) or implant abutments opened the market for digitized restorative dentistry.

The surface damage produced by the CAD/CAM milling procedure significantly reduced the strength of zirconia which could be further weakened by different surface treatment methods resulting in unexpected failures at stresses much lower than the ideal strength of the material.[3]

A seven year survival rate of 94.6 percent has been reported for CAD/CAM-generated esthetic ceramic molar crowns adhesively cemented to natural tooth preparations. Data on fatigue strength of CAD/CAM-generated esthetic posterior ceramics is lacking.[4] It appears that various stages of conventionally fabricated crowns (impression making, master cast fabrication, waxing, investing, casting, veneer addition, and finishing) may contribute to distortion of the prosthesis. Therefore, eliminating all those variables in a CAD/CAM system should minimize the variability and improve the final outcome of a prosthesis.[1]

As restorative materials, dental ceramics have disadvantages mostly due to their inability to withstand functional forces that are present in the oral cavity. Therefore, they have limited application in the molar areas.[4,5] Further development in these materials has enabled their use in posterior long-span fixed partial prosthetic restorations and structures over dental implants. Lack of literature necessitates more research in this field especially with the increasing use of such materials.[6]

Crown material and thickness have been identified as primary factors influencing the stress in the crown-cement-tooth system.[4] The need to investigate these parameters is essential for correct crown design and material selection. Reduced inter arch space determines the amount of occlusal reduction and consequently the occlusal thickness of the restoration. Due to the higher load in the posterior area, relatively higher thickness of the ceramic restoration is essential to the success and durability of such restorations.

Fatigue is described as a phenomenon in which the characteristics of materials change over time under cyclic conditions. Strength is an important mechanical property that determines the performance of a material when subjected to stress. The strength of a ceramic crown is influenced by several factors such as the shape of the prepared tooth, the material, the luting agent, and the loading conditions. The shape of the prepared tooth affects the stress distribution which is also influenced by the type of luting agent. Ceramics have little or no capacity to deform and thereby decrease the stress concentration at a crack tip. With repeated loading, these cracks fuse to a growing fissure that insidiously weakens the restoration. Processing defects at the microstructural level play a role in fracture failure and the fatigue failure of all-ceramic crowns. Increased resistance against fatigue failure could be achieved by reducing processing-related flaws or porosity in the structure.[5] It is also possible that repeated loading of porcelain crowns increases the risk of crown fracture. A recent study evaluated clinically failed all-ceramic crowns and observed that a majority of the crown failures were apparently initiated at the internal surface, indicating that this surface was placed under the greatest stress.[6,7] CAD/CAM crowns have been investigated in the literature, but recent studies on the fatigue strength of these restorations are lacking. Due to the increased demand on esthetic restorations and the ease of the single visit approach, investigating the strength of CAD/CAM restorations is necessary to understand the likelihood of clinical survival.

PURPOSE OF THE STUDY

The aim of this study was to investigate the effects of various lithium disilicate glass-ceramic thicknesses on load to fracture of CAD/CAM lithium disilicate glass-ceramic crowns subjected to cyclic fatigue.

HYPOTHESES

The null hypothesis of this study was that different thicknesses of CAD/CAM lithium disilicate glass-ceramic crowns subjected to cyclic fatigue will have no effect on load to fracture. The alternative hypothesis was that increasing thickness of CAD/CAM lithium disilicate glass-ceramic crowns subjected to cyclic fatigue results in significantly higher load to fracture.

REVIEW OF LITERATURE

HISTORY OF DENTAL CERAMICS

More than 10,000 years ago, during the Stone Age, craftsmen used stone tools to flake chips of quartz, limestone and lava. In 700 BC animal bone and ivory from elephants and hippopotamuses were used as frameworks to replace missing teeth. In 1774, a Parisian apothecary, Alexis Duchateau, with the assistance of a Parisian dentist, de Chemant, fabricated the first porcelain dentures replacing ivory dentures. Porcelain teeth were then introduced into the US by 1817.[8] In 1808 Fonzi made "terro-mettalic incorruptible," porcelain denture teeth with embedded platinum pins. Porcelain teeth continued to develop from 1822 to 1837.[9]

In 1903 Dr. Charles Land developed the first ceramic crowns in dentistry and patented the all-porcelain "jacket" crown (PJC). These crowns had excellent esthetics but lacked flexural strength which led to failures. In the late 1950s, the porcelain-fused-to-metal (PFM) crown was developed by Abraham Weinstein to reduce the risk of internal microcracking during the cooling phase of PJC fabrication. Since then, feldspathic porcelains were not used to construct all ceramic crowns without a metal coping. PFM crowns have fewer porcelain failures because the bond between the metal and porcelain prevents stress cracks from forming. The addition of a metal block-out opaque layer to mask the gray color of the metal diminished the esthetics of these restorations. Vita Zahnfabrik developed the first commercial porcelain in 1963. In 1965, McLean and Hughes improved the fracture resistance of feldspathic porcelain crowns by using a dental aluminous core ceramic. The glass matrix consisted of 40 wt% to 50 wt% Al_2O_2, which resulted in an inadequate translucency of the core material. The use of veneering porcelain was required to obtain acceptable esthetics.[9]

Particle filled glass ceramics were introduced to overcome the unacceptable esthetics of core ceramics. Fabrication techniques included the addition of lithium disilicate or fluorapatite. The dispersion of fillers in the glassy matrix strengthened the ceramic.[8]

The development of glass ceramics continued with the introduction of lithium disilicate in 2000. The addition of lithium oxide to the glass ceramic improved the mechanical properties and esthetics, which made it the material of choice for both anterior and posterior restorations. As a continuation, companies continued to improve lithium disilicate ceramics by introducing different fabrication techniques.[8]

The conventional method of pressing ceramic ingots was used by dentists for years after the introduction in 1998 of IPS Empress II by Ivoclar Vivadent. It required skillful laboratory technicians as well as a precise technique. The fundamental steps to produce a ceramic restoration include waxing, investing, burning out, pressing, finishing, and glazing. Errors could arise during any of the above-mentioned steps of the fabrication process. Time is consumed during the laboratory fabrication of such restorations and the clinician needs multiple steps in the clinic to provide the lab with the necessary information. For that reason, companies developed a digitized technique to produce lithium disilicate glass ceramic restorations. This technique utilized a computer to aid in the designing and manufacturing of the restoration. The term Computer Aided Design/Computer Assisted Manufacturing (CAD/CAM) was given to describe the technique.

CAD/CAM CERAMICS

The advancement of dental technology in the 20th century progressed remarkably. As a part of the advancements, new sophisticated dental processing machines were developed to fabricate different dental restorations with high levels of esthetics. The term CAD/CAM is a general term to describe the digital system used to design and process dental restorations. Different companies adopted this concept and named the machine according to their key feature of the processing unit. The development of digital systems to aid in the design and fabrication of dental restorations was largely researched in the 1980s by three different pioneers. Dr. Duret developed crowns with an optical impression of the abutment tooth. He designed a charge-coupled device (CCD) sensor to digitally capture a tooth preparation and machine the restoration with cutting tools. His design of the milling machine had an impact later on the development of CAD/CAM machines. He was the founder of the Sopha® system. Dr. Moermann used a chairside intra-oral camera to capture the shape and size of the abutment tooth. In 1985 he developed the Cerec® system (CEramic REConstruction). His technique allowed a same-day delivery of the restoration and spread the term CAD/CAM to the dental profession. In 1994 Dr. Anderson developed the Procera® system, which was the first to provide outsourced fabrication using a network connection.[2]

A variety of CAD/CAM systems have been introduced in the market. They all share the same processing technique to fabricate dental restorations. The abutment tooth preparation is digitized intraorally eliminating the need for a conventional impression. After that, the design is viewed on a computer monitor according to the system software. This process replaces the need for a laboratory wax up of the final restoration and enables the clinician to modify and change the design according to the clinical situation. Finally, the desired restoration is processed by a computer-assisted processing machine. This process is called milling and replaces the conventional method of investing, burnout, pressing, and ceramic build up and layering. The final restoration can be characterized prior to delivery by different stains to enhance the final esthetics of the restoration. The process requires around 90 minutes from the preparation of the abutment tooth to the delivery of the final restoration. This reduces labor, minimizes cost, provides more control of details, and offers the ability to save processing data that could be used later. Thus, if replacement of the restoration were needed, the patient would not have to be available to retake an impression.[2]

LITHIUM DISILICATE CERAMICS

Lithium disilicate ($Li_2Si_2O_5$) is a type of glass ceramic that contains lithium dioxide as the major crystalline structure. The microstructure contains small interlocking plate-like crystals that are randomly oriented and provide the strength of this type of ceramic. The crack propagation is deflected and arrested by the crystals. Lithium disilicate glass ceramic is fabricated in one of two ways: the pressable lithium disilicate (e.g. IPS emax Press, Ivoclar-Vivadent®) utilizes the lost wax technique and milled lithium disilicate (e.g. IPS emax CAD, Ivoclar-Vivadent®) utilizes a pre-crystallized milling block.[10]

The superior mechanical properties of lithium disilicate can justify its use for different dental restorations. The average biaxial flexural strength of the pressable ceramic (IPS Empress 2, Ivoclar-Vivadent®) was 407 MPa, whereas the leucite containing ceramic (IPS Empress, Ivoclar-Vivadent®) had lower average strength (175 MPa).[11]

EFFECT OF CYCLIC FATIGUE ON LOAD TO FRACTURE OF LITHIUM DISILICATE GLASS CERAMIC

The long-term survival of ceramic material is an important factor to consider when constructing different dental restorations. The strength of the ceramic depends on the internal microstructure, surface flaws, the fabrication technique, the luting agent, intraoral conditions and the thickness of the ceramic.[12]

Reports by Attia et al.[12] and Chen et al.[5] demonstrated that fracture load of CAD/CAM crowns decreased considerably after cyclic loading. The inability of ceramics to deform may lead to concentration of stresses at a crack tip. The initiation of the crack is due to a processing related porosity within the ceramic. These cracks fuse to a growing fissure that ultimately weaken the restoration and lead to a cumulative fatigue failure.[5,12] To decrease that weakness it is important to consider the ceramic thickness during fabrication.

EFFECT OF DIFFERENT THICKNESSES ON LOAD TO FRACTURE OF CAD/CAM CROWNS

There is no clear recommendation in the literature on the ideal amount of tooth reduction for all ceramic restorations. It has been documented that a 2-mm reduction of the functional cusp is required for porcelain-fused-to-metal (PFM) restorations.[9] The aggressive reduction of tooth structure has an adverse effect on the remaining tooth structure. Tooth sensitivity, exposed dentin, post-operative pulp reaction and inflammation are possible results of this reduction.[9] Dhima et al.[10] suggested that a crown thickness of 1.5 mm or greater is required for clinical applications of milled monolithic lithium disilicate crowns for posterior single teeth. No other published studies have explored the ability of various crown thicknesses milled from lithium disilicate glass ceramic full-coverage crowns to affect the load to fracture.

MATERIALS AND METHODS

MATERIAL SELECTION

The investigated material in this *in-vitro* study was lithium disilicate glass ceramic in blocks (IPS e.max CAD, Ivoclar Vivadent) Table II. The blocks were used to fabricate posterior single full contoured crowns milled in a CAD/CAM machine (E4D, D4D technologies, Texas). Ceramic crowns were cemented on woven-fiber-filled epoxy resin blocks (Type 8000 die epoxy resin kit, American Dental Supply Inc.) simulating the modulus of elasticity of spongy bone of the maxilla.[6] The test machine for both fatigue and load to fracture was an Instron ElectroPuls™ E3000 (Instron).

SAMPLE PREPARATION

The specimen design used for this study incorporated the tooth preparation for each ceramic crown as well as a water bath in one unit. The tooth preparation was made on a dentoform Ivorine molar tooth® (Columbia Dentoform Corporation, NY, USA). The preparation consisted of a 2-mm occlusal reduction, 1.4-mm axial reduction, and a shoulder finish line. The prepared dentoform molar, was then mounted on a 49 x 49 x 10 mm base plate wax block (Base Plate wax, Patterson Dental, MN, USA). A water bath (28 mm x 28 mm x13 mm) was built around the mounted tooth preparation by building up four surrounding walls using the same baseplate wax (Figure 1). The distance from each surrounding wall to the prepared tooth was approximately 6 mm. These dimensions were selected to ensure that each cemented crown was completely surrounded and able to be covered with water. When the sample design was completed, the model was duplicated in a silicone material (Dental Duplicating Silicone, MPK Enterprises, CA, USA) according to the manufacturer’s instructions (Figure 2). After the material was set, the wax block was removed, and the mold was carefully inspected to ensure the absence of any air bubbles or deficiencies.

FABRICATION OF THE RESIN DIE

The resin material used to fabricate the dental dies was an epoxy resin (Type 8000 die epoxy resin kit, American Dental Supply Inc.). The modulus of elasticity of the material was between 3 MPa to 6 MPa based on the manufacturer’s material description. The material’s modulus was validated prior to using it in this study. A rectangular cuboid block was made from the resin material with the dimensions of 1.5 mm x 1.5 mm x10 mm. The block was measured prior to testing and recorded to calculate the modulus of elasticity when subjected to fracture forces using an MTS universal testing machine (MTS Universal Testing Machine, MTS, MN, USA). The modulus of elasticity of this resin was 6 MPa. After testing the modulus of elasticity, the resin material was mixed according to the manufacturer’s instructions. The material provided was pre-measured in multiple syringes to help mix the resin accurately. A wooden spatula was included in the kit to be used to mix the resin material. After mixing the resin for 2 minutes, ensuring that the color of both materials blended homogenously, it was poured in the silicone molds. The setting time was 2 hours. After setting, the samples were removed and inspected for voids prior to finishing by removing any excess material.

DESIGNING THE CAD/CAM ALL-CERAMIC CROWNS IN THE MILLING MACHINE

After the tooth preparation was made on the dentoform, the ivorine tooth model was scanned in an E4D machine (E4D, D4D Technologies, Texas). The scanned model was displayed on the screen and dedicated software was used to fabricate the anatomical crowns (Figure 3). The tooth was designed as a lower mandibular first molar with normal anatomical features. A uniform thickness in the occlusal surface was achieved by using the design arrow from the surface of the scanned model up to the desired thickness in the software. Four groups of crowns (n = 17 per group) were prepared with four different occlusal thicknesses (2 mm, 1.5 mm, 1 mm and 0.5 mm) Table III. These thicknesses were selected because they represent the range of occlusal crown thicknesses used clinically. To check the thickness accuracy, each thickness was reflected on the design model with a specific color indicating the thickness of the anatomical surface. For example, blue indicated a 2-mm thickness on the occlusal anatomy, green represented 1.5 mm and so forth. Changes were done as needed to standardize the occlusal thickness according to the four different groups. The design model for each group was saved in the software so that the same anatomy and thickness could be reproduced throughout the study and be used for milling the CAD/CAM crowns in the milling machine.

CAD/CAM ALL-CERAMIC CROWN FABRICATION

CAD/CAM lithium disilicate glass ceramic blocks were used (IPS e.max CAD, Ivoclar Vivadent, NY, USA). Each block was inserted in the milling machine and secured in place using the latch driver provided by the E4D milling machine company. The milling order was sent from the digital software to the milling machine to mill the crowns according to the desired design. The milling process included the use of diamond burs (Diamond Burs, E4D technologies, TX, USA) under copious water irrigation to prepare the ceramic block to the desired dimensions. A new set of diamond burs was used after each 4 to 6 milled crowns when the machine indicated that the burs were dull and needed to be replaced. It took around 40 minutes for each milling process after which the crowns were cut to shape but still attached to the metal handle of the block. The milled crowns were removed from the machine with the same latch driver and a diamond disk (Dental Diamond Disk, Henry Schein Dental, USA) was used to cut the handle off. The glaze material was brushed onto the outer surface of the all-ceramic crown after stabilizing it on a putty stick. Then, it was put in the glazing oven for 20 minutes. Finally, the all ceramic crown was ready for delivery and cementation.

SURFACE TREATMENT AND CEMENTATION OF ALL-CERAMIC CROWNS

Following the manufacturer's instructions, the intaglio surface of the all ceramic crown was etched with 5-percent hydrofluoric acid (IPS ceramic etching gel, Ivoclar-Vivadent, NY, USA) for 60 seconds (Figure 4). After that, the surface was washed and dried for 3 seconds. Silane coupling agent (Silane Monobond S, Ivoclar Vivadent, NY, USA) was then applied and allowed to air dry for 60 seconds. Adhesive resin cement (RelyX Ultimate, 3M, St. Paul, MN, USA) was then injected onto the intaglio surface with an applicator tip provided in the cement kit. The excess cement was removed and the cement was light polymerized (DEMI, Kerr, Orange, CA, USA) for 20 seconds from each surface. The light curing unit light radiant exposure was 26 J/cm^2 and the irradiance was approximately 1282 mW/cm2 and measured periodically using Managing Accurate

Resin Curing (MARC®-RC) calibrator, (BlueLight analytics inc., Halifax, Nova Scotia, Canada). After that, each specimen was stored in distilled water for 24 hours prior to testing.

CYCLIC FATIGUE TESTING

Each sample was covered with distilled water (wet environment) 24 hours prior to each testing cycle to mimic the clinical situation. The dynamic loading force was set at 300N based on pilot study results where samples did not crack or fracture. The antagonist used to apply the load onto the samples was a woven-fiber-filled epoxy resin rod (NEMA Grade G-10 rod; Piedmont Plastics Inc., Charlotte, NC, USA) with a 3.2 mm diameter that had comparable modulus of elasticity to human dentin.[1] The resin rod was glued inside a stainless steel tip housing using cyanoacrylate glue (Loctite® Super Glue 0.14 Oz, Henkel Corp., USA) and 3 mm was exposed for loading. Each sample was secured into the testing machine and the mesio-buccal functional cusp of each crown was loaded at 300 N with the resin rod antagonist at a 90° angle. The number of cycles used for each sample was $1x10^6$ and the frequency was 20 Hz. Each sample took approximately 14 hours to complete $1x10^6$ cycles. When the cycles were finished, each specimen was investigated for any cracks or fractures under a light microscope. None of the crowns were cracked or fractured after cyclic loading.

LOAD TO FRACTURE TESTING

Each fatigued crown was loaded until fracture using the same Instron machine. A stainless steel piston with a tip diameter of 3.2 mm was used; a force was applied on the mesio-buccal functional cusp at a 90° angle on each fatigued crown at a cross-head speed of 0.5 mm/min until each sample fractured. That force was documented and calculations were done to record the mean and standard deviation.

SAMPLE SIZE CALCULATION

The sample size calculations were based on a within-group standard deviation of 275 N determined in a previous study.[1] With a sample size of 17 specimens per group (ceramic thickness) the study had an 80-percent power to detect a fracture strength difference of 275 N between any two thicknesses, assuming two-sided tests conducted at a 5-percent significance level.

STATISTICAL ANALYSIS

Fracture load results (mean, standard deviation, standard error, range) were summarized for each of the four thicknesses. The effects of ceramic thickness on fracture load were evaluated using one-way ANOVA. Pair-wise comparisons between thicknesses were made using Fisher's Protected Least Significant Differences to control the overall significance level at 5 percent.

RESULTS

The original mean values, standard deviation (± SD), standard errors (± SE) and range for the four thickness groups subjected to load to fracture testing are presented in Table IV. A gradual increase in load to fracture was observed as the occlusal thickness of the crowns increased. The highest mean load to fracture strength was recorded for the 2.0- mm thickness group (1701.57 N). The lowest mean load to fracture strength was for the 0.5-mm thickness group (601.55 N). None of the crowns were cracked or fractured after cyclic loading.

One-way ANOVA showed a statistically significant difference between the four groups ($p < 0.0001$). The mean load-to-fracture was significantly higher for the 2-mm thickness group compared to 1 mm ($p < 0.0001$) and 0.5 mm ($p < 0.0001$) groups. The mean load to fracture was significantly higher for the 1.5 mm thickness group compared to the 1.0 mm ($p < 0.0001$) and the 0.5 mm ($p < 0.0001$) groups. Furthermore, the mean load to fracture was significantly higher for the 1.0 mm thickness group compared with the 0.5 mm thickness ($p < 0.0001$) group. However, no significant difference was observed between the 2.0-mm thickness group and the 1.5-mm thickness group ($p = 0.325$).

TABLES AND FIGURES

TABLE I

Leucite glass ceramic classification

Particle filled glass based ceramics	Method of Fabrication	Brand Name
Leucite	• Powder and liquid • Heat pressed • CAD/CAM	IPS Empress, Vita VM9, 13 and 17. Vita PM9, IPS Inline POM, OPC. IPS Empress Esthetic
Lithium Disilicate	• Heat pressed • CAD/CAM	IPS Empress 2, IPS e.max Press. IPS e.max CAD
Fluorapatite	• Powder and liquid • Heat pressed	IPS e.max Ceram IPS e.max ZirPress

TABLE II

Materials used in this study

Material	Brand Name	Manufacturer	Composition
CAD/CAM Lithium Disilicate Glass Ceramic	IPS e.max CAD	Ivoclar Vivadent, Amherst, NY	SiO Additional contents: Li_2O, K_2O,MgO, Al_2O_3, P_2O_5
G-10 Resin	NEMA Grade G-10 rod	Piedmont Plastics Inc, Charlotte, NC	Woven-fiber-filled epoxy resin rod
Adhesive resin cement	RelyX, Ultimate	3M, St. Paul, MN	Radiopaque silanated fillers, Stabilizers, Rheological additives, Fluorescence dye, Initiators, Dark cure activator for Scotchbond Universal Adhesive.

TABLE III

Description of experimental groups

Groups	Thickness	Luting Agent
1 (n=17)	2.0 mm	Adhesive Resin
2 (n=17)	1.5 mm	Adhesive Resin
3 (n=17)	1.0 mm	Adhesive Resin
4 (n=17)	0.5 mm	Adhesive Resin

TABLE IV

Mean load-to-fracture (N) of various thicknesses of CAD/CAM lithium disilicate glass-ceramic crowns subjected to cyclic fatigue. Different uppercase letter indicates significant difference

Group	Thickness	Mean (N)	SD	SE
1 (n=17)	2.0 mm	1702 A	406.21	98.52
2 (n=17)	1.5 mm	1556 A	216.64	52.54
3 (n=17)	1.0 mm	846 B	112.15	27.20
4 (n=17)	0.5 mm	602 C	147.25	35.71

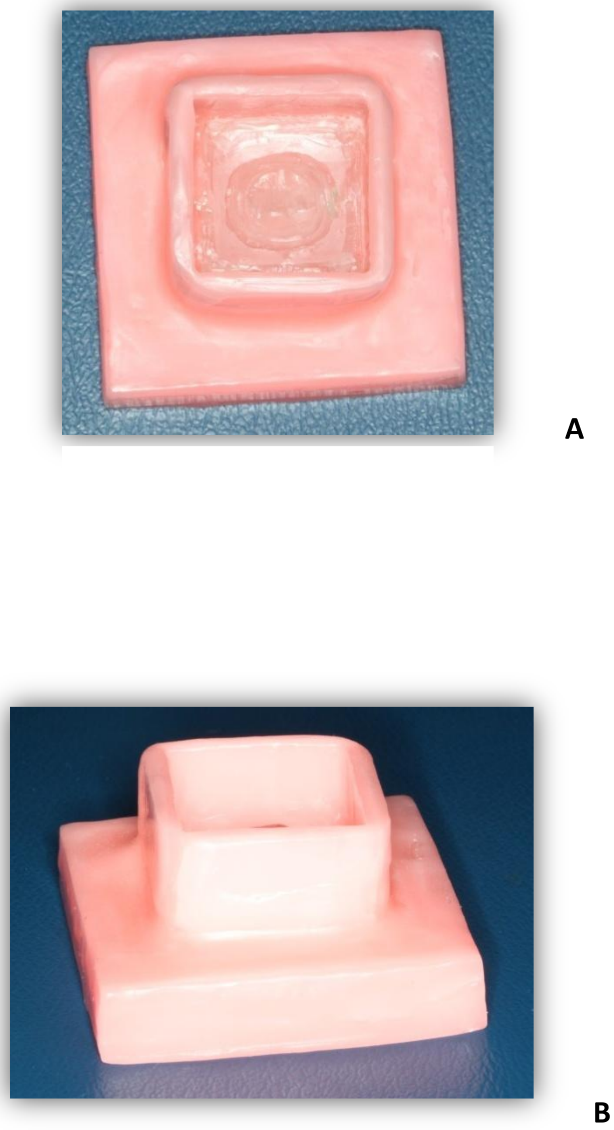

FIGURE 1. Sample design using baseplate wax to fabricate the specimen for testing. A, Occlusal view; B. Side view.

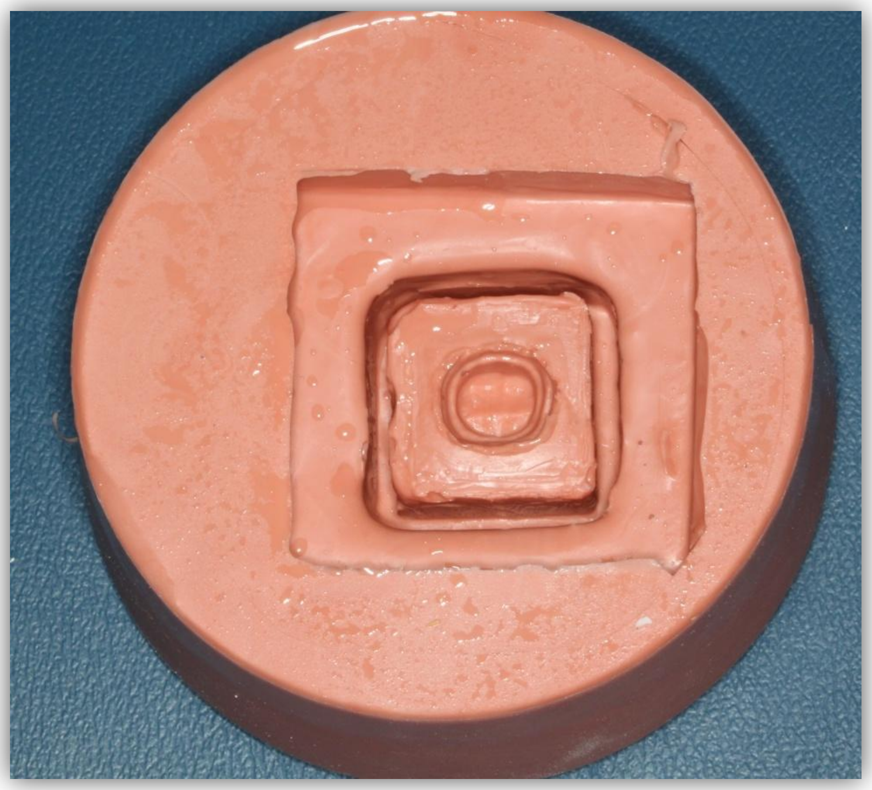

FIGURE 2. Duplication of the wax pattern using dental silicone to fabricate a mold.

FIGURE 3. Epoxy resin die material kit as provided from the manufacturer (Type 8000 die epoxy resin kit, American Dental Supply Inc.). Liquid in a pre-measured syringe was with the epoxy resin material and then poured in the silicone molds to set.

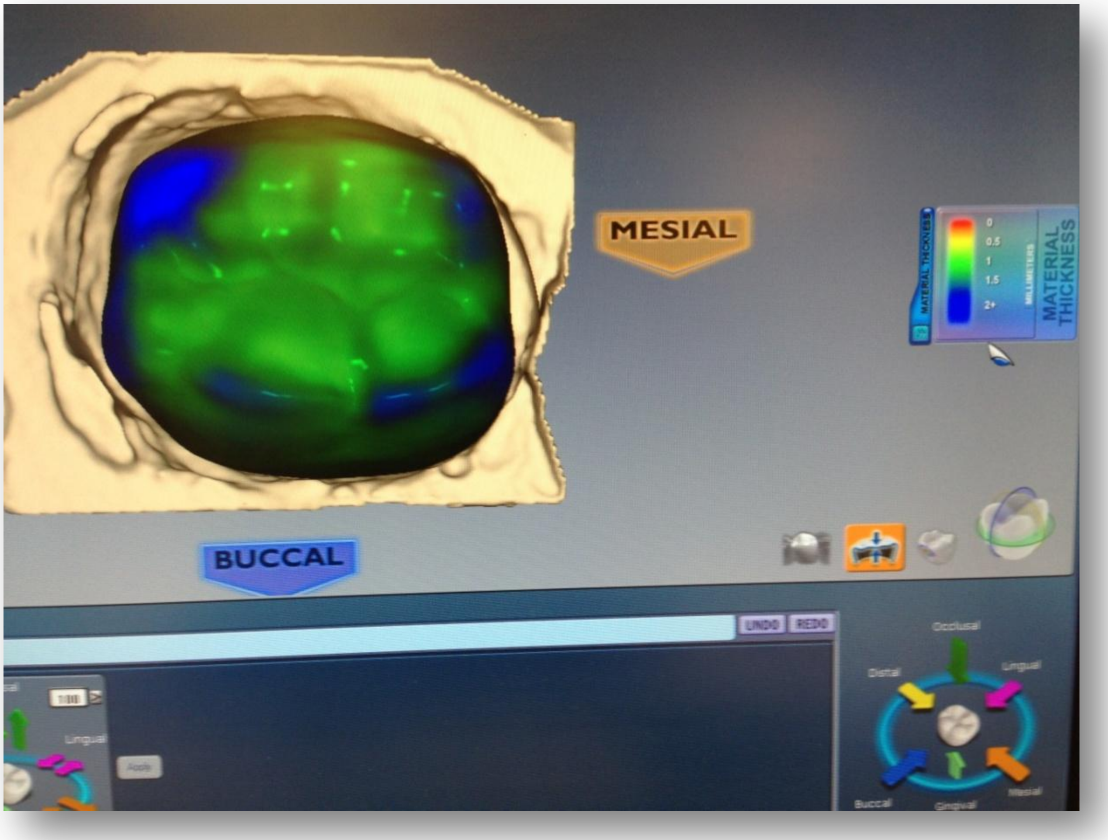

FIGURE 4. Crown design using software for CAD/CAM machine (E4D, D4D technologies, Texas).

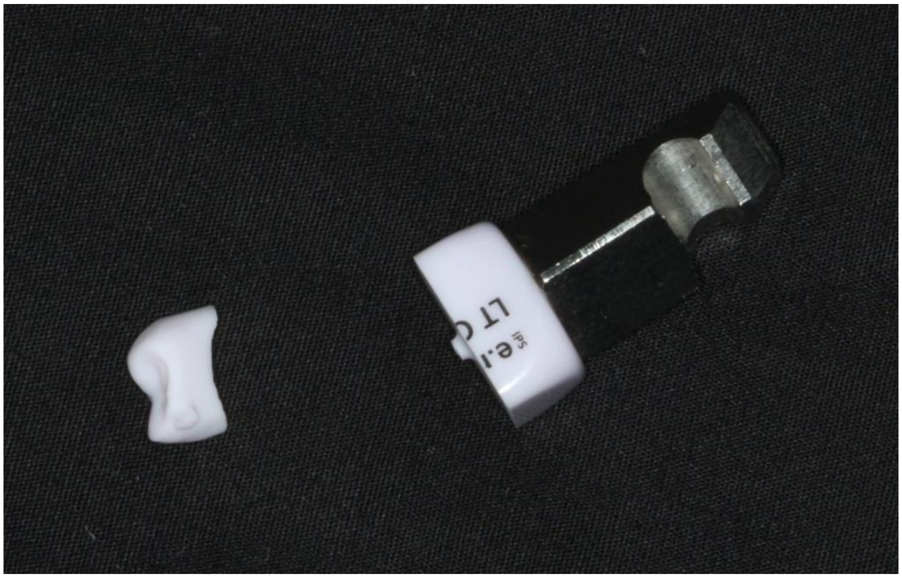

FIGURE 5. CAD/CAM all-ceramic crown after milling and separated with a disc prior to glazing in the oven.

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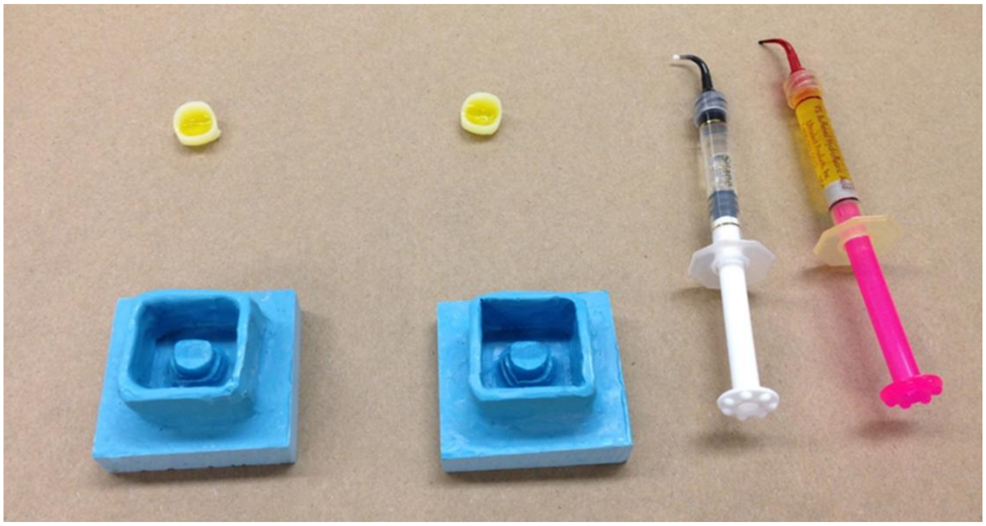

FIGURE 6. Surface treatment of All Ceramic crowns using HF acid etching and silane coupling agent.

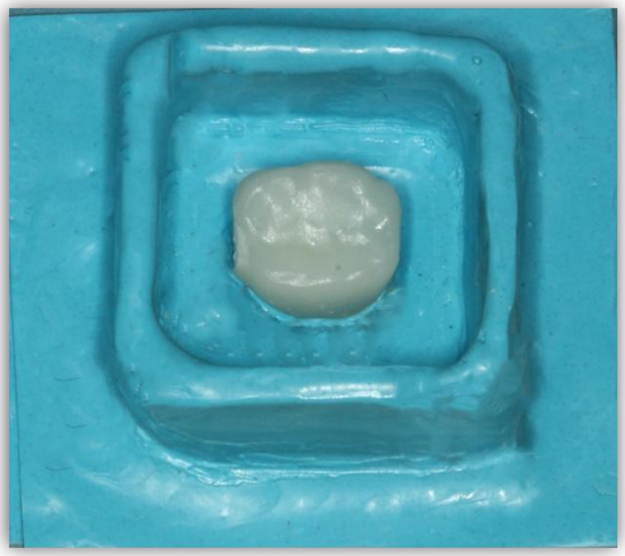

FIGURE 7. CAD/CAM all-ceramic crown after cementation on the epoxy resin die.

FIGURE 8. Four different thicknesses of lithium disilicate glass ceramic (blue: 2 mm, gray: 0.5 mm, pink: 1.5 mm, yellow: 1 mm).

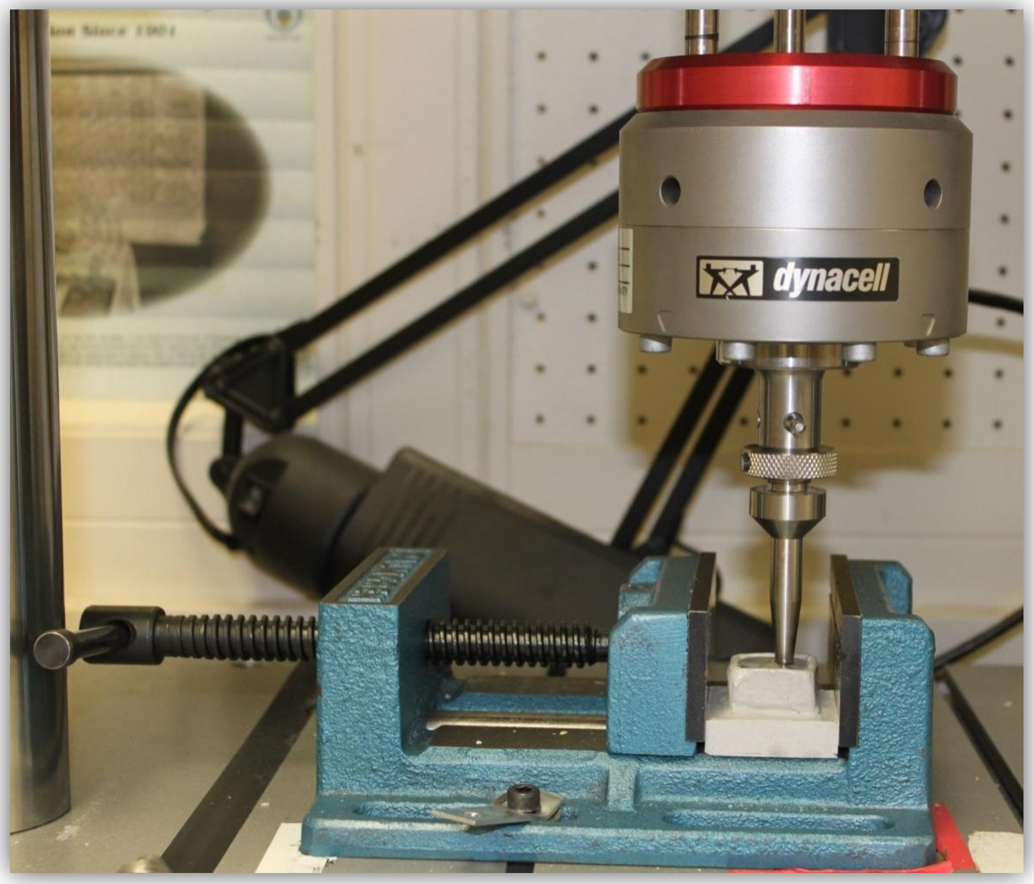

FIGURE 9. Instron machine (ElectroPuls™ E3000, Instron) after loading the specimen for cyclic loading.

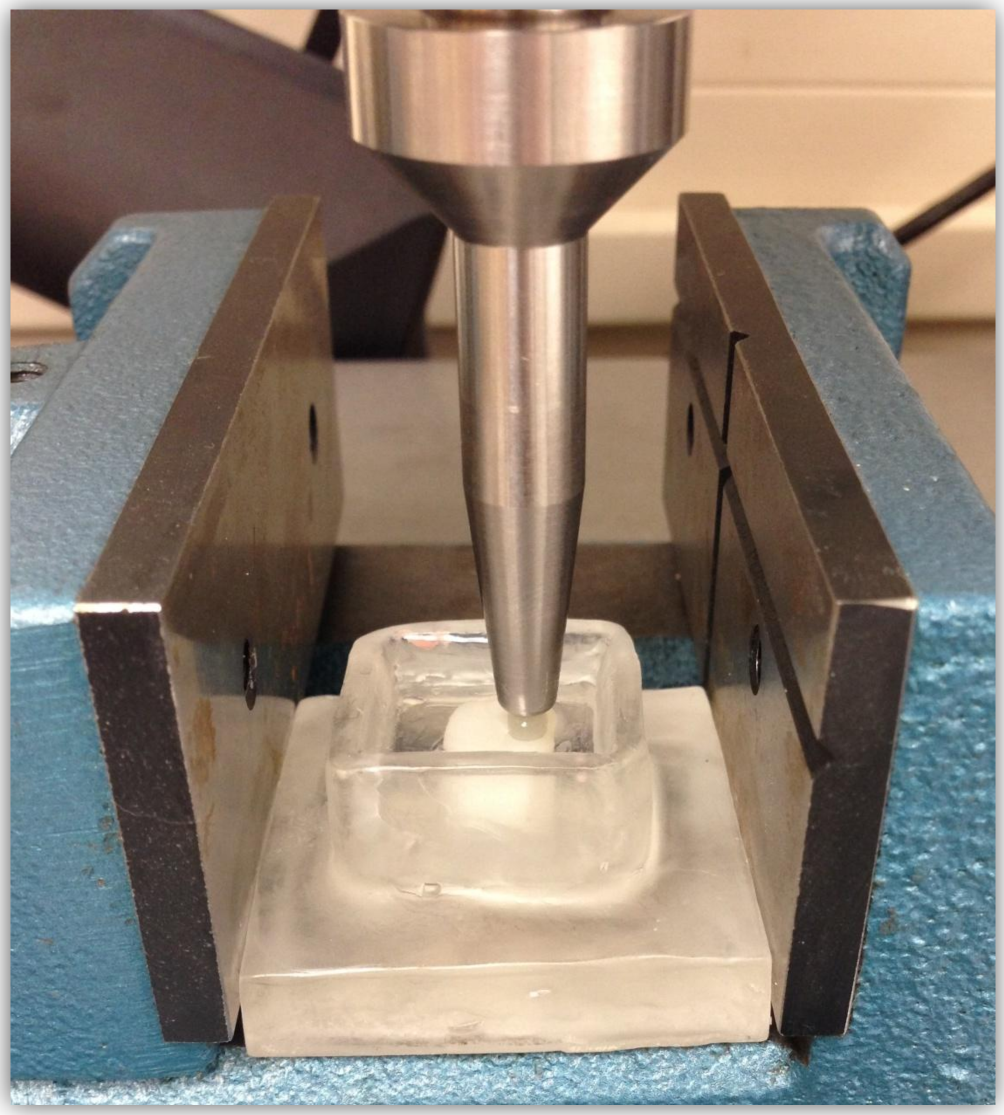

FIGURE 10. Close up view of the position of the loading tip in relation to the crown anatomy.

FIGURE 11. G10 tip (NEMA Grade G-10 rod; Piedmont Plastics Inc., Charlotte, NC, USA) used to load the specimens for cyclic loading.

FIGURE 12. G10 tips (NEMA Grade G-10 rod; Piedmont Plastics Inc., Charlotte, NC, USA) after cutting the rod into tips of the Same size for loading the specimens. Each tip was discarded after single use.
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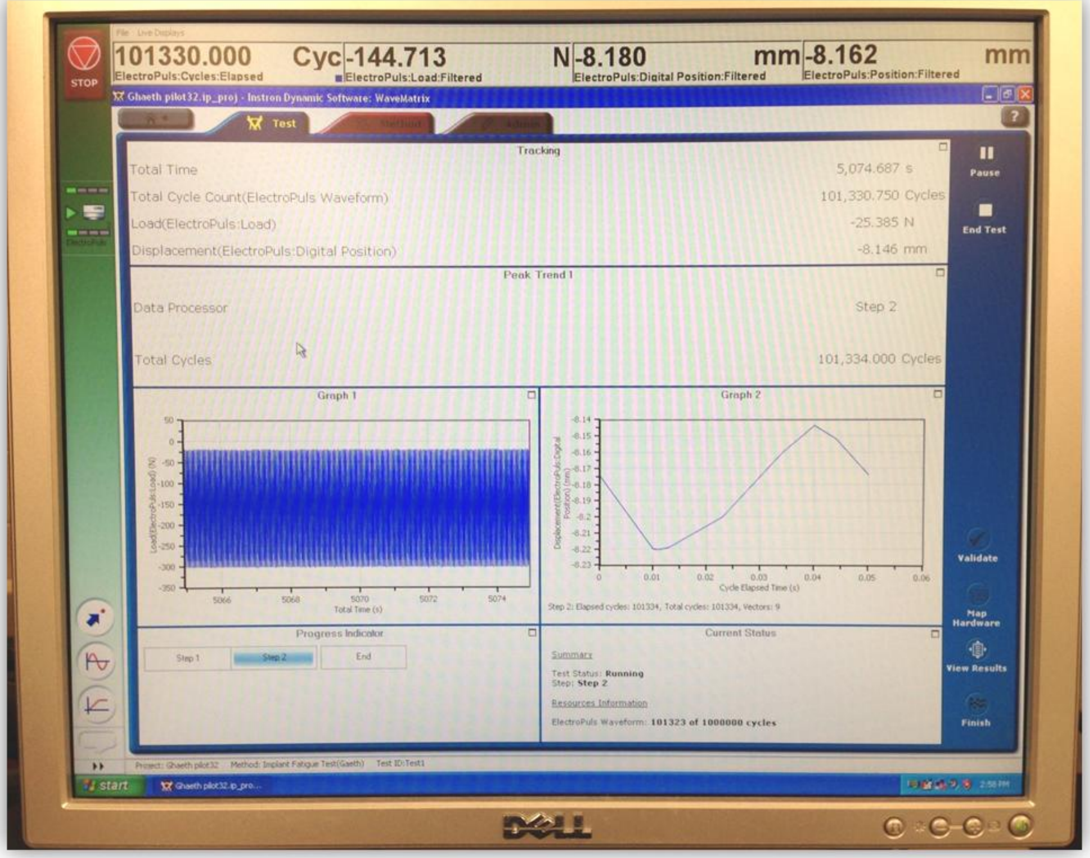

101330.000 Cyc ElectroPuls:Cycles:Elapsed

-144.713 N ElectroPuls:Load:Filtered

-8.180 mm ElectroPuls:Digital Position:Filtered

-8.162 mm ElectroPuls:Position:Filtered

Tracking

Total Time	5,074.687 s
Total Cycle Count(ElectroPuls Waveform)	101,330.750 Cycles
Load(ElectroPuls:Load)	-25.385 N
Displacement(ElectroPuls:Digital Position)	-8.146 mm

Peak Trend 1

Data Processor	Step 2
Total Cycles	101,334.000 Cycles

Step 2: Elapsed cycles: 101334, Total cycles: 101334, Vectors: 9

Progress Indicator: Step 1 | Step 2 | End

Current Status

Summary

Test Status: **Running**
Step: **Step 2**

Resources Information

ElectroPuls Waveform: **101323 of 1000000 cycles**

Project: Ghaeth pilot32 Method: Implant Fatigue Test(Gaeth) Test ID:Test1

FIGURE 13. Instron machine monitor showing the cyclic load, number of cycles, depth of the antagonist, and time.

FIGURE 14. Metal loading tip for static loading.

FIGURE 15. Failure of 2-mm ceramic crown after static load.

FIGURE 16. Failure of 1.5-mm ceramic crown after static load.

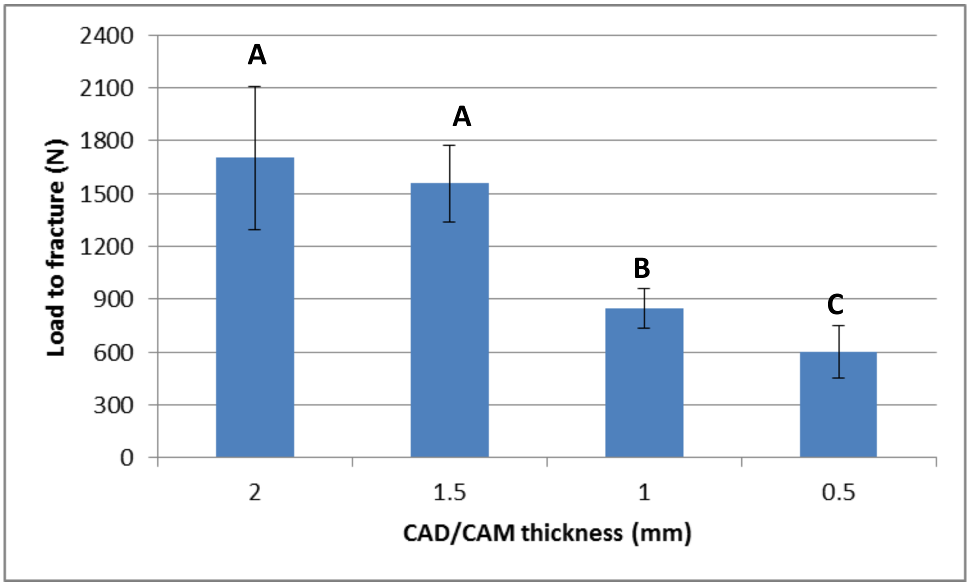

FIGURE 17. The mean load-to-fracture (N) of four different thicknesses of lithium disilicate glass ceramic fabricated using CAD/CAM.

DISCUSSION

Tooth preparation is driven by a need for equilibrium between pulp health and preservation of tooth structure on one hand, and achieving a strong crown with optimum esthetics on the other. The thickness is one of the important parameters that defines the strength of all ceramic restorations. The amount of tooth reduction facilitates the crown design and thus the crown thickness. Exceeding the average occlusal reduction (2 mm) for all ceramic restorations may cause tooth sensitivity, dentin exposure and pulp inflammation. Conversely, maintaining the desired tooth preparation will preserve tooth structure that is ideal for adhesive bonding. It is important to define the occlusal thickness of all ceramic restorations that will provide strength and durability. The thickness of all ceramic restorations has recently been investigated to determine the proper thickness for fabrication. To the best of our knowledge, there is only one study that has studied the different thicknesses of milled lithium disilicate ceramic in detail.[11]

Four different thicknesses of lithium disilicate glass ceramic were used in this study (0.5 mm, 1 mm, 1.5 mm and 2 mm). These thicknesses represent the range of ceramic thicknesses that are used clinically to restore posterior teeth. To our knowledge, no definitive information on the minimum ceramic thickness for posterior ceramic onlays and complete veneer restorations or its impact on fracture behavior is available.[13] The minimum ceramic thickness reported to have satisfactory clinical long-term results ranges between 0.3 mm and 1 mm.[14] Additionally, 1 mm and 1.5 mm are the most commonly seen clinical thicknesses in different areas of the mouth. Most of the studies in the literature use a standard thickness of 2 mm to perform their tests.[4,12,15,16] One study by

Dhima et al.[11] studied the four different thicknesses of lithium disilicate glass ceramic as was done in this study and reported similar results. Kelly et al.[6] reported a mean failure load for 1 mm thicknesses of leucite filled porcelain crowns (1610 N) whereas in our study the 1 mm group showed a mean failure load of (845 N) The reason for the difference between our study and his may be that fatigue testing in distilled water lowered the failure loads of the ceramic crown specimens compared to those tested in a dry environment.[17]

Adhesive cementation of the ceramic crowns was done using resin cement in our experiment. Studies have shown that mode of cementation influenced fracture load and adhesive cementation resulted in higher fracture loads than non-adhesive cementation.[4] A study by Consani et al.[17] reported that the resin cement showed the greater tensile strength values among the different cements used in his study.

Ideally, *in-vitro* studies of all-ceramic materials should produce failures that are comparable to those in clinical situations. Repeated chewing and other functions in the oral cavity subject all-ceramic crowns to fatigue behavior. These forces change over time in a repeated fashion and could cause the material to fail. In the current study, cyclic loading was performed prior to static loading in order to simulate some of the stresses a crown will be subjected to during mastication. Studies have shown that veneered zirconia (Y-TZP) crowns were chipped due to fatigue encountered in the veneering layer whereas lithium disilicate glass crowns were fatigue- resistant.[18] The failure mode of monolithic lithium disilicate glass crowns was bulk fracture of the substructure and veneering porcelain. Literature is short on the effect of cyclic loading on the failure behavior of lithium disilicate glass ceramic. Therefore, the current study incorporated cyclic fatigue to help to mimic the clinical situation of repeated mastication forces on lithium disilicate glass ceramic crowns.

Cyclic loading was achieved through a relatively low force repeated over 1×10^6 cycles. In this study, 300 N was chosen to perform the cyclic loading based on pilot study results. In the pilot study, samples were fatigued using three different loads (300 N, 350 N and 400 N). It was observed that both 350 N and 400 N caused crowns to fracture during fatigue loading while 300 N did not cause any cracks or fracture in any of the samples tested. Dhima et al.[10] reported mean failure load of monolithic lithium disilicate was greater than average posterior masticatory forces (150 N to 340 N). They observed that lithium disilicate behaves well under low loads and loading outcomes were accelerated using this protocol. The *in-vitro* study designs vary considerably, especially when it comes to the dry or wet testing environment and it is difficult to standardize the test environment.[10]

Zhao et al.[18] in his study tested veneer application and cyclic loading on the failure mode of lithium disilicate glass ceramic to determine whether it was an accelerating factor for failure. He reported that monolithic lithium disilicate glass ceramic showed superior performance compared to bilayered lithium disilicate glass ceramic, irrespective of fatigue load application. Carvalho et al.[19] showed that all-ceramic crowns fabricated by a CAD/CAM technique were fatigue resistant and survived beyond the normal range of masticatory forces (600 N to 900 N). The results of fracture load obtained for 2-mm thickness (1702 N) were three times higher than the normal range of posterior mastication (500 N) indicating that this restorative system will tolerate posterior loads satisfactorily. No single study compared data of fatigued and non-fatigued all ceramic crowns.

Our results are similar to results obtained from Dhima et al.[10] who reported a gradual increase in load to fracture between four different occlusal thicknesses of crowns (0.5 mm, 1 mm, 1.5 mm and 2 mm). However, there are distinct differences in the design of the two studies, which makes both studies complement each other toward a better understanding of the effect of various thicknesses of ceramic on fracture strength. The die fabrication was milled from a milling unit in the previous study whereas ours was duplicated using a silicone mold. We used an E4D milling unit to fabricate the lithium disilicate crowns while CEREC was their machine of choice. They stored their specimens 126 days prior to loading and our specimens were only stored for 24 hours prior to testing. The load tip in our study was directed towards the functional cusp (buccal) for lower molars while theirs was subjected to a mouth motion fatigue test: (antagonist contact-load-slide liftoff). The cyclic load force used was 300 N in an Instron machine in the current study, while Dhima used a force range between (350 N to 400 N) in a MTS machine. A water bath was incorporated for our specimens as the test was performed in a wet environment to resemble the clinical situation.[20] However, their test was done in dry conditions. Results of fracture load may vary whether the test was conducted in wet or dry situations. Subsequently, the failure pattern that have been observed resembles what could be seen clinically. This is attributed to testing in wet environment and submerging the samples in water. Our specimens were fabricated using an epoxy resin material whereas they used an ultrafine zirconia-silica ceramic. The differences between the modulus of elasticity of the two materials will give exaggerated results. The tip used in their study was a metal one; we used an epoxy resin tip to more closely match the modulus of elasticity of the supporting dental structures. They fatigue loaded their specimens to failure; on the contrary, we fatigued our samples then loaded them to failure trying to mimic the clinical scenario where teeth are in function for a period of time and then experience a concentrated loading event.[21] Our method was expected to give lower results than a non-fatigued method although there are no studies comparing results of fatigued and non-fatigued crowns. This is an area for further research.

Further investigation to compare different thicknesses of pressed and CAD/CAM lithium disilicate glass ceramic will be helpful to compare results. Also, testing various types of ceramics with different loading environments (wet versus dry) could aid in drawing conclusions on the mean failure loads. Selecting different anatomical teeth (premolars versus molars) would give a better understanding of the impact of force generation in different regions of the posterior segment of the arch.

SUMMARY AND CONCLUSION

From these results it can be concluded that:

1. Within the limitation of this *in-vitro* study, fatigued lithium disilicate glass ceramic crowns with 1.5-mm and 2-mm thicknesses showed significantly higher load to fracture compared with the same crown design with 0.5-mm and 1-mm thicknesses.
2. For clinical application, it is advisable to consider a crown thickness of 1.5 mm or greater of milled lithium disilicate crowns for posterior single molar teeth.

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ABSTRACT

EFFECTS OF VARIOUS THICKNESSES ON LOAD TO FRACTURE OF POSTERIOR CAD/CAM LITHIUM DISILICATE GLASS CERAMIC CROWNS SUBJECTED TO CYCLIC FATIGUE

by

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Background: New glass ceramics and Computer-Aided Design/Computer Assisted Manufacture (CAD/CAM) have become common aspects of modern dentistry. The use of posterior ceramic crowns with a high level of esthetics, fabricated using the CAD/CAM technology is a current treatment modality. Several materials have been used to fabricate these crowns, including lithium disilicate glass-ceramics, which have not been fully investigated in the literature.

Objective: to investigate the load to fracture of lithium disilicate glass ceramic posterior crowns fabricated by CAD/CAM technology with different material thicknesses adhesively cemented on epoxy resin.

Methods: Four groups of different ceramic thicknesses (0.5 mm, 1 mm, 1.5 mm, and 2 mm) were fabricated by milling CAD/CAM lithium disilicate IPS emax CAD blocks. A total of 68 posterior crowns were surface treated and luted with a resin adhesive cement on an epoxy resin model. Samples were fatigued then loaded to fracture using a universal testing machine to test the fracture strength. Statistical comparisons between various crown thicknesses were performed using one-way ANOVA followed by Fisher's Protected Least Significant Differences.

Results: There was a significant difference in the load-to-fracture (N) value for all comparisons of the four thickness groups ($p < 0.0001$), except 2 mm vs. 1.5 mm ($p = 0.325$). The mean load-to-fracture (N) was significantly higher for 2 mm than for 1 mm or 0.5 mm. Additionally, the mean load-to-fracture was significantly higher for 1.5 mm than for 1 mm or 0.5 mm. Furthermore, the mean load-to-fracture was significantly higher for 1 mm than for 0.5 mm.

Conclusion: Within the limitation of this study, it is advisable for clinical applications to consider a crown thickness of 1.5 mm or greater of milled lithium disilicate for posterior single teeth.

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