USING OF LOW MODULUS OF ELASTICITY BASE IN HIGH C-FACTOR RESIN COMPOSITE RESTORATION: AN IN VITRO STUDY

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A Thesis Submitted in Partial Fulfillment of the Requirements
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การใช้วัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำรองพื้นในโพรงฟันที่มีค่าซีแฟคเตอร์สูงที่บูรณะด้วยวัสดุเรซินคอมโพสิต: การศึกษาในห้องทดลอง

น.ส.จอมนาง อยู่หุ่น

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Field of Study	Esthetic Restorative and Implant Dentistry
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จอมนาง อยู่หุ่น : การใช้วัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำรองพื้นในโพรงฟันที่มีค่าซีแฟคเตอร์สูงที่บูรณะด้วยวัสดุเรซินคอมโพสิต: การศึกษาในห้องทดลอง. (USING OF LOW MODULUS OF ELASTICITY BASE IN HIGH C-FACTOR RESIN COMPOSITE RESTORATION: AN IN VITRO STUDY) อ.ที่ปรึกษาหลัก : รศ. ทญ. ดร.ศิริวิมล ศรีสวัสดิ์

วัตถุประสงค์ของการศึกษานี้เพื่อประเมินการรั่วซึมตามขอบของโพรงฟันคลาสไฟว์ (class V) ซีแฟคเตอร์ (C-factor) สูง ที่บูรณะด้วยเรซิน คอมโพสิต ทั้งที่ใช้และไม่ใช้การรองพื้นโพรงฟันด้วยวัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำ การทดลองนี้ใช้ฟันกรามซี่ที่สาม ที่ไม่มีรอยผุ 80 ซี่มาเตรียมโพรงฟันแบบคลาสไฟว์ขนาด 5x3x2.5 มม^3 บนพื้นผิวด้านแก้มโดยวางขอบโพรงฟันไว้บริเวณรอยต่อระหว่างเคลือบฟันกับเคลือบรากฟัน แบ่งฟันเป็น 8 กลุ่มการทดลอง: กลุ่มที่ 1 บูรณะด้วยเรซิน คอมโพสิต (Filtek^{TM} Z350 XT, 3M ESPE, USA); กลุ่มที่ 2 บูรณะด้วยเรซิน คอมโพสิตแบบบัลค์ฟิล (Filtek^{TM} Bulkfill, 3M ESPE, USA); กลุ่มที่ 3 และ 4 บูรณะด้วยเรซิน คอมโพสิต โดยทำการรองพื้นโพรงฟันด้วย โฟลเอเบิล คอมโพสิต (Filtek^{TM} Z350 XT Flowable, 3M ESPE, USA); กลุ่มที่ 5 และ 6 บูรณะด้วยเรซิน คอมโพสิต โดยทำการรองพื้นโพรงฟันด้วยด้วยเรซิน โมดิฟายด์ กลาสไอโอโนเมอร์ (Fuji II LC, GC Corporation, Japan) โดยไม่ใช้สารปรับภาพเนื้อฟันเพื่อปรับสภาพผิวโพรงฟันก่อนทำการรองพื้นโพรงฟัน; กลุ่มที่ 7 และ 8 บูรณะด้วยเรซิน คอมโพสิต โดยทำการรองพื้นโพรงฟันด้วยด้วยเรซิน โมดิฟายด์ กลาสไอโอโนเมอร์ (Fuji II LC, GC Corporation, Japan) โดยใช้สารปรับภาพเนื้อฟัน (Cavity Conditioner, GC Corporation, Japan) เพื่อปรับสภาพผิวโพรงฟันก่อนทำการรองพื้นโพรงฟัน ในกลุ่มที่ 1 – 4 ขอบโพรงฟันที่เป็นเคลือบฟันจะถูกกัดด้วยกรดและใช้สารยึดติด (Scothbond Universal, 3M ESPE, USA) ตามคำแนะนำของผู้ผลิตก่อนจะบูรณะด้วยด้วยวัสดุตามกลุ่มการทดลอง ส่วนในกลุ่มที่ 5 – 8 หลังจากทำการรองพื้นโพรงฟันด้วยเรซิน โมดิฟายด์ กลาสไอโอโนเมอร์ ขอบโพรงฟันที่เป็นเคลือบฟันจะถูกกัดด้วยกรดและใช้สารยึดติด ตามคำแนะนำของผู้ผลิตก่อนจะบูรณะด้วยด้วยเรซิน คอมโพสิต เช่นเดียวกัน หลังทำการขัดแต่ง จะถูกนำไปทำเทอร์โมไซคลิ่ง จำนวนหนึ่งหมื่นรอบด้วยระยะเวลา 60 วินาทีต่อรอบก่อนนำมาทดสอบการรั่วซึมบริเวณขอบด้วยสารซิลเวอร์ไนเตรท 50% จากนั้นจะถูกตัดในแนวใกล้แก้ม-ใกล้ลิ้น (bucco-lingually) เพื่อให้ได้พื้นผิวในการทดสอบการรั่วซึม 6 ด้านต่อซี่ หลังจากทำการบันทึกค่าลำดับคะแนนการรั่วซึม ข้อมูลได้รับการวิเคราะห์ด้วย Kruskal-Wallis test และ Mann-Whitney U Test ผลการศึกษาจากการทดสอบด้วย Kruskal-Wallis test พบความแตกต่างของค่าการรั่วซึมอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มทดลอง ที่ขอบโพรงฟันใกล้เหงือก ($P < 0.001$) จากการทดสอบด้วย Mann-Whitney U Test ที่ขอบโพรงฟันใกล้เหงือก กลุ่มที่ไม่ทำการรองพื้นโพรงฟันด้วยวัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำมีค่าการรั่วซึมน้อยกว่ากลุ่มที่ทำการรองพื้นโพรงฟันด้วยวัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำอย่างมีนัยสำคัญทางสถิติ นอกจากนี้ยังพบว่าที่ขอบโพรงฟันใกล้เหงือก กลุ่มที่ใช้สารปรับภาพเนื้อฟันมีค่าการรั่วซึมน้อยกว่ากลุ่มที่ไม่ใช้สารปรับภาพเนื้อฟันอย่างมีนัยสำคัญทางสถิติ จากผลของการศึกษาสรุปได้ว่าการรองพื้นโพรงฟันด้วยวัสดุที่มีมอดุลัสของสภาพยืดหยุ่นต่ำไม่สามารถช่วยลดการรั่วซึมบริเวณขอบโพรงฟันที่มีซีแฟคเตอร์สูงที่บูรณะด้วยเรซิน คอมโพสิต และการปรับสภาพผิวโพรงฟันด้วยสารปรับภาพเนื้อฟันก่อนทำการรองพื้นโพรงฟันด้วยเรซิน โมดิฟายด์ กลาสไอโอโนเมอร์สามารถช่วยลดการรั่วซึมบริเวณขอบโพรงฟันที่มีซีแฟคเตอร์สูง ที่บูรณะด้วยเรซิน คอมโพสิตได้

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
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Jomnang Yoohun : USING OF LOW MODULUS OF ELASTICITY BASE IN HIGH C-FACTOR RESIN COMPOSITE RESTORATION: AN IN VITRO STUDY. Advisor: ASSOC. PROF. SIRIVIMOL SRISAWASDI, D.D.S., M.S., Ph.D.

This in vitro study aims to investigate whether or not using a resin modified glass ionomer as a base or intermediate layer would improve marginal integrity of a high C-factor class V resin composite restoration. Eighty non-carious human third molars were used. A box-shaped, 5x3x2.5 mm^3, Class V cavity preparation was placed on buccal surface at the cementoenamel junction. Teeth were then randomly assigned to 8 experimental groups (n=10): group 1, Resin composite (Filtek™ Z350 XT); group 2, Filtek™ Bulkfill; groups 3 and 4, resin composite with Filtek™ Z350 XT Flowable as base; groups 5 and 6, resin composite with Fuji II LC as base; groups 7 and 8, resin composite with Fuji II LC as base with use of Cavity Conditioner. In groups 1 – 4 the prepared cavities were etched, with selective enamel etching, and the adhesive (Scothbond Universal, 3M ESPE, USA) were then applied according to manufacturer's instructions, then restored with resin composite (Filtek™ Z350 XT, 3M ESPE, USA) while in groups 5 – 8 the same bonding procedures were done after placement of RMGI base. The restorations were finished and polished, thermocycled (10,000×, 5-55°C) and stained with a 50% silver nitrate solution. After being sectioned bucco-lingually, 6 surfaces of measurement per tooth were obtained, and depth of dye penetration recorded. Microleakage data were analyzed using Kruskal-Wallis non-paramatric independent analysis and a Mann-Whitney U test. Kruskal-Wallis test indicated significant differences among 8 experimental groups for gingival ($P < 0.001$) scores. For Mann-Whitney U test, significant difference was found between group using low modulus of elasticity base and group without using low modulus of elasticity base only gingival margin ($P < 0.001$). Mann-Whitney U test also revealed significant difference between group using dentin conditioner and group without uses of dentin conditioner at gingival margin. In conclusion, based on our findings, the use of low modulus of elasticity materials does not result in better marginal seal for high C-factor Class V resin composite. The use of dentin conditioner may improve marginal integrity for resin composite restoration when RMGI is used as base.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

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CHAPTER I

INTRODUCTION

Background and Rationale

Adhesive restorative materials have now become a mainstream of direct restoration placement in restorative dentistry. Since there have been developments of a wide variety of materials with improved physical properties, reduction of technique sensitivity and, importantly, the development of excellent, reliable adhesive resins to bond filling materials to enamel and dentin surfaces (1). The use of resin composites in posterior teeth had been introduced decades ago. Success of these materials may be attributed to their adhesive properties, which allows less tooth structure removal with reduced preparation sizes and also help reinforce the remaining tooth structure (2). A clinical study had shown that painful vital teeth with incomplete fractures can be treated successfully by replacing the amalgam fillings with bonded resin composite restorations (3). However, resin composites inherited some undesirable characteristics, such as polymerization shrinkage which could resulted in marginal leakage in the restoration. Conversion of resin monomers into long chains of polymers leads to a volumetric change, which could generate shrinkage stresses in the restoration. These stresses have the potential to initiate gap formation at the restoration–tooth interface leading to microleakage, marginal discoloration, post-operative sensitivity, and eventually adhesive failures (2, 4, 5), particularly when restoring cavitity with high C-factor which yield less chance for relaxation of shrinkage stress, such pre-stressed interfaces may be more susceptible to degradation which would explain the relatively fast in vivo degradation noted for high C-factor Class-I restorations even when the predicted durable bonding was being used (6).

Many techniques and newer materials have been introduced to reduce polymerization stress such as, incremental layering technique, soft-start polymerization, and the use of low modulus of elasticity liner as an intermediate layer between restoration and tooth structure (5, 7, 8). The increasing popularity of new restorative materials called “bulk- fill” materials, are claimed to enable restoration build-up to 4 mm thick per layer. This new material class includes flowable and packable types. Dental bulk-fill composites may contain polymerization modulator chemical groups or plasticizers in their resin matrix to reduce the effect of polymerization shrinkage stress when these materials are applied in bulk (9). The main advancements in bulk-fill materials are an increased depth of cure which resulted from higher translucency and low-shrinkage stress which related to modifications in the filler content and the organic matrix (10).

Focusing on the use of low modulus of elasticity material as an intermediate layer between restoration and tooth structure, mostly glass ionomer-based or low-elastic-modulus resin-based materials are being used with this purpose. Flowable composites are not recommended for use in stress-bearing areas since they have lower physical properties compared with standard restorative composites. However, if they are used as an intermediate layer in restorations, their lower modulus of elasticity could reduce marginal microleakage, which is thought to compensate for the polymerization contraction stresses of the final restoration (11). Resin modified glass ionomer materials could act on strain and marginal leakage reduction, presenting additional benefits as adhesion on dentin and fluoride release, which could reduce the chances of secondary caries formation in composite restorations (11, 12). These liners either resin-modified glass ionomer or flowable composite are shown to provide better adaptation and act as a flexible stress-absorbing layer between restoration and tooth (5, 7). Several in vitro studies have shown that the application of intermediate layer reduces microleakage which leads to an improved marginal integrity of composite restorations (2, 12, 13). Some authors also suggested that in cases where the remaining tooth structure is minimal and large amounts of resin composite are being placed, liners or bases could limit the amount of heat generated during placement of restoration (14). Though resin modified glass ionomer cement can adhere to tooth structure without any prior treatment, studies have shown improvements of bond strength after surface treatment (conditioning) with various solutions (15-17).

From a clinical perspective, some authors suggested that the use of cavity bases would have a weakening effect on the overall strength of the restoration, resulting in more fracture of composite restorations, but has stated that the role of glass ionomers in the fracture behavior remained unclear (12, 18). The possible reason could be that a layer with a low E-modulus material placed between two high E-modulus materials (tooth and composite resin) leads to a concentration of forces in the elastic layer when the tooth is loaded (19), which could result in restorations placed with a lining being more sensitive to fatigue after repeated loading and led to higher clinical failure of the restorations either due to fracture (12). On the other hand, recent study by Sande et al: 18-year survival of posterior composite resin restorations with and without glass ionomer cement as base, concluded that the use of glass ionomer cement as base did not affect the survival of resin composite restorations with acceptable annual failure rates of about 2% after 18 years (2).

To determine the success or failure of restorations, one must assess its longevity and sealing ability under function in oral environment. The marginal adaptability of restorations is necessary for successful restoration of teeth since the interface between restoration and dental substrate is an area of clinical concern that can result in secondary caries and marginal breakdown. Therefore, microleakage can be considered as an important factor influencing the longevity of dental restorations (20).

It was still unknown whether the use of low modulus of elasticity material as a base in high C-factor class V resin composite restoration would improve marginal integrity and overall strength of high C-factor class V resin composite restoration or not. Therefore, the aim of the present study was to investigate whether or not using a low modulus of elasticity material as a base or intermediate layer would improve marginal integrity of a high C-factor class V resin composite restoration.

Research Questions

Does the use of low modulus of elasticity material as base or intermediate layer improve marginal integrity of a high C-factor resin composite restoration?

Research Objectives

The aim of this present study was to determine whether or not using a low modulus of elasticity material as a base or intermediate layer would improve marginal integrity of a high C-factor resin composite restoration.

Research Hypothesis

1. The use of low modulus of elasticity material as a base or intermediate layer does not improve marginal integrity of a high C-factor resin composite restoration.
2. Different application patterns of low modulus of elasticity material as a base or intermediate layer has no effect in improving marginal integrity of a high C-factor resin composite restoration.
3. The use of dentin conditioner prior to placement of resin modified glass ionomer as a base or intermediate layer has no effect in improving marginal integrity of a high C-factor resin composite restoration.

Conceptual Framework

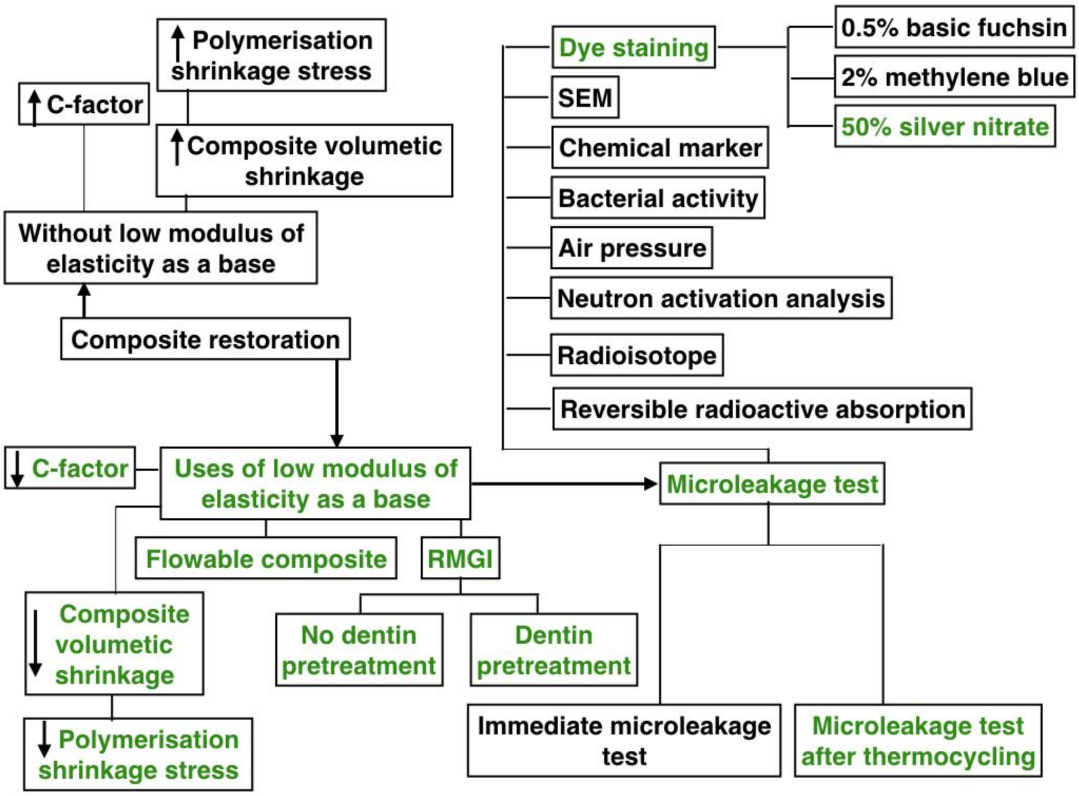


Figure 1: Diagram of conceptual framework

Key Words

Composite, Dentin conditioner, Low modulus of elasticity base, Microleakage, Resin modified glass ionomer, Silver nitrate

Limitations

1. Only one commercial RMGI: Fuji II LC (GC Co, Japan), was used in this study, since each brand consisted of different compositions, the outcomes might be different.

2. Only one brand of flowable composite; Filtek Z350 XT Flowable Restorative (3M ESPE, USA) was used in this study, since each brand consisted with different compositions, the outcomes might not be the same.

3. Only one brand of dentin conditioner (Cavity conditioner; GC Co, Japan) was used in this study, since each brand varies in concentration of the acid, it’s effect to dentin would not be the same.

4. Only one type of Cavity (Class V) was examined in this study. Since class V cavity represent the situation of maximum polymerization shrinkage stress with C-factor of 5/1 surfaces.

CHAPTER II
REVIEW OF LITERATURE

Dentin

Dentin is a hydrated composite structure composed of the collagen-based organic matrix with mineral reinforcement, varying with anatomical location (21, 22). Furthermore, dentin is modified by physiological, aging and disease processes which creates different forms of dentin (22). These altered forms of dentin may be the precise forms that are most important in restorative dentistry. Some of the variations of dentin include primary, secondary, reparative or tertiary, sclerotic, transparent, carious, demineralized, remineralized, and hypermineralized. They reflect alterations in the fundamental components of the structure as defined by changes in their arrangement, interrelationships or chemistry. A number of these may have important implications for our ability to develop long lasting adhesion or bonds to this structure (22).

Dentin permeability is variable and location dependent, being greater near the pulp and pulp horns than adjacent areas, reflecting differences in tubule density and increasing diameter of the tubules closer to the pulp. Therefore, bonding to deep dentin has been expected to be more challenging than to superficial dentin, due to the reduced area of solid intertubular dentin associated with the increased moisture content (23). Dentin level after removal of cusp tips was considered as superficial dentin, one millimeter below the superficial dentin level was considered as deep dentin (21, 23).

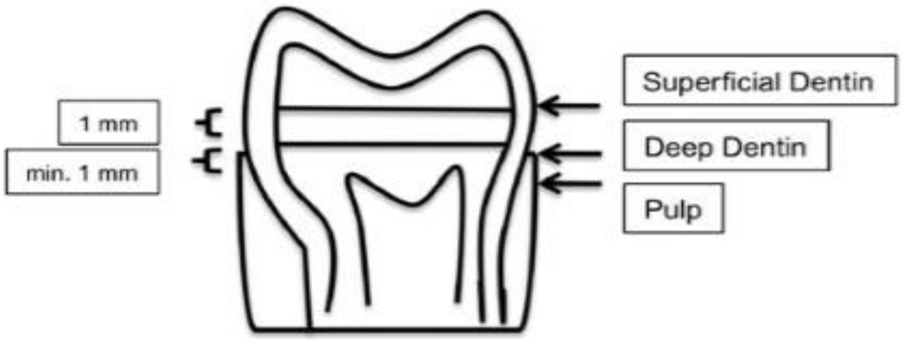


Figure 2: Sketch of the position of superficial and deep dentin in relation to the cusp tips and pulp horns.
Note that 1 mm below superficial dentin was considered as deep dentin. With X-rays, it was made sure that dentin was available at least 1 mm above the pulp horns, Ozcan and Mese (23).

High C-factor resin composites restoration

Resin composites are used for various applications in dentistry, including filling materials, cavity liners, inlays, onlays, pit and fissure sealants, provisional restorations, cores and buildups, crowns, cements for single or multiple tooth prostheses and orthodontic devices, endodontic sealers, and root canal posts. It is no doubt that uses of resin composites will continue to grow both in frequency and application due to their versatility (24). Resin composites inherit characteristics, such as polymerization shrinkage and stress which could led to tissue deflection and marginal microleakage resulting in clinically detectable margin in. Much effort in research was spent on new materials and techniques to prevent clinical failures associating with secondary caries and marginal leakage of resin composite restorations (2).

To describe correlation between shrinkage with stress values in a tooth cavity, the term ‘cavity configuration factor’ (C-factor) was created, and defined as the ratio between bonded and unbonded surfaces of the composite restoration (25). Polymerization shrinkage stress is generated during polymerization of the composite, pulling the adhesive from the cavity wall which put bonded interfaces under severe tension, particularly, when restoring cavities with high C-factor. This phenomenon is especially pronounced in a Class-I and Class V cavity with five bonded walls and only one free surface, revealing a C-factor of 5/1 (6). High shrinkage stresses generated could induce gaps between the restoration and the cavity wall resulting in microleakage, post-operative sensitivity and other related clinical complications. Such pre-stressed bonded interfaces could result in degradation of bonding interfaces which notably shown in high C-factor restorations, even when durability proven adhesives are being used (6, 26)

Low modulus of elasticity Material

Flowable composite

Flowable composites were introduced in the mid-1990s and became widely used for a broad range of restorative applications. Flowable composites have been recommended for use as a liner in resin composite restorations and for use as a restorative material in small Class V cavities (27). They contained the same, but 20–25% less, filler particles than the convention resin composites resulting in less rigidity. The use of flowable composites as an intermediary layer is suggested to reduce interfacial debonding and cuspal deflection. Their easy handling properties, enhanced flow, reduced elastic modulus and better wettability may result in improved placing characteristics, reduce voids at the cervical interface and may counteract microleakage by improved interfacial bonding and by forming a stress-absorbing layer. Several in vitro studies have shown that flowable resin composites reduced microleakage, while some studies could not confirm improved marginal adaptation (28). The use of a flowable composite as an intermediate layer resulted in significantly less cuspal deflection than without a flowable composite as an intermediate layer. In contrast, another study using a photoelastic model reported that the use of flowable composite as an intermediate layer increased shrinkage stress at the adhesive interface (29, 30).

Resin modified glass ionomer (RMGI)

Glass ionomer cements (GICs) have been popular in clinical dentistry for many years. These cements have the advantages of their ability to chemically bond to hydroxyapatite, release fluoride over a long period which may result in secondary caries prevention, and good biocompatibility. GICs are materials made of calcium, strontium aluminosilicate glass powder (base) combined with a water-soluble polymer (acid). When these components are mixed together, they undergo a setting reaction involving neutralization of the acid groups by the powdered solid glass base (15, 31). However, the two main disadvantages of conventional GICs are the lack of command cure and moisture sensitivity. To overcome these problems, light cured glass ionomers were developed and was released to the market (32). Resin modification of GICs was done to improve physical properties of these materials while maintaining the benefits of the conventional GICs. These new materials are called resin modified glass ionomer (RMGI) or hybrid ionomers (33). They are defined as hybrid materials that retain a significant acid – base reaction as part of their overall curing process. In their simplest form, these are GICs with the addition of a small quantity of a resin such as hydroxyethyl methacrylate (HEMA) or Bis – GMA in the liquid. More complex materials have been developed by modifications of the Polyacid with side chains that can be polymerized by a light – curing mechanism (34). RMGI undergoes the original acid–base setting reaction and combined with monomers and photochemical polymerization initiators (35). This photochemical reaction reduces sensitivity to moisture and dehydration which associated with the acid–base setting reaction of conventional GICs (35). RMGI are expected to obtain the benefits of conventional GICs, such as fluoride release resulting in caries prevention, and thermal compatibility with the tooth compared with conventional GICs (35), RMGI have better working characteristics and the ability to bond to dentin (36, 37). The chemical reaction occurred when the carboxylic components of the cement and the calcium present in tooth structure reacted consequently allowing bonding to tooth structure to be established (38). Moreover, to the formation of ionic bonding, RMGI present micro-mechanical interlocking with the conditioned dentin (36, 39).

RMGI have certain unique properties which make them useful as restorative and adhesive materials. Those properties include adhesion to moist tooth structure and base metals, anticariogenic properties due to their fluoride releases, thermal compatibility, biocompatibility and low toxicity (40). This class of material has been frequently used as liner/base in restoration because of its excellent seal to dentin, which is important in preventing post-operative sensitivity (41, 42). RMGI liners are well known for their ability of minimizing post-operative sensitivity, as shown in numerous clinical studies (43-47). This is a result of two properties: RMGI materials are self- adhesive, not requiring removal of the smear layer (38) and the low modulus of these materials (38) allow them to buffer the effects of polymerization shrinkage of composites (48, 49). Also they are less moisture sensitive due to their hydrophilicity and water content (50, 51). Additionally, their high fluoride release (52) has been shown to help protect adjacent tooth structure (41, 53). Though studies have reported that RMGI adhere to tooth structure without prior treatment, other studies have shown improvements of bond strength after treatment of dental surface with various solutions (15, 16, 54). Cavity conditioning plays a more important role in providing effective bonding with RMGI. Pretreatment with a diluted polyalkenoic acid conditioner is advised to remove the smear layer and partially demineralize dentin with retained smear plugs. This surface conditioning could improve the bonding of RMGI through the formation of a sub-micron hybrid layer and chemical bonding with the remaining hydroxyapatite around the exposed collagen (55). Self-etch primers such as Vitremer primer are reported to modify the smear layer and improve the wettability of the dentin and monomer penetration into it (56).

Microleakage testing

The effects of bacterial leakage upon the dental pulp were well investigated (57, 58). Prevention of bacteria leakage into margins of restorations is an absolute goal in adhesive dentistry.

In early 1860s, the effort in determining the effectiveness of sealing ability of dental restoratives, microscopic examination of amalgam marginal contraction was carried out by Tomes, followed by experiments into the leakage of dye indicators around the margins of amalgam packed into glass tubing (59). Since these early experiments, researchers have put in much effort to study leakages of dental materials and to improve the marginal seal of restoration which later termed 'micro-leakage'.

Microleakage is defined as the passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material applied to it (60). Various techniques have been proposed to demonstrate that margins of restorations allow active movement of ions and molecules. These techniques include the use of bacteria, compressed air, chemical and radioactive tracers, electrochemical investigations and, perhaps most commonly of all, the use of dye penetration studies. Investigation of microleakage has been done both in vivo and in vitro. In vitro experiments were set into two categories; those which use a clinically relevant model with attempts to reproduce the oral situation, and those in which the model does not represent oral situation and is purely a test of the material's properties (59).

The dye penetration technique is one of the most used methods to investigate marginal integrity of the restoration (61). Several dye agents with different concentrations had been introduced into the technique, in which 0.5% basic fuchsin, 2% methylene blue and 50% silver nitrate solution have been most frequently used (59). This technique involves immersing restored tooth in a dye solution for a predetermined period, followed by washing and sectioning of the specimen followed by examination under magnification to determine the extent of dye penetration along the tooth-restoration interfaces (62, 63).

Evaluation of specimens, in most microleakage studies involving tracer penetration, uses a two-surface scoring method. The specimen was sectioned longitudinally through the center of the restoration (59, 64, 65). Christen and Mitchell (66) developed a system to evaluate the total marginal interface of the restoration. They scored multiple surfaces of the restoration and presented this as a more realistic evaluation of the leakage pattern. Wenner et al. (67) conducted a pilot study scoring six surfaces of three sections of a tooth through the restoration and found that the probability of finding a false negative was 33 percent if only a single section was evaluated. Mixson et al. (68) compared the two-surface and multiple-surface scoring methodology and suggested that microleakage at the proximal corners of the restoration may be more severe. The scoring of the specimen was based on standard criteria developed by researchers assigning numerical value to represent the extent of dye penetration (60, 69). The interpretation of specimens has been criticized as relying on qualitative and subjective judgment in evaluation (60, 69, 70).

Although, several choices of dyes were mentioned in literatures, many researchers have chosen 50% silver nitrate (w/v), using different immersion times of specimens in the agent and different times to reveal the silver. The amount and distribution of silver show the extent of damage at the restoration-tooth interface, which can be measured by the use of various micro-investigation techniques. The use of silver nitrate solution is considered a very severe test due to their penetrative capacity. The diameter of the silver ion is very small (0.059 nm) when compared to the mean size of a bacteria (0.5-1.0 μm) (71).

Wu and Cobb (62) developed the silver staining technique to investigate microdefects in resin composite. Silver was selected as the staining agent because of their strong optical contrast and their penetrative capacity. This technique involves immersion of the specimens in a 50% silver nitrate solution for two hours in the dark. The specimens are then rinsed to remove silver ions on the surface, and immersed in photo developing solution while exposed to fluorescent light for six hours. The silver ions absorbed in the specimens precipitate as silver particles during this stage. Specimens for microleakage studies were then sectioned. The degree of leakage may then be measured in level of penetration defined by many authors or by percentages of leaked silver to the bonding interfaces of sectioned specimen. Silver nitrate had been widely used for investigating the degradation of tooth-material interface, since Sano, et al. (72) detected the presence of silver nitrate in the hybrid layer, calling the phenomenon nanoleakage. Several researchers (59, 73) followed this method of using silver nitrate as a tracer for leakage analysis because of the contrast quality observed in microleakage.

Taylor and Lynch stated that the main disadvantages of this type of assessment were the numerical scoring system of increasing degrees of leakage assigned by the operator, although the evaluation were often carried out by more than one examiner, was somewhat subjective. Furthermore, the assessment of the restoration as a whole was difficult when viewing only individual small sections of tooth (59). Most researchers have taken single sections from the midpoint of a restoration when there was little, if any, evidence to suggest that this would reflect the true state of the other restoration margins (59). Literature reveals that whilst many choices of dye are available, researchers tend to use the same dye. It is impractical to use a dye particle which has a diameter greater than that of the internal diameter of dentinal tubues (l-4 μm) since it is unlikely that the dye used would represent the bacterial penetration of these tissues which is being investigated. However, dye penetration studies in dentin will exhibit some dentin staining which should be distinguished from the actual gap between the cavity wall and restoration (59).

Thermocycling

While clinical trials are the best way to provide information about reliability and long-term performance of dental materials (74), they are expensive and more time-consuming. Also, by the time the study is published the products under investigation might have already been discontinued.

Thermocycling stimulates aging process of the restoration on an accelerated basis (75), causing marginal degradation in all types of restorative material at a much faster rate than seen in appropriate controls (76, 77). Study has shown that the thermocycling model will accelerate the process of microleakage in vitro by inducing failure of the restoration (78-82). The cracks along adhesive layer occurred due to stress generated during thermal change leading to gap formation. Changing gap dimensions caused in- and outflow of oral fluids, a process known as percolation (83).

Microleakage tests are often used as predictors of clinical performance for new generation of dental adhesive restorative approaches and materials (84). These tests usually include thermocycling to simulate intraoral conditions (61, 74), which requires exposure of specimens to water baths set at temperatures that resemble those found in the oral cavity. The rationale behind this is that marginal percolation can be caused by differences in the coefficient of thermal expansion between dental tissues and the restorative material. The polymerization shrinkage, poor bonding of restorative materials to tooth tissues and coefficient of thermal expansion are often found as the main factors for microleakage (74). One concern of the thermocycling regimen is that the temperature variations between 5°C and 55°C do not necessarily alters or causes damages at the tooth-restoration interfaces. Moreover, the presence of water may enabled or facilitated hydrolysis of the bonding agent and its union with tooth tissue (74). As known, water acts as plasticizer of polymers and reduces the marginal integrity of restorations being a stress-raising factor (83, 84).

Study by Li et al. (74) showed that thermocycling did not affect nanoleakage for both dental adhesive systems used in the experiment. The patterns and the extent of nanoleakage were not affected by the thermocycling. The results are in accordance with previous studies on microleakage of various dentin bonding agents stated that no significant differences were detected in microleakage between before and after thermocycling (51, 85-89). Thermocycling with a different number of cycles, i.e. 250 and 1000 cycles, resulted in no significant difference in dye penetration (86, 87). The results might be the consequences from using small number of cycles in the studies, which was stated by Gale and Darvell to be too low for an aging effect to be obtained (83). Gale and Darvell, (1999) also proposed that 10,000 cycles of thermocycling could represent 1 year of function in vivo (83).

CHAPTER III
MATERIALS AND METHODS

Research Design

This study was an in vitro experimental study with the aim to measure the effect of low modulus of elasticity base or intermediate layer on marginal integrity of a high C-factor composite restoration using microleakage test.

Research Methodology

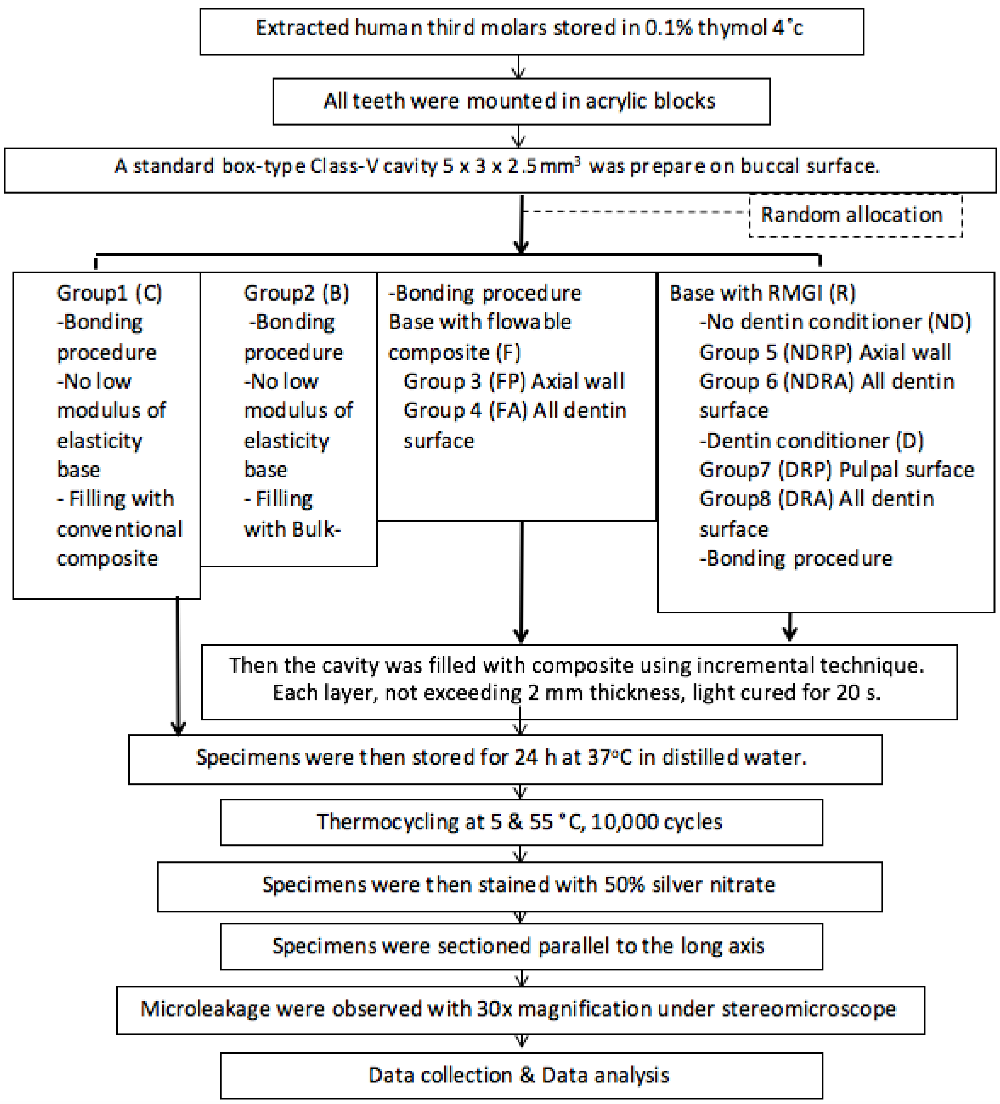


Figure 3: Diagram of study design

Population and sample

The sample size was determined according to previous published articles (90-92); which have experimental design using microleakage testing in composite restoration, the most frequently used sample size is 10 samples per group.

Preparation of specimens

Eighty human third molars (gathered following informed consent approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2017-068) were cleaned with pumice and store in 0.1% Thymol solution at 4 $^{\circ}C$ and used within 1 month after extraction.

All teeth were then mounted in 2.5x2.5x2 cm^3 acrylic blocks (occlusal surface perpendicular to the long axis), exposing 2 mm below the CEJ. A standard high C-factor class V cavity was prepared on buccal surface of each tooth. The preparations were done with high speed diamond burs under copious water coolant. After every five preparations, the burs were discarded and replaced with a new one. The gingival cavosurface margins of the preparation were placed at the cementoenamel junction. The dimension of final preparation was 3.0 mm occlusogingivally, 5.0 mm mesiodistally and 2.5 mm deep. The occlusal cavosurface margins of the preparation were beveled (Figure 1a). The specimens were then randomly divided into eight groups (n=10 per group) corresponding to eight experimental groups of different insertion techniques. The materials used in this experiment were listed in table 1.

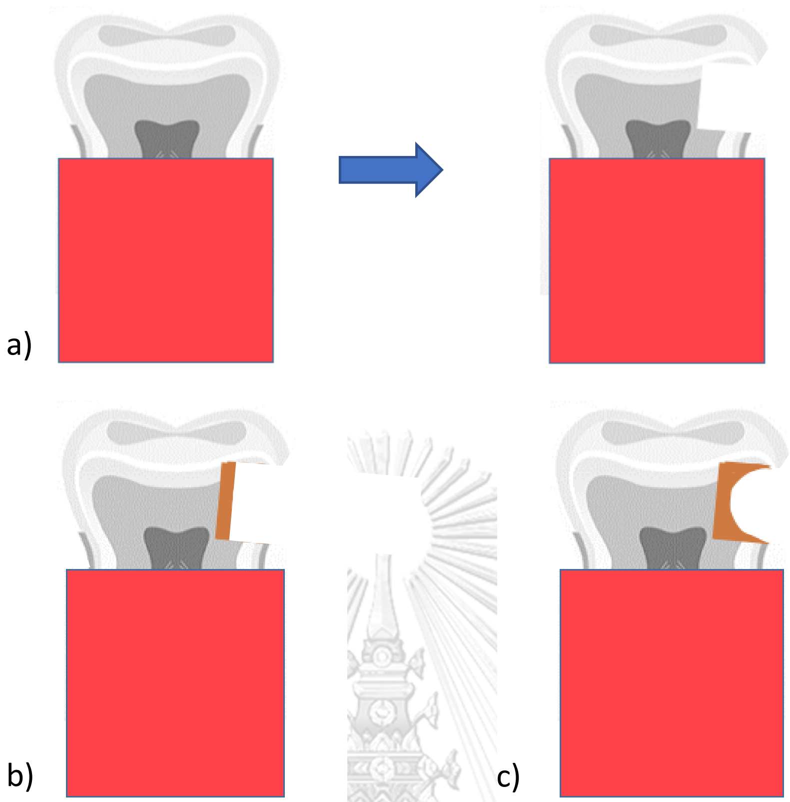


Figure 4: a) Cavity preparation 4x4x2.5 mm^3

b) Base material covering axial surface (P)

c) Base material covering all dentin surface (A)

Group 1 (C) — Bonding procedures were carried out according to the manufacturer's instructions. The prepared cavities were etched, with selective enamel etching, using a 34% phosphoric acid (Scothbond Universal Etchant, 3M, USA) for 15 s, rinsed thoroughly with distilled water for 10 s, and air dried for 2 s. Adhesive (Scothbond Universal, 3M ESPE, USA) was then applied to the entire preparation with a microbrush using rubbing motion for 20 s. A gentle stream of air was blown over the liquid for about 5 s until no fluid movement was observed and the solvent has evaporated completely then light cured for 10 s (DemiTM Plus; Kerr, USA) with 1,100 mW/cm2 intensity. The cavity was then filled with Filtek Z350 XT shade A3 (3M ESPE, St Paul, MN, USA) incrementally with each layer not exceeding 2 mm and light cured for 20 s.

Group 2 (B) — Bonding procedures were carried out according to the manufacturer's instructions same as in group 1. The cavity was then filled with Filtek Bulk Fill shade A3 (3M ESPE, St Paul, MN, USA) and light cured for 40 s.

Using low modulus of elasticity material as base

Using flowable composite as base:

Group 3 (FP) — Bonding procedures were carried out according to the manufacturer's instructions same as in group 1. A 1-mm-thick (measuring with a periodontal probe) flowable (F) composite (FiltexTM Z350 XT Flowable Restorative, 3M ESPE, USA) was applied as base using the closed sandwich technique on the axial wall, then light cured for 20s (Figure 1b).

Group 4 (FA) Bonding procedures were carried out according to the manufacturer's instructions same as in group 1. A 1-mm-thick (measuring with a periodontal probe) flowable (F) composite (FiltexTM Z350 XT Flowable Restorative, 3M ESPE, USA) was applied as base, covering whole dentin surface on the axial wall up to surrounding walls (A) (Figure 1c), then light cured for 20s.

Using resin modified glass ionomer as base:

No dentin conditioner was applied to the following 2 groups:

Group 5 (NDRP) — A 1-mm-thick RMGI (Fuji II LC, GC Corporation, Japan) was applied as base using the closed sandwich technique on the axial wall (P), then light cured for 30s. Bonding procedures were carried out according to the manufacturer's instructions same as in group 1.

Group 6 (NDRA) — A 1-mm-thick RMGI (Fuji II LC, GC Corporation, Japan) was applied as base, covering whole dentin surface on the axial wall up to surrounding walls (A), then light cured for 30s. Bonding procedures were carried out according to the manufacturer's instructions same as in group 1.

Table 1: Material, Manufacturer and Component

Material	**Components**
Scothbond Universal (3M ESPE, USA)	1. Etchant: 34% phosphoric acid, water, synthetic amorphous silica, polyethylene glycol, aluminium oxide. (Scotchbond Universal Etchant) 2. Adhesive: MDP phosphate monomer, dimethacrylate resins, HEMA, methacrylate-modified polyalkenoic acid copolymer, filler, ethanol, water, initiators, silane
Resin modified glass ionomer (RMGI) Fuji II LC (GC Corporation, Japan)	**Powder**: 100% Fluoro-alumino-silicate glass **Liquid:** 35% HEMA, 25% Distilled water, 24% Polyacrylic acid, 6% Tartaric acid and 0.10 camphorquinone
Cavity Conditioner (GC Corporation, Japan)	20% Polyacrylic acid
Filtex™ Bulk Fill (3M ESPE, USA)	Bis-GMA (1–10%), UDMA (10–20%), Bis-EMA (1–10%), Procrylat resins Zirconia/silica, Ytterbium trifluoride (64.5% wt)
Filtex™ Z350 XT Flowable Restorative (3M ESPE, USA)	Bis-GMA, Bis-EMA, TEGDMA 5–20 nm Zr/silica nanoparticles + 0.6–1.4 m nano-clusters (65% wt)
Filtex™ Z350 XT (3M ESPE, USA)	BIS-GMA, BIS-EMA, UDMA, and TEGDMA, 5–20 nm Zr/silica nanoparticles + 0.6–1.4 m nano-clusters (82% wt)

HEMA: Hydroxyethyl methacrylate; Bis-GMA: Bisphenol A-glycidyl methacrylate 2,2-bis [4-(2-hydroxy-3-methacryloxypropoxy) phenyl] propane; TEGDMA: Triethyleneglycol dimethacrylate; UDMA: Diurethane dimethacrylate; GPDM: Glycero-phosphate dimethacrylate; PAMM: Phthalic acid monoethyl methacrylate

Dentin conditioner (Cavity Conditioner, GC Corporation, Japan) was applied to the following 2 groups:

Group 7 (DRP) — A dentin conditioning agent (Cavity Conditioner, GC Corporation, Japan) was applied to dentin surfaces for 10s using a sponge, rinsed thoroughly with water, and dried. A 1-mm-thick RMGI (Fuji II LC, GC Corporation, Japan) was applied as base using the closed sandwich technique on the axial wall (P), then light cured for 30s. Bonding procedures were carried out according to the manufacturer's instructions same as in group 1.

Group 8 (DRA) — Dentin conditioning procedures were carried out according to the manufacturer's instructions, same as in group 7. A 1-mm-thick RMGI (Fuji II LC, GC Corporation, Japan) was applied as base, covering whole dentin surface on the axial wall up to surrounding walls (A), then light cured for 30s. Bonding procedures were carried out according to the manufacturer's instructions same as in group 1.

The cavity was then filled with Filtek Z350 XT shade A3 (3M ESPE, St Paul, MN, USA) incrementally with each layer not exceeding 2 mm and light cured for 20 s. The teeth were then stored for 24 h at 37°C in distilled water.

Microleakage testing

Specimens were thermocycled for 10,000 times with a dwell time of 60 s (5°C, 35°C, 55°C and 35°C for 5,25,5, and 25 s, respectively) (93, 94).

The samples were then immersed in a 50% silver nitrate solutions for 2 hours, washed, and then immersed in a photographic developer (D-76; Kodak Co, Rochester, NY, USA) for 8 hours under fluorescent light, and abundantly washed under running water (95). The specimens were sectioned bucco-lingually, parallel to the long axis to obtain 5 pieces. Only the middle 3 pieces with 6 surfaces of measurement per tooth were observed. The restorations were analyzed at occlusal margin (enamel margin) and gingival margin (dentin margin) separately with a stereomicroscope at a 30x magnification (ML9300 MEIJI, JAPAN). The extent of dye penetration was scored according to the following scoring system from previous studies (96, 97). (Table 2 & Figure 2)

Table 2: Dye Penetration scoring system

Score	Extent of dye penetration
0	No dye penetration
1	Dye penetrated between the restoration and the tooth along the restoration-occlusal or restoration-gingival interface up to half the length of the occlusal or gingival wall.
2	Dye penetrated beyond half of the length of the occlusal or gingival wall of the restoration but not reaching the axial wall.
3	Dye penetrated along the entire length of the occlusal or gingival wall and reaching the axial wall.

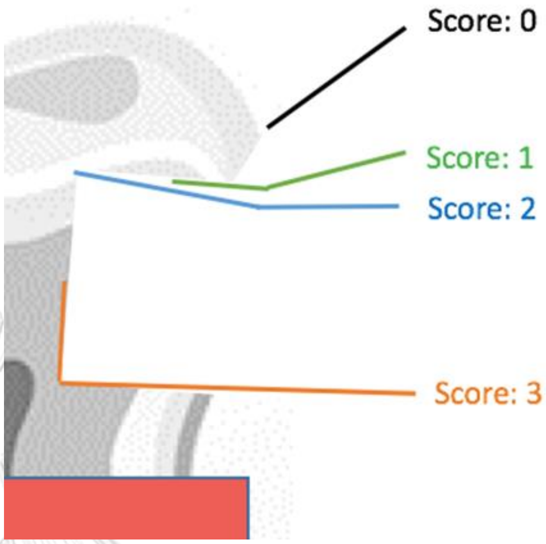


Figure 5: Microleakage Score

Data collection

The sections of each restoration were scored by the same operator for occlusal margin and gingival margin separately, and the most severe microleakage score was recorded as the score for that restoration. All the specimens were re-evaluated and scored for the second time 24 hours after the first evaluation by the same operator to provide reliability of measurements.

Data analysis

The statistical analysis was done with the Kruskal-Wallis non-paramatric independent analysis and the Mann-Whitney U test to evaluate differences between experimental groups at a significance level of 0.05 using software SPSS 20.0 for Windows (Chicago, IL, USA).

CHAPTER IV
RESULTS

Microleakage scores for the occlusal and gingival margins are presented in table 3. Stereomicroscopic images for the sectioned specimens were illustrated at occlusal margin and gingival margin in figure 3.

Table 3: Frequency of marginal leakage in occlusal (enamel) and gingival (dentin) margins. N (%)

		Occlusal (Enamel)				Gingival (dentin)			
Group	Groups codes	Scores				Scores			
		0	1	2	3	0	1	2	3
1	C	7	2	1	0	0	8	1	1
		70%	20%	10%	0%	0%	80%	10%	10%
2	B	6	4	0	0	0	10	0	0
		60%	40%	0%	0%	0%	100%	0%	0%
3	FP	6	4	0	0	0	3	0	7
		60%	40%	0%	0%	0%	30%	0%	70%
4	FA	4	5	1	0	0	6	3	1
		40%	50%	10%	0%	0%	60%	30%	10%
5	NDRP	1	2	4	0	0	0	3	4
		14%	29%	57%	0%	0%	00%	43%	57%
6	NDRA	8	2	0	0	0	0	2	8
		80%	20%	0%	0%	0%	0%	20%	80%
7	DRP	6	4	0	0	0	5	3	2
		60%	40%	0%	0%	0%	50%	30%	20%
8	DRA	5	4	1	0	0	6	4	0
		50%	40%	10%	0%	0%	60%	40%	0%

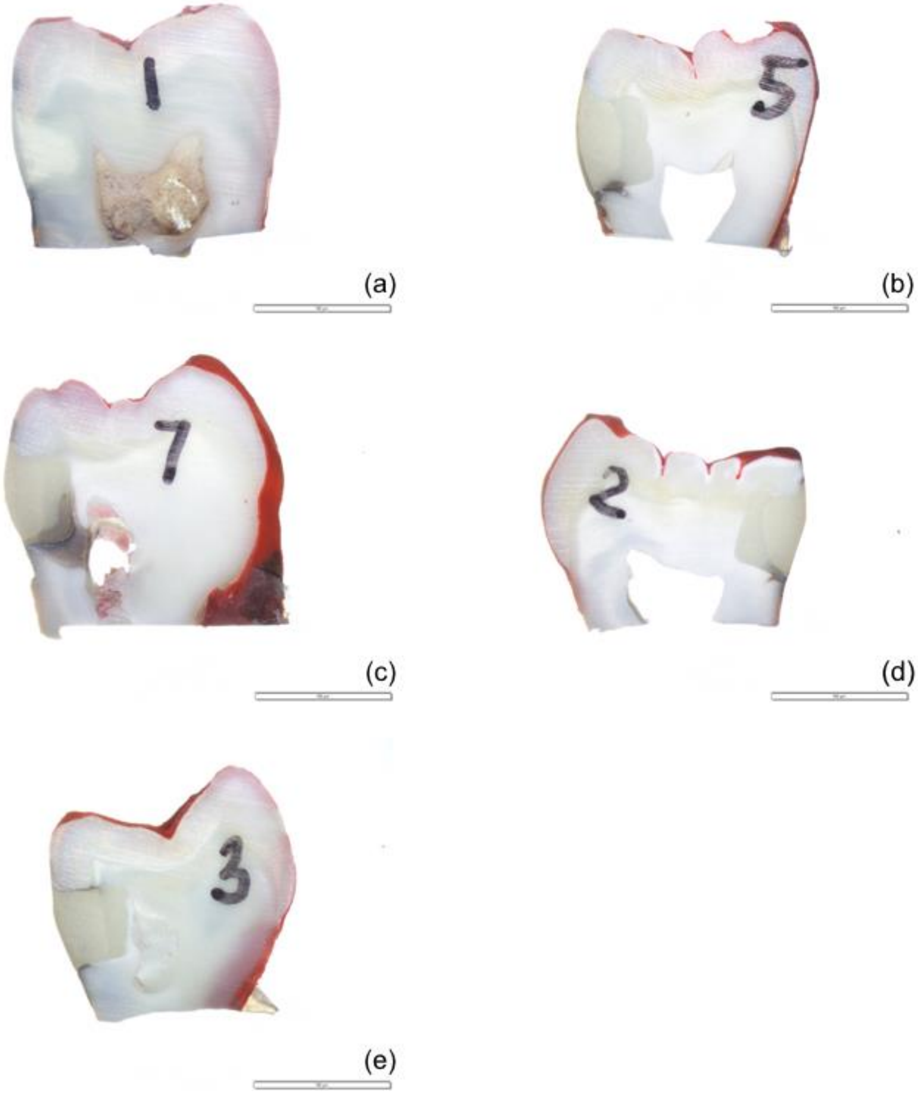


Figure 6: Representative stereomicroscopic images of various leakage scores

a) Stereomicroscopic figure; leakage score 0 at occlusal margin, leakage score 1 at gingival margin

b) Stereomicroscopic figure; leakage score 0 at occlusal margin, leakage score 2 at gingival margin

c) Stereomicroscopic figure; leakage score 0 at occlusal margin, leakage score 3 at gingival margin

d) Stereomicroscopic figure; leakage score 1 at occlusal margin, leakage score 1 at gingival margin

e) Stereomicroscopic figure; leakage score 2 at occlusal margin, leakage score 1 at gingival margin

Occlusal margin (enamel margin)

Kruskal-Wallis test found no significant differences among 8 experimental groups for occlusal margin scores (P = 0.051).

Multiple pairwise comparisons were not performed because the overall test did not show significant differences across samples.

For Mann-Whitney U test, no significant difference was found between group using low modulus of elasticity base and group without low modulus of elasticity base (P = 0.306). No statistical significant differences were found between different patterns of low modulus of elasticity base (P = 0.407). Also, no significant differences between group using dentin conditioner and group without uses of dentin conditioner prior to placement of resin modified glass ionomer base was found (P = 0.598).

Gingival margin (dentin margin)

Kruskal-Wallis test indicated significant differences among 8 experimental groups for gingival margin scores (P < 0.001).

Multiple comparisons were performed because the overall test showed significant differences across samples. Significant differences detected in pairwise comparisons test (P < 0.05) are shown in table 4.

For Mann-Whitney U test, significant difference was found between group using low modulus of elasticity base and group without low modulus of elasticity base (P < 0.001). No statistical significant differences were found between different patterns of low modulus of elasticity base (P = 0.211), and from pairwise comparison test no significant differences was found for groups FP and FA, NDRP and NDRA, DRP and DRP (Table 5). Mann-Whitney U test also revealed significant difference between group using dentin conditioner and group without uses of dentin conditioner prior to placement of resin modified glass ionomer base (P = 0.000). From pairwise comparison test no significant difference was found between group NDRP and DRP, while significant difference was found between group NDRA and DRA (Table 6).

Table 4: Significant differences found in pairwise comparison of microleakage between the groups for gingival margin (dentin margin)

Groups	Groups	*p* Value
B	FP	0.011
B	NDRP	0.005
B	NDRA	<0.001
C	NDRA	0.004
DRA	NDRA	0.015
FA	NDRA	0.033

Table 5: Pairwise comparison of microleakage between different pattern of low modulus of elasticity base for gingival margin (dentin margin)

Groups	Groups	*p* Value
FP	FA	0.875
NDRP	NDRA	1.000
DRP	DRA	1.000

Table 6: Pairwise comparison of microleakage between group using and without used of dentin conditioner prior to placement of resin modified glass ionomer base for gingival margin (dentin margin)

Groups	**Groups**	***p* Value**
NDRP	DRP	1.000
NDRA	DRA	0.015

CHAPTER V
DISCUSSION AND CONCLUSIONS

Discussion

Bonding resin composite to dentin has always been a challenge since adhesion to dentin is more difficult (23). Dentin contains more water than enamel and their hydroxyapatite crystals are randomly arranged in an organic matrix. Dentinal tubules contained vital processes of the pulp which makes dentin a sensitive structure. Fluid present in dentinal tubules constantly flows outwards which reduces the adhesion of the composite resin to dentin bond (98). The restoration–dentin interface is where microleakage is most likely to occur. Many techniques and materials have been developed to obtain reliable bond to dentin, while durable bond to enamel could be achieved with phosphoric acid etching (99). Recently developed materials such as bulk-fill composite has been recommended due to its superior properties of increased depth of cure from higher translucency and low-shrinkage stress related to modifications in the filler content and the organic matrix (10). Dental bulk-fill composites may contain polymerization modulator chemical groups or plasticizers in their resin matrix to reduce the effect of polymerization shrinkage stress when these materials were applied in bulk (9). The use of an intermediate layer of low modulus of elastic materials as a stress-relieving layer during polymerization shrinkage has also been recommended to create better marginal seal (11, 26, 100, 101). While some studies were against the use of an intermediate layer of low modulus of elastic materials as a stress-relieving layer (12, 30), they recommended that the combination of a thin adhesive resin with a hybrid composite resin showed excellent clinical performance (12).

In this study, microleakage testing with silver nitrate staining in high C-factor resin composite restoration using various materials and methods of application after thermocycling for 10,000 cycles was performed. The microleakages at enamel and dentin margins were observed separately. At enamel margin, no statistic significant differences for microleakage score was found between 8 experimental groups. The reason behind this could be resulted from the method used in this study. In all groups, the occlusal carvosurface was bonded directly to the composite in the same manner. Bonding procedure was carried out using selective enamel etching in combination with thin layer of adhesive. Unlike dentin margin where tooth-restoration bonding interface is known to be weaker, different methods and materials of restoration used are more likely to affect the sealing ability of the restoration. When bonding to enamel, the etch and rinse approach resulted in the highest bonding effectiveness with the μTBSs of 39 and 40 MPa (102). Enamel is homogeneous in nature and primarily composed of hydroxyapatite. Etchants dissolve hydroxyapatite crystals in enamel, creating pits by which the adhesive resin is readily absorbed by capillary attraction, creating macrotags of resin that envelop the individually exposed hydroxyapatite crystals. Additionally, resin microtags extend within tiny etch pits in the enamel prism cores. While resin tags in the interprismatic spaces provide the majority of micromechanical adhesion (103). Study by Barkmeier et al. reported that the 35% phosphoric acid conditioning of enamel produced significantly greater surface roughness than that achieved with any of the self-etch systems. The same study also examined the effect of increasing conditioning time on both surface roughness and shear bond strength of a resin composite to enamel (104).

Although, there are some previous studies stating that the low modulus of elasticity materials gave similar results to the conventional composite (101, 105, 106), the present study found that restorations without low modulus of elasticity materials as base significantly scored less than the restorations with low modulus of elasticity materials in microleakage score at dentin margin. From this finding, the first hypothesis of this study which stated that the use of low modulus of elastic material as a base or intermediate layer did not improve marginal integrity of a high C-factor resin composite restoration is accepted. This finding is in accordance with previous studies which stated that liners did not reduce stress and microleakage (29, 30, 107). These materials showed shrinkage stress comparable to conventional resin restorative materials, therefore, the use of these materials, both flowable composites and RMGI, did not lead to polymerization stress reduction at the adhesive interface

(107). Higher microleakage at dentin margin in the groups using low modulus of elasticity materials as base may be attributed to the low filler content of the flowable resin composite, associated with high percentage of organic matrix (Bis-GMA and TEGDMA) which reduced overall composite viscosity (108), and polymerization shrinkage stress of resin-modified glass-ionomers (109). RMGIs are susceptible to gain or loss of moisture. Water movement can occur within RMGI during setting, even under sealed conditions, i.e., cavity liner and/or base. Two distinct chemical reactions involving water were reported for RMGIs: the first reaction corresponds to the use of intrinsic water in the RMGI for initial setting and the second one is attributed to subsequent extrinsic water sorption for acid/glass reaction (110). Under sealed conditions, RMGI shrunk more than resin composite because of absence of humidity (30), a significant amount of water is required to compensate for the RMGIs shrinkage stress (111). The higher stress generated in restoration which low modulus of elasticity base was used could resulted in higher microleakage at dentin margin, while bonding interface at enamel margin, which is known to be stronger, is more likely to withstand those stresses.

When comparing different patterns of application of base, both enamel and dentin margins gave the same results which groups with low modulus of elasticity base covering only the axial wall did not give different performance in terms of microleakage to groups with low modulus of elasticity base covering all dentin surface of the cavity. The results in this study showed no statistical different in microleakage between different application patterns of low modulus of elasticity base, this could be due to the differences of volume of base used was minimal resulting in similar effect of their low modulus of elasticity properties (105, 112). Therefore, the second hypothesis of this study which stated that different patterns of low modulus of elasticity materials applied as base or intermediate layer had no effect in improving marginal integrity of a high C-factor resin composite restoration is accepted. Though without statistical significant difference FP show higher frequency of leakage of score 3 than FA at dentin margin, this finding could suggest that in case where flowable composite base is use extending the base out to dentin margin could result in the better seal. Their easy handling properties, enhanced flow, and better wettability resulted in voids reduction at the cervical interface and may counteract microleakage by improved interfacial bonding and forming a stress-absorbing layer (11).

The use of dentin conditioner prior to application of RMGI base in this study gave better results in microleakage test than without dentin conditioner, with statistic significances. When the tooth is cut, the result is a surface covered with a thin layer (1–2 μm) of debris, known as the smear layer, attached to the underlying dentin. It comprises mineral phase embedded in denatured collagen (113), and is effectively a structure with less defined order than either enamel or dentine. Bond strengths and durability of bonding vary according to the precise details of the cutting process applied to the tooth (114). The aim of conditioning dentin is to remove smear layer with little or no attack to the underlying sound dentin. It also opens the dentinal tubules and partially demineralizes the upper layer of the tooth, leading to an increase of surface area and exposure of micro-porosities, which allow freshly placed glass-ionomer paste to penetrate the surface to an extent. The result is a degree of micro-mechanical attachment, and better adaption of RMGI when the cement has hardened (17, 115). In groups which RMGI base covered whole dentin surfaces, the explanation could be that the weaker bond between RMGI and unconditioned dentin could not withstand the polymerization shrinkage from resin composite resulting in micro gaps at RMGI-dentin interface. While in groups which RMGI base covered only the axial wall, the effect of dentin conditioning on adhesion of RMGI is not pronounced. With stronger bond between RMGI and conditioned dentin, the low elastic-modulus properties of the RMGI could help absorbed polymerization shrinkage stress to some degree resulting in less microleakage, in groups where low modulus of elasticity base is used, as demonstrated in this study. This result is in accordance with previous studies which stated that pretreatment of the dentin surface by dentin conditioner has been shown to be effective in improving bond strength especially with RMGI (17, 116). Therefore, the third hypothesis of this study which stated that the use of dentin conditioner prior to placement of resin modified glass ionomer as a base or intermediate layer has no effect in improving marginal integrity of a high C-factor resin composite restoration is rejected. In pairwise comparison test at dentin margin, NDRA significantly scored higher microleakage than DRA while no significance was found between NDRP and DRP. Also at dentin margin NDRA scored higher microleakage than all other experimental groups, though with significance only to B, C, DRA and FA in pairwise comparison test. From this finding, author suggest that when RMGI base is being used, especially where RMGI is extended to the margin of the restoration, application of dentin conditioner prior to placement of RMGI base is strongly recommended.

When comparing different base materials used, the results of this study showed that the use of flowable composite base at the dentin margin show similar microleakage when compared to resin modified glass ionomer cement, which could be resulted from the similar properties of the two materials. However, focusing only the groups using flowable composite base and groups using resin modified glass ionomer cement base without uses of dentin conditioner at the dentin margin, significant difference in microleakage scores were observed, where flowable composite base performed better. This finding is in accordance with previous study which stated that at the dentin margin flowable composites showed significantly less microleakage when compared to resin modified glass ionomer cement (26).

As mentioned earlier that bonding to dentin has been proven to be more difficult and less predictable than to enamel. In this study, bulk-fill material is also being tested. The main advancements in bulk-fill materials are an increased depth of cure which probably resulted from higher translucency and low-shrinkage stress due to modifications in the filler content and the organic matrix. At dentin margin, bulk-fill composite showed less microleakage when compared to all others experimental groups. None of the specimen in group B scored higher than microleakage score 1 at dentin margin. With this finding, author suggests that bulk-fill materials should be considered as a material of choice for restoring a high c-factor cavity which involved dentin margin.

The silver nitrate dye method is known as an acceptable technique of measuring microleakage, however, it is a very severe test because the silver ion is extremely small (with a dimension of 0.059 nm) when compared to the size of a typical bacterium (0.5–1.0 μm) and thus is more penetrative. It could be assumed that any materials or methods of restoration that prevented leakage of silver ions also prevented leakage of the bacteria (117). In group NDRP, we found enamel cracks in 3 specimens. The data obtained from the 3 specimens were excluded. The cracks might have gained even more accesses for silver ion resulting in more severe microleakage scores. Careful samples selection prior to the experimental procedure should be taken into account, whether or not these cracks occurred after the restoration has been placed. Sequences of crack formation can alter the results and leads to misinterpretations of the result.

The limitations of this study are that the restorative materials when tested in vitro failed to simulate the dynamic intra oral thermal changes induced by routine eating and drinking. Thermocycling is used in most in vitro studies to simulate stresses when restorative materials have been placed in dental cavity. However, the absence of dentinal fluid flow and the completely altered dentinal surface due to extraction of the specimens made it hard to relate the results with clinical conditions (118, 119). The results obtained from this study may not be directly described clinical situation, they can only provide some information regarding the performance of the restorative techniques evaluated. Further clinical study with long term follow-up is still needed.

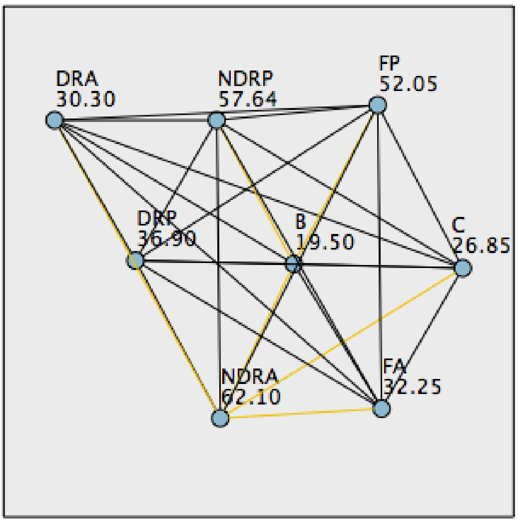
Conclusion

Based on our findings, the use of low modulus of elasticity materials as a base or intermediate layer did not improve marginal integrity of a high C-factor resin composite. A well performed bonding procedure in combination with Bulk-fill resin composite or conventional resin composite are sufficient for restoring a high c-factor class V cavity. Different application patterns of low modulus of elasticity material as a base or intermediate layer had no effect in improving marginal integrity of a high C-factor resin composite restoration. The use of dentin conditioner improved marginal integrity for resin composite restoration when RMGI is used as base.

APPENDIX

Table 7: Pairwise comparison of microleakage between experimental groups for gingival margin (dentin margin)

Pairwise Comparisons of Group



Each node shows the sample average rank of Group.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
B-C	7.350	9.193	.799	.424	1.000
B-DRA	-10.800	9.193	-1.175	.240	1.000
B-FA	-12.750	9.193	-1.387	.165	1.000
B-DRP	-17.400	9.193	-1.893	.058	1.000
B-FP	-32.550	9.193	-3.541	.000	.011
B-NDRP	-38.143	10.131	-3.765	.000	.005
B-NDRA	-42.600	9.193	-4.634	.000	.000
C-DRA	-3.450	9.193	-.375	.707	1.000
C-FA	-5.400	9.193	-.587	.557	1.000
C-DRP	-10.050	9.193	-1.093	.274	1.000

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
C-FP	-25.200	9.193	-2.741	.006	.171
C-NDRP	-30.793	10.131	-3.040	.002	.066
C-NDRA	-35.250	9.193	-3.834	.000	.004
DRA-FA	1.950	9.193	.212	.832	1.000
DRA-DRP	6.600	9.193	.718	.473	1.000
DRA-FP	21.750	9.193	2.366	.018	.504
DRA-NDRP	27.343	10.131	2.699	.007	.195
DRA-NDRA	31.800	9.193	3.459	.001	.015
FA-DRP	-4.650	9.193	-.506	.613	1.000
FA-FP	19.800	9.193	2.154	.031	.875
FA-NDRP	-25.393	10.131	-2.507	.012	.341
FA-NDRA	-29.850	9.193	-3.247	.001	.033
DRP-FP	15.150	9.193	1.648	.099	1.000
DRP-NDRP	20.743	10.131	2.048	.041	1.000
DRP-NDRA	25.200	9.193	2.741	.006	.171
FP-NDRP	-5.593	10.131	-.552	.581	1.000
FP-NDRA	-10.050	9.193	-1.093	.274	1.000
NDRP-NDRA	-4.457	10.131	-.440	.660	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Table 8: Microleakage data for occlusal margin (enamel margin)

Specimen	C	B	FP	FA	NDRP	NDRA	DRP	DRA
1	0	0	1	2	2	0	0	2
2	0	0	0	1	1	0	1	1
3	1	0	0	0	1	0	0	0
4	0	1	1	0	2	0	1	0
5	0	0	0	0	2	0	1	1
6	2	1	1	1	2	0	0	0
7	0	0	1	1	-	1	0	0
8	1	1	0	1	-	0	0	1
9	0	0	0	1	0	1	1	1
10	0	1	0	0	-	0	0	0

Table 9: Microleakage data for gingival margin (dentin margin)

Specimen	C	B	FP	FA	NDRP	NDRA	DRP	DRA
1	1	1	3	1	3	3	1	2
2	1	1	1	2	3	2	1	1
3	1	1	3	3	2	3	2	1
4	2	1	3	1	2	3	1	2
5	3	1	3	1	3	3	1	2
6	1	1	3	1	3	3	3	1
7	1	1	1	1	-	3	2	2
8	1	1	3	1	-	3	3	1
9	1	1	1	2	2	2	1	1
10	1	1	3	1	-	3	2	1

REFERENCES

1. Burrow MF. Composite adhesive restorative materials for dental applications. Non-Metallic Biomaterials for Tooth Repair and Replacement: Elsevier; 2013. p. 235-69.
2. van de Sande FH, Rodolpho PA, Basso GR, Patias R, da Rosa QF, Demarco FF, et al. 18-year survival of posterior composite resin restorations with and without glass ionomer cement as base. Dent Mater. 2015;31(6):669-75.
3. Opdam NJ, Roeters JJ, Loomans BA, Bronkhorst EM. Seven-year clinical evaluation of painful cracked teeth restored with a direct composite restoration. J Endod. 2008;34(7):808-11.
4. Fonseca BM, Dias KR, Ferreira J, Silva IR, Rabello TB. An in vitro evaluation of microleakage in class V cavities restored with silorane-based resin composite using different adhesive systems. Braz Dent Sci. 2012;15(2).
5. Suhasini K, Madhusudhana K, Suneelkumar C, Lavanya A, Chandrababu KS, Kumar PD. Clinical performance of Class I nanohybrid composite restorations with resin-modified glass-ionomer liner and flowable composite liner: A randomized clinical trial. J Conserv Dent. 2016;19(6):510-5.
6. Shirai K, De Munck J, Yoshida Y, Inoue S, Lambrechts P, Suzuki K, et al. Effect of cavity configuration and aging on the bonding effectiveness of six adhesives to dentin. Dent Mater. 2005;21(2):110-24.
7. Sampaio PC, de Almeida Junior AA, Francisconi LF, Casas-Apayco LC, Pereira JC, Wang L, et al. Effect of conventional and resin-modified glass-ionomer liner on dentin adhesive interface of Class I cavity walls after thermocycling. Oper Dent. 2011;36(4):403-12.
8. Baracco B, Perdigao J, Cabrera E, Ceballos L. Two-year clinical performance of a low-shrinkage composite in posterior restorations. Oper Dent. 2013;38(6):591-600.
9. Goracci C, Cadenaro M, Fontanive L, Giangrosso G, Juloski J, Vichi A, et al. Polymerization efficiency and flexural strength of low-stress restorative composites. Dent Mater. 2014;30(6):688-94.
10. Tekin TH, Kanturk Figen A, Yilmaz Atali P, Coskuner Filiz B, Piskin MB. Full in-vitro

analyses of new-generation bulk fill dental composites cured by halogen light. Mater Sci Eng C Mater Biol Appl. 2017;77:436-45.

11. Kasraei S, Azarsina M, Majidi S. In vitro comparison of microleakage of posterior resin composites with and without liner using two-step etch-and-rinse and self-etch dentin adhesive systems. Oper Dent. 2011;36(2):213-21.

12. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. J Adhes Dent. 2007;9(5):469-75.

13. Kowalczyk P. Influence of the shape of the layers in photo-cured dental restorations on the shrinkage stress peaks-FEM study. Dent Mater. 2009;25(12):e83-91.

14. Goodis HE, White JM, Marshall SJ, Koshrovi P, Watanabe LG, Marshall GW, Jr. The effect of glass ionomer liners in lowering pulp temperatures during composite placement, in vitro. Dent Mater. 1993;9(3):146-50.

15. Tanumiharja M, Burrow MF, Tyas MJ. Microtensile bond strengths of glass ionomer (polyalkenoate) cements to dentine using four conditioners. J Dent. 2000;28(5):361-6.

16. Setien VJ, Armstrong SR, Wefel JS. Interfacial fracture toughness between resin-modified glass ionomer and dentin using three different surface treatments. Dent Mater. 2005;21(6):498-504.

17. Nicholson JW. Adhesion of glass-ionomer cements to teeth: A review. Int J Adhes Adhes 2016;69:33-8.

18. Demarco FF, Correa MB, Cenci MS, Moraes RR, Opdam NJ. Longevity of posterior composite restorations: not only a matter of materials. Dent Mater. 2012;28(1):87-101.

19. Tam LE, Pilliar RM. The effect of interface stiffness on dentin-composite interfacial fracture resistance. J Dent. 2000;28(7):487-93.

20. Jia S, Chen D, Wang D, Bao X, Tian X. Comparing marginal microleakage of three different dental materials in veneer restoration using a stereomicroscope: an in vitro study. BDJ Open. 2017;3:16010.

21. Yang B, Ludwig K, Adelung R, Kern M. Micro-tensile bond strength of three luting resins to human regional dentin. Dent Mater. 2006;22(1):45-56.

22. Marshall GW, Jr., Marshall SJ, Kinney JH, Balooch M. The dentin substrate:

structure and properties related to bonding. J Dent. 1997;25(6):441-58.
23. Ozcan M, Mese A. Adhesion of conventional and simplified resin-based luting cements to superficial and deep dentin. Clin Oral Investig. 2012;16(4):1081-8.
24. Ferracane JL. Resin composite--state of the art. Dent Mater. 2011;27(1):29-38.
25. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin-composites: a systematic review. Dent Mater. 2005;21(10):962-70.
26. Baig MM, Mustafa M, Al Jeaidi ZA, Al-Muhaiza M. Microleakage evaluation in restorations using different resin composite insertion techniques and liners in preparations with high c-factor – An in vitro study. King Saud University Journal of Dental Sciences. 2013;4(2):57-64.
27. Pashley DH, Tay FR. Aggressiveness of contemporary self-etching adhesives. Part II: etching effects on unground enamel. Dent Mater. 2001;17(5):430-44.
28. van Dijken JW, Pallesen U. Clinical performance of a hybrid resin composite with and without an intermediate layer of flowable resin composite: a 7-year evaluation. Dent Mater. 2011;27(2):150-6.
29. Kwon Y, Ferracane J, Lee IB. Effect of layering methods, composite type, and flowable liner on the polymerization shrinkage stress of light cured composites. Dent Mater. 2012;28(7):801-9.
30. Oliveira LC, Duarte S, Jr., Araujo CA, Abrahao A. Effect of low-elastic modulus liner and base as stress-absorbing layer in composite resin restorations. Dent Mater. 2010;26(3):e159-69.
31. Kiri L, Boyd D. Predicting composition-property relationships for glass ionomer cements: a multifactor central composite approach to material optimization. J Mech Behav Biomed Mater. 2015;46:285-91.
32. Guggenberger R, May R, Stefan KP. New trends in glass-ionomer chemistry. Biomaterials. 1998;19(6):479-83.
33. McCabe JF. Resin-modified glass-ionomers. Biomaterials. 1998;19(6):521-7.
34. Nagaraja Upadhya P, Kishore G. Glass Ionomer Cement – The Different Generations. Trends Biomater Artif Organs. 2005;18(2):158 - 65.
35. Yelamanchili A, Darvell BW. Network competition in a resin-modified glass-

ionomer cement. Dent Mater. 2008;24(8):1065-9.

36. Fagundes TC, Toledano M, Navarro MF, Osorio R. Resistance to degradation of resin-modified glass-ionomer cements dentine bonds. J Dent. 2009;37(5):342-7.

37. Fagundes TC, Barata TJ, Bresciani E, Cefaly DF, Carvalho CA, Navarro MF. Influence of ultrasonic setting on tensile bond strength of glass-ionomer cements to dentin. J Adhes Dent. 2006;8(6):401-7.

38. Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwaert J, Hellemans L, Lambrechts P, et al. Evidence of chemical bonding at biomaterial-hard tissue interfaces. J Dent Res. 2000;79(2):709-14.

39. Coutinho E, Yoshida Y, Inoue S, Fukuda R, Snauwaert J, Nakayama Y, et al. Gel phase formation at resin-modified glass-ionomer/tooth interfaces. J Dent Res. 2007;86(7):656-61.

40. Lohbauer U. Dental Glass Ionomer Cements as Permanent Filling Materials? — Properties, Limitations and Future Trends. Materials. 2010;3:76-96.

41. Rusin RP, Agee K, Suchko M, Pashley DH. Effect of a new liner/base on human dentin permeability. J Dent. 2010;38(3):245-52.

42. Christensen GJ. Preventing postoperative tooth sensitivity in class I, II and V restorations. J Am Dent Assoc. 2002;133(2):229-31.

43. Gordan VV, Mjor IA, Hucke RD, Smith GE. Effect of different liner treatments on postoperative sensitivity of amalgam restorations. Quintessence Int. 1999;30(1):55-9.

44. Akpata ES, Sadiq W. Post-operative sensitivity in glass-ionomer versus adhesive resin-lined posterior composites. Am J Dent. 2001;14(1):34-8.

45. Duke ES, Robbins JW, Trevino D. The clinical performance of a new adhesive resin system in class V and IV restorations. Compendium. 1994;15(7):852, 4, 6 passim; quiz 64.

46. Browning WD. The benefits of glass ionomer self-adhesive materials in restorative dentistry. Compend Contin Educ Dent. 2006;27(5):308-14; quiz 15-6.

47. Tantbirojn D, Poolthong S, Leevailoj C, Srisawasdi S, Hodges JS, Randall RC. Clinical evaluation of a resin-modified glass-ionomer liner for cervical dentin hypersensitivity treatment. Am J Dent. 2006;19(1):56-60.

48. Alomari QD, Reinhardt JW, Boyer DB. Effect of liners on cusp deflection and gap

formation in composite restorations. Oper Dent. 2001;26(4):406-11.
49. Alomari Q, Ajlouni R, Omar R. Managing the polymerization shrinkage of resin composite restorations: a review. SADJ. 2007;62(1):12, 4, 6 passim.
50. Friedl KH, Powers JM, Hiller KA. Influence of different factors on bond strength of hybrid ionomers. Oper Dent. 1995;20(2):74-80.
51. Prati C, Tao L, Simpson M, Pashley DH. Permeability and microleakage of Class II resin composite restorations. J Dent. 1994;22(1):49-56.
52. Mitra SB. In vitro fluoride release from a light-cured glass-ionomer liner/base. J Dent Res. 1991;70(1):75-8.
53. Tantbirojn D, Douglas WH, Versluis A. Inhibitive effect of a resin-modified glass ionomer cement on remote enamel artificial caries. Caries Res. 1997;31(4):275-80.
54. Hamama HH, Burrow MF, Yiu C. Effect of dentine conditioning on adhesion of resin-modified glass ionomer adhesives. Aust Dent J. 2014;59(2):193-200.
55. Cardoso MV, Delme KI, Mine A, Neves Ade A, Coutinho E, De Moor RJ, et al. Towards a better understanding of the adhesion mechanism of resin-modified glass-ionomers by bonding to differently prepared dentin. J Dent. 2010;38(11):921-9.
56. Marquezan M, Fagundes TC, Toledano M, Navarro MF, Osorio R. Differential bonds degradation of two resin-modified glass-ionomer cements in primary and permanent teeth. J Dent. 2009;37(11):857-64.
57. Bergenholtz G, Cox CF, Loesche WJ, Syed SA. Bacterial leakage around dental restorations: its effect on the dental pulp. J Oral Pathol. 1982;11(6):439-50.
58. Brannstrom M. Infection beneath composite resin restorations: can it be avoided? Oper Dent. 1987;12(4):158-63.
59. Taylor MJ, Lynch E. Microleakage. J Dent. 1992;20(1):3-10.
60. Kidd EA. Microleakage: a review. J Dent. 1976;4(5):199-206.
61. Alani AH, Toh CG. Detection of microleakage around dental restorations: a review. Oper Dent. 1997;22(4):173-85.
62. Wu W, Cobb EN. A silver staining technique for investigating wear of restorative dental composites. J Biomed Mater Res. 1981;15(3):343-8.
63. Wu W, Cobb E, Dermann K, Rupp NW. Detecting margin leakage of dental composite restorations. J Biomed Mater Res. 1983;17(1):37-43.

64. Charlton DG, Moore BK, Swartz ML. In vitro evaluation of the use of resin liners to reduce microleakage and improve retention of amalgam restorations. Oper Dent. 1992;17(3):112-9.

65. Charlton DG, Moore BK. In vitro evaluation of two microleakage detection tests. J Dent. 1992;20(1):55-8.

66. Christen AG, Mitchell DF. A fluorescent dye method for demonstrating leakage around dental restorations. J Dent Res. 1966;45(5):1485-92.

67. Wenner KK, Fairhurst CW, Morris CF, Hawkins IK, Ringle RD. Microleakage of root restorations. J Am Dent Assoc. 1988;117(7):825-8.

68. Mixson J, Eick JD, Chappell RP, Tira DE, Moore DL. Comparison of two-surface and multiple-surface scoring methodologies for in vitro microleakage studies. Dent Mater. 1991;7(3):191-6.

69. Going RE. Microleakage Around Dental Restorations: A Summarizing Review. J Am Dent Assoc. 1972;84(6):1349-57.

70. Shortall AC. Microleakage, marginal adaptation and composite resin restorations. Br Dent J. 1982;153(6):223-7.

71. Pintado MR, Douglas WH. The comparison of microleakage between two different dentin bonding resin systems. Quintessence Int. 1988;19(12):905-7.

72. Sano H, Takatsu T, Ciucchi B, Horner JA, Matthews WG, Pashley DH. Nanoleakage: leakage within the hybrid layer. Oper Dent. 1995;20(1):18-25.

73. Li H, Burrow MF, Tyas MJ. Nanoleakage patterns of four dentin bonding systems. Dent Mater. 2000;16(1):48-56.

74. Li H, Burrow MF, Tyas MJ. The effect of thermocycling regimens on the nanoleakage of dentin bonding systems. Dent Mater. 2002;18(3):189-96.

75. Lloyd BA, McGinley MB, Brown WS. Thermal stress in teeth. J Dent Res. 1978;57(4):571-82.

76. Andrews JT, Hembree JH, Jr. Marginal leakage of amalgam alloys with high content of copper: a laboratory study. Oper Dent. 1980;5(1):7-10.

77. Yates JL, Murray GA, Hembree JH, Jr. Cavity varnishes applied over insulating bases: effect on microleakage. Oper Dent. 1980;5(2):43-6.

78. Crim GA, Shay JS. Microleakage pattern of a resin-veneered glass-ionomer cavity

liner. J Prosthet Dent. 1987;58(3):273-6.
79. Crim GA, Garcia-Godoy F. Microleakage: the effect of storage and cycling duration. J Prosthet Dent. 1987;57(5):574-6.
80. Darbyshire PA, Messer LB, Douglas WH. Microleakage in class II composite restorations bonded to dentin using thermal and load cycling. J Dent Res. 1988;67(3):585-7.
81. Davis EL, Joynt RB, Wieczkowski G, Jr., Laura JC. Bond durability between dentinal bonding agents and tooth structure. J Prosthet Dent. 1989;62(3):253-6.
82. Arcoria CJ, Vitasek BA, DeWald JP, Wagner MJ. Microleakage in restorations with glass ionomer liners after thermocycling. J Dent. 1990;18(2):107-12.
83. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent. 1999;27(2):89-99.
84. Bauer JR, Reis A, Loguercio AD, Barroso LP, Grande RH. Effects of aging methods on microleakage of an adhesive system used as a sealant on contaminated surfaces. J Appl Oral Sci. 2005;13(4):377-81.
85. Rossomando KJ, Wendt SL, Jr. Thermocycling and dwell times in microleakage evaluation for bonded restorations. Dent Mater. 1995;11(1):47-51.
86. Mandras RS, Retief DH, Russell CM. The effects of thermal and occlusal stresses on the microleakage of the Scotchbond 2 dentinal bonding system. Dent Mater. 1991;7(1):63-7.
87. Retief DH. Are adhesive techniques sufficient to prevent microleakage? Oper Dent. 1987;12(4):140-5.
88. Uno S, Finger WJ. Phosphoric acid as a conditioning agent in the Gluma bonding system. Am J Dent. 1995;8(5):236-41.
89. Youngson CC, Jones JC, Fox K, Smith IS, Wood DJ, Gale M. A fluid filtration and clearing technique to assess microleakage associated with three dentine bonding systems. J Dent. 1999;27(3):223-33.
90. Douglas WH, Fields RP, Fundingsland J. A comparison between the microleakage of direct and indirect composite restorative systems. J Dent. 1989;17(4):184-8.
91. Bonilla ED, Stevenson RG, Caputo AA, White SN. Microleakage resistance of minimally invasive Class I flowable composite restorations. Oper Dent. 2012;37(3):290-8.

92. Raskin A, D'Hoore W, Gonthier S, Degrange M, Dejou J. Reliability of in vitro microleakage tests: a literature review. J Adhes Dent. 2001;3(4):295-308.

93. Sangwichit K, Kingkaew R, Pongprueksa P, Senawongse P. Effect of thermocycling on the durability of etch-and-rinse and self-etch adhesives on dentin. Dent Mater J. 2016;35(3):360-8.

94. Deng D, Yang H, Guo J, Chen X, Zhang W, Huang C. Effects of different artificial ageing methods on the degradation of adhesive-dentine interfaces. J Dent. 2014;42(12):1577-85.

95. Costa JF, Siqueira WL, Loguercio AD, Reis A, Oliveira E, Alves CM, et al. Characterization of aqueous silver nitrate solutions for leakage tests. J Appl Oral Sci. 2011;19(3):254-9.

96. Wahab FK, Shaini FJ, Morgano SM. The effect of thermocycling on microleakage of several commercially available composite Class V restorations in vitro. J Prosthet Dent. 2003;90(2):168-74.

97. Manhart J, Schmidt M, Chen HY, Kunzelmann KH, Hickel R. Marginal quality of tooth-colored restorations in class II cavities after artificial aging. Oper Dent. 2001;26(4):357-66.

98. Garg N, Garg A. Textbook of operative dentistry: Boydell & Brewer Ltd; 2010.

99. Frankenberger R, Lohbauer U, Roggendorf MJ, Naumann M, Taschner M. Selective enamel etching reconsidered: better than etch-and-rinse and self-etch? J Adhes Dent. 2008;10(5):339-44.

100. Simi B, Suprabha B. Evaluation of microleakage in posterior nanocomposite restorations with adhesive liners. J Conserv Dent. 2011;14(2):178-81.

101. Armstrong SR, Keller JC, Boyer DB. The influence of water storage and C-factor on the dentin-resin composite microtensile bond strength and debond pathway utilizing a filled and unfilled adhesive resin. Dent Mater. 2001;17(3):268-76.

102. Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, et al. Adhesion to enamel and dentin: current status and future challenges. Oper Dent. 2003;28(3):215-35.

103. Van Meerbeek B, Van Landuyt K, De Munck J, Inoue S, Yoshida Y, Perdigao J. Bonding to Enamel and Dentin. JB Summitt, Robbins, JW, Hilton, TJ, Schwartz, RS (Ed.).

Fundamentals of Operative Dentistry: A contemporary Approach (s. 183-260). Illinois. Quintessence Publishing Co, Inc; 2006.

104. Barkmeier WW, Erickson RL, Kimmes NS, Latta MA, Wilwerding TM. Effect of enamel etching time on roughness and bond strength. Oper Dent. 2009;34(2):217-22.

105. Kemp-Scholte CM, Davidson CL. Marginal integrity related to bond strength and strain capacity of composite resin restorative systems. J Prosthet Dent. 1990;64(6):658-64.

106. Kemp-Scholte CM, Davidson CL. Complete marginal seal of Class V resin composite restorations effected by increased flexibility. J Dent Res. 1990;69(6):1240-3.

107. Cadenaro M, Marchesi G, Antoniolli F, Davidson C, Dorigo ED, Breschi L. Flowability of composites is no guarantee for contraction stress reduction. Dent Mater. 2009;25(5):649-54.

108. Labella R, Lambrechts P, Van Meerbeek B, Vanherle G. Polymerization shrinkage and elasticity of flowable composites and filled adhesives. Dent Mater. 1999;15(2):128-37.

109. Bryant RW, Mahler DB. Volumetric contraction in some tooth-coloured restorative materials. Aust Dent J. 2007;52(2):112-7.

110. Young AM. FTIR investigation of polymerisation and polyacid neutralisation kinetics in resin-modified glass-ionomer dental cements. Biomaterials. 2002;23(15):3289-95.

111. Chutinan S, Platt JA, Cochran MA, Moore BK. Volumetric dimensional change of six direct core materials. Dent Mater. 2004;20(4):345-51.

112. Svizero Nda R, D'Alpino PH, da Silva e Souza MH, de Carvalho RM. Liner and light exposure: effect on in-vitro Class V microleakage. Oper Dent. 2005;30(3):325-30.

113. Ogata M, Harada N, Yamaguchi S, Nakajima M, Pereira PN, Tagami J. Effects of different burs on dentin bond strengths of self-etching primer bonding systems. Oper Dent. 2001;26(4):375-82.

114. Koibuchi H, Yasuda N, Nakabayashi N. Bonding to dentin with a self-etching primer: the effect of smear layers. Dent Mater. 2001;17(2):122-6.

115. Van Meerbeek B, Yoshida Y, Inoue S, De Munck J, Van Landuyt K, Lambrechts P. Glass-ionomer adhesion: the mechanisms at the interface. J Dent. 2006;34(8):615-7.

116. El-Askary FS, Nassif MS. The effect of the pre-conditioning step on the shear bond strength of nano-filled resin-modified glass-ionomer to dentin. Eur J Dent. 2011;5(2):150-6.

117. Abdalla AI, Davidson CL. Comparison of the marginal integrity of in vivo and in vitro Class II composite restorations. J Dent. 1993;21(3):158-62.

118. Attar N, Turgut MD, Gungor HC. The effect of flowable resin composites as gingival increments on the microleakage of posterior resin composites. Oper Dent. 2004;29(2):162-7.

119. Pashley DH. Clinical considerations of microleakage. J Endod. 1990;16(2):70-7.

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