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Original Article
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Effect of resin cement thickness and ceramic thickness on fracture resistance of enamel-bonded ceramic

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Abstract

Objective This study aimed to evaluate the fracture resistance of enamel-boned ceramic with variations in cement and ceramic thickness.

Materials and methods Leucite-reinforced and lithium-disilicate porcelain laminates (0.5 and 1 mm thick) were fabricated and cemented to human enamel using bonding agent and resin cement with the thicknesses of 30 and 100 µm. Non-cemented porcelain laminate was used as control. Fracture load (Newton) was obtained by pressing a 2 mm-diameter indenter rod against ceramic until the laminates fractured. Independent t-tests were used to compare mean fracture loads (MFL).

Results The results obtained from both type of ceramic were in the same trend. No difference in MFL between two test groups was found between 0.5 mm laminate groups (leucite-reinforced ceramic: 30 µm-771.56 ± 107.35; 100 µm-810.06 ± 110.26; lithium-disilicate ceramic: 30 µm-2471.81 ± 339.52; 100 µm-2666.58 ± 245.15). On the other hand, when laminate thickness was 1 mm, MFL of 30 µm group was significantly higher than that of 100 µm group (leucite-reinforced ceramic: 30 µm-2666.20 ± 220.46; 100 µm-1748.39 ± 245.24; lithium-disilicate ceramic: 30 µm-3547.38 ± 310.30; 100 µm-2622.17 ± 256.99).

Conclusion The effect of cement thickness was clearly observed when the thickness of porcelain laminate was 1 mm. An increase in cement thickness from 30 to 100 µm could significantly decrease the enamel-bonded ceramic strength. When the thickness of porcelain laminate was 0.5 mm, no significant effect of cement thickness was observed.

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Key words: *cement thickness; compressive fracture resistance; leucite-reinforced ceramic; lithium disilicate ceramic; porcelain laminate veneers*

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Introduction

Nowadays, the need for esthetic dental treatment is continually increasing because more and more people desire a bright, smooth, harmonious smile. Available treatments can include either tooth whitening, orthodontic treatment,[1] minimal reshaping and realignment of anterior teeth,[2,3] or porcelain laminate veneers (PLVs) can also be proposed as a treatment plan.[4-7]

Many reports in the literature have demonstrated an excellent outcome of PLVs.[8-21] Major factors associated with the strength and durability of PLVs include bonding quality of the ceramic to the tooth structure,[10] the adhesive cementation, and the thickness of the ceramic itself.[22] The use of PLVs has become more reliable as bonding procedure has improved.[23] PLVs are sometimes designed to cover the occlusal surface of the tooth. That means the restorations have to bear normal chewing force, which averages 400-500 N at the mandibular first molar.[24]

Factors causing failure of PLVs include occlusion, preparation design, adhesive used, presence of composite fillings,[16] and compromised bonding with dentine.[10,25] If the enamel surface is compromised, a full-coverage crown should be considered instead.[26]

The first kind of ceramic used in dentistry to fabricate PLVs was feldspathic porcelain. This type of porcelain can provide a superior natural look, translucency, and internal characteristics of the restorations.[27] Later, leucite-reinforced and lithium disilicate ceramics were introduced. They possess higher compressive and flexural strength, and esthetics comparable to feldspathic porcelain.[28,29] Even in a case of moderate tooth discoloration, these ceramics can acceptably mask the underlying color.[30] Consequently, these two materials gain more and more popularity in Thai dental market.

The strengthening mechanism of a leucite-reinforced ceramic is the difference in the coefficients of thermal expansion (CTE) between the glass phase and the crystal phase (35-45% leucite crystals); while lithium disilicate (IPS e.max; IvoclarVivadent) consists of approximately 70% needle-like crystals. The difference in crystal shape and fraction contributes to the increased strength of lithium disilicate ceramic. These qualities result in an increase in strength and provide these ceramics with flexural strength of 160 MPa and 400 MPa, respectively.[28] As a result, these materials are ideally suited for veneers, inlays, onlays and crowns.[29,31,32] Also, these materials are gaining their popularity in Thailand.

Until today, few studies have investigated ceramic strength in association with tooth structure and cementation. Recent study of Piemjai and Arksornnukit showed that porcelain laminate was more resistant to fracture when adhesively bonded to the enamel surface rather than the dentin surface.[33] Other studies concluded that luting film thickness had a significant effect on bond strength[34] and ceramic strength.[22,35] Nonetheless, no study has yet evaluated the effect of cement thickness on the fracture resistance of both leucite-reinforced and lithium disilicate PLVs cemented to the enamel surface. Therefore, the aim of this study was to investigate whether resin luting film thickness had a significant effect on the strength of the bonded ceramic, by means of load to fracture testing.

Materials and methods

Fabrication of tooth structure samples

Collected human lower third molars were stored at 4°C in a solution of 0.1% thymol for 24 h, followed by placing in a solution of normal saline. Only sound teeth were included. Teeth were grinded on the buccal side using a carborundum disc with water coolant in order to achieve a flat area of at least 3 x 6 mm^2. The flat surface was then polished with a series of sandpaper discs (OptiDisc; Kerr Corporation, CA, USA) If there was dentin exposure, the specimen was excluded from the study.

Next, each tooth was sectioned with an IsoMet low-speed saw (Buehler, Lake Bluff, IL, USA) in order to obtain specimens with dimensions of 3 x 6 x 4 mm^3. The specimens were embedded in unfilled resin, with the flat, polished enamel surface exposed.

Fabrication of ceramic specimens

Wax specimens, 0.5 mm and 1 mm thick, were made using customized molds in order to control the dimensions of each wax (3.5 x 6.5 mm^2) Ingots used were IPS Empress Esthetic (IvoclarVivadent, Schaan, Liechtenstein (Lot#KM0486)) ETC2 and IPS e.max Press (IvoclarVivadent, Schaan, Liechtenstein (Lot#M72418)) LT shade A3. All of the porcelain laminates were fabricated by a one dental technician (S.K. Dental Laboratory, Bangkok, Thailand) in accordance with the manufacturer's recommendations.

After the porcelain laminates were divested, their dimensions were measured using an electronic digital caliper (Mitutoyo, Japan) to ensure the desired size and uniform thickness of each specimen.

Surface treatment of ceramic specimens

The internal surface of each porcelain laminate was first etched with porcelain etchant according to manufacturer's instruction (4% HF; Bisco, Schaumburg, IL, USA): 1 min for IPS Empress Esthetic, and 20 sec for IPS e.max. After the ceramic surface was washed and dried, silane primer (Kerr Corporation, CA, USA, Lot #4403066) was applied. While waiting to be cemented, the treated ceramic specimens were kept away from light.

Preparation of enamel surface

The enamel surface was etched with a microbrush dipped in gel etchant (37% phosphoric acid; Kerr Corporation, CA, USA, Lot#4346594) for 30 sec. Next, the gel was rinsed off and the etched surface was blot-dried with gauze. Then OptiBond FL Adhesive (Kerr Corporation, CA, USA, Lot#4346594) was applied and light-cured with an Elipar^{TM} S10 LED curing light (3M ESPE, Seefeld, Germany).

Cementation process

The prepared enamel and porcelain laminates were randomly assigned to 4 control and 8 test groups as shown in Table 1. There were 12 samples in each group. Light-cured resin cement (NX3 Nexus third generation, Kerr Corporation, CA, USA, Lot#4285136) was applied on the prepared enamel surface. Then a prepared porcelain laminate was vertically pressed, treated surface down, with a 1,000-gram durometer for 10 sec; meanwhile, excess cement oozed out. If the sample belonged to the 30 µm group, porcelain laminate would be placed on the cement without any spacer. If the sample belonged to the 100 µm group, two folds of a 50-µm-thick celluloid strip would be placed between the enamel surface and the ceramic bar at both ends as a spacer to control cement thickness. After removal of excess cement, 20 second-light-activation was performed with an Elipar S10 curing light five times per specimen in different directions. Light intensity was checked by a radiometer (Optilux model 100; Kerr Corporation, CA, USA) to ensure constant light intensity (600 mW/cm^2) for every specimen.

Prior to the experiment, pilot study was carried out to determine if the constant thickness of cement could be obtained. The authors found that a thickness of 30 µm was reproducible if the porcelain laminate was pressed with 10N force for 10 sec. Meanwhile, the cement film thickness of 100 µm was controlled by inserting a spacer between the enamel surface and the porcelain laminate while cementing with a pressing force of 10N for 10 sec. The chosen spacer was two folds of a celluloid strip of known thickness (50 µm). These methods of cementation ensured a constant cement thickness. To verify the thickness of the cement, the specimens were cross-sectioned and observed under a stereomicroscope.

All cemented specimens were stored in 37°C deionized water for 24 h before testing to allow possible post-cure polymerization of the luting cement.

Fracture resistance test

A unit of porcelain laminate cemented on the enamel surface was subjected to a compressive test using a universal testing machine (Instron model 5566, Canton, MA, USA) at a crosshead speed of 0.5 mm/min. The crosshead surface was flat and circular, 2 mm in diameter. The tin foil was placed between the cross head tip and porcelain laminate. The crosshead of the testing machine stopped when a sudden drop appeared on the recording chart as a result of catastrophic failure. All fracture loads were recorded in Newton (N).

Data analysis was done using SPSS version 16 for Windows. Independent t-tests were performed to find difference of MFL between test groups in the same type of ceramic ($\alpha = 0.05$).

Results

Unluted ceramic in control groups had lower MFLs comparing to luted groups, regardless of the ceramic type and thickness.

For leucite reinforced ceramic 0.5 mm, there was no statistical difference in MFL between the 30 µm and 100 µm groups ($p > 0.05$). On the other hand, for the 1.0 mm groups, the MFL of the 30 µm group was significantly higher than that of the 100 µm group ($p < 0.05$). The group with a 1.0-mm porcelain laminate using 30-µm cement exhibited the highest MFL among all the leucite reinforced groups.

The results obtained from testing lithium disilicate groups were in accordance with those from leucite reinforced groups, i.e. there was no significant difference between the 0.5-mm test groups, while the 1-mm test groups exhibited a significant difference ($p < 0.05$).

Discussion

This study tested the compressive fracture resistance of two types of ceramic cemented to human enamel tooth surfaces with light-cured resin cement. There were 2 thicknesses of each ceramic type: 0.5 mm and 1 mm and 2 thicknesses of cement film: 30 µm and 100 µm. Because of the difficulty in finding incisors and variation in enamel thickness caused by aging of the teeth, lower third molars of the same size were selected instead, so that the thickness of the remaining enamel after being flattened down would be comparable. Consequently, the results demonstrated here might not be fully reflected the real clinical situations. Although the precise thickness of the remaining enamel could not be controlled, the tooth selection procedure may help lessen the variation in thickness.

The fabricated porcelain laminates were cemented with light-cured resin cement to simulate porcelain laminates cemented on human teeth. Many previous studies have utilized a similar specimen design, e.g. Prakki *et al.*[22] and Scherrer *et al.*[35]

According to Christensen and Christensen,[11] an acceptable resin cement film thickness should be no more than 120 μm. Consequently, this study chose thicknesses of 30 μm and 100 μm. Moreover, these thicknesses were reproducible in the pilot experiment.

In the non-cement groups, the MFLs were much lower owing to the fact that ceramic was strong to compression, weak to tension, and brittle. This finding was in accordance with Prakki *et al.*[22], who found that unluted groups had lower fracture loads compared with luted groups, and that thin ceramic groups had lower

Table 1 Mean fracture load (N), standard deviation (SD), and statistical analysis

Group	Ceramic type and thickness	Cement thickness	MFL (SD)
1	Leucite-reinforced 0.5 mm	Control (no cement)	15.51 (2.97) *a*
2		30 μm	771.56 (107.35)
3		100 μm	810.06 (110.26)
4	Leucite-reinforced 1.0 mm	Control (no cement)	58.02 (15.32) *a*
5		30 μm	2,666.20 (220.46)
6		100 μm	1,748.38 (245.24)
7	Lithium-disilicate 0.5 mm	Control (no cement)	47.09 (7.02) *a*
8		30 μm	2,471.81 (339.51)
9		100 μm	2,666.58 (245.15)
10	Lithium-disilicate 1.0 mm	Control (no cement)	145.88 (25.01) *a*
11		30 μm	3,547.38 (310.30)
12		100 μm	2,622.17 (256.99)

MFL: mean fracture load (N); SD: standard deviation. n = 12; α = 0.05; Vertical lines indicate a significant difference. *a*; Generally, regardless of ceramic type and thickness, MFL of samples with cement thickness (either 30 or 100 μm) is higher than samples without cement (control group)

MFLs compared with thick ceramic groups. Scherrer *et al.*[35] also gave additional reasons for this finding. They stated that treating the ceramic surface with hydrofluoric acid and the silanization process, together with cementation with resin cement, smoothed out the sharp edges and roughness of the surface flaws. Moreover, Addison, Marquis, and Fleming concluded that resin cement created a resin-ceramic hybrid layer and modified stress patterns during tensile loading.[36]

This study evaluated two types of ceramic, leucite-reinforced ceramic and lithium disilicate ceramic (Empress Esthetic and e.max), fabricated into two thicknesses and cemented with two film thicknesses of cement. There was no significant difference found for 0.5 mm Empress Esthetic between the 30 µm cement group and the 100 µm cement group. Likewise, for 0.5 mm e.max groups there was no significant difference in fracture load between the 30 µm cement group and the 100 µm cement group as shown in Table 1. The reason for these findings might be that the ceramic was so thin that the effect of the different cement film thickness was not easily observed. Anyway, at a ceramic thickness of 0.5 mm, e.max still demonstrated a higher fracture load compared with Empress Esthetic. The materials' own mechanical property played a role in this significant difference.[27]

On the contrary, when the ceramic sample thickness was increased to 1 mm, fracture load significantly increased in both Empress Esthetic and e.max groups. This finding was in accordance with the publication of Kelly JR, the bonded ceramic would sustain less stress at 0.5 mm.[38] Within the same ceramic group, the MFL of the 100 µm cement group was significantly lower than that of the 30 µm cement group as shown in table 1. The thicker ceramic can tolerate the tension generated at the opposite side of the compression better than the thinner ceramic.[37] When a ceramic specimen was uniformly bonded to a less stiffer cement, high tensile stress developed in the ceramic at ceramic-cement interface right below the load.[38] Furthermore, the thicker the cement was, the more the ceramic would subside.[39] These factors may explain why the effect of thicker cement can be clearly seen in the 1 mm ceramic groups.

The present results reflected a similar trend to the findings of Scherrer *et al.*[35], who demonstrated a lower fracture load for ceramics cemented with thicker cement (297 µm: 2.02 kN) compared with ceramics cemented with thinner cement (26 µm: 2.30 kN). Also, Tuntipraworn,[39] whose study results showed a similar trend, concluded that thicker cement resulted in the lower fracture strength of a porcelain jacket crown.

The study by Prakki *et al.,*[24] however, did not show the same results. There were many differences in the materials and methods used. Ceramic was cemented to dentin with RelyX ARC (3M ESPE, St. Paul, MN, USA). Ceramic plates were fabricated from Duceram Plus (Degussa, Rosbach, Germany). The thicknesses of the ceramic were 1 and 2 mm. Cement thicknesses were 100, 200, and 300 µm. The study demonstrated that the fracture load of the 300 µm group was statistically lower than that of the 100 µm group. Nevertheless, the differences in setting, as stated earlier, made it difficult to directly compare the results from that study with the current study.

Leucite-reinforced and lithium disilicate ceramics are steadily gaining in popularity because of their versatility of use and the promising results of the monolithic all-ceramic concept. Future investigations should continue to utilize the types of ceramic used in this study, varying the thicknesses of ceramic and cement, to better simulate the clinical situation of a crown cemented to dentin.

Conclusions

The thicker cement group (100 μm) showed a decreased mean fracture load for the 1 mm ceramic plates only. On the contrary, no significant difference was found for the 0.5 mm group. This was the case for both types of ceramics tested. Non-cemented ceramics showed a significantly lower mean load to fracture than cemented ceramics. These results were also found in both types of ceramics tested.

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ผลของความหนาของเรซินซีเมนต์และเซรามิกต่อความต้านทานการแตกของเซรามิกที่ยึดกับเคลือบฟัน

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บทคัดย่อ

วัตถุประสงค์ เพื่อศึกษาผลของความหนาของเรซินซีเมนต์และความหนาของเซรามิกต่อความต้านทานการแตกของเซรามิกที่ยึดกับผิวเคลือบฟัน

วิธีการทดลอง ยึดชิ้นเซรามิกชนิดลูไซต์รีอินฟอร์ซ และลิเธียมไดซิลิเกตที่หนา 0.5 และ 1 มม. กับผิวเคลือบฟันมนุษย์ด้วยเรซินซีเมนต์ที่หนาแตกต่างกัน (30 และ 100 ไมโครเมตร) กลุ่มควบคุมคือเซรามิกที่ไม่ได้ยึดกับผิวเคลือบฟัน แล้วนำไปทดสอบความต้านทานการแตกชนิดแรงอัดด้วยหัวกดหน้าตัดรูปวงกลมรัศมี 1 มม. บันทึกเป็นค่าแรงที่กดจนเซรามิกแตก (นิวตัน) ผลการทดลองที่ได้วิเคราะห์ด้วยสถิติ independent t-test ที่ระดับนัยสำคัญ 0.05

ผลการทดลอง ผลของเซรามิกทั้งสองชนิดออกมาในแนวทางเดียวกันคือ ในพวกกลุ่มเซรามิกที่หนา 0.5 มม. ไม่พบความแตกต่างของค่าแรงกดแตกเฉลี่ยระหว่างกลุ่มซีเมนต์หนา 30 และ 100 ไมโครเมตร (ลูไซต์รีอินฟอร์ซ: 30 ไมโครเมตร-771.56 ± 107.35; 100 ไมโครเมตร-810.06 ± 110.26; ลิเธียมไดซิลิเกต: 30 ไมโครเมตร-2471.81 ± 339.52; 100 ไมโครเมตร-2666.58 ± 245.15) ส่วนกลุ่มที่หนา 1 มม. ค่าแรงกดแตกเฉลี่ยของกลุ่มซีเมนต์ 30 ไมโครเมตรสูงกว่าของกลุ่ม 100 ไมโครเมตรอย่างมีนัยสำคัญ (ลูไซต์รีอินฟอร์ซ: 30 ไมโครเมตร-2666.20 ± 220.46; 100 ไมโครเมตร-1748.39 ± 245.24; ลิเธียมไดซิลิเกต: 30 ไมโครเมตร-3547.38 ± 310.30; 100 ไมโครเมตร-2622.17 ± 256.99)

สรุป เมื่อเซรามิกหนา 0.5 มม. จะไม่พบความแตกต่างของแรงกดแตกเฉลี่ยเมื่อซีเมนต์หนาต่างกัน ในขณะที่เซรามิกที่หนา 1 มิลลิเมตร ซีเมนต์ที่หนาส่งผลให้ค่าแรงกดแตกเฉลี่ยลดลงอย่างมีนัยสำคัญ และการยึดเซรามิกกับผิวเคลือบฟันด้วยเรซินซีเมนต์ทำให้ค่าแรงกดแตกเฉลี่ยของเซรามิกเพิ่มขึ้น

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