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Effect of deep margin elevation with resin composite and resin-modified glass ionomer on marginal sealing of CAD/CAM ceramic inlays: an in vitro study

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Effect of deep margin elevation with resin composite and resin-modified glass ionomer on marginal sealing of CAD/CAM ceramic inlays: an in vitro study

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A Thesis Submitted in Partial Fulfillment of the Requirements
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การศึกษาผลการยกระดับขอบโพรงฟันด้วยเรซินคอมโพสิต และเรซินมอดิฟายด์กลาสไอโอโนเมอร์ ซีเมนต์ ต่อการผนึกขอบบนวัสดุเซรามิคอินเลย์ที่ใช้เครื่องคอมพิวเตอร์ออกแบบและผลิตชิ้นงาน ในห้องปฏิบัติการ

น.ส.จรัสวรรณ วิจิตรโกเมน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	Effect of deep margin elevation with resin composite and resin-modified glass ionomer on marginal sealing of CAD/CAM ceramic inlays: an in vitro study
By	Miss Jaraswan Vichitgomen
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor SIRIVIMOL SRISAWASDI, D.D.S., M.S., Ph.D.

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จรัสวรรณ วิจิตรโกเมน : การศึกษาผลการยกระดับขอบโพรงฟันด้วยเรซินคอมโพสิต และเรซินมอดิฟายด์กลาสไอโอโนเมอร์ซีเมนต์ ต่อการผนึกขอบบนวัสดุเซรามิคอินเลย์ที่ใช้เครื่องคอมพิวเตอร์ออกแบบและผลิตชิ้นงาน ในห้องปฏิบัติการ. (Effect of deep margin elevation with resin composite and resin-modified glass ionomer on marginal sealing of CAD/CAM ceramic inlays: an in vitro study) อ.ที่ปรึกษาหลัก : รศ.ทพญ. ดร.ศิริวิมล ศรีสวัสดิ์

วัตถุประสงค์ เพื่อประเมินความสามารถในการผนึกขอบของวัสดุบูรณะต่างชนิดในการยกระดับขอบโพรงฟันบนวัสดุบูรณะด้วยลิเทียมซิลิเกตที่เสริมความแข็งแรงด้วยเซอร์โคเนีย (ZLS) โดยใช้เครื่องคอมพิวเตอร์ออกแบบและผลิตชิ้นงาน (CAD/CAM) การศึกษาโพรงฟันทั้งหมด 30 ตัวอย่าง ได้ถูกเตรียมให้มีขอบด้านเหงือกที่ด้านประชิดต่ำกว่ารอยต่อเคลือบฟันกับเคลือบรากฟัน ชิ้นตัวอย่างได้ถูกกระจายแบบสุ่มเป็นจำนวน 3 กลุ่ม กลุ่มที่ 1 กลุ่มควบคุม ไม่มีการยกระดับขอบโพรงฟัน ขอบอินเลย์วางบนเนื้อฟันโดยตรง กลุ่มที่ 2 และ3 คือ กลุ่มเรซินคอมโพสิต และกลุ่มเรซินมอดิฟายด์กลาสไอโอโนเมอร์ ได้ถูกทำการยกระดับขอบโพรงฟันให้อยู่เหนือรอยต่อเคลือบฟันกับเคลือบรากฟันด้วยเรซินคอมโพสิต และเรซินมอดิฟายด์กลาสไอโอโนเมอร์ ตามลำดับ ชิ้นงานวัสดุบูรณะด้วยลิเทียมซิลิเกตที่เสริมความแข็งแรงด้วยเซอร์โคเนีย ถูกยึดด้วยยูนิเวอซอลบอนดิ้ง และเซลฟ์แอดฮีซีฟเรซินซีเมนต์ ตัวอย่างทั้งหมดได้ถูกเพิ่มอายุโดยการแช่น้ำเป็นเวลา 6 เดือน ความสามารถในการผนึกขอบได้ถูกประเมินด้วยกล้องจุลทรรศน์สเตอริโอ (Stereomicroscope) กำลังขยาย 40 เท่า โดยพิจารณาจากค่าความลึกของการแทรกซึมของซิลเวอร์ไนเตรต ตามแนวขอบของวัสดุหรือโพรงฟันที่กำหนด ผลการศึกษา การทดสอบทางสถิติครัสคอล-วาลลิส (Kruskal-Wallis test) และการทดสอบทางสถิติแมน-วิตนี่ย (Mann-Whitney U test) พบว่า ที่บริเวณผิวเนื้อฟัน กลุ่มควบคุมและกลุ่มเรซินคอมโพสิต มีค่ารอยซึมเล็ก (microleakage score) ที่ไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติ (alpha = 0.05) ในขณะที่ กลุ่มเรซินมอดิฟายด์กลาสไอโอโนเมอร์ มีค่ารอยซึมเล็กที่มากกว่ากลุ่มควบคุมและกลุ่มเรซินคอมโพสิตอย่างมีนัยสำคัญทางสถิติ (alpha = 0.05)

สรุป เมื่อมีข้อบ่งชี้ของการยกระดับโพรงฟัน เรซินคอมโพสิตทำงานได้ดีกว่าเมื่อเปรียบเทียบกับเรซินมอดิฟายด์กลาสไอโอโนเมอร์ ในแง่ของความสามารถในการผนึกขอบ

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

6175802132 : MAJOR ESTHETIC RESTORATIVE AND IMPLANT DENTISTRY
KEYWORD: Deep margin elevation, Marginal sealing

Jaraswan Vichitgomen : Effect of deep margin elevation with resin composite and resin-modified glass ionomer on marginal sealing of CAD/CAM ceramic inlays: an in vitro study. Advisor: Assoc. Prof. SIRIVIMOL SRISAWASDI, D.D.S., M.S., Ph.D.

Purpose. To evaluate the marginal sealing ability of different restorative materials used in deep margin elevation (DME) on zirconia-reinforced lithium silicate CAD/CAM ceramic restoration. Methods. A total of 30 Class II cavities were prepared in freshly extracted human molars with the proximal gingival margin located 1 mm below the cemento-enamel junction (CEJ). All specimens were randomly assigned to one of three groups (n=10): control group, resin composite group (Filtek™ Z350 XT), and resin-modified glass ionomer group (Vitremer™ Tricure). In group 1, control group, no DME was performed. The inlay margin of the control group was placed directly onto dentin. In groups 2 and 3, DME was used to elevate the margin to 1 mm above the CEJ with resin composite and resin-modified glass ionomer, respectively. Zirconia-reinforced lithium silicate CAD/CAM ceramic restorations were then bonded onto all specimens with a universal bonding and self-adhesive resin cement. All specimens were aged by water storage for 6 months. Marginal sealing ability at different interfaces was evaluated with a stereomicroscope at a 40x magnification by scoring the depth of silver nitrate penetration along the adhesive surfaces. Statistical differences between groups were analyzed using the Kruskal-Wallis and Mann- Whitney U tests. Results. At the dentin interface, there was no significant difference in microleakage scores in the control group and resin composite group ($p = 0.577$); however, the RMGI group had a significantly higher microleakage compared to the control group ($p = 0.004$) and resin composite group ($p = 0.007$). Conclusion. When DME is indicated, resin composite performed better as a DME material when compared to RMGI in terms of marginal sealing ability.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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Jaraswan Vichitgomen

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CHAPTER I INTRODUCTION

Rationale and Significance of the Problem

Resin composite materials have been developed for direct restorations of the carious lesion and have been improved for aesthetic dental treatment.[1-6] At present, restoring a large dental cavity with margins extending deep into the proximal area, below the cemento-enamel junction has been a common clinical situation.[7] In large cavities, problems that mostly occurred when restoring deep proximal area were biological problems and technical operative problems.[8] Two possible ways to regain the necessary space were surgical crown lengthening or orthodontic movement.[9, 10] Technical problems, such as impression taking process in the subgingival area, adhesive cementation, finishing and polishing of the margin, were related to the inferior visibility of access to the deep parts of the cavity.[11] Moreover, insufficient isolation of the operating area led to improper moisture control, blood and/or saliva contamination which negatively affected the final restoration longevity. Therefore, the concept of

deep margin elevation has been brought up as an alternative to surgical crown lengthening.[12]

Deep margin elevation is a less invasive alternative procedure to relocate the proximal cavity margin from subgingival to supragingival position using direct restorative techniques before placing an indirect restoration.[13] According to previous literature, deep margin elevation was generally completed with resin-based materials. Another alternative margin elevation material is resin-modified glass ionomer (RMGI).[14-17]

At the subgingival margin, the problem of limiting or no enamel present still remained and left only dentin and cementum as the main substrates for adhesion.[18] Adhesion to dentin depended on numerous factors related to the substrate morphology, the type of adhesive, and application technique sensitivity.[5, 19, 20] Therefore, bonding to deep cervical dentin margin might not be predictable and safe as bonding to enamel[21], and might be associated with higher risks of microleakage, bacterial penetration, hypersensitivity, and secondary caries.[22]

Various types of ceramics, available in the market, have been improved in strength, esthetics, and method of fabrication. In recent years, zirconia-reinforced lithium silicate ceramic (ZLS), has been launched and claimed that 10% by weight zirconia could reinforce the material. ZLS combines the positive mechanical characteristics of the zirconia with the glass-ceramic esthetic appearance. Nowadays, computer-aided-design and computer-aided-manufacturing (CAD/CAM) technology has grown in popularity with the development of machine-made esthetic restoration by providing more conservative and simplified restorative procedures to increase the longevity of restorations.[23, 24] Restorations of large cavity defects utilizing indirect CAD/CAM technique have been proven as a reliable procedure over long term periods.[25] There have been few studies reporting the effect of marginal sealing of indirect restoration with deep margin elevation focusing on one material with different viscosities.[26, 27] However, no research has been done on the effect of deep margin elevation with a different material, such as resin composite or resin-modified glass ionomer, on marginal sealing of CAD/CAM zirconia-reinforced lithium silicate ceramic (ZLS).

Research question

Do different restorative materials used in deep margin elevation affect marginal sealing ability of ZLS and dentin after aging?

Research Objective

To evaluate the marginal sealing ability of different restorative materials used in deep margin elevation on zirconia-reinforced lithium silicate CAD/CAM ceramic restoration.

Hypotheses

Null Hypotheses

1. There is no significant difference in the marginal sealing ability between different restorative materials performed with deep margin elevation technique on zirconia-reinforced lithium silicate CAD/CAM ceramic inlay.

2. There is no significant difference in the marginal sealing ability between restorations performed with and without deep margin elevation technique on zirconia-reinforced lithium silicate CAD/CAM ceramic inlay.

Alternative Hypotheses

1. There is at least one significant difference in the marginal sealing ability between different restorative materials performed with deep margin elevation technique on zirconia-reinforced lithium silicate CAD/CAM ceramic inlay.

2. There is at least one significant difference in the marginal sealing ability between restorations performed with and without deep margin elevation technique on zirconia-reinforced lithium silicate CAD/CAM ceramic inlay.

Conceptual Framework

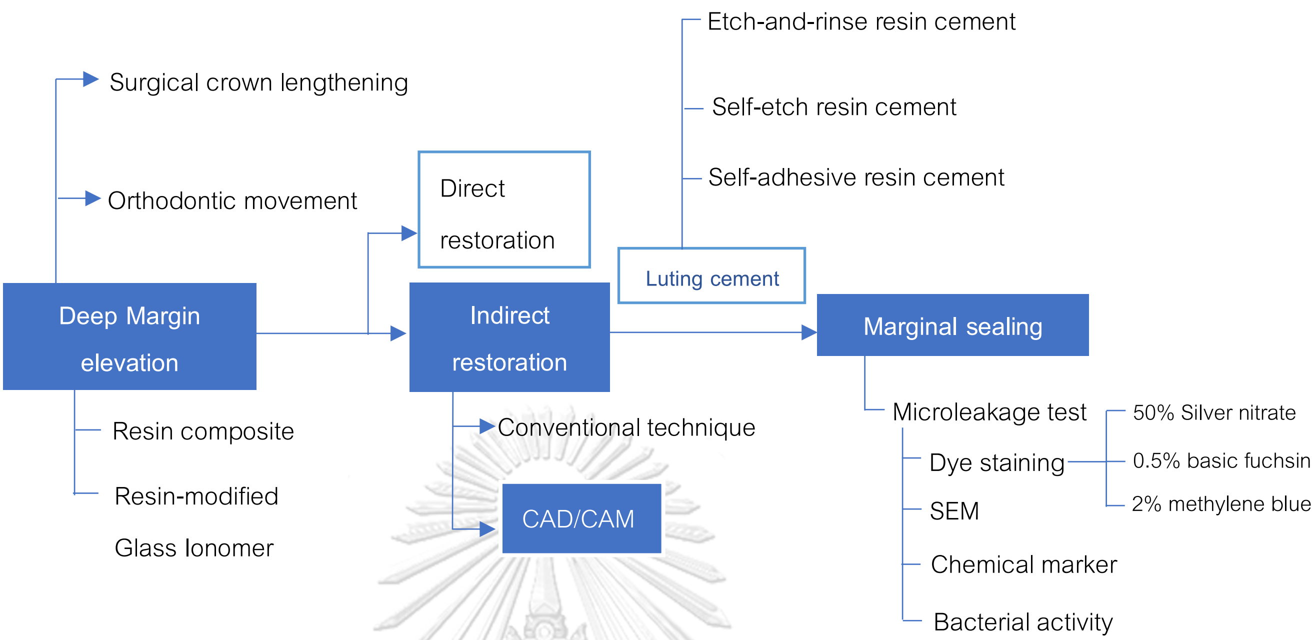


Figure 1. Conceptual Framework

Keyword

Deep margin elevation, marginal sealing

Expected benefit of the study

Outcome of this study may provide useful information regarding the use of deep margin elevation in deep proximal cavity restored with zirconia-reinforced lithium silicate ceramics indirect restoration.

CHAPTER II REVIEW OF THE LITERATURES

The literatures in the following topics were reviewed.

1. Deep margin elevation
2. Adhesive systems
3. Luting cement
4. Dental Chairside CAD/CAM Ceramic Materials
5. Marginal sealing
6. Aging process

1. Deep margin elevation (DME)

In 1998, the technical term named cervical margin relocation (CMR) was initially proposed by Dietschi and Spreafico[28], suggesting the possibility to relocate the cervical margin supragingivally by applying proper increment of resin composite over the existing margins.[28] In 2012, deep margin elevation referring to the same technique was

introduced by Magne and Spreafico.[29] This technical name has been refined by several authors; for instance, cervical margin relocation[21], and proximal box elevation.[30-35] According to the literature, deep margin elevation was typically completed by placing of direct resin-based composite with or without a matrix to elevate the gingival margin underneath indirect restorations.[36] An alternative margin elevation material was water-based, hydrophilic material placed in conjunction with the open-sandwich technique. It is commonly accepted that glass ionomer cement (GICs) possesses several benefits over current resin-based composite systems, which include fluoride release, chemical adhesion to tooth structure, pulpal biocompatibility, comparable elastic modulus to dentin, bacterial (*Streptococcus mutans*) resistance, biocompatibility to periodontal tissues, lower contraction stress, and self-polymerization benefit specific to GICs.[14, 37, 38]

Deep margin elevation procedure has the potential to save time, and resources, especially biological tissue. It has been widely accepted that this biologic width must be respected when restorative procedures were performed, otherwise, it could lead

to an inflammatory response from the periodontium due to microbial biofilm on restorations placed in deep areas. Clinically, this reaction led to gingivitis or periodontitis, including loss of attachment, periodontal pocket formation, bleeding suppuration, swelling, and gingival recessions.[39]

The biological problems in deep proximal cavities often refer to possible violation of the biological width, distance less than 3 mm between the restorative margins and the alveolar crest, which could cause detrimental effects on neighboring soft and hard periodontal tissues. Furthermore, excess material at deep subgingival level was hardly detectable and removable.[35] Supragingival repositions of deep margin provided isolation and improvement in impression taking procedure when the gingival margin of Class II interproximal cavity could not be isolated with rubber dam alone, in alternative to perform surgical crown lengthening, and particularly in adhesive cementation process which was the mandatory factors influencing success of the restorations.[40] Therefore, in certain situations, deep margin elevation could be one of the possible adjunctive solutions for clinicians and patients to choose from.[29]

Limited or no enamel present at deep cervical margins, leaving only dentin and cementum as the main substrates for adhesion, was the problem of extensive subgingival defects regardless of the technique applied.[18] Adhesive bonding to etched enamel was proved to be efficient and stable.[18] On the other hand, adhesion to dentin depended on numerous factors related to substrate morphology[19], type of the adhesive[20], and sensitive application technique.[5] Therefore, adhesive bonding to deep cervical dentin could not be considered predictable and safe.

Several studies evaluated the effect of deep margin elevation on the marginal quality of the adhesively luted restorations by using scanning electron microscopy (SEM) to observe quality of margins on gold-sputtered epoxy resin replicas. Then they calculated the margin continuity before and after thermo-mechanical loading (TML), following the well-established protocol in accordance with previous studies.[13, 30, 31, 33]

Frankenberger et al. reported that restoration placed with conventional technique showed superior marginal adaptation compared to deep margin elevation technique after being subjected to thermo-mechanical loading.[31] Most studies found

that the integration at enamel and dentin interfaces and at inlay with luting composite margins significantly deteriorated after thermo-mechanical loading. However, Thermo-mechanical loading did not affect marginal quality regardless of the materials tested.[13, 30, 31, 33-35, 41]

To evaluate whether polymerization shrinkage of composite material used for DME could affect the quality of the margins. Zaruba et al. stated that two 1.5-mm increments of a fine hybrid composite applied for DME did not perform any better than one 3-mm increment, in terms of marginal adaptation of the final restoration.[13] On the contrary, Frankenberger et al. and Roggendorf et al. showed that marginal integration to dentin of a restorative composite was improved when composites were layered in three consecutive 1-mm increments when compared to one 3-mm increment.[30, 31] Juloski et al. also stated that DME technique with multiple layer application achieved better performance in terms of marginal quality to dentin compared to a single layer application.[21]

For the materials used in deep margin elevation, only one study from Grubbs et al. showed that the materials used for deep margin elevation, such as RMGIs, GICs, resin composite, and bulk fill composite, did not influence results in terms of marginal quality and fracture resistance.[36] One study focused on the microtensile bond strength (µTBS) of composite inlays to proximal box floor.[34] The results showed that µTBS value increased in group elevated with composite using self-adhesive resin cement. Conversely, in etch-and-rinse adhesive, there was no significant difference between the group with DME and no DME.[34]

Concerning the marginal sealing ability of DME, a study by Köken et al. investigated the effect of DME with different viscosity resin composites. The results showed that leakage score at dentin interface was not significantly different between the two tested resin composite groups, but was significantly lower in the control group. It was concluded that the performance of different viscosity composites, as indicated by marginal sealing ability, were comparable for DME.[26]

The performance of the DME technique on indirect restoration was evaluated by many researchers and had acceptable results. However, no data is focusing on the effectiveness of the DME technique on the marginal sealing ability using different restorative materials. This brings to the research question of this study.

2. Adhesive systems

The applications of dental adhesive systems are generally characterized by three different substances: etching, priming, and bonding. Etching is the application of an acid agent to demineralize the dental substrate surface. Priming is the preparation of the etched surface before the application of the adhesive. Bonding is the application of the hydrophobic resin bond adhesive over enamel and dentin.

The adhesives could be classified by the bonding strategies, as etch-and-rinse systems and self-etching systems.[22] The etch-and-rinse systems require phosphoric acid etching and rinsing of enamel and dentin prior to applying adhesive agents, whereas the self-etching systems contain acidic functional monomers which can condition both enamel and dentin simultaneously, without rinsing.

Etch-and-rinse systems could be classified as three-step etch-and-rinse adhesive and two-step etch-and-rinse adhesive.[42] They required an acid-etching step and rinsing of enamel and dentin before applying adhesive agents. Three-step etch-and-rinse adhesives involved the application of primer and adhesive separately, while two-step etch-and-rinse adhesives used a self-priming adhesive. Consequently, self-priming adhesives were more permeable to water, with the possible formation of water blisters at the resin-dentin interface.[43] In vitro studies found that three-step etch-and-rinse adhesives bonded more effectively, with a better marginal seal than two-step etch-and-rinse adhesives because the latter had more difficulty in removing all residual solvent which led to increased permeability. Moreover, the excessive presence of humidity resulted in incomplete monomer polymerization and water absorption in the hybrid layer that may cause degradation via resin hydrolysis.[43-45]

Universal adhesive has been introduced since 2011 in adhesive dentistry. This product is known as “multi-mode” or “multi-purpose” because it can be applied to bond tooth structure by etch-and-rinse technique or self-etch technique using the

same single bottle of adhesive solution. Moreover, manufacturers stated that universal adhesives could be used for the placement of both direct and indirect restorations and were compatible with self-cured, light-cured, and dual-cured resin-based cement, and could be bonded to metal, zirconia, porcelain, and composite. Selective-etch approach, phosphoric acid pre-etching at the enamel, was recommended to overcome the weakness of previous generation of single-step self-etch adhesives, and to achieve a durable bond to enamel.[46] Wagner et al. concluded that application of an etching step prior to universal adhesive application significantly improved their dentin penetration pattern and the bond strength values of the universal adhesives.[47]

3. Luting cements

One of the factors affecting the clinical success of an indirect restoration procedure depends on the cementation technique, creating a link between restoration and tooth. Luting cements available to date have been categorized into five main classes, which are zinc phosphate cements, polycarboxylate cements, glass-ionomer cements, resin-modified glass ionomer cements, and resin composite cements.[48] There

were no certain cement types suitable for all kinds of indirect restorative procedures. Proper application required understanding and awareness of pros and cons of each material.[48] Resin-composite cements have been widely used for luting all-ceramic crowns and fixed partial dentures. For glass-ceramics restorations, resin cements were clinically used to gain a strong and durable bond to enamel and dentin.[49] Resin cements were types of resin composite with lower viscosity and lower filler content. They consisted of fine inorganic filler particles and resin matrix, such as bis-GMA or urethane dimethacrylate.

Conventional resin cements could be categorized according to polymerization type: chemically activated (self-cured), photo-activated (light-cured), and dual-cured cement. Self-cured cements were commonly used for cementation of metallic restoration. Light-cured cements, on the other hand, had an indication limited to thin transparent restoration due to light intensity reduction. Dual-cured cements were manufactured to have a longer working time and the ability to convert to a high degree of conversion in the presence of light.[50] Resin cement can also be categorized by

adhesive system used either etch-and-rinse adhesive system or self-etching adhesive system. The disadvantages of these cements were the multi-step application technique which sometimes was considered to be technique sensitive and time-consuming.[51] Nowadays, development of resin cements as self-adhesive luting cements has become popular due to their simplicity with no pretreatment requirement of the tooth surface. Several studies have evaluated bond strength of self-adhesive resin cements compared to the conventional multi-step application technique. The results showed favorable bond strength behavior on dentin, while lower bond strength was found on enamel surfaces compared to those provided by multi-step luting agents.[52]

Clinically, if the adhesive bond or the adhesive bonding process is compromised, marginal microleakage between tooth and restorative material is likely to occur. Marginal leakage created potential for secondary caries and could result in further bond failure which progressed to pulpal pathology.[53]

4. Dental Chairside CAD/CAM Ceramic Materials

The uses of ceramic in restorative treatments have become popular and many of these restorations can be fabricated by both traditional laboratory methods and computer-aided design/computer-aided manufacturing (CAD/CAM) technique.[54] Some authors claimed that production and application of restorations prepared with CAD/CAM technology systems provided better performances than restorations performed with conventional laboratory procedures in terms of esthetic quality, clinical duration, and marginal precision.[55, 56]

During the past decade, new dental ceramic materials such as glass ceramics, poly-crystalline alumina, and zirconia-based ceramics have been successfully introduced. Most materials are now fully produced in an ideal industrial environment ensuring quality standards for CAD/CAM technology. Feldspathic ceramics, such as Vita Mark II, Vitablocs® TriLuxe, Triluxe Forte and RealLife® (Vita Zahnfabrik, Bad Sackingen, Germany), Cerec Blocs (Sirona Dental Systems, Bensheim, Germany) contain silicon oxide at about 60-64% by volume, and aluminum oxide at about 20-23% by volume.

Leucite-reinforced ceramic, such as IPS Empress CAD (Ivoclar-Vivadent, Schaan, Liechtenstein) was a glass-based ceramic containing particles of the crystalline mineral leucite in glass matrix. These materials were suitable for veneers, inlays/onlays, and single crowns. Although these materials had high esthetic properties, they were not considered to be strong enough for posterior load-bearing areas.[57] While lithium disilicate glasses, IPS e.max CAD (Ivoclar-Vivadent Schaan, Liechtenstein), were developed to enhance mechanical properties, and to increase the indications of material such as three-unit fixed dental prostheses in the anterior region. IPS E.max CAD had their flexural strength between 350MPa and 450MPa which was higher than leucite-reinforced dental ceramic.[57] The material was supplied in pre-crystallized metasilicate phase or blue state. At this stage, the block can be easily milled and must be recrystallized with heat treatment. Mechanical property of full-crystalized stage of this material increased after firing.[57]

In recent years, zirconia-reinforced lithium silicate (ZLS) was introduced as a new material for dental restoration. It combined the favorable esthetic appearance of

lithium disilicate glass-ceramic and the positive mechanical properties of zirconia. ZLS was based on a lithium-metasilicate (Li_2SiO_3) glass-ceramic, reinforced with about 10% of zirconium dioxide (ZrO_2), and crystallized by diphosphorus pentoxide (P_2O_5) as nucleation agent of lithium-metasilicate. According to the manufacturer's instructions, ZLS could be etched and cemented with adhesive systems.[58]

ZLS blocks are currently available at the pre-crystallized stage as Vita Suprinity® (VITA Zahnfabrik, Bad Sackingen, Germany), and at the fully crystallized stage as Celtra®Duo (Dentsply DeTrey). The CAM processing of ZLS Vita Suprinity is comparable with lithium disilicate ceramic materials in the aspect of crystallization. If requires crystallization firing at 840°C for 25 minutes after milling, to achieve the final density, whereas the ZLS Celtra Duo (Dentsply Sirona), a crystallized ceramic, which is suitable for chairside application as the final restoration ready to use after additional firing at 820°C for 8 minutes.[59] After the final crystallization process, ZLS is composed of four times smaller lithium silicate crystals than lithium disilicate glass-ceramic. The collected data proved that ZLS exhibited superior mechanical properties compared to

lithium-disilicate glass ceramics, and comparable to those of existing zirconia-based ceramics. The comparison with enamel also showed that the material was suitable for oral function, even in the posterior regions where the masticatory forces range between 600 and 900 N.[58]

CAD/CAM technology is easy to use, reduces laboratory materials, and saves time. CAD/CAM ceramics used in conjunction with the deep margin elevation technique offer the possibility to conserve tooth structure, improve esthetic, minimize cost, and ease adjustment and reparability.

5. Marginal sealing

Marginal discrepancy in the cemented restoration resulted in exposing luting agent to the oral environment. Larger marginal discrepancy and subsequent exposure of the dental luting agent to oral fluid enhanced the risk of cement dissolution. Such dissolution could promote shrinkage and microleakage, caused by a lack of adhesion between luting agent and tooth structure on one side and luting agent and restoration on the other side. Microleakage was defined as the movement of fluids carrying

bacteria and other molecules and ions between restoration and tooth. Although it was difficult to detect clinically, microleakage was considered to be a major factor influencing the longevity of dental restorations, since it might lead to staining at the margins of fillings, causing damage of the restorations at the marginal areas, recurrent caries at the tooth/restoration interface, hypersensitivity of restored teeth, or development of pulpal pathology. Caries as well as restoration dislodgment were the most common reasons for failure of indirect restorations.[60] Clinical studies had shown that poor marginal sealing ability of a restoration correlated with increased plaque retention, reduced gingival health, and involvement in the formation of marginal gaps, and subsequent leakage between the cavity wall and restoration.[61]

There were various techniques to assess marginal leakage include scanning electron microscopy, chemical and radioactive tracers, bacterial activity, and dye staining.[61] The dye penetration technique was one of the most used methods for assessing marginal seal.[62] Different kinds of dye agents have been introduced into the technique. 0.5% basic fuchsin, 2% methylene blue, and 50% silver nitrate solution

have been most frequently used. This technique involved the placement of restored teeth in a dye solution for a certain period. This was followed by washing and sectioning of the specimen and examination under magnification to determine the extent of leakage around tooth/restoration interface to verifiy in contrasting colors at the tooth-restoration interface.

For the evaluation of specimens, most studies used two-dimensional visualization and required cutting of the specimens, longitudinally through the center of the restoration. Wenner et al. found that there was the probability of finding a false negative if only a single section was evaluated.[63] Wu et al. developed silver staining technique to demonstrate microdefects in resin composite.[64] Silver was selected as the staining agent because of the strong optical contrast of silver particles, and the ability to penetrate specimens due to their small size. The technique required immersion of specimens for 2 hours in the dark, commonly using a 50% solution of silver nitrate. Then the specimens were rinsed and immersed in developing solution. Specimens for microleakage studies were sectioned. Then degree of leakage could be

measured for the level of penetration defined by many authors or by percentages of leaked silver to the bonding interfaces of the sectioned specimen.

6. Aging process

Adhesive restorations are often situated in wet environments surrounded by saliva.[65] Several previous studies have immersed samples into distilled water to assess bonding durability.[66-68] Intraoral temperature varied depending on eating, drinking, and breathing habits. Rapid temperature changes inevitably affected the stability of adhesive restoration. Different in vitro artificial aging methods, such as water storage, thermocycling, NaOCl storage, and pH cycling, may have different effects on the degradation of adhesive–dentine interfaces.[69] Long-term water storage at a constant temperature or thermocycling were the most commonly practiced methods to simulate the aging process that influenced resin bonds to ceramic surfaces.[66] For aging by water storage, specimens were stored in distilled water at 37°C. The period of immersion in solution has been ranging from a few months to years.[67] A decrease in bonding effectiveness was thought to be caused by degradation of interface

components by hydrolysis process. During the storage period, antibiotics, sodium azide[70], and chloramine[71] could be added to prevent bacterial growth.

CHAPTER III MATERIALS AND METHODS

Research Design

This study was an in vitro experiment. The intervention of this study was diversified types of materials used for deep margin elevation, followed by placement of CAD/CAM zirconia-reinforced lithium silicate inlay. Dependent variable was the microleakage score after aging with 6 months water storage.

Research Methodology

Diagram of study design

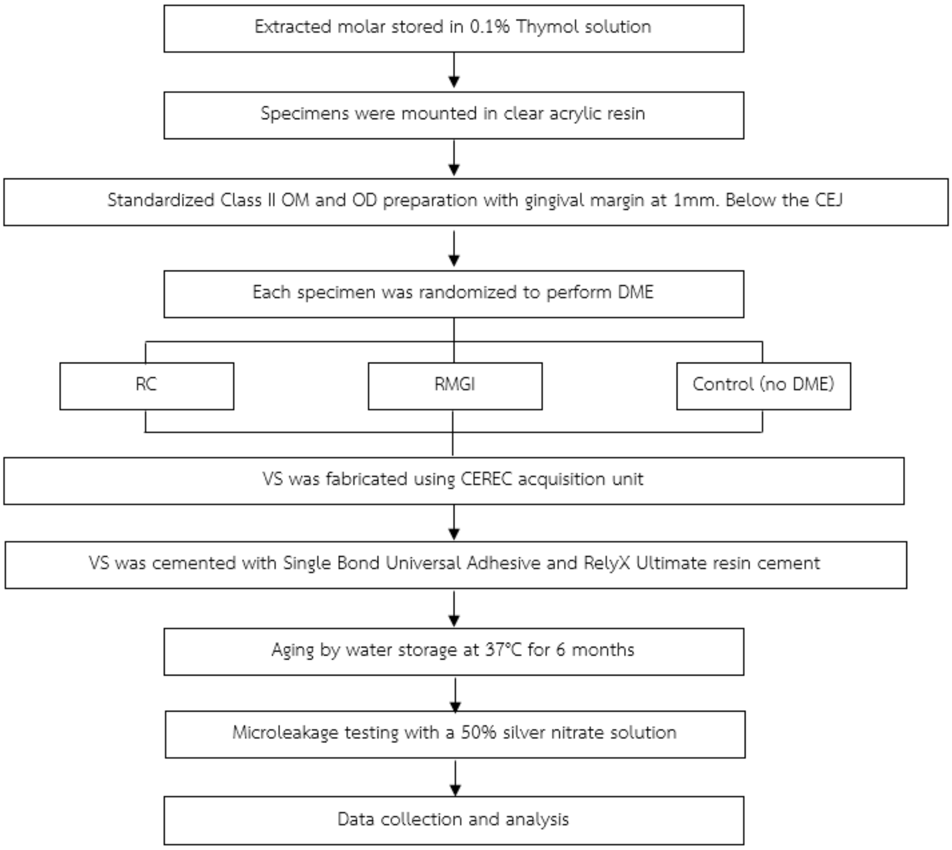


Figure 2. The diagram of study design

Abbreviations:

RC = resin composite, RMGI = resin-modified glass ionomer, CT= control, VS = Vita Suprinity®

Sample size description

The sample size was calculated using means and standard deviations obtained from a pilot study. The calculation was performed using G*Power application based on 5% Type I Error, and 80% study power. The sample size calculation was 8 specimens for each group. To compensate for the error, 2 specimens were added up in each group. Therefore, the number of specimens per group was 10, and a total of 30 specimens were used in this study.

Table 1. Data of material composition and manufacture instruction

Materials	Composition	Manufacturer's instruction
Vita Suprinity® **(Vita Zahnfabrick, Bad Säckingen)** **Lot No. 81174**	SiO_2, Li_2O, K_2O, P_2O_5, Al_2O_3, ZrO_2, CeO_2, pigments	Crystallization in furnace (Programat P700, Ivoclar Vivadent) at 840°C for 20 mins.
Filtex^{TM}Z350 XT **(3M ESPE, USA)** **Lot No. N965114**	Bis-GMA, Bis-EMA, UDMA, and TEGDMA, 5–20 nm Zr/silica nanoparticles + 0.6–1.4 nm nanoclusters (82% wt)	Incremental placement (2mm) Light cure for 40s
Vitremer^{TM} Tricure **(3M ESPE, USA)** **Lot No. NA53150**	1 – Primer (Vitrebond copolymer, HEMA, ethanol and photoinitiators) 2 – Powder (Sr-Al-F silicate glass, potassium	1. Primer application for 30 s 2. Air thin for 15 s 3. Light cure for 20 s 4.Manipulation and placement with Snap-fit syringe

	persulfate and ascorbic acid) 3 – Liquid (polycarboxylic acid with pendant methacrylate groups, Vitrebond copolymer, HEMA, ethanol and photoinitiators) 4 – Finishing Gloss (bis-GMA and photoinitiators)	5. Light cure for 40 s

Table 2. Luting systems used in the study.

Luting systems	Manufacturers	composition
Single Bond Universal Lot No. 6677622	3M ESPE	10-MDP, Bis-GMA, phosphate monomer, dimethacrylate resins, HEMA, methacrylatemodified polyalkenoic acid copolymer, filler, ethanol, water, initiators, silane-treated silica
RelyX^{TM} Ultimate Lot No. Y40317	3M ESPE	Base paste: methacrylate monomers, radiopaque silanated fillers, initiator, stabilizer, rheological additives Catalyst paste: methacrylate monomers, radiopaque alkaline (basic) fillers, initiator, stabilizer, pigments, rheological additives, fluorescence dye, dark cure activator for Single Bond Universal

Table 3. Instrument used in this study

Instrument	Manufacturer
Cerec 4 CAD/CAM system	Dentsply Sirona, USA
Ceramic furnace	Programat P700, Ivoclar Vivadent, Schaan, Liechtenstein, Germany
LED Light-Curing System: Demi™ Plus	Kerr, USA
Snap-fit™ syringe	Centrix, USA
Stereomicroscope ML 9300	Meiji, Japan
Radiometer Model 100 Optilux	Kerr. USA
Low-Speed Cutting Machine: Isomet®1000	Buehler, USA
Grinder-Polisher Machine (Automet® 250)	Buehler, USA
Durometer, ASTM D 2240 Type A	PTC Instrument, USA

Table 4. Description of groups according to variables

Group	Restorative material for DME	Restorative material for inlay	Adhesive system	Resin cement
1. CT	-	VITA Suprinity®	Single Bond Universal	RelyX™ Ultimate
2. RC	Filtex™Z350 XT	VITA Suprinity®	Single Bond Universal	RelyX™ Ultimate
3. RMGI	Vitremer™ Tricure	VITA Suprinity®	Single Bond Universal	RelyX™ Ultimate

RC, resin composite; RMGI, resin-modified glass ionomer; CT, control group

Methods

This study was approved by the ethical committee of the Faculty of Dentistry, Chulalongkorn University, Thailand (approval number: HREC-DCU 2020-028).

Specimen selection and preparation

Thirty extracted human molars were selected for this study, with informed consent, and stored in a 0.1% thymol solution at 4°C for a period no longer than 3 months. The teeth were debrided of residual plaque, soft tissue, and calculus using a hand scaler and examined to ensure that they were free of defects: no caries, no crack, completely formed apexes using a stereomicroscope (ML 9300; Meiji Techno Co. Ltd., Japan) at 40X magnification. All 30 specimens were mounted in polyvinyl chloride (PVC) molds using acrylic resin (Trey Resin II, Shofu, Kyoto, Japan) at a level of 3-mm apical to the specimen cementoenamel junction (CEJ). All teeth were cut at 4 mm above the CEJ using a slow-speed diamond saw (Isomet 1000 Precision Saw, Buehler, Lake Bluff, IL, USA) under water cooling to expose flat dentin surfaces. **(Figure 3)**

Class II box type cavities were prepared on one side of the proximal surfaces in each tooth with the cavity divergence limited from 5° to 15°. Cavities were cut using coarse diamond burs under profuse water cooling (80 μm diamond, Intensiv SA, ISO No. 314546, Grancia, Switzerland). The dimensions of the proximal box (buccolingual width) were 3 mm at the gingival wall and diverged to 4 mm at the occlusal surface, occluso-gingival height was 5 mm with a distance from the gingival margin to the axial wall of 1.5 mm. At the occlusal surface, the width was diverged to the center of the teeth from 4 mm to 5 mm (**Figure** *4*) to create a mechanical lock when inserted restorations. The gingival floor of the control group, RC group, and RMGI group was prepared 1 mm below the CEJ. The inner angles of the cavities were rounded and finished using 25 μm diamond burs (Intensiv SA, ISO No. 314546, Grancia, Switzerland).

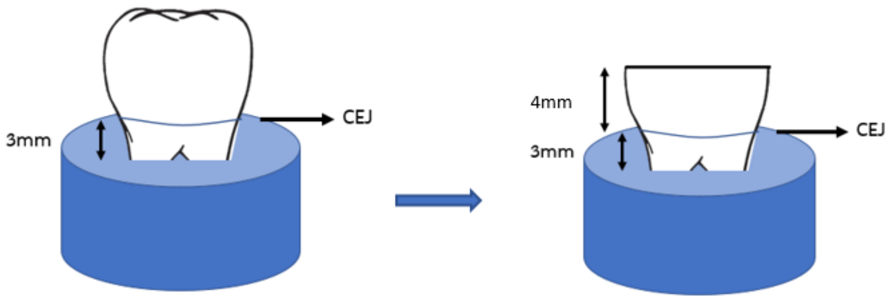


Figure 3. Preparation of dentin specimen

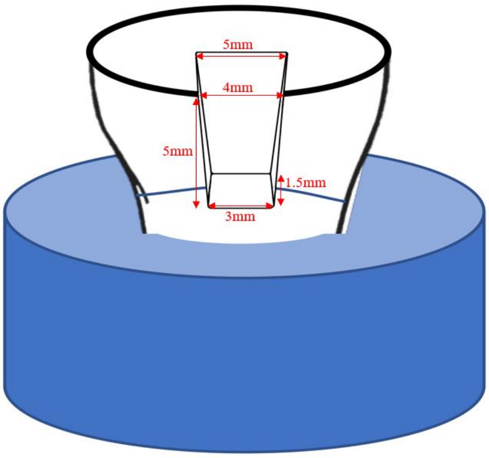


Figure 4. Illustrations of the preparation design used for all experimental groups.

Specimens were randomly assigned to one of three groups (n=10) according to the restorative material used for DME (**Table 4**) as followed. Group 1: control group (CT) margins were not elevated. Group 2: resin composite group (RC) Filtek^{TM} Z350 XT (3M, ESPE, USA) was placed in one 2-mm-increment. Group 3: resin-modified glass ionomer group (RMGI), Vitremer^{TM} Tricure (3M, ESPE, USA), was placed in one 2-mm-increment. The proximal boxes of all specimens (n=30) were located 1 mm beneath the cementoenamel junction (CEJ). Data of material composition and manufacture instruction used in the study were described in **Table 1**.

Specimens in the RC, RMGI groups were undergone DME of the proximal box to raise the gingival margin 2 mm, by placing the material at the gingival floor until

marginal location was 1 mm occlusal to the CEJ, using Tofflemire matrix bands (Henry Schein, Melville, NY, USA). A 2-mm space was marked on the inner side of the matrix, to avoid overfilling. The proximal boxes of specimens in the RC group were selectively etched with 37.5% phosphoric acid etchant (3M, ESPE, USA), rinsed and blot-dried with foam pellets, and bonded with Single Bond Universal adhesive following manufacture's instruction. The bonding layer was light cured for 10 s. Then resin composite material; Filtek™ Z350 XT, was placed with a 2-mm-height in the proximal box and polymerized for 20 s from the occlusal surface. Matrix band was removed, and the material was polymerized for another 20 s. For specimens in the RMGI group, according to manufacturer instructions, the Vitremer primer was applied and air-dried. The primer layered was light cured for 20 s. The RMGI; Vitremer™ Tricure, was carefully manipulated with powder-to-liquid weight ratio of 2.5:1. The mixing time was limited to 45 s and the working time was 3 m at room temperature (23°C) in each specimen. Then RMGI was delivered into deep part of cavity preparation using a Snap-fit syringe (Centrix, USA) by carefully inserting the tips and injected to the proximal boxes, with nominal manipulation to minimize voids, 2-mm in height. The RMGI material was light

cured for 40 s from the occlusal surface. After removal of the matrix band, the material was cured for another 40 s. All polymerization performed in this study was accomplished using an LED light curing unit (Demi Plus, Kerr Corporation, Orange, CA, USA) with 1,100 mW/cm^2 intensity. The proximal surfaces of the DME were polished with a series of OptiDisc Contouring and Polishing Discs (coarse, medium, and fine) (Kerr). The thickness of elevated restorations was checked not to exceed 2 mm. Specimens were stored in distilled water during the inlay fabrication.

Digital Impression, Design, and Processing

All inlay preparations were optically impressed and digitally designed using the Cerec Omnicam acquisition unit (CEREC AC, software package 4.4.3, Dentsply/Sirona, York, PA, USA). All inlays' cement space was set to 120 µm as recommended for a clinically acceptable marginal gap.[72] Vita Suprinity® (VITA Zahnfabrik) were fabricated for each specimen (n=30).

Surface pre-treatment and cementation procedure

Specimens were luted with RelyX Ultimate resin cement using Single Bond Universal Adhesive. Data of luting material composition used in the study was described in **Table 2**.

At ZLS surface: Vita Suprinity® (VITA Zahnfabrik) was etched with 4.5% hydrofluoric acid (HF, IPS ceramic etching; Ivoclar Vivadent) for 20 s and rinsed with water for 60 s. Subsequently, the etched ceramic was cleaned in the ultrasonic bath with 98 % alcohol for 3 mins and air-dried. After that, RelyX^{TM} Ceramic Primer (3M ESPE, USA) was applied at the etched surface and waited for 60 s, and air dried for 5 s. Single Bond Universal Adhesive (3M ESPE, USA) was applied uniformly creating a thin coating for 15 s. Resin cement, RelyX^{TM} Ultimate (RXU, 3M ESPE, USA), was applied copiously to the ceramics using the auto-mix syringe.

At DME/Dentin surface: Prepared cavity with DME and/or dentin was selectively etched at enamel margin with the 37.5% phosphoric acid etching gel (Scotchbond Etchant, 3M ESPE, USA) and allowed to react for 15 s. Then rinsed thoroughly with

water for 15 s and blot dried with foam pellets. Single Bond Universal was applied uniformly creating a thin coating for 15 s.

After loading the luting cement in all groups, the inlay was seated under a constant load of 1 kg, placed on the top of the ceramic disc using a custom-made loading device (Durometer, ASTM D 2240 Type A, PTC Instrument, USA) then tacked polymerized for 2 seconds. The excess cement was removed with a sickle scaler. The light guide was held perpendicularly and within 1 mm away from inlay for 20 s per surface. Then, the load was removed, and the specimen was additionally light cured from the top and proximal surfaces for 40 s (120s in total). Light output from the light-polymerizing unit was tested every 10 specimens to ensure constant light intensity using a radiometer (Model 100 Optilux, Kerr Corporation, Orange,CA, USA) throughout the experiment. The restoration margins were covered with a water-based glycerin gel. Inlays were polymerized for 20 seconds on each of the surfaces: occlusal, lingual, buccal, and proximal surfaces to eliminate the oxygen inhibited layer. Margins were

gently finished with Optidisc (Kerr) (**Figure 5**). All the procedures were done by one operator.

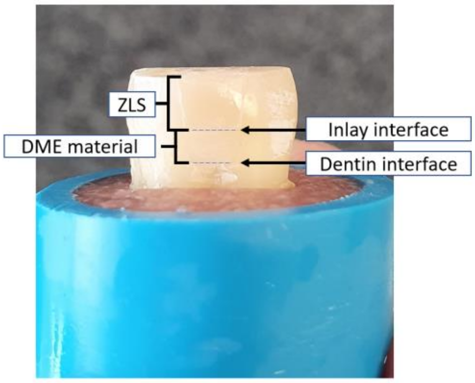
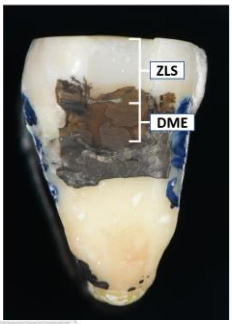


Figure 5. Representative specimen after DME with resin composite and cemented with ZLS ceramic at proximal view

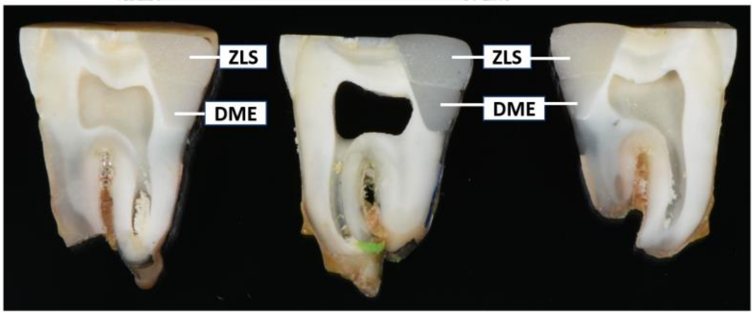
Microleakage testing

All specimens were stored in deionized water at 37°C for 6 months. The deionized water was routinely changed every week. All tooth surfaces were covered with nail varnish and left exposed the 1 mm around the area of the adhesive interfaces between inlay and tooth and the DME on the proximal aspect of the tooth. Root apexes were covered with sticky wax. The samples were immersed in a 50% silver nitrate solution for 2 hours and washed thoroughly with water. Nail varnish around the

tooth was removed with acetone. Specimens were immersed in a photographic developer (D-76; Kodak Co, Rochester, NY, USA) for 8 hours under fluorescent light, and abundantly washed under running water. Each specimen was sliced to two cuts using Isomet (Buehler, Lake Bluff, NY, USA) along their long axes and perpendicularly to the proximal margins. (**Figure 6**)



A



B

Figure 6. A) Specimen after immersion in silver nitrate solution at proximal view
B) Sliced specimens

Four measurement sites per tooth were observed. Microleakage scores were recorded and averaged in each specimen. All the restorations were analyzed at the

dentin interface and inlay interface separately with a stereomicroscope at a 40x magnification (ML9300 MEIJI, JAPAN). The extent of dye penetration was independently scored by one examiner with blind technique according to the following scoring system from the previous studies[26]. 0: no dye penetration, 1: dye penetration up to 1/3 of gingival floor or inlay interface, 2: dye penetration up to 2/3 of gingival floor or inlay interface, 3: dye penetration of more than 2/3 to entire gingival floor or inlay interface, 4: dye penetration through the axial wall. (**Figure 7**)

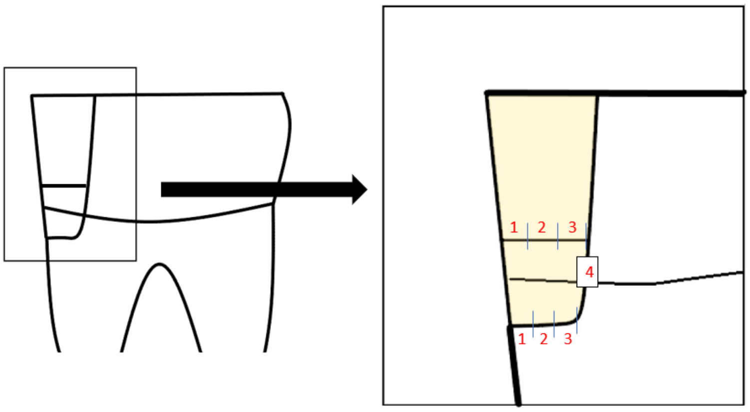


Figure 7. Illustration of the scoring system used in this study

Data collection and analysis

At the dentin interface, the Kruskal Wallis test and Dunn's post hoc test were used to assess the differences in microleakage scores between the DME and control

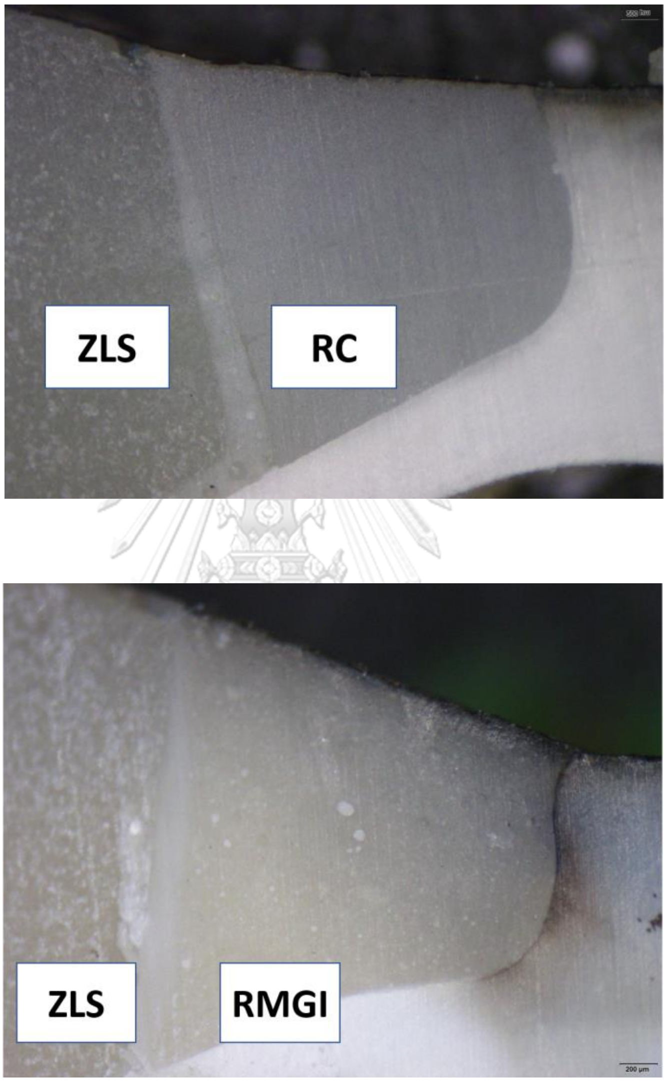
groups, followed by the Mann-Whitney U test to determine whether there was a significant difference between the two groups. At the inlay interface, the Mann-Whitney U test was used to evaluate the differences in microleakage scores between DME groups. The level of significance was set to $p < 0.05$. Data of quantitative margin analysis were collected and analyzed using a statistical software SPSS 22.0 (SPSS, Chicago, IL, USA).

CHAPTER IV RESULTS

Microleakage along the dentin interfaces significantly differed among the three groups (Kruskal-Wallis test, p = 0.004). Dunn's post hoc test showed a statistically significant difference between the control group and the RMGI group, and the composite and RMGI group. RMGI group had the highest microleakage score (score 4) while the lowest microleakage score (score 0.5) was in the control group. The Mann-Whitney U test showed no significant difference in microleakage scores at dentin/inlay interface and dentin/composite interface (p = 0.577); however, at dentin/RMGI interface, the microleakage score was significantly higher compared to dentin/inlay interface (p = 0.004) and dentin/composite interface (p = 0.007). Descriptive statistics for microleakage scores are shown in **Table 5**.

At inlay interfaces, the Mann-Whitney U test showed a significant difference between the RMGI group and the resin composite group. Microleakage score at RMGI/inlay interface had higher leakage value than composite/inlay interface (p = 0.004). The highest microleakage score, score 2, was found in the RMGI group. The

lowest microleakage score was found in both groups with a score of 0. Descriptive statistics for microleakage scores are shown in **Table 6**.



A

B

Figure 8. A) Microleakage image of specimen DME with resin composite; score 1(x40)
B) Microleakage image of specimen DME with RMGI; score 4 (x40)

Table 5. Descriptive statistics for leakage scores recorded at dentin interface

Microleakage score	n	Mean	SD	Median	Interquartile range	
					25th percentile	75th percentile
1. Control group[A]	10	1.15	0.412	1.00	1.00	1.50
2. Resin composite group[A]	10	1.23	0.344	1.00	1.00	1.50
3. RMGI group[B]	10	2.37	1.082	2.37	1.44	3.56

n: number of specimens; SD: standard deviation

Differences among groups, analyzed using Kruskal-Wallis test, followed by Dunn's post hoc test. Same superscript letters indicated no statistically significant difference at $p<0.05$

Table 6. Descriptive statistics for leakage scores recorded at inlay interface

Microleakage score	n	Mean	SD	Median	Interquartile range	
					25th percentile	75th percentile
1. Resin composite group[A]	10	0.23	0.251	0.16	0.00	0.50
2. RMGI group[B]	10	1.20	0.762	1.00	0.62	2.00

n: number of specimens; SD: standard deviation

Differences among groups, analyzed using Mann-Whitney U test, $p = 0.004$

Same superscript letters indicated no statistically significant difference at $p < 0.05$

CHAPTER V DISCUSSION AND CONCLUSION

Discussion

This study investigated marginal sealing ability of resin composite and resin-modified glass ionomer (RMGI) used for deep margin elevation on zirconia-reinforced lithium silicate CAD/CAM ceramic restoration. The null hypothesis was rejected since the RMGI group showed a significantly higher microleakage score than the composite and control groups at dentin interfaces. Moreover, the RMGI group had a significantly higher microleakage score than the composite group at the inlay interfaces.

Scientific publications available on DME were generally based on marginal quality. In vitro studies were mostly performed with thermal and/or mechanical occlusal stress.[13, 30, 31, 41] The finding mainly concluded that the quality of the margins, under scanning electron microscopic observations, had a promising result but a significant decrease of margins' quality after thermal and mechanical stress was observed.[13, 26, 31, 41] Still, the evaluation of marginal quality under scanning electron microscopy when performed at low magnification could not be interpreted if margins

were properly sealed. Adhesive restorations were often situated in wet environments surrounded by saliva. It is important to consider not only the initial bonding performance but also long-term bonding durability in the oral environment. Therefore, several laboratory protocols were developed to predict bond durability. The most validated method to assess adhesion durability involved aging of specimens.[73] Long-term water storage was the most common artificial aging technique. Several studies reported significant decreases in bond strengths.[70, 74, 75] In this study, specimens were aged by storing in deionized water at 37°C for 6 months.

Marginal gaps along the interface between restoration and cavity floor have been shown to be sites for biofilm or plaque accumulation.[76] Although it is difficult to detect clinically, microleakage is considered to be a major factor influencing longevity of dental restorations. Microleakage is defined as the movement of fluids carrying bacteria and other molecules and ions between restoration and tooth. Dye penetration technique has been one of the most used methods for assessing marginal seal.[62] Wu et al. developed the silver staining technique to demonstrate microdefects in resin

composite.[64] In this study silver nitrate was used as the staining agent due to the strong optical contrast of silver particles, and the ability to penetrate specimens. To date, only two studies investigated the effect of marginal sealing ability at deep proximal area below the CEJ by using the silver nitrate staining technique. The study from Zavattini et al. investigated microleakage of deep class II cavities, 1.5 mm below CEJ, by using a three-step adhesive system (Optibond FL, Kerr) and three resin-based composite materials; micro-hybrid composite (Premise, Kerr), preheated composite (Premise, Kerr), and flowable composite (Premise flowable, Kerr), to restore deep class II cavities. Specimens were thermocycled in distilled water for 1000 cycles (5-55°C). The analysis of microleakage, using a microtomography system, found that flowable resin composite should be avoided at the dentin/cementum margin due to the highest leakage among the groups.[27] In contrast, the study from Koken et al. evaluated marginal sealing ability, at the proximal margin 1mm below the CEJ, after DME using a universal adhesive (G-Premio Bond, GC Corp.) with microhybrid (Essentia; GC Corp.) and a flowable resin composite (G-ænial Universal Flo; GC Corp.). The result after examination with a digital microscope found that the performances of all groups were

comparable.[26] The result of the present study found that the performance of DME with resin composite was comparable to the control group. This was in alignment with previous studies.[26, 31, 41] The result showed that majority of microleakage occurred at dentin margin, indicating that optimum dentin adhesion remained a challenge.

With regard to the most appropriate materials used for DME, the study from Grubbs et al. investigated the effects of four different materials: resin composite, bulk fill resin composite, glass ionomer, and resin-modified glass ionomer. They found that the material used did not affect on margin quality and fracture resistance.[36] The materials used in this study were resin composite (Filtek™ Z350 XT, 3M, ESPE, USA) and RMGI (Vitremer™ Tricure, 3M, ESPE, USA), which have been widely used in deep class II restoration.[77, 78] RMGIs were basically formed by adding methacrylate components to the polyacrylic acid, which were polymerizable by light-curing supplementing the fundamental acid-base reaction.[79] Unlike other RMGIs on the market, Vitremer™ Tricure (3M, ESPE, USA) had a setting reaction that allowed the free-radical methacrylate to cure without using light, or “dark cure”. According to the

manufacturer, Vitremer had the best features of conventional glass ionomers and light cure systems. In deep proximal cavity, the light transmission might not be completely predictable especially in real clinical situations, demanding careful consideration. Scientific reports on RMGIs about microleakage were varied. Mitra et al. supported the finding that Vitremer had less microleakage than Fuji II LC, suggesting that the statistical difference in microleakage between Vitremer and Fuji II LC might be explained by their thermal expansion coefficients (CTE). Vitremer with a CTE closer to tooth structure was expected to exhibit less leakage.[80] However, Fritz et al. reported that the marginal adaptation of Fuji II LC and Vitremer were statistically similar after 24 h of water storage.[81] While Abdalla et al. found that Fuji II LC was statistically superior to Vitremer in 2-year clinical performance.[82] According to this present finding, the RMGI group had a significantly higher microleakage score. This result may be explained by RMGI's hygroscopic expansion when placed in water.[83] The RMGI is thought to have expanded more than other materials due to hygroscopic expansion. The presence of hydroxyethyl methacrylate (HEMA) in RMGI could explain this material specific outcome. HEMA has been known to be unstable and could have contributed to some

expansion.[84] Water was crucial in the deterioration of bonding interfaces.[65, 85] A decrease in bonding effectiveness has been thought to be caused by degradation of interface components via hydrolysis process. Furthermore, absorbed water might weaken the material, and excessive water uptake could even result in microcracks of the restored tooth. The conditioner or primer used in conjunction with the use of RMGICs also played a greater role in achieving effective bonding of teeth with RMGICs. In Fuji II LC, conditioning with polyacrylic acid partially dissolved the smear layer resulting in superficial demineralization of dentin,[86] while Vitremer used Vitrebond copolymer and HEMA as a primer. Even though pH of Vitremer's primer was low enough to react with smear layer from the dentin surface, Vitrebond copolymer may react with tooth structure and formed a polyalkenoate salt that prevented the penetration of resin part of material into dentinal tubules, and might cause the material to be prone to leakage.[87, 88] The fact that the RMGIs material used in this study manipulated from powder and liquid requiring a correct proportioning with subsequent proper manual manipulation. In clinical situation, these variants are exacerbated when the operator does not carefully follow the manufacturer's

recommendation, which might interfere in the physical and mechanical properties of the material. The encapsulated materials might benefit this problem and could facilitate the agglutination and insertion in the cavity. No capsulated type of RMGIs were utilized for DME, possibly giving reason for further investigation of this type of RMGI in this role.

On the other hand, the result showed that microleakage at dentin interfaces in the control group and resin composite group were comparable. Moreover, at the inlay interfaces, microleakage scores of the resin composite group were lower than the RMGI group. Cavity preparation for ceramic inlays had a high configuration factor (C-factor) producing high stress.[89] The efficacy of DME material adhesion is critical. This was due to the stress caused by adhesive shrinkage in a narrow cement space which had a high C-factor. A study by Itthipongsatorn et al. investigated the efficacy of 3-step etch-and-rinse adhesive (Scotchbond Multipurpose, 3M, ESPE), universal adhesive (Single Bond Universal, 3M, ESPE), and resin luting cement (RelyX Ultimate and RelyX Unicem, 3M, ESPE) boned with ZLS ceramics. The result found that Single Bond Universal with RelyX

Ultimate and a self-etch adhesive system could achieve significantly greater microshear bond strength than the RelyX Unicem, self-adhesive, luting system.[90] Single Bond Universal adhesive (3M, ESPE, USA) and RelyX Ultimate resin cement (3M, ESPE, USA) were the only adhesive and luting cement used in this study. Our research showed the same trend, indicating that resin cement and resin composite could result in positive outcomes even after water storage for 6 months. However, since the analysis only used one adhesive and one resin luting cement, the findings might not be applicable to all clinical situations. Moreover, the reason why the RMGI group leaked more than the resin composite group could be due to adhesion issues. However, leakage and bond strength were independent parameters to evaluate the quality of adhesion between restorative materials and dental tissues. Since, we did not measure the bond strength test, the results were purely speculative. Further study should be conducted to assess the bond strength of materials on DME.

The main reason for using the DME technique in daily practice is to avoid the inherent difficulty of capturing a deep margin with an impression, optically or

otherwise. An in vitro study, as presented in this paper, is not capable of simulating all clinically relevant aspects of predicting clinical behavior. One of the aspects to be mentioned was the preparation design, in a normal clinical situation, the preparation designs were influenced by several factors, such as the extent of pathology or material properties.[13, 91] The extent of cavity led to different boundary conditions which also played an important role in stress development.[91] However, the preparation design used in present study did not represent this aspect, and it might not be a universally applicable method due to the difficulty in standardization. The present study, therefore, focused primarily on marginal sealing in vitro as a key prerequisite for clinical success.

Limitations

This study involved several limitations, as follows:

1. This in vitro study may not be able to simulate all clinically relevant aspects to predict clinical behavior but focused on the marginal sealing ability as fundamental prerequisite for clinical success.
2. This study used only one ceramic system (zirconia-reinforced lithium silicate); therefore, the results may not be applicable to other dental ceramics.
3. This study used only one bonding and luting system (Single Bond Universal and RelyX^{TM} Ultimate); therefore, the results may not be applicable to other dental bonding and luting systems.

Suggested further studies

Further studies with cavity design that closely mimics clinical conditions are recommended to simulate the oral condition before specific protocols of deep margin elevation can be universally recommended in patients. The particularly new injectable type materials such as new flowable composite should be examined to perform DME

due to the physical and mechanical features that the manufacturer claim to be beneficial. Furthermore, variation in dental ceramic, dental adhesive, and dental luting systems, as well as the combination with the different aging processes or experimental test designs, are recommended for further research. Moreover, future trials should include well-designed randomized controlled clinical trials focusing on verifying the features of the DME technique on the long-term clinical outcome of teeth restored with indirect adhesive restorations.

Conclusion

Within the limitations of the present experimental procedure, it can be concluded that resin composite performed better as a DME material when compared to RMGI in terms of marginal sealing ability. However, caution is recommended in extrapolating this finding to clinical situations.

Clinical implication

Improvements in material technology and clinical techniques led to increasing indications for minimally invasive treatment approaches. Deep margin elevation, an

example of an elaborate clinical technique, is a two-step procedure for restoring deep and undermining defects in the proximal area. Deep margin elevation can be achieved with resin composite. Resin-modified glass ionomer must be used with caution due to the high microleakage scores.

Declaration of Conflicting interest

The authors declare that there is no conflict of interest.

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APPENDICES

Appendix A. The average microleakage scores of control group at dentin interface

Specimen number	Average microleakage score
	Dentin interface
1	1
2	1
3	1
4	1.5
5	1
6	1.5
7	2
8	1
9	1
10	0.5

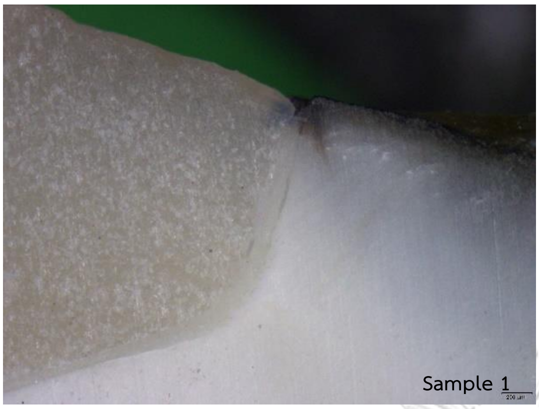
Appendix B. The average microleakage scores of resin composite group at dentin interface and inlay interface.

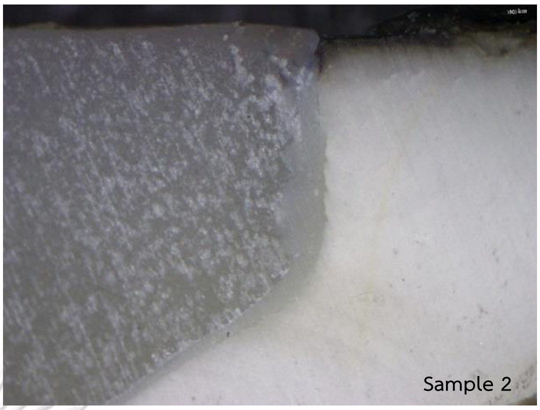
Specimen number	Average microleakage score	
	Dentin interface	Inlay interface
1	1.5	0.5
2	1.5	0.5
3	1	0.5
4	1.25	0.25
5	2	0
6	1	0
7	1	0
8	1	0.5
9	1	0
10	1	0

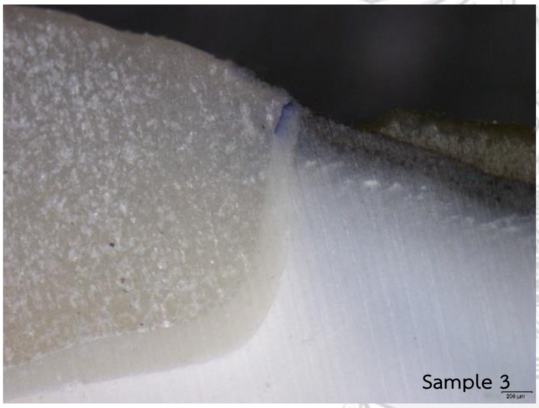
Appendix C. The average microleakage scores of resin-modified glass ionomer group at dentin interface and inlay interface.

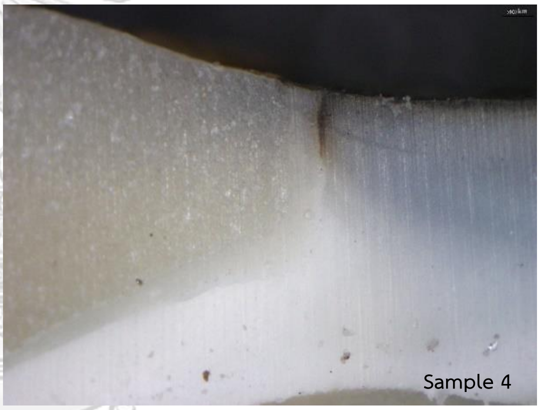
Specimen number	Average microleakage score	
	Dentin interface	Inlay interface
1	1	1
2	1.5	1
3	2.5	2
4	2.5	2
5	1.5	2
6	3.5	0
7	2.25	0.75
8	1.25	0.25
9	4	2
10	3.75	1

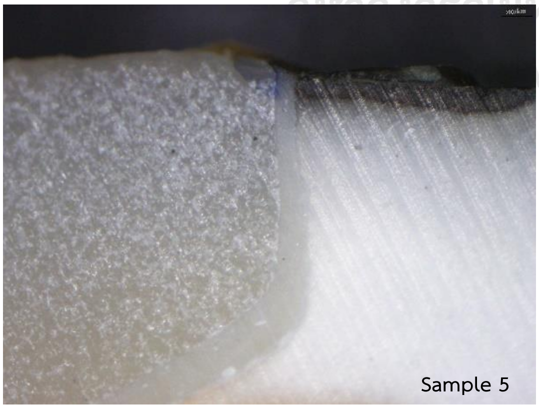
Appendix D. Picture of specimens from control group

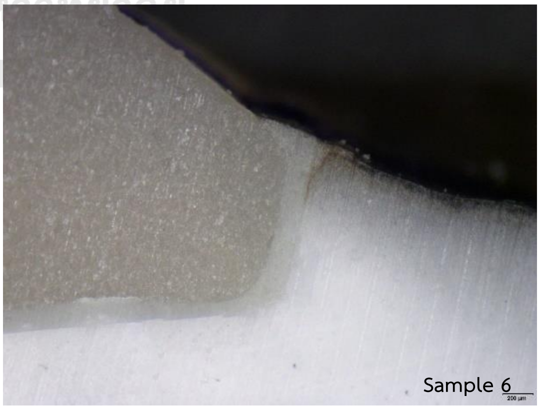


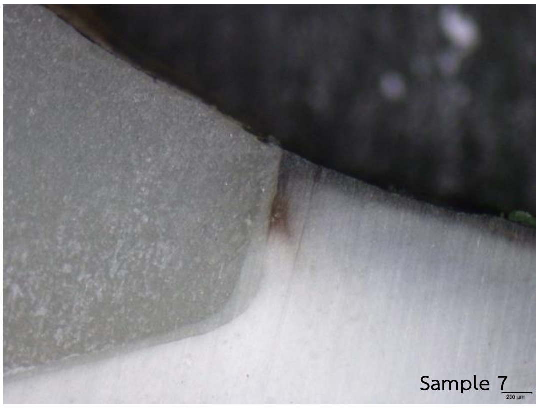


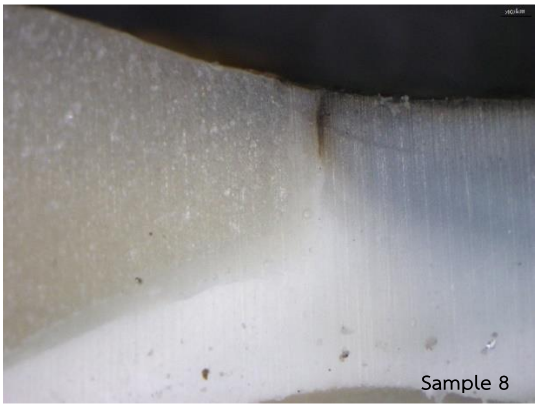









Sample 7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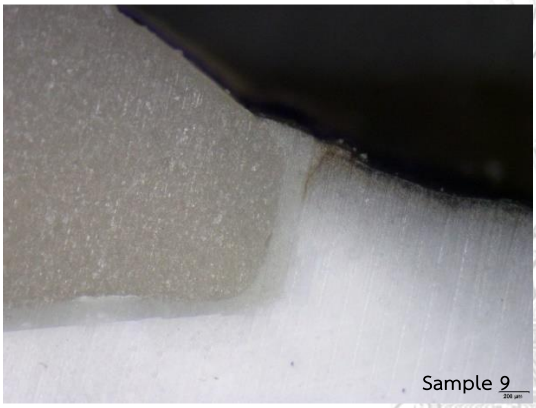
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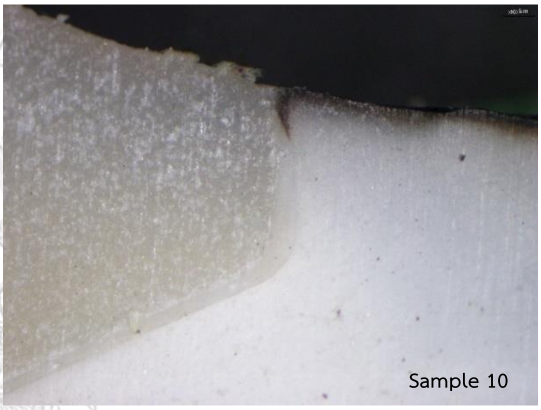
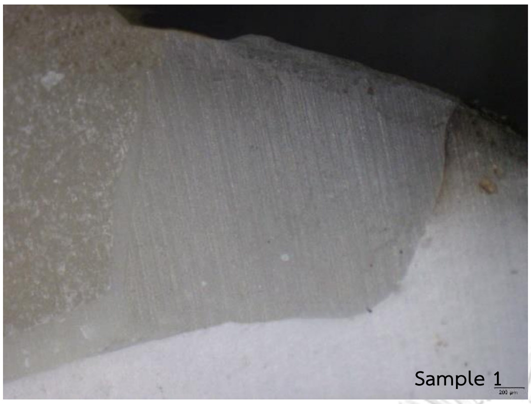
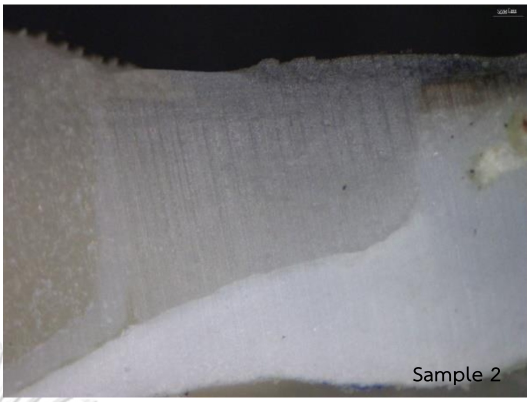
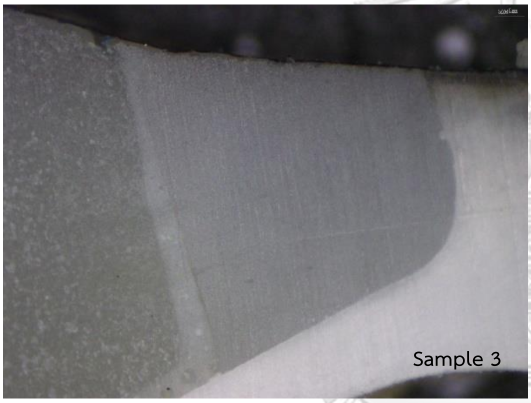
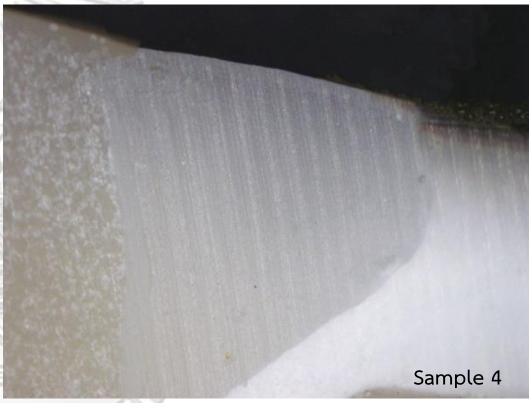

Sample 10

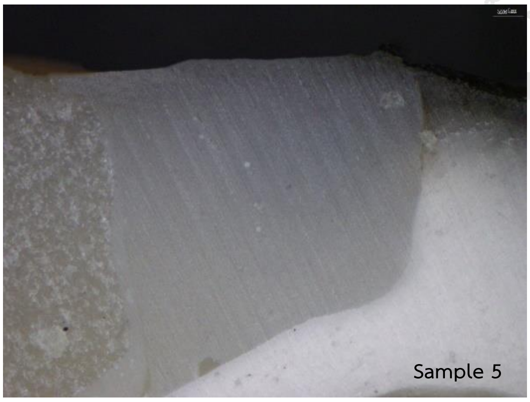
Appendix E. Pictures of specimens from composite group

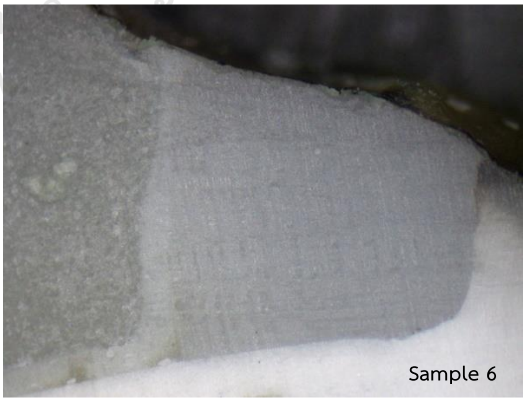


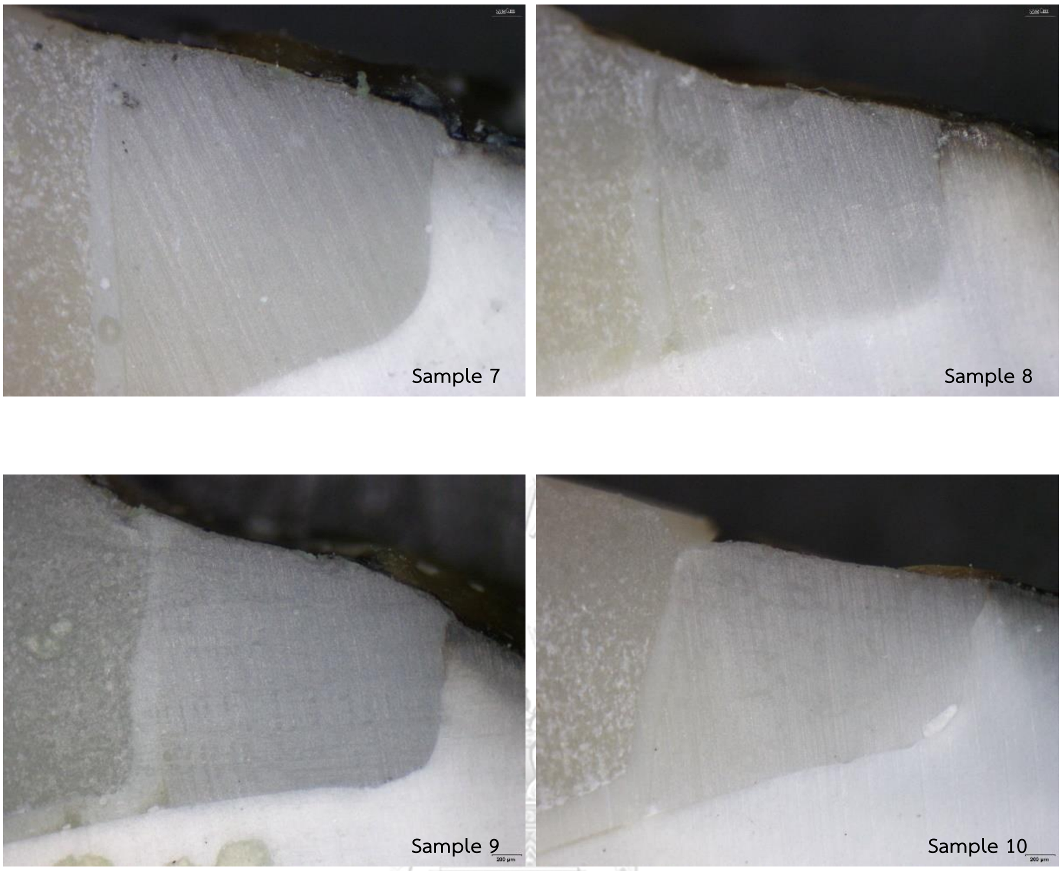




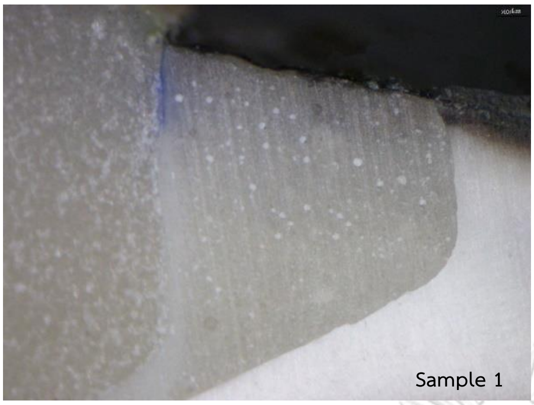


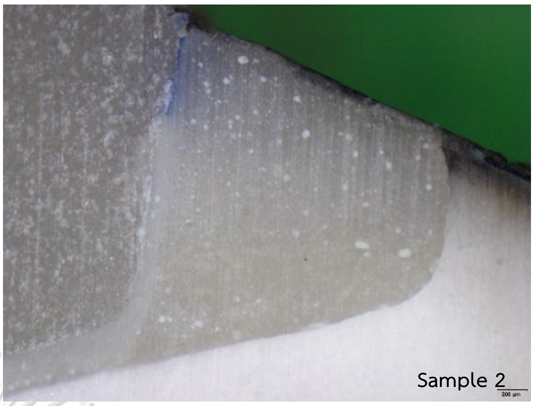


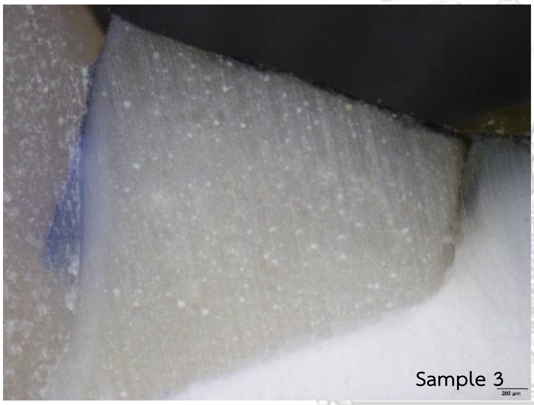


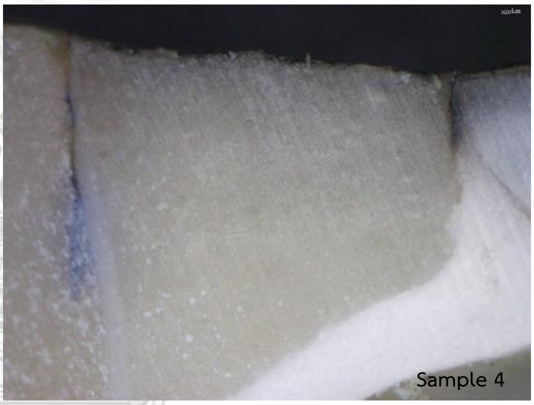

Sample 7
Sample 8
Sample 9
Sample 10

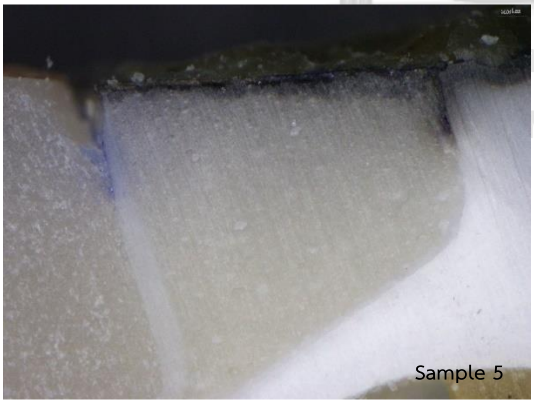
Appendix F. Pictures of specimens from resin-modified glass ionomer group

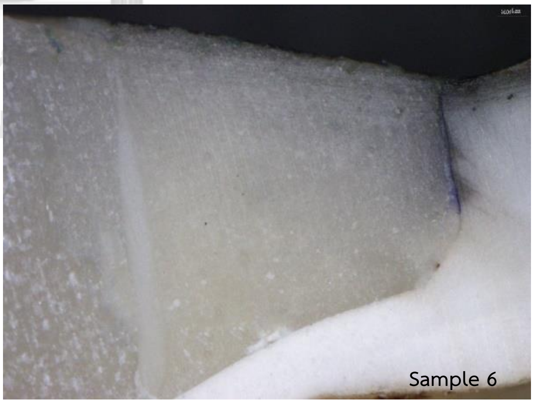


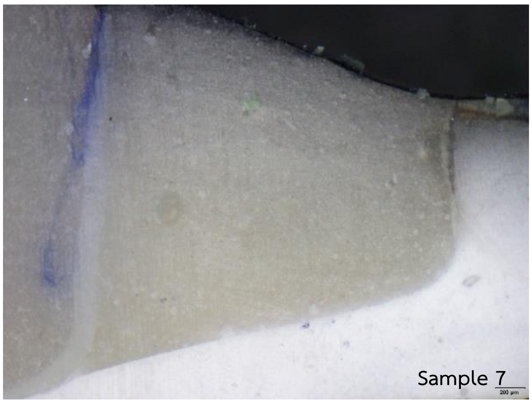


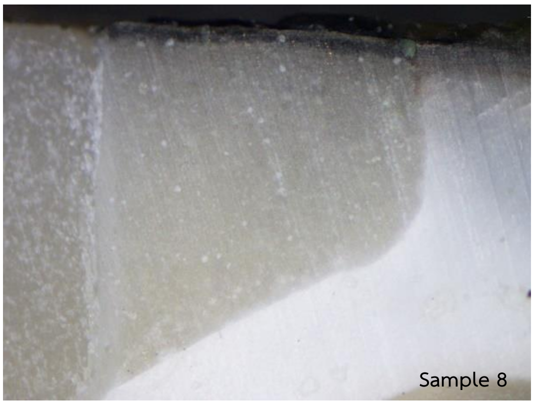


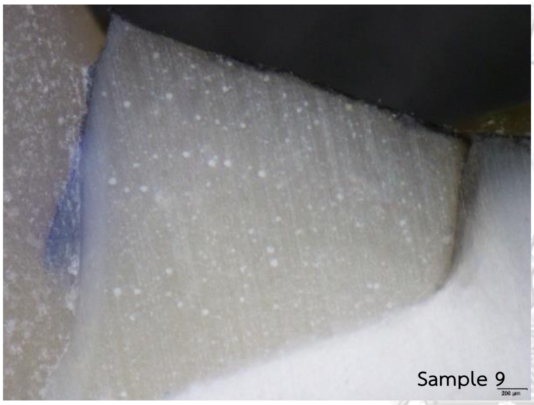


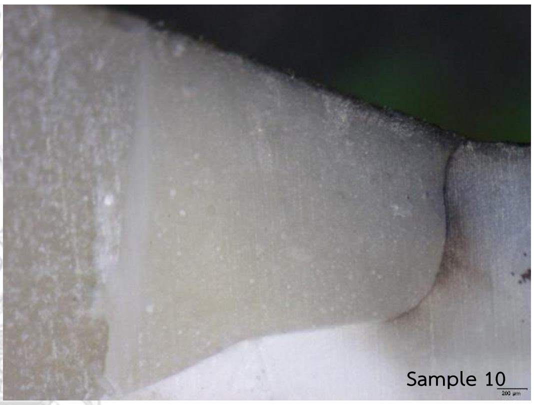





Sample 7


Sample 8


Sample 9


Sample 10

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