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Influence of Ceramic Thickness and Ceramic Materials on Fracture Resistance of Posterior Partial Coverage Restorations

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Clinical Relevance

This study demonstrated lithium disilicate glass ceramic significantly improved fracture resistance when compared to a leucite-reinforced glass ceramic, even at a thickness below the manufacturer's suggested minimum. The use of lithium disilicate may have advantages in clinical situations of minimal occlusal clearance.

SUMMARY

This study evaluated the influence of ceramic thickness and ceramic materials on fracture resistance of posterior partial coverage ceramic restorations. Forty extracted molars were allocated into four groups (n=10) to test for two variables: 1) the thickness of ceramic (1 mm or 2 mm) and 2) the ceramic materials (a lithium disilicate glass-ceramic [IPS e.max] or leucite-reinforced glass ceramic [IPS Empress]). All ceramic restorations were luted with resin cement (Variolink II) on the prepared teeth. These luted specimens were loaded to failure in a universal testing machine, in the compression mode, with a crosshead speed of 1.0 mm/min. The data were analyzed using two-way analysis of variance and the Tukey Honestly Significantly Different multiple comparison test (α =0.05). The fracture resistance revealed a significant effect for materials (*p*<0.001); however, the thickness of ceramic was not significant (*p*=0.074), and the interaction between the thickness of ceramic and the materials was not significant (*p*=0.406). Mean (standard deviation) fracture resistance val-

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DOI: 10.2341/12-459-L

ues were as follows: a 2-mm thickness of a lithium disilicate bonded to tooth structure (2505 [401] N) revealed a significantly higher fracture resistance than did a 1-mm thickness of leucite-reinforced (1569 [452] N) and a 2-mm thickness of leucite-reinforced ceramic bonded to tooth structure (1716 [436] N) ($p<0.05$). There was no significant difference in fracture resistance values between a lithium disilicate ceramic at 1-mm thickness (2105 [567] N) and at 2-mm thickness. Using a lithium disilicate glass ceramic for partial coverage restoration significantly improved fracture resistance compared to using a leucite-reinforced glass ceramic. The thickness of ceramic had no significant effect on fracture resistance when the ceramics were bonded to the underlying tooth structure.

INTRODUCTION

All-ceramic restorations have been shown to demonstrate superior optical properties over ceramic metal restorations.[1-3] In addition, the mechanical requirements of adhesively retained all-ceramic restorations can typically be met with less tooth reduction than is required of metal-ceramic or all-ceramic cohesively retained restorations. While the concept of using ceramic in posterior teeth dates back to the late 1800s, it was not considered practical until the advent of adhesive protocols. In addition, adhesively retained restorations negate the need to extend preparations to sound tooth structure purely for establishing resistance and retention form. Preservation of sound tooth structure is of interest because loss of tooth structure involves biologic compromise.[4] As the physical requirements of a restoration align to provide greater respect for the biologic requirements of a restored tooth, there is a greater chance for long-term success of the tooth/restoration partnership. For this reason, adhesively retained ceramic onlays warrant consideration as an effective means of restoring posterior teeth. Previous studies revealed the high survival rate of partial coverage glass ceramic to measure between 92% and 97% during observation periods extending up to five years[5-9] and to measure 94% to 98% at the seven- and eight-year intervals, respectively.[10] Despite the high survival rate of restorations, fracture of the ceramic material is the most frequently reported complication resulting in failure. Investigations of clinically failed all-ceramic restorations have shown that the failure stresses depend on their mechanical properties.[11,12]

Occlusal thickness requirements for traditional ceramics dictate a 2-mm minimum to achieve optimal compressive strength. Undulations present in tooth anatomy are impractical to mirror in kind during tooth preparation. Establishing clearance for a 2-mm minimum thickness of restorative material in all areas, including fossa and fissures, results in areas of tooth reduction that exceed 2 mm in other areas, such as cuspal inclines. Increased tooth reduction directly relates to greater probability of enamel loss; enamel is critical to the long-term success of adhesively retained restorations.[13] Dimensional loss of enamel with preparation can be exaggerated in the already-worn dentition. A posterior partial coverage restoration with minimal thickness of ceramic has the potential to conserve and protect tooth structure, preserve enamel, and safeguard pulpal vitality while achieving the desired esthetic results.[14,15] However, reduced thickness of occlusal ceramic may have a negative effect on the mechanical properties of the material since the strength of ceramic is inversely related to the square of the ceramic thickness.[16,17] Several all-ceramic materials have been used to fabricate these partial coverage adhesively retained restorations. The heat-pressed technique was introduced to dentistry in the early 1990s as an innovative processing method for all-ceramic restorations. Applying this technique, a leucite-reinforced glass ceramic (IPS Empress, Ivoclar Vivadent Inc, Amherst, NY, USA) can be processed into various shapes (veneer, inlay, onlay, or single crown). More recently, a lithium disilicate-reinforced glass ceramic (IPS e.max, Ivoclar Vivadent) with further improved physical and mechanical properties was developed. Often improved physical properties of ceramics are countered by less favorable optical properties. However, as a result of the favorable optics (shade and translucency) of lithium disilicate, it can be used to create esthetically acceptable full-contour restorations. The purpose of this study was to evaluate the influence of ceramic materials and their thickness on fracture resistance of posterior partial coverage restorations. The null hypothesis was that fracture resistance of posterior partial coverage restorations would not be affected by the choice of ceramic materials (a lithium disilicate–reinforced ceramic or a leucite-reinforced ceramic) or the ceramic thickness (1 mm or 2 mm).

METHODS AND MATERIALS

Selection and Preparation of Teeth

Forty extracted human molar teeth were selected. Teeth were included based on the specific criteria that they were intact and lacked cracks or fractures in the crown, contained no evidence of caries, and had no prior restorations. The teeth were cleaned of surface debris, disinfected in 0.5% sodium hypochlorite, and kept in distilled water until the study began. The occluso-cervical and mesio-distal dimensions of the teeth were measured three times using a dial caliper accurate to within 0.1 mm (Masel Dental Dial Caliper; Masel, Carlsbad, CA, USA), and the averages were determined. The teeth were ranked according to the decreasing mesio-distal dimension. The ranked teeth were divided into four groups: the first tooth was assigned to group 1, the second to group 2, the third to group 3, the fourth to group 4, the fifth to group 4, the sixth to group 3, the seventh to group 2, and the eighth to group 1. This procedure was repeated until each group had a sample size of 10 teeth. Each group was assigned to one of the four test groups with a combination of ceramic thickness and ceramic materials. The teeth were attached with sticky wax (Kerr sticky wax; Kerr, Orange, CA, USA) to a dental surveyor rod (J.M. Ney Co, Bloomfield, CT, USA) on a vertically prepared surface so that the long axis of the teeth would be parallel to the surveyor rod. The teeth were lowered into a copper cylinder and positioned in the center of the cylinder with the buccal cemento-enamel junction 3 mm above the top of the copper-mounting cylinder. Premixed autopolymerizing resin (Pattern Resin; GC America, Alsip, IL, USA) was injected into the cylinder until it was completely full. After acrylic resin polymerization, the dental surveyor rod was detached, and the specimens of teeth were stored in distilled water at room temperature. The mounted teeth were allocated into four groups (n=10) and restored with a leucite-reinforced ceramic (IPS Empress; Ivoclar Vivadent) or a lithium disilicate ceramic (IPS e.max; Ivoclar Vivadent) as follows: 1) IPS e.max 1-mm (EX-1): 2-mm occlusal reduction restored with 1 mm of a lithium disilicate ceramic; 2) IPS e.max 2-mm (EX-2): 2-mm occlusal reduction restored with 2 mm of a lithium disilicate ceramic; 3) IPS Empress 1-mm (EMP-1): 2-mm occlusal reduction restored with 1 mm of a leucite-reinforced ceramic; and 4) IPS Empress 2-mm (EMP-2): 2-mm occlusal reduction restored with 2 mm of a leucite-reinforced ceramic. A clinician prepared the teeth in all groups according to preparation designs previously described in the literature.[13] All teeth received a 2-mm occlusal reduction, maintaining cusp steepness of 45° relative to the occlusal surface (Figure 1). All specimens were prepared using a high-speed electric handpiece and diamond rotary cutting instrument under cool-water irrigation. An impression of each prepared tooth was made with light-body and heavy-body vinyl polysiloxane using a dual-phase single-stage technique, according to the manufacturer's instructions.

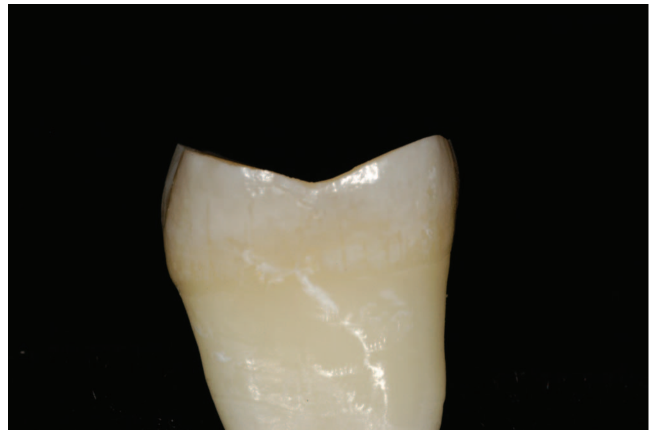

Figure 1. *All teeth received a 2-mm occlusal reduction, maintaining cusp steepness of 45° relative to the occlusal surface.*

Fabrication of Ceramic Restorations

After 24 hours, all dies were poured using vacuum-mixed die stone (Fuji Rock; GC America). Accuracy of die stone and water were ensured by measuring and dispensing from an automated system (Smart Box; AmannGirrbach, Vorarlberg, Austria). Die stone was allowed to set for 24 hours to ensure uniform hardness. All dies were carefully removed and model trimmed and sealed with die sealer (MS1; Harvest Dental, Brea, CA, USA). The 40 posterior partial coverage restorations were waxed and carefully measured using a digital caliper to ensure uniform thickness for each test group. Wax patterns were sprued and invested per manufacturer instructions—Ceravety (Shofu Incorporated; San Marcos, CA, USA) for IPS e.max restorations and Speed vest (Ivoclar Vivadent) for IPS Empress restorations. All pressings were done utilizing a speed burn-out technique (20-30 minutes after investing, rings were placed in a preheated burnout oven at 843°C). All restorations were divested using 50-μm particle size aluminum oxide. IPS e.max exhibits a strong reaction layer after pressing, which requires ultrasonic treatment for 10 minutes utilizing Invex liquid (Ivoclar Vivadent), followed by additional sandblasting with 50-μm aluminum oxide to insure complete removal of the reaction layer. The sprues were separated from the restorations and the restorations were measured for accuracy. The restorations fit the dies with minor adjustment; this was due to the accuracy of investment materials and the smooth, nonretentive nature of the test patterns. Restorations were carefully measured with a microcaliper and adjusted where necessary using a fine diamond bur (ZR8881.FGL.016, Komet USA, Rock Hill, SC, USA) and water in order to achieve the desired test thicknesses. A thin layer of glaze paste was applied to each restoration. The restorations were placed on a pillow tray and then baked in a ceramic furnace (Programat P700; Ivoclar Vivadent) following the manufacturer's instructions (785°C for IPS e.max and 790°C for IPS Empress).

All sets of restorations were acid-etched according to the manufacturer's recommendations (IPS Ceramic Etching Gel; Ivoclar Vivadent): for 60 seconds for the leucite-reinforced ceramic and for 20 seconds for the lithium disilicate ceramic. The by-products were eliminated from the internal aspects of the restorations by immersing them in isopropyl alcohol and placing them in an ultrasonic cleaner for five minutes.

Cementation Procedure

Specimen cementation included mechanical debridement using aluminum oxide abrasion (PrepStart; Danville Engineering, San Ramon, CA, USA) with a particle size of 27 μm at 0.28 MPa at a distance of 2 mm from the tooth surfaces.[18] The prepared teeth were etched for 15 seconds with 37% phosphoric acid (Etch-37; Bisco Inc, Schaumburg, IL, USA), rinsed for 10 seconds, and dried sparingly. The dentin primer of a fourth-generation adhesive system (All-Bond II; Bisco) was applied to specimens according to manufacturer instructions and gently air-dried. A thin layer of unfilled resin (D/E Resin; Bisco) was applied to the specimens. The internal surfaces of the ceramic restorations were cleaned with 37% phosphoric acid for 60 seconds, dried, and silanated with ceramic primer (Scotch Bond Primer; 3M ESPE, St Paul, MN, USA). The ceramic veneers were luted with light-polymerizing composite resin cement (Variolink II; Ivoclar Vivadent). The restorations were seated with finger pressure and light-polymerized with a wave length of 480 nm and a light intensity of 1100 mW/cm^2 (±10%) for a five-second burst (Optilux 501; Kerr), and then the excess was removed to simulate intraoral conditions. Specimens were then polymerized for 40 seconds on all surfaces for a total of 120 seconds. Any remaining excess was removed with a scalpel blade (Bard Parker #12; Becton Dickinson and Co, Franklin Lakes, NJ, USA), and all restoration margins were polished with fine polishing disks (Sof-Lex; 3M ESPE). The bonded specimens were stored at room temperature with 100% relative humidity for 48 hours prior to fracture testing.

Measurement of Fracture Resistance

Each specimen was mounted on a metal holder in a universal testing machine (Model 5585H; Instron Corp, Norwood, MA, USA), equipped with a 10-kN load cell at a crosshead speed of 1.0 mm/min. All of the specimens were tightened and stabilized to ensure that the loading stainless-steel ball of 6-mm diameter was positioned on the central occlusal surface of ceramic onlays. A 6-mm-diameter stainless-steel ball, the size of which was similar to that of a molar cusp, was positioned on the central fossa of the occlusal surface of the restoration to simulate an occlusal contact point of an antagonist tooth.[19] A load was applied until catastrophic failure occurred. The ultimate load to failure was recorded in newtons (N), and the means and standard deviations (SDs) were calculated. The fractured surfaces were then examined to obtain the catastrophic mode of failure. All restorations were inspected under 10× magnification. The catastrophic failure was classified in accordance with one of the following criteria: a cohesive failure not involving tooth (Type I), a cohesive failure involving any interface (Type II), a cohesive failure involving the crown (root preserved) (Type III), and a fracture involving root (Type IV). Parametric statistical analyses were performed at a 95% confidence interval using statistical software (SAS V.9.1, SAS Institute Inc, Cary, NC, USA). Groups were analyzed using a two-way analysis of variance with ceramic thickness and ceramic material as the variables, followed by a Tukey Honestly Significantly Different multiple comparison test to evaluate differences among the testing groups.

RESULTS

Ceramic materials had a significant effect on the fracture resistance values ($p<0.001$); however, the thickness of ceramic was not significant ($p=0.074$), and the interaction between the thickness of ceramic and ceramic material was not significant ($p=0.406$). The highest mean (SD) fracture resistance was obtained from a 2-mm thickness of a lithium disilicate glass ceramic (2505 ± 401 N), followed by a 1-mm thickness (2105 ± 567 N) of a lithium dislilicate glass ceramic (Figure 2). This represents approximately 15% to 30% more than the lowest mean obtained from those groups of a 1-mm thickness (1569 ± 452 N) and a 2-mm thickness (1716 ± 436 N) of teeth restored with a leucite-reinforced glass ceramic. There was no significant

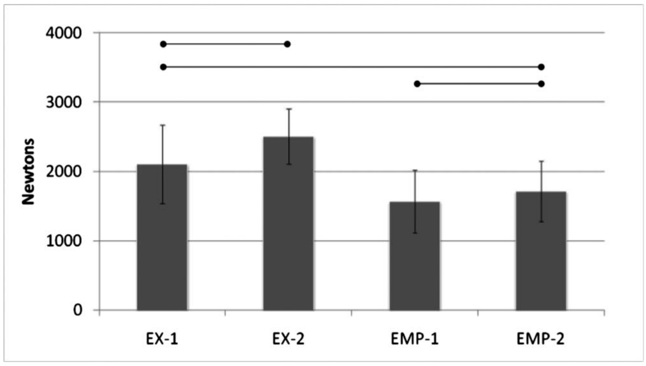

Figure 2. *Schematic representation of the mean and standard deviation of load to failure in each testing group. Note that the same running bar showed no significant difference among the groups.*

difference in fracture resistance between the 2-mm thickness group and the 1-mm thickness group in both ceramic materials. The mode of failure in the majority of the specimens involved ceramic fracture with a cohesive failure not involving tooth (Type I) (Figure 3A) and ceramic fracture with a cohesive failure involving the interface (Type II) (Figure 3B). Several fractured ceramic specimens involved coronal tooth structure but were not catastrophic (Type III). None of the ceramic specimens revealed root fracture in conjunction with failure (Table 1).

DISCUSSION

Restoration longevity depends not only on the ceramic material used but also on adherence to strict bonding protocols and the characteristics of the remaining tooth structure. Considering the brittle nature and limited flexural strength of glass ceramics, adhesive cementation with resin cements must be used to increase the fracture resistance of the restoration.[20,21] An enamel substrate favorably influences the predictability of bonded restorations.[22,23] A previous study[13] demonstrates that the amount of remaining circumferential enamel to retain posterior partial coverage should be at least 1 mm. In the present study, all specimens were prepared with 2-mm occlusal reduction, providing a relatively consistent adhesive substrate. Certainly the underlying tooth structure contributed to the strength of the ceramic to resist fracture upon loading. The contributions of the underlying tooth structure being relatively even, clearly the stronger the properties of the ceramic material itself, the better the fracture resistance of the tooth/restoration complex. Lithium disilicate and leucite-reinforced glass ceramics are both recommended for use in posterior restorations and therefore were selected for the present study. Previous studies[24,25] of lithium disilicate demonstrate a flexural strength of approximately 400 MPa and a fracture toughness value of 3.3 MPa $\times$ m$^{1/2}$, which are almost three times the values of a leucite-reinforced glass ceramic. As a result of the increased crystallinity of lithium disilicate ceramic, the material provides a tighter interlocking matrix in its structure and prevents the propagation of microcracks. Because of the improvement in mechanical properties, it is deemed a material that can withstand higher masticatory forces and provide improved clinical performance.[26,27] The present finding was consistent with those of previous reports. The results of the present study support the first null hypothesis, since there was no significant difference in load to failure values for ceramics of different thickness (1 mm or 2 mm). The results of the study reject the second null hypothesis, since there was a significant

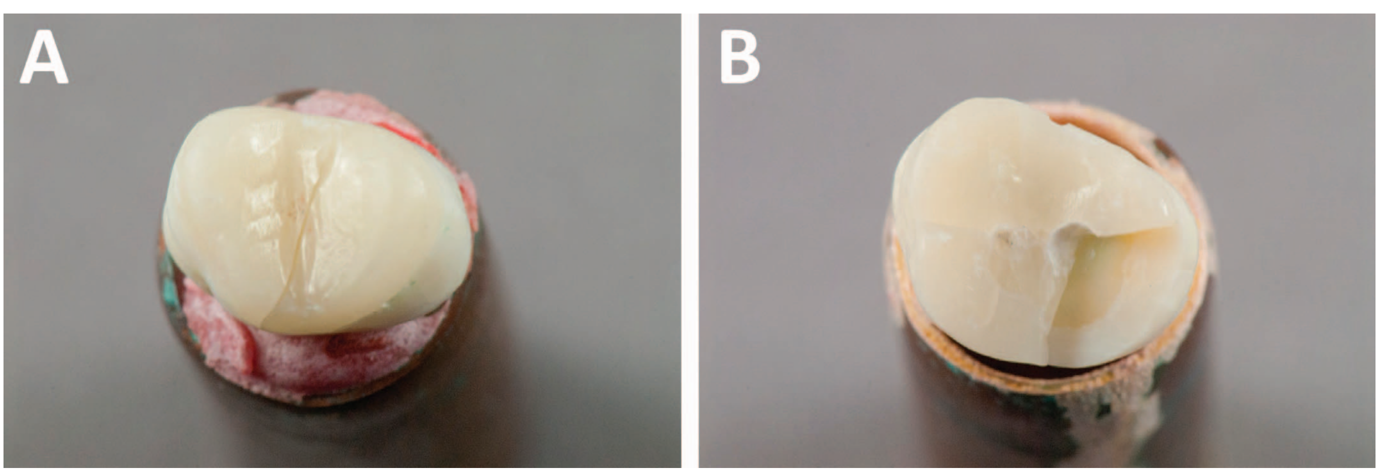

Figure 3. *Representative photographs of failed specimens: A, a cohesive failure not involving the tooth (Type I); B, a cohesive failure involving any interface (Type II).*

Table 1: *Mode of Failure in All Testing Groups. Note a Cohesive Failure Not Involving Tooth (Type I), a Cohesive Failure Involving Any Interface (Type II), a Cohesive Failure Involving the Crown (Root Preserved) (Type III), and a Fracture Involving Root (Type IV)*

Group	Type and Thickness of Ceramic	Mode of Failure			
		I	II	III	IV
EX-1	1-mm thickness lithium disilicate	7	3	0	0
EX-2	2-mm thickness lithium disilicate	5	2	3	0
EMP-1	1-mm thickness leucite-reinforced	8	1	1	0
EMP-2	2-mm thickness leucite-reinforced	7	2	1	0

difference in load to failure for different ceramic materials (lithium disilicate glass ceramic or leucite-reinforced glass ceramic).

In summary, the fracture resistance of posterior partial coverage restorations is affected relative to the choice of ceramic materials, but not relative to ceramic thickness. In general, 1.5 mm of occlusal thickness is recommended as a minimum for lithium disilicate ceramics. Previous studies[28] reported that the thickness of monolithic ceramic material had no effect on the failure distribution. Change in thickness would create minimal influences on overall flexural strength of the material. The results of the present study corroborate this finding and suggest that the thickness might be decreased to 1 mm when the ceramic is lithium disilicate–reinforced glass and when it is effectively bonded to the underlying tooth structure. This finding does not suggest a change in generalized preparation design; there is still a need to have adequate space in which to reproduce esthetic and functional anatomy. Instead, the results support the clinical acceptability of lithium disilicate glass ceramic as thin as 1 mm in thickness in areas of minimal occlusal clearance. Several specimens revealed fractured tooth structure after load. A causative reason for this could be that the load to failure was high enough to exceed the proportional limit of the tooth. It must also be considered that extracted human teeth offer large variation in quality and that the standardization of this type of specimen is difficult. Based on the results of load to failure, it is unlikely that the masticatory system approaches the type of loads used in the study unless the patient is the victim of blunt-force trauma. The average human bite forces for posterior teeth have been reported in the literature[29] to be a maximum of 500-600 N.

There are several limitations to the present study. The study was limited solely to loading in a vertical vector. Evaluation with varied loading vectors may provide information that more accurately reflects the dynamic nature of the oral environment. In addition to the traditional heat-pressed technique, CAD/CAM fabrication techniques are available in today's market. The leucite-reinforced and lithium disilicate glass ceramic restorations made with different fabrication techniques (heat pressed or CAD/CAM) can be considered for clinical trials to compare and confirm the effect of fabrication process on ceramics with similar compositions. However, this study provides further information on the *in vitro* strength of dental ceramics used for posterior partial coverage restorations, at the same time acknowledging the need for future studies that incorporate varied fabrication protocols and the challenges of the oral environment.

CONCLUSIONS

Within the limitations of this *in vitro* study, a lithium disilicate glass ceramic for partial coverage restorations significantly improved fracture resistance compared to a leucite-reinforced glass ceramic. The thickness of ceramic had no significant effect on fracture resistance when ceramics were bonded to the underlying tooth structure.

Acknowledgement

The authors would like express their gratitude to Ivoclar Vivadent for the donation of ceramic materials used in this study.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 4 July 2013)

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