EFFECT OF GLASS-IONOMER LINING CEMENT THICKNESS ON DYE LEAKAGE AND GAP FORMATION OF RESIN COMPOSITE RESTORATIONS

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ABSTRACT

Objectives: To investigate the effect of resin-modified glass-ionomer lining cement (RMGIC) thickness on internal adaptation of resin composite restorations. Methods: Sixty occlusal cavities in 3 mm depth were prepared on extracted human third molars. The cavities were divided into the two main groups according to the adhesive used: an etch-and-rinse adhesive (Single Bond 2) or a self-etching adhesive (Clearfil SE Bond). The specimens were further divided into three subgroups according to the three restorative procedures: no liner/base, lined with RMGIC (Vitrebond), or based with RMGIC. All cavities were then restored with a resin composite. After 24 h, each restored cavity was cut bucco-lingually to obtain two specimens. A specimen was used for a dye leakage test, while the other was investigated for gap formation using scanning electron microscope. The percentages of dye staining and gap formation were then calculated.

Results: For the Single Bond 2 groups, the absence of lining/base showed the lowest dye staining at the pulpal walls, which was significantly lower than that with thin RMGIC lining ($P = 0.045$). For the Clearfil SE Bond groups, there was no significant difference among the restorations without or with RMGIC lining or base ($P > 0.05$). For the restorations bonded with Single Bond 2, a significantly higher gap formation at the vertical wall was observed in the restorations with RMGIC lining than those without lining/base ($P = 0.015$). For the Clearfil SE Bond groups, gap formations at vertical walls were not significantly different among the groups ($P > 0.05$). No significant difference in gap formations at pulpal walls was found among any of the experimental groups ($P > 0.05$). For comparison between the two adhesives, no significant difference in dye leakage or gap formation, regardless of pulpal or vertical wall, was observed.

KEY WORDS: DYE LEAKAGE/ GAP/ GLASS-IONOMER LINING/BASE CEMENT/ INTERNAL ADAPTATION/ RESIN COMPOSITE

87 pages

ผลของความหนาของซีเมนต์กลาสไอโอโนเมอร์ชนิดรองพื้นต่อการรั่วซึมสีและการเกิดช่องว่างภายในวัสดุบูรณะเรซินคอมโพสิต

EFFECT OF GLASS-IONOMER LINING CEMENT THICKNESS ON DYE LEAKAGE AND GAP FORMATION OF RESIN COMPOSITE RESTORATIONS

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บทคัดย่อ

ในการศึกษานี้มีวัตถุประสงค์ เพื่อบ่งชี้ถึงความหนาของวัสดุรองพื้นซีเมนต์กลาสไอโอโนเมอร์ชนิดดัดแปลงด้วยเรซินที่มีผลต่อความแนบสนิทภายในของวัสดุบูรณะเรซินคอมโพสิต นำฟันกรามมนุษย์ซี่ที่สามจำนวน 60 ซี่ มากรอแต่งโพรงฟันความลึก 3 มิลลิเมตรในด้านบดเคี้ยว โดยแบ่งโพรงฟันออกเป็น 2 กลุ่มใหญ่ กลุ่มแรกใช้สารยึดติดชนิดเอทช์แอนรินซ์ (Single Bond 2) และอีกกลุ่มใช้สารยึดติดชนิดเซลฟ์เอทช์ (Clearfil SE Bond) ในแต่ละกลุ่มใหญ่ มีการแบ่งเป็นกลุ่มย่อยตามวิธีการบูรณะ 3 วิธีได้แก่กลุ่มที่ไม่มีวัสดุรองพื้น กลุ่มที่รองพื้นด้วยซีเมนต์กลาสไอโอโนเมอร์ชนิดดัดแปลงด้วยเรซิน (วิทรีบอนด์) หนา 0.5 มิลลิเมตร และกลุ่มที่รองพื้นด้วยซีเมนต์กลาสไอโอโนเมอร์ชนิดดังกล่าว หนา 1.0 มิลลิเมตร แล้วโพรงฟันทั้งหมดถูกบูรณะด้วยวัสดุเรซินคอมโพสิต (แซดสองห้าศูนย์เอกซ์ที) และนำไปเก็บในน้ำกลั่นอุณหภูมิ 37 องศาเซลเซียสเป็นเวลา 24 ชั่วโมง จากนั้นนำฟันไปตัดที่ตำแหน่งกึ่งกลางวัสดุบูรณะในแนวด้านแก้ม-ลิ้นได้เป็น 2 ชิ้นงาน นำชิ้นงานแรกไปทดสอบการรั่วซึมสี (2%เมทิลีนบลู) ตรวจสอบระยะทางที่มีการรั่วซึมสี ในส่วนอีกชิ้นงานที่ได้ไปตรวจช่องว่างภายในที่เกิดขึ้น โดยใช้กล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด และคำนวณค่าเป็นร้อยละของการรั่วซึมสีและการเกิดช่องว่างภายใน จากผลการศึกษาพบว่า ในส่วนของวัสดุบูรณะที่ใช้สารยึดติดชนิดเอทช์แอนรินซ์และไม่ใช้วัสดุรองพื้นมีค่าการรั่วซึมสีบริเวณรอยต่อวัสดุ-โพรงฟันในแนวนอนต่ำที่สุด ซึ่งต่ำกว่าวัสดุบูรณะที่ใช้วัสดุรองพื้นหนา 0.5 มิลลิเมตรอย่างมีนัยสำคัญ ($P = 0.045$) ส่วนวัสดุบูรณะที่ใช้สารยึดติดชนิดเซลฟ์เอทช์ไม่พบความแตกต่างอย่างมีนัยสำคัญระหว่างกลุ่มวัสดุบูรณะที่ไม่ใช้วัสดุรองพื้นกับวัสดุบูรณะที่ใช้วัสดุรองพื้น ($P > 0.05$) ในส่วนวัสดุบูรณะที่ใช้สารยึดติดชนิดเอทช์แอนด์รินซ์และใช้วัสดุรองพื้นหนา 0.5 มิลลิเมตรมีการเกิดช่องว่างภายในบริเวณรอยต่อวัสดุ-โพรงฟันในแนวตั้งมากกว่าวัสดุบูรณะที่ไม่ใช้วัสดุรองพื้นอย่างมีนัยสำคัญ ($P = 0.015$) และไม่พบความแตกต่างอย่างมีนัยสำคัญในการเกิดช่องว่างภายในบริเวณรอยต่อวัสดุ-โพรงฟันในแนวตั้งของกลุ่มวัสดุบูรณะที่ใช้สารยึดติดชนิดเซลฟ์เอทช์ ($P > 0.05$) นอกจากนี้ ไม่พบความแตกต่างอย่างมีนัยสำคัญในการเกิดช่องว่างภายในบริเวณรอยต่อวัสดุ-โพรงฟันในแนวนอน ($P > 0.05$) และไม่พบความแตกต่างระหว่างการใช้สารยึดติดทั้งสองชนิดในทั้งการทดสอบการรั่วซึมสีและการเกิดช่องว่างภายในบริเวณรอยต่อวัสดุ-โพรงฟันทั้งแนวตั้งและแนวนอน

87 หน้า

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RMGIC, GIC	Resin-modified, glass-ionomer cements
SE	Clearfil SE Bond
TE	Single Bond
N	Restoration with no lining
L	Restoration with lining
B	Restoration with base
Co, R	Resin composite
P	At the pulpal walls
V	At the vertical walls
D	Dentin

CHAPTER I
INTRODUCTION

Currently, resin composite has gradually replaced amalgam for dental restorations. It is a material of choice for several dental practitioners in restoring anterior and posterior teeth.[1, 2] Although resin composite contains many advantages such as its natural tooth-color, tooth structure preservation and mercury-free, it has some disadvantages especially polymerization contraction.[3] Formation of a polymer network during the polymerization reaction provides a denser structure that causes volumetric shrinkage about 1.67-5.68 % of the total material volume.[4] Polymerization shrinkage may produce internal gap formation, marginal gap staining or secondary caries.[4] Internal or marginal gaps between the restorative material and cavity walls may induce post-operative tooth sensitivity, which is the consequence of the dentinal fluid movement.[5, 6]

When remaining dentin in a cavity is minimal, the cavity should be lined or based. The liner is the 0.5-mm thickness (or less) of biocompatible material placed under the restorations, which can provide therapeutic effects and pulp protection. The base is about 1.0-mm thick biocompatible material placed under the restorations, which protects the pulp, acts as dentin substitute and a thermal insulation. In fact, the cavity with the liner/base uses less amount of resin composite for restoring. This means the overall polymerization shrinkage is reduced.

Glass-ionomer cements are able to bond chemically to enamel and dentin during the setting process and usually recommended to be used as a base and liner beneath a resin composite restoration.[7, 8] There are some *in vivo* studies showing that the cavity walls in a deep cavity should be lined or based with a biocompatible material, such as glass-ionomer cement or calcium hydroxide, which helps the pulp to recover from any operative injuries.[8, 9] From the survey, 52 dental schools in the North America generally recommended under-graduated dental students to place a

glass-ionomer base or liner in the deep cavity prior to an amalgam or composite restoration.[10] It is suggested that a base or liner should be applied on dentin at the pulpal floor of a deep cavity when remaining dentin thickness is only or less than 1 mm.[11]

However, the glass-ionomer cement lining/base is subjected to the contraction stress from an overlying resin composite restoration. The stress developed by the polymerization contraction of resin composite (bonded to a glass-ionomer cement base) is capable of disrupting the cement-dentin bond at the interface.[12] The better performance to withstand the shrinkage force of resin-modified, glass-ionomer cement (RMGIC) than the conventional glass-ionomer cement may be attributed to the instant set of the resin-modified type as well as the higher initial bond strength to dentin.[11] A significantly lower shrinkage of resin composite, when curing in contact with the set RMGIC liner, than that of curing alone without liner is reported.[13] The use of RMGIC as an intermediate layer between resin composite and cavity floor can promote a decrease in polymerization contraction force of resin composite and provide a better 'marginal' adaptation.[14]

Nevertheless, several laboratory studies represent the 'internal' gaps detected between the floor of cavities and RMGIC base.[15-18] The wider micro-gaps at the base-dentin interface in comparison to the interface bonded with an adhesive without the base is demonstrated.[16] Moreover, the high curing shrinkage *volume* of RMGIC may negatively affect the marginal integrity.[15, 16] However, low shrinkage *stress* may occur from the RMGIC because of its low rigidity and good stress distribution within the material.[15] This is unexpected negative outcome of lining/base placement since the current opinion in operative dentistry suggests that it is beneficial to place a glass-ionomer cement liner or base. The reason for the increased 'internal' leakage is unclear, but it may be a result from the overall polymerization contraction stress which tends to separate the liner and base from the dentinal cavity floor. Placing a thicker base may resist the shrinkage force and provide a better stress distribution within glass-ionomer cement resulting in an improved seal restoration with less internal gap formation.

Currently, it seems to have no investigation on the appropriate thickness of the liner/base that provides the best internal adaptation of the resin composite restoration. Therefore, the purpose of this study is to investigate the proper thickness of RMGIC liner/base that provides the internal adaptation under the occlusal resin composite restorations.

CHAPTER II
OBJECTIVES

The purpose of this study is to evaluate the effect of thickness of RMGIC lining/base on internal adaptation, using dye leakage and micro-gap formation detection evaluation of occlusal resin composite restoration. Moreover, the effect of an etch-and-rinse adhesive or a self-etching adhesive on internal adaptation is also evaluated.

CHAPTER III
HYPOTHESIS

1.H_0 : there is no significant difference in *internal dye leakage* of occlusal resin composite restorations among using RMGIC as a 0.5-mm lining, 1.0-mm base or without the lining/base

H_1 : there is a significant difference in *internal dye leakage* of occlusal resin composite restorations among using RMGIC as a 0.5-mm lining, 1.0-mm base or without the lining/base

2.H_0 : there is no significant difference in *internal dye leakage* of occlusal resin composite restorations between 2-step etch-and-rinse or self-etching adhesive

H_1 : there is a significant difference in *internal dye leakage* of occlusal resin composite restorations between 2-step etch-and-rinse or self-etching adhesive

3.H_0 : there is no significant difference in *internal gap formation* of occlusal resin composite restorations among using RMGIC as a 0.5-mm lining, 1.0-mm base or without the lining/base

H_1 : there is a significant difference in *internal gap formation* of occlusal resin composite restorations among using RMGIC as a 0.5-mm lining, 1.0-mm base or without the lining/base

4.H_0 : there is no significant difference in *internal gap formation* of occlusal resin composite restorations between 2-step etch-and-rinse or self-etching adhesive

H_1 : there is a significant difference in *internal gap formation* of occlusal resin composite restorations between 2-step etch-and-rinse or self-etching adhesive

CHAPTER IV
LITERATURE REVIEW

4.1 Resin composite

4.1.1 Compositions and types

Currently, resin composite, a tooth-colored restorative material, has gradually replaced amalgam for dental restoration and is a material of choice for several dental practitioners in restoring anterior and posterior teeth.[1, 2] Resin composite mainly consists of a polymeric resin matrix, reinforcing fillers, silane coupling agent, and chemical agents that promote polymerization (Fig. 4.1).[2, 3, 19]

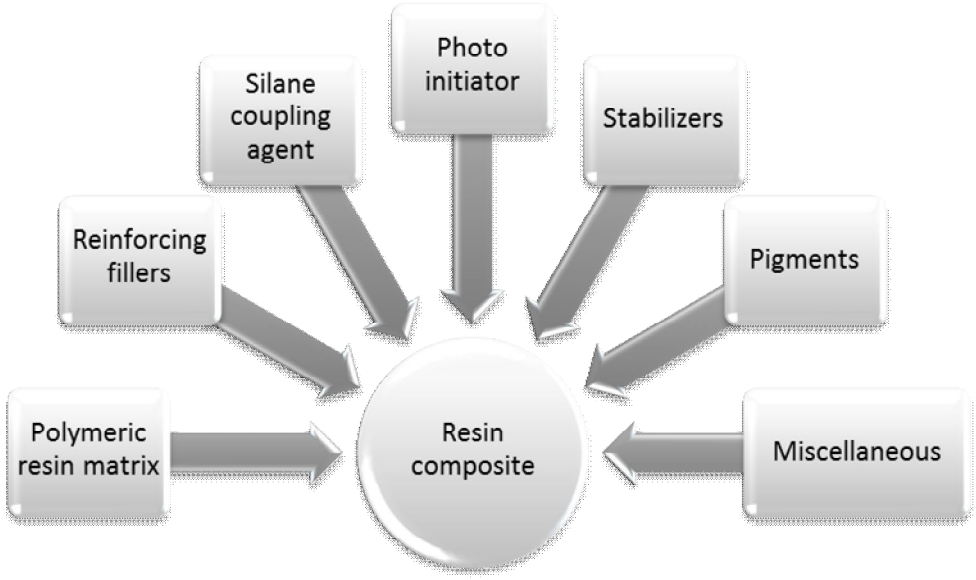


Figure 4.1 The main compositions of resin composite.

Predominantly used monomer is bisphenol A-glycidyl methacrylate (bis-GMA), which is a high viscosity resin.[19] Other monomers used as a diluent monomer are urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA) or poly (ethylene glycol) dimethacrylate (PEGDMA). Physical characteristics are

improved by combining more than one type of monomer to form a mixed polymer, which is referred as a copolymer.[20] Cross-linking monomers join long-chain polymers along the chain to improve the material strength.[21]

Fillers are added into the resin matrix to reduce polymerization shrinkage by decreasing the amount of resin.[22] Moreover, the added fillers increase the physical properties of resin composite. Effects of filler on the behavior of resin composite depend on types of filler (surface, size and shape), surface modifiers, optical index, filler loading and size distribution.[22] It is critical for the filler to be enveloped by resin, and this limits the amount of filler that can be incorporated into resin matrix. The interface between filler and resin is a high-stress area when resin is cured and, for this reason, the surface treatment of fillers, namely silanization, is mandatory to overcome the breakdown of interface.[21] Furthermore, there are some minor elementary compositions- i.e. photo-initiators (such as camphorquinone, phenylpropanedione or lucirin), pigments, photo-inhibitors, are also included in resin composite.[21]

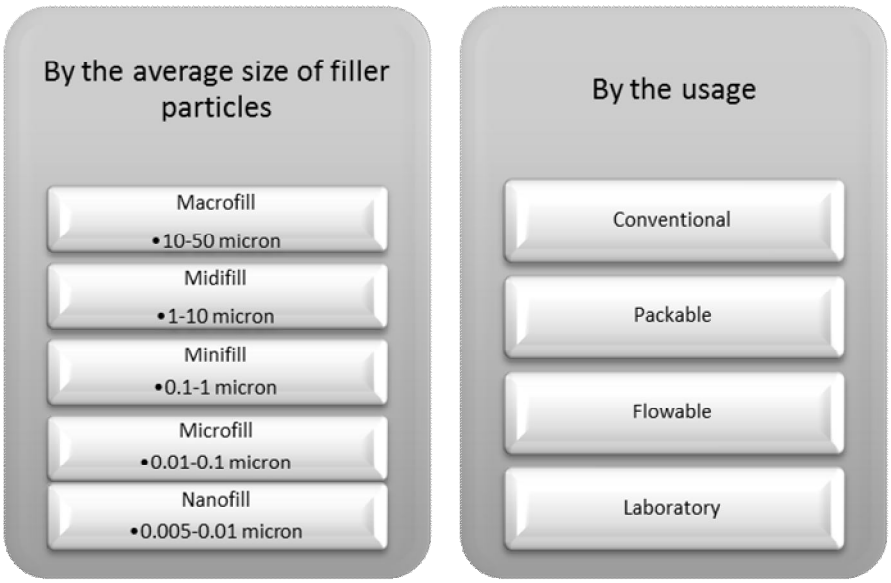


Figure 4.2 Resin composite classifications according to the average size of filler particles and their usage.

Resin composite can be classified in according to the average filler particle sizes and usages (Fig. 4.2). By the average size of filler particles, resin

composite is classified according to the particle size as follows: Macrofill (10-50 μm), Midifill (1-10 μm), Minifill (0.1-1 μm), Microfill (0.01-0.1 μm) and Nanofill (0.005-0.01 μm).[21] For the nano-particles type, there are nano-filled and nano-hybrid resin composites.

The nano-filled resin composite has a very good polish-ability with improved wear resistance.[21] When a nano-sized particle is scratched out, it leaves a smaller crater behind and affects the surface characteristics of the restoration less than the larger crater that a macro-sized particle does. In other words, the smaller particles the composite contains, the more resistant of resin composite to wear in the mouth is expected.[21] The nano-hybrid is modified form micro-hybrid resin composite that contains a cluster of nano-sized particles instead of the macro-sized particles. It is difficult to classified the nano-hybrids type out from micro-hybrid type because their physical properties are similar, but the nano-hybrid composite is commonly superior in wear resistance.[22]

Resin composite can be classified according to their usage- i.e. conventional, packable, flowable and laboratory resin composite. [20, 21] The conventional resin composite is the material with normal viscosity. Packable resin composite is a high-viscosity material which can be packed into the cavity, but the adaptability to cavity walls is usually inferior to the conventional type.[22] On the other hand, flowable resin composite has a low viscosity to improve the adaptation, and it is used as a polymerization stress absorber layer in the elastic cavity wall concept.[23] However, flowable resin composite has a low strength, so it cannot be used in stress-bearing area.[20] Laboratory resin composite is generally designed for the fabrication of the indirect resin composite inlays/onlays or veneers. This resin composite type is cured by heat, light and/or high pressure under non-oxygen condition, so it is almost completely cured and has improved physical properties.[20]

4.1.2 Polymerization shrinkage and its effect

Resin composite contains many advantages, such as natural tooth-color, mercury-free, preservation of tooth structure, easy to manipulate and low cost (compared to indirect restorations). However, it has some disadvantages such as low wear resistance, not as strong as amalgam and polymerization contraction (Fig. 4.3).[3]

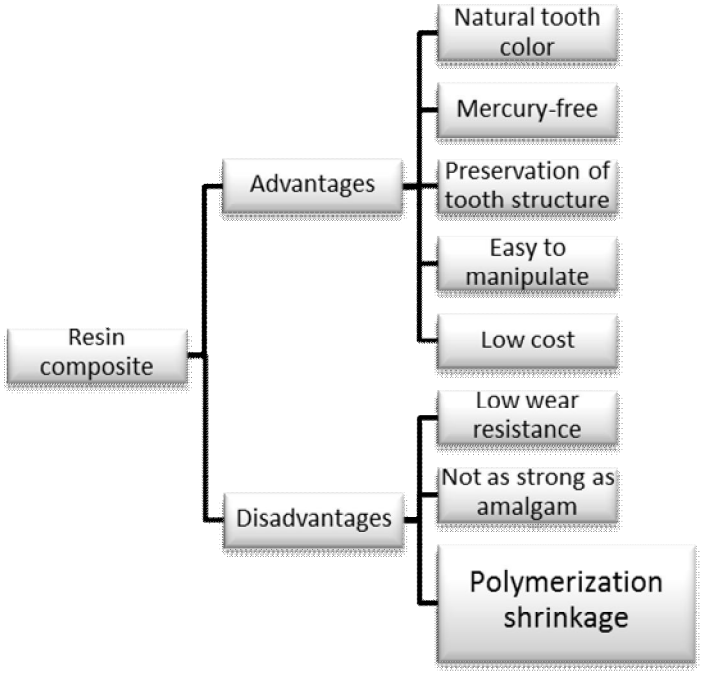


Figure 4.3 The advantages and disadvantages of resin composites.

Formation of a polymer network during the polymerization reaction provides a denser structure that causes volumetric shrinkage about 1.67-5.68% of the total material volume [(4)]. Polymerization shrinkage may produce internal gap formation, marginal staining or secondary caries (Fig. 4.4).[(6)] Internal gaps between the restorative material and cavity walls may induce post-operative tooth sensitivity which is the consequence of the dentinal fluid movement.[(5, 6)]

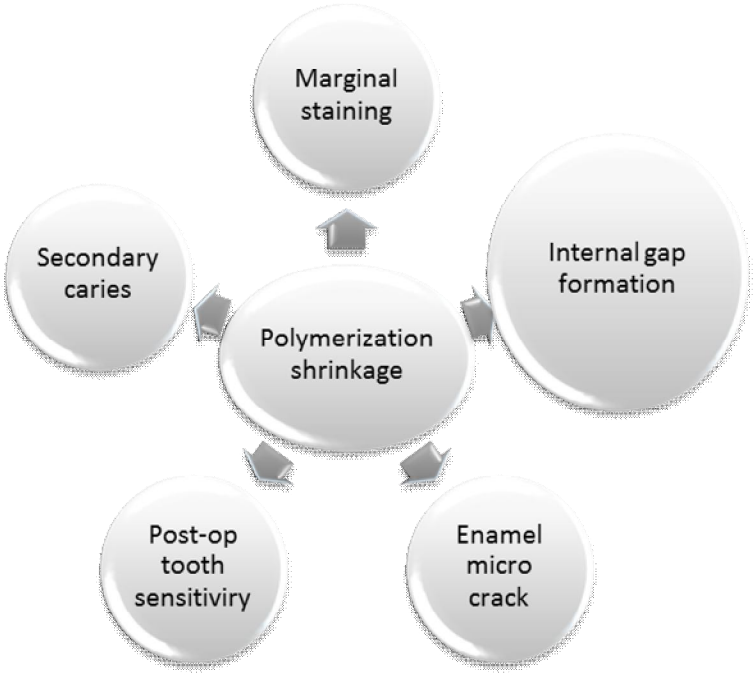


Figure 4.4 The effects of polymerization shrinkage.

When resin composite is cured, a shrinkage stress is generated from the polymerization shrinkage that is influenced by modulus of elasticity, filler content, configuration factor (C-factor), placement and curing techniques and elastic cavity wall concept.[24]

There are many attempts to reduce the polymerization shrinkage stress (Fig. 4.5).[3, 4, 25] Decreasing the modulus of elasticity of resin composite tends to reduce the polymerization shrinkage.[26] The low modulus of elasticity results in capable to release stress of resin composite. Increasing the filler amount decreases the resin matrix and improves the physical properties especially decreasing in polymerization shrinkage.[19] Modifying the resin composite's formula is another attempt. This formula alteration, such as silorane-based resin matrix, causes less volumetric polymerization shrinkage by the opening of aromatic rings in the resin matrix structure. However, it only reduces the volumetric change of the material, but not the polymerization stress.[27]

The "C-factor" refers to the area of bonded to unbonded surface in a tooth cavity. The higher C-factor is, the higher polymerization shrinkage stress is generated. For the resin composite placement techniques, bulk filling in a large and deep cavity

may lead to incomplete curing of the resin composite so that using a layering technique is recommended. There are many techniques to place the increments of resin composite: horizontal technique, oblique technique and success cusp build-up technique.[4] The horizontal technique is to fill up the resin composite horizontally layer by layer, which increases the total shrinkage stress. The oblique technique is to fill the resin composite in a wedged shape incrementally. The success cusp build-up technique is to put the first resin composite layer horizontally, then put the next resin composite layers against the cusps in wedged shape as in the oblique technique. These two techniques just are placing the wedge-shape composite increments in series to decrease the polymerization shrinkage stress.[4]

Moreover, light-curing method may relieve the polymerization stress by using the low-energy light at an initial stage following by the high-energy light, namely soft-start polymerization technique.[28, 29] Theoretically, the point before resin composite sets and changes from paste to solid, namely the gel point, could be postponed by using the initial low-intensity light curing so that the polymerization shrinkage stress can be relieved. This follows with the high-intensity light in order to cure the material completely.

The adhesive and the low-elastic modulus liner and base play an important role in a stress relief.[23] Using a thick filled adhesives or liner/base placement may act as a stress absorber between resin composite and tooth cavity wall.[30] When the resin composite is polymerized, it shrinks and creates stress. This stress can be released by the layer of the low-modulus of elasticity material, i.e. - the thick filled adhesive or liner/base beneath the resin composite restoration.

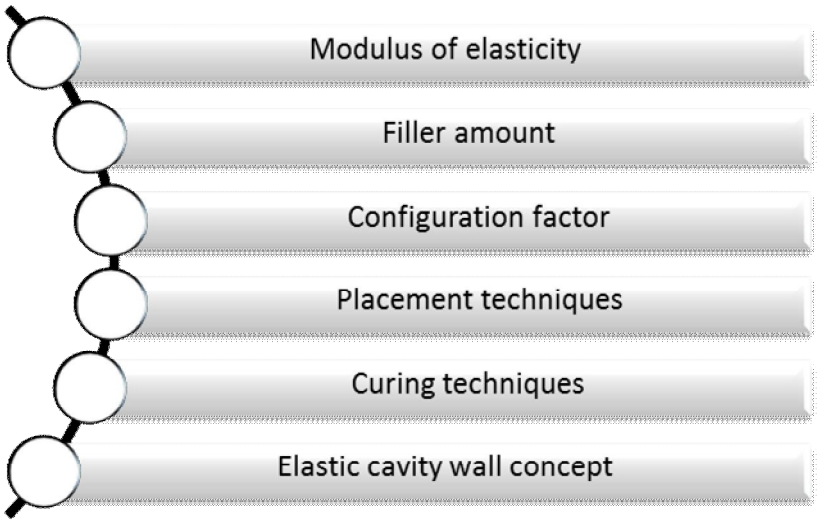


Figure 4.5 Factors affecting the polymerization shrinkage.

4.2 Adhesives

4.2.1 Compositions and types

Dental adhesives are mainly classified into the 2 major systems: etch-and-rinse and self-etching adhesives (Fig. 4.6).[21, 31] The etch-and-rinse system is the most conventional form, requiring a separate 10-40% phosphoric acid etching step (which provides the most reliable etching pattern on enamel) to etch enamel and dentin, a subsequent rinse, and application of primer and bond.[31] The primer contains bi-functional monomers, which has the hydrophilic part for adhesion with acid-etched dentin and the hydrophobic part for adhesion with resin bonding. Solvent or 'the water chaser', which is acetone, ethanol, or water, acts as a vehicle that carries the monomers into the tooth structure.[21, 32] The bonding agent is light-curing dimethacrylate oligomers and commonly recommended to be polymerized prior to placing resin composite so that the set adhesive layer can resist to the polymerization shrinkage force.[33]

The etch-and-rinse system can be further classified into 3-step (etching, priming, bonding) type and 2-step (etching, and priming/bonding mixed in one bottle) type.[31] The 3-step etch-and-rinse adhesive offers excellent bond strengths to a variety

of surfaces. For 2-step etch-and-rinse adhesive, it needs several layers of primer/bonding application to reach the good bond strength.[34-36]

On the other hand, the self-etching adhesive is more user friendly and classified into 2-step (priming, bonding) and 1-step (all-in-one) type.[37] The traditional self-etching primer contains acidic monomer that partially removes smear layer, without opening the whole dentinal tubules, and etch the tooth surface simultaneously without rinsing step is required.[21, 36] The acidic monomers have a variety of acidity- strong, moderate or mild type.[32, 38, 39] The pH of strong self-etching adhesive is lower than 1, so it can remove smear layer better than the moderate (pH 1-2) and mild (pH more than 2) self-etching adhesives.[32, 38, 39] The strong self-etching adhesive creates the deep micro-pores in the etched tooth structure that the resin bonding cannot completely penetrate into. Using strong self-etching adhesive generally results in a lower bond strength than using moderate or mild self-etching adhesive. Mild self-etching adhesive provides the most promising bond strength, especially regarding to bond stability.[40]

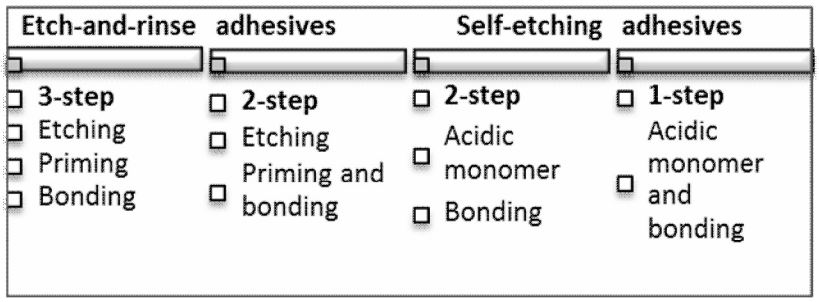


Figure 4.6 Types of adhesives.

4.2.2 Basic principle of adhesion

Adhesion involves molecular interactions at the interface between the different materials.[41] For proper adhesion, intimate contact between the adhesive and the substrate is needed. This intimate contact is affected by wettability of the substrate surface, the viscosity of adhesive and the morphology of surface roughness.[41] The wet substrate surface and the low viscosity of adhesive allow the good adhesion. The rougher surface creates the more bonding area and conduces to the better adhesion.

Enamel mainly consists of hydroxyapatite and a minimal amount of water, so it is effectively bonded to resin composite using a hydrophobic adhesive.[39, 42] Enamel etching was introduced by Buonocore in 1950s.[31] Acid etching on enamel creates soluble mono-calcium phosphate monohydrate. After rinsing, the enamel prisms are exposed, and the surface energy is improved, which dental adhesive can penetrate and create the micro-resin tags.

By composition, dentin contains higher water and organic contents than enamel. In the past, acid etching on dentin was prohibited because of the belief that the acid may be harmful to dentin. Currently, a total-etching technique is used, and bonding agent is applied to both enamel and dentin. Acid etching produces a rough surface into which resin bonding flows and opens the dentinal tubules that resin bonding forms resin tags in a penetration depth of 10-20 microns, depending on etching time.[43]

Therefore, dentin is more hydrophilic and difficult to bond with a hydrophobic adhesive.[42] In etch-and-rinse adhesive, acid etching removes smear layer and demineralizes dentin to prepare a clean and good-wettability surface for bonding.[31] Then, priming is an important step to prepare and sustain the exposed collagen fibers for penetration of bonding. Next, hydrophobic resin from bonding agent infiltrates primed collagen fibers in demineralized dentin to form the hybrid layer (hybridization) (Fig. 4.7).[21, 31, 36, 37, 44]

For a mild self-etching adhesive, the acidic monomer only modifies smear layer, which is finally incorporated into the resin-bonded interface.[21, 31, 35] Simultaneously, the resin monomer(s) fills the smear layer and exposed collagen fibers to form hybrid layer. For a strong self-etching adhesive, the acidic monomer removes smear layer and opens dentinal tubules. The adhesive resin of bonding agent fills the exposed collagen fibers to form hybrid layer and dentinal tubules to form resin tags, and the micromechanical retention is once established (Fig. 4.7).[31, 35]

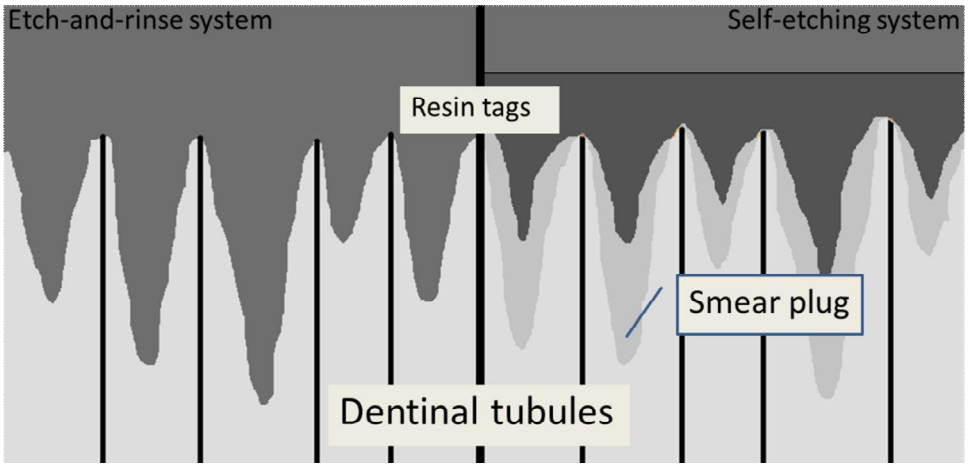


Fig.4.7 Hybridization and resin tags: etch-and-rinse system (left) and self-etching system (right).

4.3 Glass ionomer cements

4.3.1 Compositions and mechanism of setting

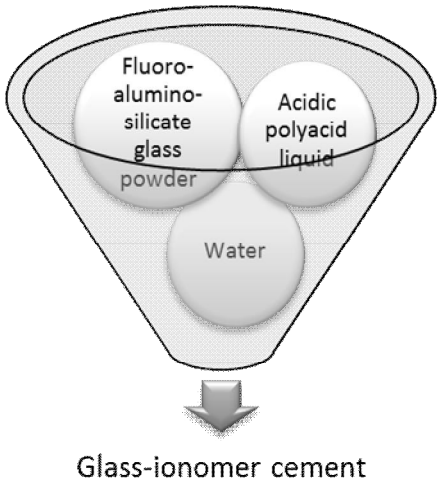


Fig.4.8 Compositions of conventional glass-ionomer cement.

Conventional glass-ionomer cement consists of fluoroaluminosilicate glasses powder (SiO_2, Al_2O_3, CaF_2 and others), acidic polyacid liquid (acrylic acid, itaconic acid, maleic acid, tartaric acid) and water (Fig. 4.8). The conventional cement sets by acid-base reaction.[2] The mechanism of setting starts after mixing the glass

powder and the polyacid liquid. Firstly, the acid attacks the glass particles to release calcium ions, namely dissolution phase. The calcium ions move into a liquid phase of cement and form the initial gel matrix of calcium polyacid salt, which this initial set begins 5-10 min after mixing. After that, aluminium polyacid salt is developed and becomes the dominant component in post-set hardening phase. Finally, the set material is strengthened by cross-linking of the polymers, and the physical and mechanical properties are improved within 24 h (Fig 4.9).[45]

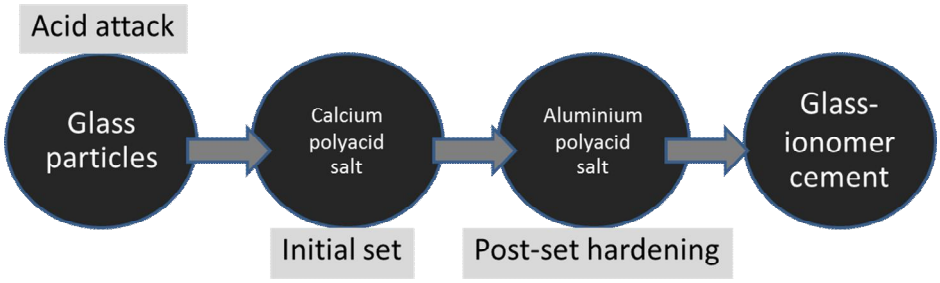


Fig.4.9 Setting mechanism of conventional glass-ionomer cement.

4.3.2 Adhesion of glass-ionomer cement to enamel and dentin

Glass-ionomer cements chemically bond to enamel and dentin during the setting process. The mechanism of adhesion regards to an ionic interaction with calcium and phosphate ions released from the surfaces of enamel and dentin, which is more effective if the tooth surface is clean (less smear layer).[46, 47] When the setting cement contacts to the tooth surface, there is an ion exchange between carboxyl group of polyacrylic acid and calcium ions of hydroxyapatite crystals in enamel and dentin (Fig. 4.10). These interactions create the ion-enrich layer which might bond tightly to enamel and dentin.

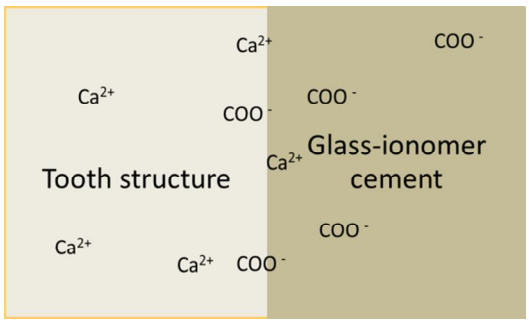


Fig.4.10 Ionic interaction between tooth surface and glass-ionomer cement: COO^- = carboxyl ions, Ca^{2+} = calcium ions.

Whereas the adhesion of glass-ionomer cement to enamel is completely obtained from ionic and polar forces (hydrogen bond), the adhesion to dentin is more complicated because of the heterogenicity of dentin.[48, 49] Dentin has lower calcium carboxylate bond formation with calcium ions due to lower hydroxyapatite contents than enamel has.[46] After cavity preparation, there is a difference in dentin surface cut by a diamond or carbide bur: the surface prepared with diamond bur has thicker smear layer, which affected the adhesion between tooth surface and glass ionomer cement.[47, 50]

4.3.3 Glass ionomer cement liner/base

Many types of dental cement have been used as a base or liner under restoration for decades, such as zinc phosphate cement, zinc oxide eugenol cement or polycarboxylate cement.[7, 21] Recently, the most popular base or lining material is glass ionomer cement, which posses numerous desired properties and is recommended to use as a base and liner replacing dentin.[7, 8] The conventional glass ionomer cement is based on the reaction of silicate glass powder and polyalkenoic acid, namely an acid-base reaction. This cement is able to bond chemically to enamel and dentin during the setting process. Moreover, it is a good biocompatible dental material.[1] However, the conventional glass ionomer has a significant disadvantage due to water solubility and water absorption that decrease the strength and increase dimensional change.[51] The conventional glass ionomer cements also have slow setting time. Resin-modified, glass-ionomer cement (RMGIC) with lower solubility, less water sorption (than conventional type) and light-command setting was developed to solve these problems (Fig. 4.11).

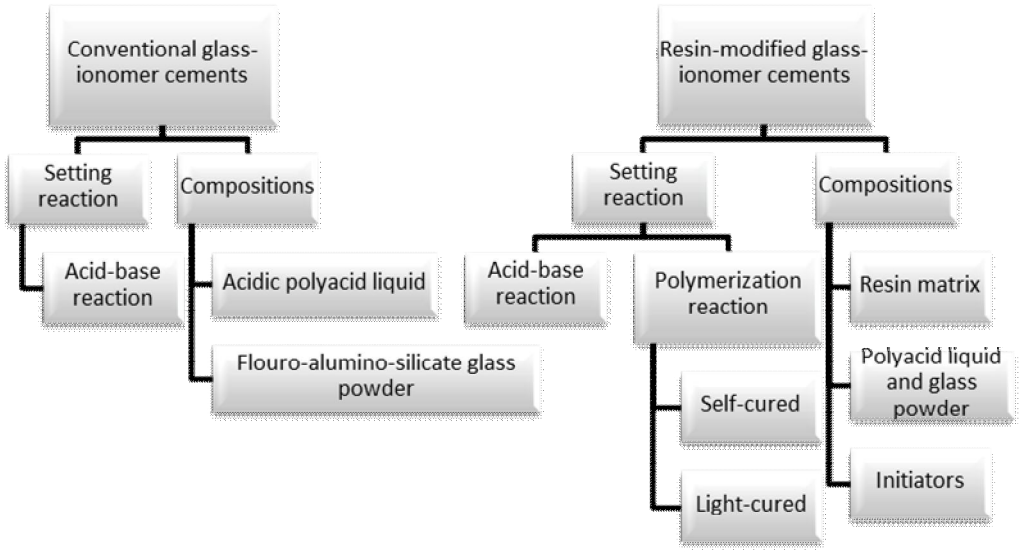


Fig.4.11 Setting mechanisms and compositions of glass-ionomer cements

RMGIC contains a small quantity of polymerizable resin component that can bond with resin-based material. Chemical-setting type of RMGIC combines an acid-base reaction of the conventional glass ionomer with a self-cured, amine-peroxide polymerization reaction. The light-cured system is developed by adding polymerizable functional methacrylate groups with a photo-initiator into the conventional cement.[52] It has been also developed by modifying the polyalkenoic acid with polymerizable side chains that could be light cured. RMGIC remains the "true" glass ionomer cement due to the ability to set by acid-base reaction.[52] It undergoes both an acid-base reaction as well as the polymerization with light-curing by photo-initiation and/or self-curing of methacrylate carbon double bonds.[51] In other words, the acid-base reaction is supplemented by a resin polymerization reaction initiated by a light-curing or self-curing process.

Selection of a lining/base material must be considered the biological compatibility.[53] There are some studies showing that the cavity walls in a deep cavity should be lined or based with a biocompatible material, such as glass-ionomer cement or calcium hydroxide, before placing a resin composite restoration.[8, 9] From the survey, 52 dental schools in the North America taught under-graduated dental students to place a glass-ionomer cement base or liner in the deep cavity prior to a

final restoration.[10] Even the freshly prepared glass-ionomer cement is acidic and mildly cytotoxic because of the polyacid in its components, the acidity decreases during the setting of glass-ionomer cement overtime. Pulpal biocompatibility of glass-ionomer material has been attributed to the weak-acid nature of polyalkenoic (polyacrylic) acid, which is unable to diffuse through dentin due to its high molecular weight, and also the buffering capacity of dentin.

The glass-ionomer cement is proved to be acceptable, both biologically and clinically, for using as a liner/base material. Based on the clinical need of good adhesion between glass-ionomer cement liner/base and resin composite, RMGIC appears to be the material of choice.[54] In contrast, RMGIC has been reported to provide some detrimental effect to the pulp.[48] It can be explained on basis of HEMA content which may diffuse through dentin and cause a variety of negative effects, ranging from inflammation of the pulp to allergic reaction.[11] However, one study revealed that no significant difference in post-operative sensitivity, either in daily function or in response to a cold stimulus, was observed between the restorative procedures with or without the glass-ionomer cement liner.[55] The clinical results with this type of glass-ionomer cement liner/base material that have been reported to date are generally positive. [5, 55-57] In case of using RMGIC lining/base, pulpal inflammatory reaction caused by the infiltration of monomer components through dentinal tubules is minimal or usually absent after 1 month.[11]

Not only the biological compatibility, but also the mechanical and physical properties must be considered for selection of lining/base materials.[53] The glass-ionomer cement is inevitably subjected to contraction stress from an overlying resin composite restoration. The stress developed by the polymerization contraction of resin composite (bonded to a glass-ionomer base) is capable of disrupting the cement-dentin bond at the interface.[12] The better performance of RMGIC than the conventional glass-ionomer cement may be attributed to the instant set of the material as well as higher initial bond strength to dentin to resist the contraction force.[48] One laboratory study showed less shrinkage for resin composite when curing in contact with the set RMGIC liner than curing alone.[13] Placing RMGIC as a lining/base decreases the amount of resin composite in a same cavity volume, so using RMGIC as

a lining/base commonly reduces the overall polymerization shrinkage of the resin composite restoration.

On the contrary, several studies represent the internal gaps detected between the floor of cavities and RMGIC liner/base, which is higher in comparison to the interface bonded with an adhesive without liner/base.[15-18]. These make us rethinking about the suggestion in placing liner/base before restoration with a resin composite, although the reason for the increased internal leakage is unclear. It may be an effect from the polymerization contraction stress that tends to separate the liner/base from the cavity floor rather than glass-ionomer cement - resin composite interfacial separation. (Fig. 4.12)

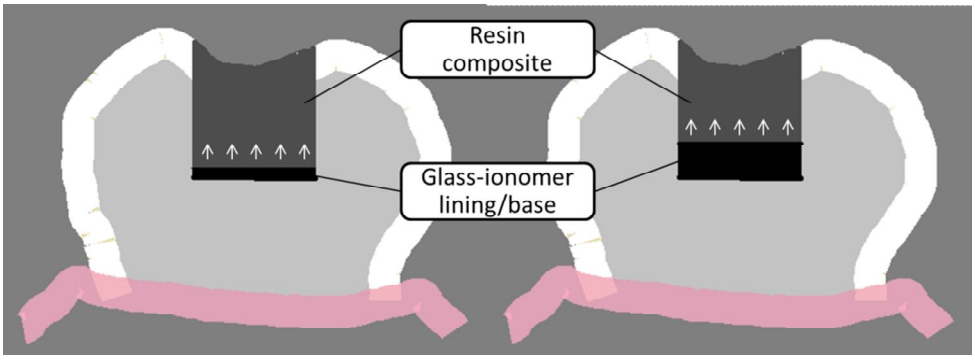


Fig.4.12 The polymerization shrinkage of resin composite may pull the glass-ionomer lining/base up from the cavity floor.

The thickness of the liner/base may be an important factor that could decrease polymerization shrinkage stress and promote better internal adaptation. It seems that placing the “thick” liner/base may act as a stress absorber for polymerization shrinkage stress distribution (Fig. 4.12). Moreover, increasing the thickness of lining/base decreases the volume of resin composite used in a cavity. That decreases the polymerization shrinkage of resin composite and, finally, decreases the stress.[12, 16] Under the limitation of the minimal required thickness of resin composite restoration, it remains doubtful how thick the liner/base should be placed to obtain acceptable adaptation. Therefore, the purpose of this study is to investigate the effect of RMGIC lining thickness under occlusal resin composite restorations on the

internal adaptation investigated by using dye leakage test and micro-gap formation detection with SEM.

4.4 The internal adaptation measurement

4.4.1 Destructive methods

The internal adaptation of restorations can be measured directly by sectioning the restorations. The sectioned specimens reveal the restoration-tooth interfaces. There are two common ways to detect the interface showing the internal adaptation. One is to stain with the dye along the restoration-tooth interfaces (dye leakage test). If there are some micro-gaps at the interface, the dye is occupied in the micro-gaps, and the stained interface can be measured as the internal leakage or un-adaptation. Staining distance and volume depend on molecular size of dye.[58] The small molecular sized dye could be occupied much more than the large molecular sized dye in the micro-gaps. There are many types of dyes, such as normal dyes and fluorescent dyes. The normal dyes staining at the interfaces can be visibly detected while the fluorescent dyes can be detected under the ultra-violet light.[58]

The other way to detect the micro-gaps at the restoration-tooth interface is to "observe" it by using SEM. The SEM can magnify the tooth-restoration interface and reveal adapted or un-adapted area.[16] Before the specimens are investigated by SEM, the specimens must be dried and coated with gold particles. In some cases, if the specimens are dried, the micro-crack or pseudo-gaps would be occurred. The replica technique helps solving this problem.[59] Resin replica is made from the resin pouring into the impression of the restoration-tooth interface. When the resin sets, the resin replica is obtained and then coated with gold particles before SEM investigation.[59]

4.4.2 Non-destructive methods

There are many ways to evaluate the internal adaptation of restorations indirectly. By these ways, it does not need to section the specimens.

Micro-computed tomography or micro-CT is the way to investigate inside of specimens.[60] The 360^{o} radioscopic image data on an inspection object placed on a

sample table is obtained using an X-ray Image Intensifier by turning the table while irradiating object with X-rays.[60] So, the three-dimensional images are obtained and able to evaluate the internal adaption.[61]

Optical coherence tomography or OCT is so useful in medical investigation that uses Low-Coherence Interferomery concept.[62] The principle is to use the laser across the specimens, gain the three-dimensional images and investigate some disturbances inside, such as abnormal retina, hyperlipidemia. OCT is also used in evaluation of internal adaptation of the restorations.[62] OCT use of a light source that generates a high power broadband light with a wavelength of 1,310 nm has been reported to generate images to a depth of approximate 2 mm into the subsurface of the tooth.[63]

CHAPTER V
MATERIALS AND METHODS

Materials

- Human third molars without caries, cracks, restorations, or any defects
- Filtek Z250XT (3M ESPE, St. Paul, MN, USA)
- Etchant (3M ESPE, St. Paul, MN, USA)
- Single Bond 2 (3M ESPE, St. Paul, MN, USA)
- Clearfil SE Bond (Kuraray Medical Inc., Okuyama, Japan)
- Vitrebond (3M ESPE, St. Paul, MN, USA)
- Diamond cylindrical aerotor bur #010 (Intensiv, Grancia, Switzerland)
- Slow-speed round steel burs #016 (Jota, Ruthi, Switzerland)
- Slow-speed flame-shaped fine diamond bur (Composhape, Intensiv, Grancia Switzerland)
- Composite instruments (Hu-Friedy, Chicago, IL, USA)
- Light emitting diode (LED) light curing unit (Bluephase, Ivoclar Vivadent, Schann, Liechtenstein)
- Low-speed diamond saw (Isomet, Buehler, Lake bluff, IL, USA)
- Cyanoacrylate adhesive (Model Repair II Blue, Dentsply, SANKIN, Tokyo, Japan)
- Scanner (HP Color LaserJet CM1312 MFP, Hewlett-Packard Development Company, Palo Alto, CA, USA)
- SEM (JSM-6610LV, JEOL, Tokyo, Japan)
- Methylene blue dye 2% (M-Dent Blue, Bangkok, Thailand)
- Light-body condensation silicone (Silagum, DMG, Hamburg, Germany)
- Epoxy resin (Aka-cure slow, Akasel Aps, Merlose, Denmark).
- Silicon-carbide paper # 600, 1200, 2500 and 4000 grit (Buehler™, Buehler Ltd., Lake Bluff, IL, USA)

- EDTA 17% (M-Dent, Bangkok, Thailand)
- Transparent adhesive tape (3M ESPE, St. Paul MN, USA)

Table 5.1: Restorative dental materials used in this study.

Restorative materials	Manufacturers	Types	Compositions	Lot. Numbers	Method of applications
Filtek Z250XT	3M ESPE, St. Paul, MN, USA	Nanohybrid composite	65-90% silane treated ceramic, 1-10% silane treated silica, Bis-GMA, UDMA, Bisphenol-a-polyethyleneglycol diether dimethacrylate	N262698	1.Fill three increments (first horizontal layer and follow with wedge-shaped increments against the cusps) (Fig. 5.1) 2.Light curing for 40s to each layer
Adper Scotchbond etchant and Single Bond 2	3M ESPE, St. Paul, MN, USA	Two-step, etch-and-rinse adhesive	Etchant: 35% phosphoric acid; Adhesive: ethyl alcohol, Bis-GMA, silane treated silica, HEMA, UDMA, glycerol 1,3-dimethacrylate, copolymer of acrylic and itaconic acids, water	N274273, N343246	1.Etch with etchant for 15s and rinse off with water spray 2.Apply bond for 15s, twice 3.Air flow gently 4.Light curing for 20s
Clearfil SE Bond	Kuraray Medical Co., Okuyama, Japan	Two-step, self-etching adhesive	Primer: 10-MDP, HEMA, hydrophilic dimethacrylate, Di-camphorquinone, N,N-diethanol-p-toluine, water Bonding:10-MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, di-camphorquinone, N,N-diethanol-p-toluine, silanated colloidal silica	081177	1.Apply primer for 20s 2.Dry with mild air flow 3.Apply bonding 4.Air flow gently 5.Light curing for 20s
Vitrebond	3M ESPE, St. Paul, MN, USA	RMGIC for lining/base	Powder: > 95% Glass powder, diphenyliodonium chloride Liquid: copolymer of acrylic and itaconic acids, water, 2-hydroxyethyl methacrylate	N360592	1.Mix one drop liquid and one scoop powder 2.Apply as a liner (0.5 mm) or base (1.0 mm) (Fig. 13) 3.Light curing for 30s

HEMA(2-hydroxyethyl methacrylate);

Bis–GMA(bisphenol A diglycidyl methacrylate); UDMA(urethane dimethacrylate);

10-MDP (10-Methacryloyloxydecyldihydrogenphosphate)

Methods

This study was approved by Faculty of Dentistry and Faculty of Pharmaceutical Sciences Institutional Review Board with MU-DT/PY-IRB 2012.016/1403.

Tooth preparation

Sixty human third molars without dental caries, cracks or any defects were collected from the patients with age 18-30 years old. Debris, soft tissues and calculus were removed by ultrasonic scaler, and the tooth surfaces were polished with pumice. The teeth were kept in 0.1% thymol solution at 4 ºC before use.

On each tooth, class I cavity at the center of occlusal surface in the dimension of 3.0 x 3.0 x 3.0 mm (in approximate, ± 0.10 mm) was prepared using a #010 aerotor cylindrical diamond bur (Intensiv, Grancia, Switzerland) with water coolant. The cavity dimension was measured using a verneer caliper (Mitutoyo Corporation, Tokyo, Japan). Next, the pulpal floor of cavity was ground using a #016 slow-speed round steel bur (Jota, Ruthi, Switzerland). The dental burs were changed at every five cavities. If any pulpal exposure occurred during the cavity preparation, the prepared tooth was excluded.

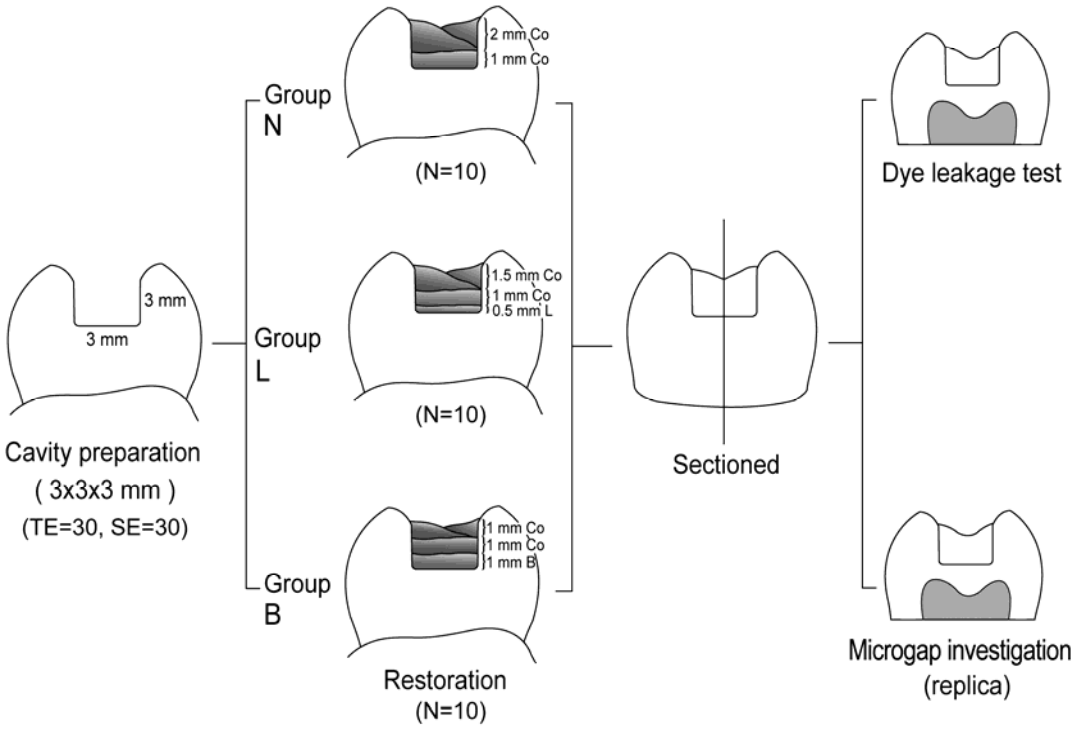


Figure 5.1: The specimen preparation of 3 x 3 x 3 mm box-shaped occlusal cavities were prepared on human third molars. Divided into three groups according to the restorative procedures, the teeth were restored and kept in 100% humidity for 24 h. Then, all restored teeth were sectioned in bucco-lingual direction to obtain specimens for the dye leakage test and micro-gap investigation (replica technique). TE = restorations bonded with Single Bond 2, SE = restorations bonded with Clearfil SE Bond, Co = resin composite, L = RMGIC lining, B = RMGIC base, Group N = cavity restored with resin composite without lining/base, Group L = cavity restored with resin composite after 0.5-mm thick RMGIC lining, Group B = cavity restored with resin composite after 1.0-mm thick RMGIC base.

Restorative procedures

Sixty cavities were prepared and then randomly divided into 6 groups, 10 of each (Fig. 5.1) as follows:

- Group NTE: the cavity was restored with nanohybrid resin composite (Z250XT, 3M ESPE, St. Paul, MN, USA) (shade A2) without lining/base, using a two-step, etch-and-rinse adhesive (Single Bond 2, 3M ESPE, St. Paul, MN, USA)

- Group LTE: the cavity was lined with 0.5-mm thickness of a RMGIC (Vitrebond, 3M ESPE, St. Paul, MN, USA) and restored with Z250XT, using Single Bond 2 adhesive
- Group BTE: the cavity was based with 1.0-mm thickness of Vitrebond and restored with Z250XT, using Single Bond 2 adhesive
- Group NSE: the cavity was restored with Z250XT without lining/base, using a two-step, self-etching adhesive (Clearfil SE Bond, Kuraray, Okuyama, Japan)
- Group LSE: the cavity was lined with 0.5-mm thickness of Vitrebond and restored with Z250XT, using Clearfil SE Bond adhesive
- Group BSE: the cavity was based with 1.0-mm thickness of Vitrebond and restored with Z250XT, using Clearfil SE Bond adhesive.

Without polymerization shrinkage stress from resin composite, another 10 cavities were additionally prepared and placed only glass-ionomer lining or base. Five cavities were lined with 0.5-mm thickness of Vitrebond while the other five cavities were based with 1.0-mm thickness of Vitrebond, without adhesive application and resin composite restoration.

Vitrebond was mixed according to the manufacturer's instruction. The two components were mixed together within 10-15 s, carried into the cavity with Dycal carrier and polymerized with a LED light-curing unit (Bluephase, Ivoclar Vivadent, Schaan, Liechtenstein) in the low-intensity mode (light intensity = 650 mW/cm^2) for 30 s. The thickness of the lining/base (0.5 mm as a lining or 1.0 mm as a base) was controlled by measuring the changed cavity depth with a verneer caliper's rod. After the cavity was lined or based, the remaining cavity depth was approximately 2.5 mm or 2.0 mm respectively. If the lining/base was too thin, additional lining/base was immediately added and polymerized. If the lining/base was too thick, the specimen was excluded from the study.

In the etch-and-rinse groups, acid etchant (3M ESPE, St. Paul, MN, USA) was applied for 15 s and rinsed off with air-water spray from a triple syringe. Next, an etch-and-rinse adhesive (Single Bond 2) was applied following the manufacturers' instructions (Table 5.1). In the self-etching groups, self-etching adhesive (Clearfil SE Bond) was also applied following the manufacturer's instruction in the self-etching groups (Table 5.1).

After that, a uniform 1.0-mm thickness (in approximate, using verneer caliper's rod to measure the changed cavity depth) of resin composite was placed as a first incremental layer using a composite instrument (Hu-Friedy, Chicago, IL, USA) and polymerized with the LED light-curing unit in the high-intensity mode (1,200 mW/cm^2) for 40 s. The thickness of the first increment was evaluated by using a verneer caliper's rod to measure the decreased cavity depth. The other two increments were gradually placed in the two wedge-shape layers (Fig. 5.1) and polymerized for 40 s each. The cavity was completely filled into slightly flat-contour occlusal surface. The restorative margins were finished to remove the excess of resin composite with a slow-speed, flame-shaped fine diamond bur (Composhape, Intensiv, Grancia, Switzerland).

Each restored tooth was kept in distilled water at 37 ºC for 24 h and then sectioned at the center of restoration in bucco-lingual direction with diamond blade under water coolant (Isomet, Buehler, Lake bluff, IL, USA). Two specimens were obtained from each sectioned tooth - one specimen was used for internal dye leakage test and the other was used for micro-gap detection in SEM (Fig. 5.1). Next, the sectioned surfaces were sequentially polished by silicon carbide papers #800, 1200, 2500 and 4000 grit 10 times each under water coolant.

Internal dye leakage and micro-gap formation detection

For the dye leakage test, transparent adhesive tape (3M ESPE, St. Paul, MN, USA) was placed at 0.5-1.0 mm far from the restoration/tooth interface of the sectioned tooth. One drop of 2% methylene blue dye (M-Dent Blue, Bangkok, Thailand) was applied along the restoration/tooth interface for 5 s and then rinsed off with distilled water. The stained specimens were scanned using a scanner (HP Color LaserJet CM1312 MFP, Hewlett-Packard Development Company, Palo Alto, CA, USA) at the highest resolution (1,200 dpi) and saved as TIFF files. Then, the TIFF pictures files were processed by the ImageTool 3.0 software (the Department of Dental Diagnostic Science at The University of Texas Health Science Center, San Antonio, Texas, USA) for obtaining the stained distances and total distances of pulpal and vertical walls, in mm. In brief, the total distances of pulpal walls (P) and the dye-

stained interfaces at the pulpal wall (x) were measured and then calculated into % leakage at pulpal wall as follow:

% of stained interface at the pulpal wall = (x / P) x100.

Similarly, the total distances of vertical walls ($V=V_1+V_2$, V_1 is the distance of right vertical wall; V_2 is the distance of left vertical wall) and the dye-stained interfaces at the vertical wall (y) were measured and then calculated into % leakage at vertical wall as follow:

% of stained interface at the vertical wall = (y / V) x100.

For SEM micro-gap investigation, 17% EDTA solution (M-Dent, Bangkok, Thailand) was applied on the surface of sectioned specimen for 10 s and then rinsed off with water spray in order to remove smear layer from the cutting and polishing processes. Prepared for SEM investigation, the specimen must be dried, which the procedure strongly affects the water-based glass-ionomer cement material. Artificial cracks can be formed on the dried glass-ionomer cement, which interferes the investigation. Thus, an indirect investigation with the resin replica technique was employed.[64] An impression of the EDTA-treated surface was taken with light-body silicone impression material (Silagum, DMG, Hamburg, Germany), and then a replica was made by pouring epoxy resin (Aka-cure slow, Akasel Aps, Merlose, Denmark; mixing ratio - 100 g resin base to 12 g catalyst, setting time 24 h) into the impression.

The bonded interfaces and internal gaps were examined from the replicas using SEM (JSM-6610LV, JEOL, Tokyo, Japan) at magnifications as follows - x20 to detect an overview of the entire restoration, x40 to detect the closer view of restoration divided into four parts and x1,000 to detect the representative bonded interfaces. Using the ImageTool 3.0 software, the x20 pictures were measured the total and gap distances of the pulpal and vertical walls. The x40 pictures were used to confirm the gap formation. In brief, the total distances of pulpal walls (P) and the gapformation at the pulpal wall (x) were measured and then calculated into % gap at pulpal wall as follow:

% of gap formation at the pulpal wall = (x / P) x100.

Similarly, the total distances of vertical walls ($V=V_1+V_2$, V_1 is the distance of right vertical wall; V_2 is the distance of left vertical wall) and the gap formation at the vertical wall (y) were measured and then calculated into % gap at vertical wall as follow:

% of gap formation at the vertical wall = (y / V) x100.

Representative x1,000 pictures were selected for the representations of bond interfaces.

Since the data were not normally distributed, Kruskal-Wallis non-parametric statistical test was used to analyze any significant differences of the percentage of internal dye leakage or micro-gap formation among the experimental groups ($p<0.05$). Mann-Whitney *U* test was further used for comparison the percentage of dye leakage as well as the percentage of gap formation between the groups.

CHAPTER VI
RESULT

The data distribution (range, mode and median) of the percentages of internal dye leakage at the *pulpal* and *vertical* walls in each group is presented in Table 6.1. In the restorations bonded with the two-step etch-and-rinse adhesive (Single Bond 2), the percentages of leakage at the *pulpal* walls were- no lining/base (NTE), ranged from 0 – 55.82%; with RMGIC lining (LTE), ranged from 0 – 100%; and with RMGIC base (BTE), ranged from 0 – 88.06%. There were less than 3 repeated data at the *pulpal* wall in the BTE group, so the mode value did not display. For the restorations bonded with the self-etching adhesive (Clearfil SE Bond), the percentage of leakage at the *pulpal* walls were- no lining/base (NSE), ranged from 0 – 13.58%; with RMGIC lining (LSE), ranged from 0 – 70.82%; and with RMGIC base (BSE), ranged from 0 – 74.02%.

In the restorations bonded with the two-step etch-and-rinse adhesive (Single Bond 2), the percentages of leakage at the *vertical* walls were- NTE, ranged from 0 – 15.03%; LTE, ranged from 0 – 27.72%; and BTE, ranged from 0 – 13.67%. For the restorations bonded with the self-etching adhesive (Clearfil SE Bond), the percentage of leakage at the *vertical* walls were- NSE, ranged from 0 – 18.10%; LSE, ranged from 0 – 16.83%; and BSE, all were 0%.

Table 6.1: The minimum, maximum, mode and median of internal dye leakage at the *pulpal* and *vertical* walls in each group.

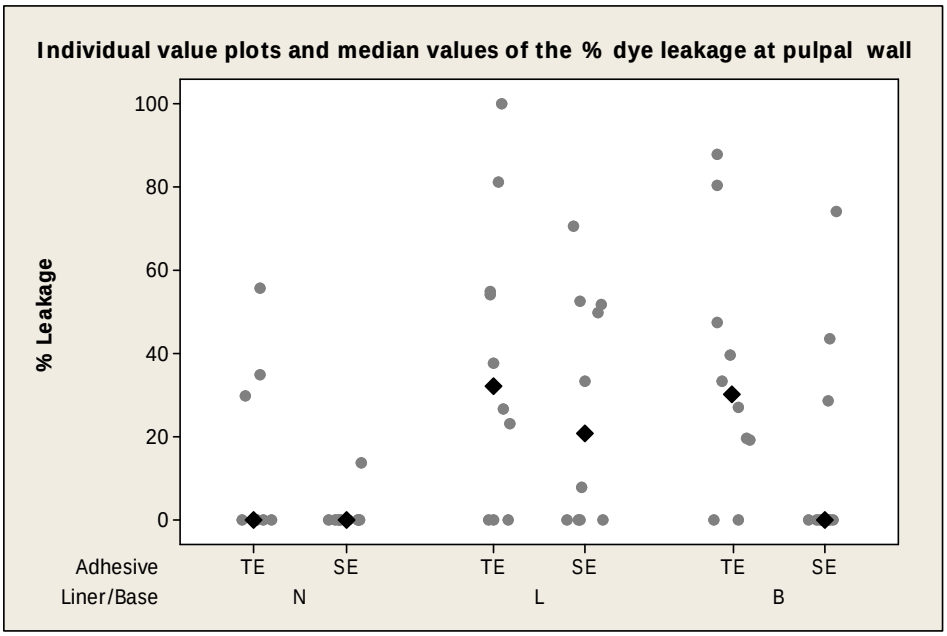
Groups	Internal dye leakage (%)							
	Pulpal walls				*Vertical* walls			
	Min	Max	Mode	Median	Min	Max	Mode	Median
NTE	0	55.82	0	$0^{a,d}$	0	15.03	0	0^{A}
LTE	0	100.00	0	32.10^{b}	0	27.72	0	4.07^{A}
BTE	0	88.06	-	$30.11^{a,b}$	0	13.67	0	0^{A}
NSE	0	13.58	0	$0^{c,d}$	0	18.10	0	0^{A}
LSE	0	70.82	0	$20.53^{a,b,d}$	0	16.83	0	0^{A}
BSE	0	74.02	0	$0^{a,b,d}$	0	0	0	0^{A}

Any significant difference is labeled with the different superscript small letter (*pulpal*) or capital letter (*vertical*).

NTE, LTE and BTE = the restorations bonded with Single Bond 2- with the presence of no lining/base, RMGIC lining, or RMGIC base, respectively; NSE = the restorations bonded with Clearfil SE Bond- with the presence of no lining/base, RMGIC lining or RMIGC base.

Figure 6.1 shows the individual value plots and medians of the internal dye leakage (in percentage) at *pulpal* wall and *vertical* wall from the restorations with lining (L), base (B) and control (N - no lining/base). There were low incidences of the dye leakage at the *vertical* walls, which no significant difference was found among the no lining/base, lining and base groups ($P > 0.05$). Moreover, at the *vertical* wall, there was no significant difference in the dye leakage between the two adhesive groups with the same restorative procedure (without or with lining or base) ($P > 0.05$).

In contrast, a significant difference in the dye leakage at *pulpal* wall was found among the groups ($P \leq 0.05$). For the restorations bonded with Single Bond 2**,** the absence of lining/base showed the lowest dye leakage at the *pulpal* wall. This was significantly lower than that of the restorations with thin lining of glass-ionomer cement ($P= 0.019$). Increase the thickness of glass-ionomer cement placement as a base reduced the dye leakage, which the value was not significantly different from the non-lining/base group ($P > 0.05$). However, there was no significant difference in the dye leakage between the lining group and the base group ($P > 0.05$). For the restorations bonded with Clearfil SE Bond, the absence of lining/base showed the lowest incidence of dye leakage at the *pulpal* walls, but it was not significantly different from the restorations with the glass-ionomer cement lining or base ($P > 0.05$). In comparison between the two adhesives, there was no significant difference in the dye leakage at the *pulpal* walls between the two adhesive groups.



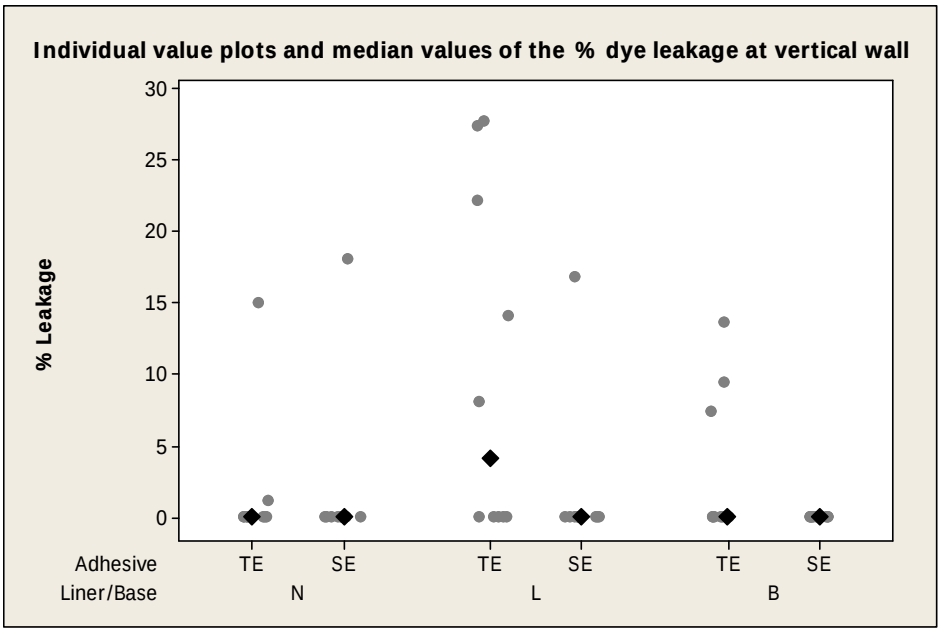


Figure 6.1: Individual value plots and medians of the internal dye leakage (in percentage) at *pulpal* wall and *vertical* wall from the restorations with lining, base and control (no lining/base): TE = the two-step, etch-and-rinse adhesive (Single Bond 2) groups, SE = the two-step, self-etching adhesive (Clearfil SE Bond) groups, N = the restorations with no lining/base, L= the restorations with 0.5-mm thickness of RMGIC lining, B = the restorations with 1.0-mm thickness of RMGIC base, ● = individual value plot, ♦ = median value.

The percentages (in range, mode and median) of micro-gap formation at the *pulpal* walls in each group were presented in Table 6.2 and detailed as follow: NTE ranged from 0 – 84.30%, LTE ranged from 0 – 100%, BTE ranged from 0 – 62.04%, NSE ranged from 0 – 34.27%, LSE ranged from 0 – 91.38% and BSE ranged from 0 – 64.87%.

The percentages (in range, mode and median) of micro-gap formation at the *vertical* walls in each group were presented in Table 6.2 and detailed as follow: NTE ranged from 0 – 9.30%, LTE ranged from 0 – 32.03%, BTE ranged from 0 – 25.01%, NSE ranged from 0 – 32.40%, LSE ranged from 0 – 29.73%, and all data in BSE group were 0 %.

Table 6.2: The minimum, maximum, mode and median of the micro-gap formation at the *pulpal* and *vertical* walls in each group

Groups	Micro-gap formation (%)							
	Pulpal walls				*Vertical* walls			
	Min	Max	Mode	Median	Min	Max	Mode	Median
NTE	0	84.30	0	0^{a}	0	9.30	0	0^{A}
LTE	0	100.00	0	6.95^{a}	0	32.03	-	14.85^{B}
BTE	0	62.04	0	27.75^{a}	0	25.01	0	$0^{A,B}$
NSE	0	34.27	0	0^{a}	0	32.40	0	0^{A}
LSE	0	91.38	0	8.40^{a}	0	29.73	0	$0^{A,B}$
BSE	0	64.87	0	9.99^{a}	0	0	0	$0^{A,B}$

Any significant difference is labeled with the different superscript small letter (pulpal) or capital letter (vertical).

NTE, LTE and BTE = the restorations bonded with Single Bond 2- with the presence of no lining/base, RMGIC lining, or RMGIC base, respectively; NSE = the restorations bonded with Clearfil SE Bond- with the presence of no lining/base, RMGIC lining or RMIGC base.

Figure 6.2 shows the individual value plots and medians of the micro-gap formation (in percentage) at *pulpal* wall and *vertical* wall from the restorations with lining (L), base (B) and control (N- no lining/base). When the two adhesives were compared, there was no significant difference in micro-gap formation at the *pulpal* and *vertical* wall between the two adhesive groups with the same restorative procedure (without or with lining or base) ($P > 0.05$).

At the pulpal wall, there was no significant difference in the micro-gap formation among the six experimental groups ($P > 0.05$). At the *vertical* wall, the

absence of lining/base showed the lowest micro-gap formation for the restorations bonded with Single Bond 2. This was significantly lower than the restorations with thin RMGIC lining (P = 0.006). Increase the thickness of RMGIC as a base reduced the gap formation at the *vertical* wall, which was not significantly different from the control without lining/base (P > 0.05). Nevertheless, there was no significant difference in micro-gap formation between the two lining/base groups (P > 0.05).

For the restorations bonded with Clearfil SE Bond, the no lining/base group and the group with RMGIC base mostly showed no micro-gap formation at the *vertical* wall. This was not significantly different from the restorations with the glass-ionomer cement lining group that showed a low incidence of gap formation (P > 0.05).

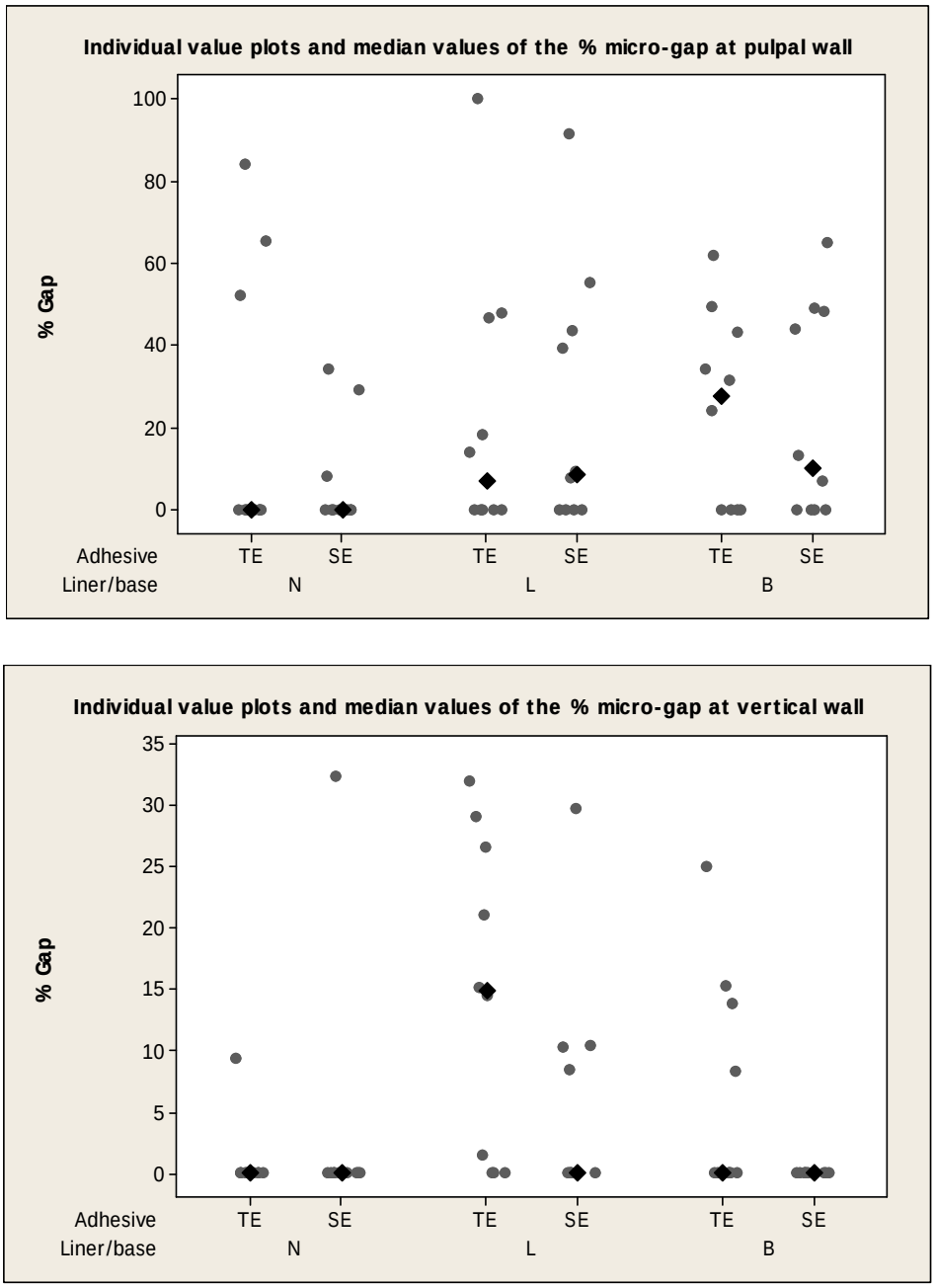


Figure 6.2: Individual value plots and medians of the micro-gap formation (in percentage) at *pulpal* wall and *vertical* wall from the restorations with lining, base and control (no lining/base): TE = the two-step, etch-and-rinse adhesive (Single Bond 2) groups, SE = the two-step, self-etching adhesive (Clearfil SE Bond) groups, N = the restorations without lining/base, L= the restorations with 0.5-mm thickness of RMGIC lining, B = the restorations with 1.0-mm thickness of RMGIC base, ● = individual value plot, ♦ = median value.

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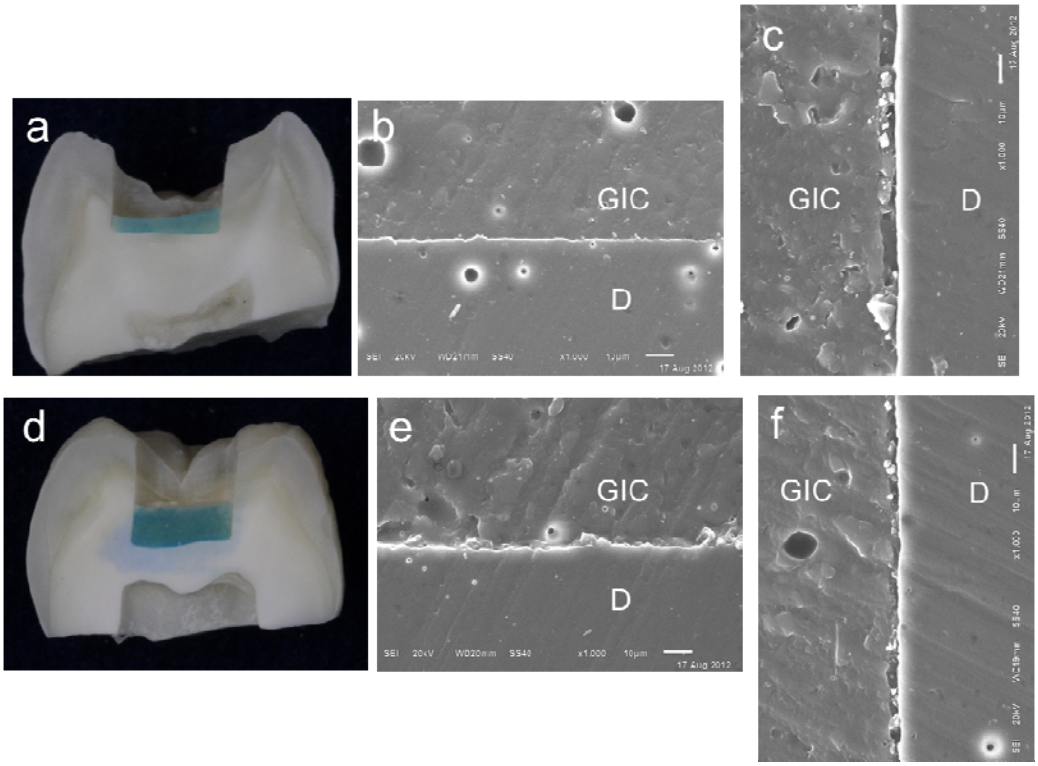

Figure 6.3: The cavity lined with RMGIC lining (a-c) or base (d-f), without resin composite restoration showed no dye leakage at both *pulpal* and *vertical* walls but there were some pale-blue stained areas in RMGIC lining/base itself, which was different from the dark-blue stained at the interfacial areas (a, d). The SEM picture showed the good adaptation of RMGIC lining over the dentinal *pulpal* wall (b), but micro-gap was occasionally observed at the dentinal *vertical* wall (c). The SEM picture showed the good adaptation of RMGIC base over the dentinal *pulpal* wall (e) with some micro-gaps at the dentinal *vertical* wall (f). GIC = RMGIC lining/base, D = dentin.

The images of the specimens that RMGIC lining or base was placed into the cavity without resin composite are presented in figure 6.3 (a-f). For the glass-ionomer lining or base placed on the *pulpal* walls without resin composite on top, there was no dye leakage at both *pulpal* and *vertical* walls; some dye staining into RMGIC material was observed (Fig. 6.3 a, d). SEM micrographs confirmed the good adaptation at the pulpal walls between dentinal floor and the lining/base material (Fig.

6.3 b, e). However, there were some micro-gaps occasionally detected at the vertical walls in SEM micrographs (Fig. 6.3 c, f).

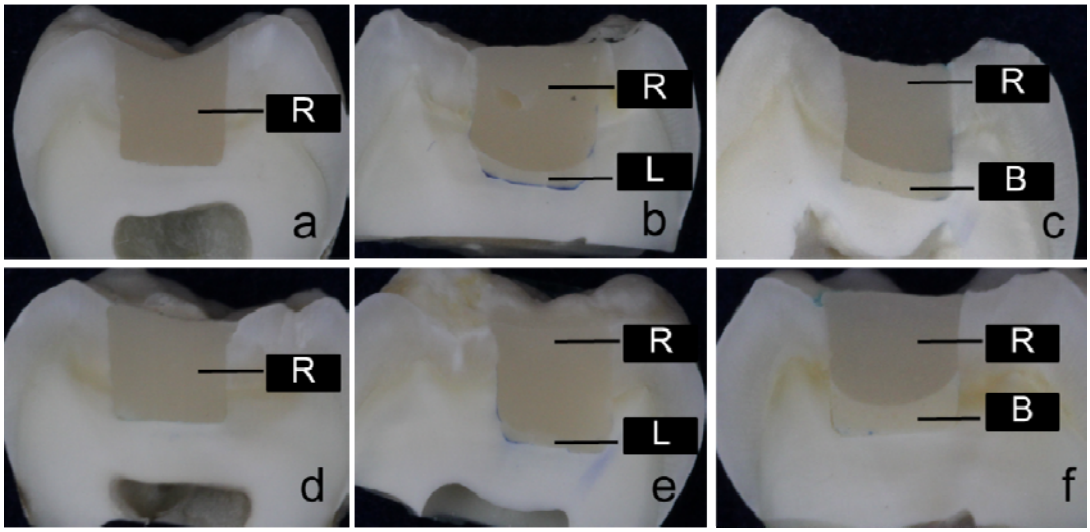

Figure 6.4: The restorations bonded with Single Bond 2 (a, b, c) and with Clearfil SE Bond (d, e, f): The restorations without lining/base generally showed no internal dye leakage at *pulpal* and *vertical* walls (a, d). The restorations with 0.5 mm thickness of RMGIC lining frequently showed internal dye leakage at the *pulpal* walls (b, e). The restoration with 1.0 mm thickness of RMGIC base occasionally showed some internal dye staining at *pulpal* walls (c, f). R = resin composite, L = RMGIC lining, B = RMGIC base.

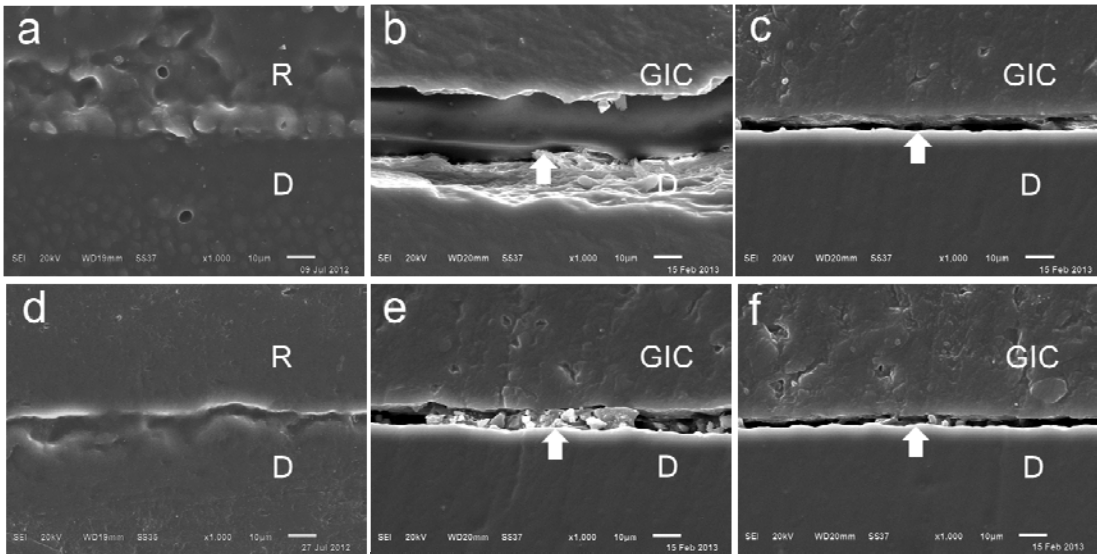

Figure 6.5 The restorations bonded with Single Bond 2 (a, b, c) and with Clearfil SE Bond (d, e, f). The restorations without lining/base commonly showed no micro-gap formation at the *pulpal* wall (a, d). The restoration with 0.5-mm thickness of RMGIC lining usually showed wider micro-gap (5-10 micron) at the *pulpal* walls (b, e) than the restoration with 1.0-mm thickness of RMGIC base (1-3 micron) (c, f), GIC = RMGIC lining/base, D = dentin, the white arrow = micro-gap formation.

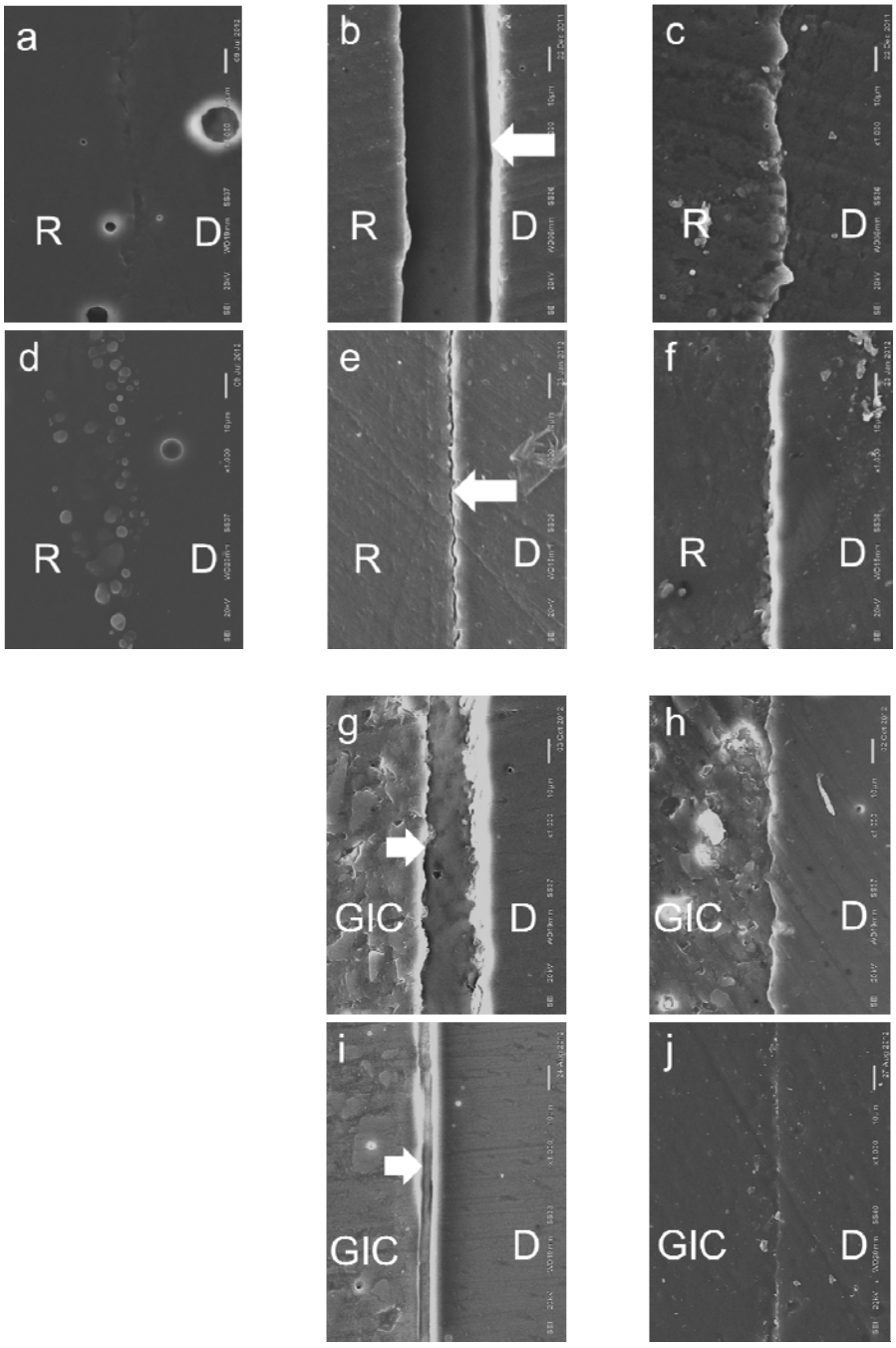

Figure 6.6 The restorations bonded with Single Bond 2 (a, b, c, g, h) and with Clearfil SE Bond (d, e, f, i, j): The restorations without lining/base (a, d) and the restorations with 1.0 mm thickness of RMGIC base (c, f, h, j) generally showed no micro-gap formation at *vertical* walls. The restoration with 0.5-mm thickness of RMGIC lining occasionally showed micro-gaps at the *vertical* walls (b, e, g, i), which the wide gap (15-20 micron) was observed in the Single Bond 2 group, R = resin composite, D = dentin, the white arrow = micro-gap formation.

Figures 6.4 – 6.6 show the representative images of internal dye leakage and SEM micrographs (micro-gap detection) of the restorations in the six experimental groups. The restorations without RMGIC lining/base mostly had no internal dye leakage or micro-gap formation (Fig. 6.4-6.6 a, d). These showed good adaptation at both *pulpal* and *vertical* walls, which was similar in both adhesives. The restorations with 0.5-mm thickness of RMGIC lining frequently revealed internal dye leakage, especially at the *pulpal* wall (Fig. 6.4 b, e) and micro-gap formation at both *pulpal* and *vertical* walls (Fig. 6.5-6.6 b, e and Fig. 6.6 g, i). The micro-gaps could be found at both between RMGIC lining and dentin (Fig. 6.6 g, i), and between resin composite and dentin (Fig. 6.6 b, e). However, the gap formation in the restorations with 0.5-mm thickness of RMGIC lining that bonded with Single Bond 2 tended to be wider than that of the restorations with 0.5-mm thickness of RMGIC lining that bonded with Clearfil SE Bond. The wide gaps in the Single Bond 2 groups revealed the dentin exposed or some cohesive failure of RMGIC lining at the interface. The restorations with 1.0-mm thickness of RMGIC base occasionally showed some internal dye leakage at both *pulpal* and *vertical* walls (Fig. 6.4 c, f), and micro-gap formation was sometimes detected at the *pulpal* wall (Fig. 6.5 c, f). There was no significant difference between the Single Bond 2 groups and the Clearfil SE Bond groups. There was no significant difference between the restorations bonded with Single Bond 2 and with Clearfil SE Bond.

CHAPTER VII
DISCUSSION

The null hypothesis that there is no significant difference in internal dye leakage or micro-gap formation among the resin composite restorations with 0.5-mm RMGIC lining, 1.0-mm RMGIC base or without lining/base is rejected. The restorations with the lining tend to show the higher incidences of internal dye staining and micro-gap formation than the restorations without lining/base, which is corresponded to the results of other studies.[7, 65] One study investigated in lining/base placed under Class V resin composite restorations in the anterior teeth[7]. The finding indicates that the presence of a base or liner results in the greater leakage than the restoration without liner/base. One study investigated in Class V resin composite restorations in third molars and found that micro-gaps were wider when lining was presented.[16] Another study investigated in occlusal resin composite restorations with lining/base and found that micro-gaps were frequently detected.[65] However, one study, which investigated in lining/base under Class I restorations, did not agree with these and found that lining with RMGIC resulted in no significant difference in gap formation at the dentin/resin adhesive interface in comparison to that without lining.[66]

When using etch-and-rinse adhesive, it seems that the restorations with liner tends to have the wider internal gap formation than the base group. There may be two factors that affect the polymerization shrinkage forces in such cavities. Firstly, increasing the thickness of lining/base minimizes the resin composite volume used in the cavity, and decreasing the resin composite volume reduces the polymerization shrinkage forces.[12, 13] Secondly, the different lining/base thickness may affect the different polymerization stress releasing pattern. From the elastic cavity wall concept, the stress breaker layer is very important to distributing stress from the polymerization.[33] The use of thick RMGIC lining/base may result in the better stress

relaxation and absorption.[67] The too thin RMGIC lining/base may decrease this ability in stress distribution. In this study, the thin RMGIC lining tends to provide higher micro-gap formation than the thick RMGIC base when using with the 2-step etch-and-rinse adhesive.

Beside of this, the stress distribution in restorations bonded with etch-and-rinse may be different from restorations bonded with self-etching. There is one study that investigated in the polymerization shrinkage direction.[68] It detected the filler movements in a restoration bonded with self-etching adhesive during polymerization. In the upper region of the class I cavity, the filler movements were mainly downward, but the direction gradually changed upward to the curing light source at the deeper parts of the cavity.[68] In contrast, most of the filler movements was completely upward to the curing light source in the unbonded cavity.[68] It is assumed that there may be more upward filler movements in the deeper part of restoration bonded with etch-and-rinse adhesive than with self-etching adhesive. Thus, this may create a higher shrinkage force that might pull the liner up and separated from the cavity floor.

Moreover, there was an incidence that internal leakage or micro-gap formation usually occurred at the pulpal walls higher than at the vertical walls. It may be explained by the difference in stress distribution pattern. From the three dimensional photo-elastic model study in the second premolar, the stress occurred much higher at the pulpal wall and the angles of the cavity when lining/base was applied under the restoration.[23] The resin composite restoration without lining/base also showed the high stress at the pulpal wall and the angle of the cavity.[23] Moreover, the movement of the resin composite fillers during polymerization is mainly upward from the deeper part while the movement was commonly downward in the upper part.[68] Thus, both resin composite and RMGIC lining/base can be pull up from the pulpal floor and the angles of the cavity.

In the restorations with the lining/base, the gap formations mainly occurred between the RMGIC lining/base and dentin, not at the resin composite-RMGIC lining/base interface. This was similar to the result from one study which investigated in class V resin composite restorations with RMGIC lining/base. Gap

formation was found at the RMGIC-dentin interface from the SEM image, while there was no gap formation at the RMGIC-resin composite.[16] Another study revealed that there was only 0.83% of gap formation between the RMGIC lining and resin composite.[65]

In comparison to the control without polymerization shrinkage stress from resin composite, another 10 cavities with RMGIC lining/base were additionally tested as the control group. Interestingly, the lining/base without resin composite restoration had the good internal adaptation. It means that the micro-gaps were exactly formed from the polymerization shrinkage stress of the resin composite. In fact, the RMGIC lining has less shrinkage effect by itself. The low modulus of elasticity of glass-ionomer cement may release stress from polymerization shrinkage and result in the good adaptability.[17] Incidentally, the study investigating the effect of RMGIC placement on human dentin permeability found that RMGIC liner significantly reduced the dentinal fluid flow and exhibited excellent seal on dentin with either a smear layer or open dentinal tubules.[65]

However, the hypothesis that there is no significant difference in the internal dye leakage or micro-gap formation between the restorations bonded with the etch-and-rinse adhesive and self-etching adhesive has been accepted. There was one study showing the similar results[69], which investigated in the cavities without lining/base and with RMGIC lining. It found that dentin bonding treated cavities without lining revealed the smallest internal gap volumes.[65] Conversely, there are some studies showed that self-etching adhesives provided the better adaptation than etch-and-rinse adhesives.[70, 71] One study investigated in the restorations of packable resin composite bonded with the self-etching adhesive and demonstrated the minimum micro-leakage in comparison to the etch-and-rinse adhesive.[70] Another study investigated in Class V resin composite cavities on human molars.[71] In that study, using the etch-and-rinse adhesive showed a clear, thick hybrid layer with long resin tags and few voids while using the self-etching adhesive did not show a clearly recognizable hybrid layer, but no voids and continuous adaptation were observed.[71]

However, a significant difference has been detected in the etch-and-rinse groups, *not* in the self-etching groups. The predominant results in the etch-and-rinse groups may be explained. When the cavities were restored, the composite restorations that perfectly bonded to enamel and dentin would shrink directly from the free surface toward the fixed boundary.[72] If there is any impaired bonded area, the resin composite contracts from the weak bonded area toward the strong bonded area.[72] There is one study that investigated in the polymerization shrinkage direction.[68] It detected the filler movements in a restoration bonded with self-etching adhesive during polymerization. In the upper region of the class I cavity, the filler movements were mainly downward, but the direction gradually changed upward to the curing light source at the deeper parts of the cavity.[68] In contrast, most of the filler movements was completely upward to the curing light source in the unbonded cavity.[68] The etch-and-rinse adhesive seems to have a better adhesion to enamel than to dentin.[34, 73] When polymerized, resin composite bonded with an etch-and-rinse adhesive may shrink upward to the well-bonded enamel margins, which may pull the RMGIC lining/base from dentin. The self-etching adhesive can predominantly bond well to dentin which is superior to that of enamel, [34, 74] the resin composite in the upper part of the cavity may shrink laterally and downward to the dentin wall, so there may be less upward shrinkage force in the deeper part of the cavity (Fig. 7.1).[72]

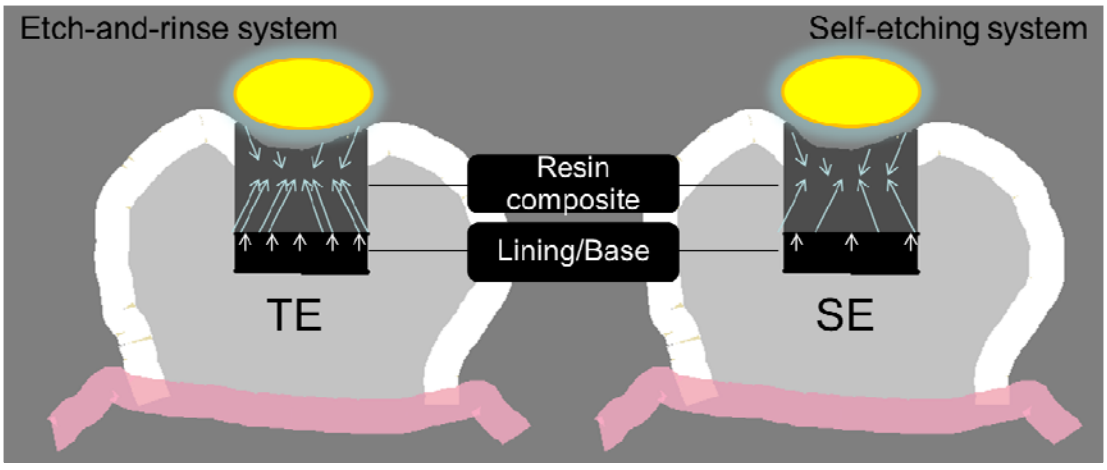

Figure 7.1 Expected polymerization shrinkage direction of resin composite bonded with etch-and-rinse adhesive (TE) and resin composite bonded with self-etching adhesive (SE)

For the lining/base placement, the Dycal carrier was used to carry the proper amount of Vitrebond into the cavity (approximately 0.5 mm- and 1.0 mm-thick). The thicker lining (≥ 0.6 mm) or base (≥ 1.1 mm) were excluded because the preparation to remove the excess lining/base by using a bur or hand instrument can cause the rougher surface. This may enhance the adhesion between the glass-ionomer lining/base and resin composite.[75] Conversely, the excessive lining/base removal removes the oxygen-inhibiting layer on the surface and may diminish the bond between RMGIC lining/base and resin composite by the absence of such layer.[76] On the other hand, in the cavity with too thin lining/base after light curing, the newly mixed lining/base was immediately added on the surface until reaching the required thickness and polymerized.

In this study, each restored cavity was sectioned into the two specimens. The sectioned specimens were not identical due to the tooth loss from the cutting procedure with the thickness of the slow-speed diamond saw (0.3 mm) and during the polishing by the series of silicon-carbide papers. However, the specimens had to be polished for the SEM investigation because the cutting saw caused roughness and thick smear layer on the surface which interfere the observation. Both cutting and polishing processes created the smear layer on the surfaces. However, it left the minimal amount of smear layer on the surface after 4,000-grit silicon-carbide paper was finally used to polish the specimens. Thus, rinsing with EDTA solution rinsing in short time was used to remove the remaining smear layer after final polishing.

In the SEM preparation procedure, the specimen must be dried that causes pseudo-gaps and cracks in the specimen with glass-ionomer cement. There was a study that drying the glass-ionomer specimen before SEM investigation caused cracks and artificial gaps formation.[77] The epoxy-resin replica technique was used to solve this problem.[59, 78] The sectioned specimens were impressed by the light-body silicone impression material that transferred all the restoration interfaces into the impressions. Then, the epoxy-resin was poured into the impression to receive an analog of the sectioned specimens. The replica can be dried through the SEM procedure without any crack or gap formation.[59]

Deep class I occlusal cavity preparation was used in this study because of the highest C-factor that presents the maximum polymerization shrinkage stress.[33, 67] One study found that the cavities with the higher C-factor presented the highest internal gap formations.[79] Moreover, it is practical to well control the thickness of liner/base in such cavity. However, when a liner/base was applied in the cavity, the C-factor as well as the total polymerization shrinkage force of resin composite was reduced. Hence, the thickness of first increment of resin composite placed in cavities was controlled in this study. The uniform 1.0-mm thickness of the first resin composite increment produces the similar polymerization shrinkage force in every experimental group. However, the C-factor in the other classes of cavity is different. For example, the C-factor in class II cavity (=2-3) is less than class I cavity (=5). It is interesting to further investigate the internal adaptation of the RMGIC lining/base under class II resin composite restorations.

The bulk filling technique was not used in this study because of the limitation in depth of curing as well as the different polymerization shrinkage forces. The curing depth of the resin composite is approximately 2.0 mm, but the cavity depth in this study is 3.0 mm. If the bulk filling technique was used, the thickness of the first resin composite increment would have not been equal. This might result in the different polymerization shrinkage force to the bond interface (which should be controlled) that affects the adaptation of adhesive or lining/base to dentinal floor.

Vitrebond, a resin-modified GIC lining cement (powder-liquid type), is widely used as a lining/base under resin composite restorations due to good biocompatibility to the pulp [8, 11] and fluoride releasing ability[52]. Recently, a new liquid-paste type RMGIC has been introduced. Increased the amount of resin monomers added to the glass ionomer may be responsible for the improved light-command setting[80] and easy mixing. Bond strength to dentin of this new type of RMGIC is just comparable or even lower to the powder-liquid type of RMGIC.[48, 56] Therefore, higher internal dye leakage or micro-gap formation is expected when using the liquid-paste type of RMGIC as a lining/base. The investigation on the internal adaptation on this new type of RMGIC lining should be further investigated.

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APPENDIX

Table 1: The dimension of prepared cavities (mm)

Tooth no.	Depth	B-L	M-D
1	3.1	3.02	3.05
2	3.08	3.06	2.99
3	3	3	3.16
4	3.13	3.01	3.02
5	3.1	2.98	3.03
6	2.99	3.01	3
7	3.2	2.88	3.09
8	3	3.1	3.01
9	3.17	3	3.05
10	3.01	3.01	3.04
11	3.1	3.07	3.05
12	3.15	3.03	3.07
13	3.08	3	3.11
14	2.98	3	3
15	3	3.1	3.09
16	2.97	3.14	3.04
17	3	3.02	3.06
18	3.25	3.1	3
19	3.09	3	3.02
20	3.15	3.07	3.06
21	3.14	2.99	3
22	3.11	3	3.1
23	3.08	2.99	3.05
24	3.06	3	3.07
25	3.04	3.09	3.11
26	3	3.05	3.02
27	3.01	3.02	3.03
28	3.18	2.89	3.02
29	3.02	3.01	3
30	3	3.09	3.06

Table 1: The dimension of prepared cavities (mm) (cont.)

Tooth no.	Depth	B-L	M-D
32	3.14	3.12	3
33	3.26	2.99	3.04
34	3.12	3.14	3.21
35	3.1	3	3.19
36	3.2	3.01	2.98
37	3.15	3.12	3.15
38	3	3.1	3.07
39	3	3.13	3.06
40	2.98	3.1	3.16
41	3.18	3.07	3.11
42	3.15	2.98	3.08
43	2.89	3.21	3.17
44	3.04	3.09	3.16
45	2.98	3.1	3.06
46	3.01	3.19	3.02
47	3.16	3.02	3
48	3.12	3.14	3.02
49	3.09	3	3.08
50	2.99	3.07	3.1
51	3.17	3.27	3.04
52	3	3.04	3.08
53	3.1	3.16	3.08
54	3.08	3.1	3.2
55	3.04	2.97	2.98
56	3.14	3.16	3.17
57	3.17	3.17	3
58	3.12	3.2	3.02
59	3.09	2.98	3.05
60	2.99	3.11	3.03
means	3.078	3.061333	3.063
SD	0.078929	0.078297	0.05826

Table 2: Dimensions of cavities and stained distances of NTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	152.9	144.59	297.49	3.03	44.72	0.455483	15.03244
2	160	180.28	340.28	3.14	4	0.036911	1.175503
3	204.05	190.47	394.52	3.26	0	0	0
4	160.32	154.77	315.09	3.12	0	0	0
5	153.67	139.76	293.43	3.1	0	0	0
6	183.58	156.3	339.88	3.2	0	0	0
7	145.7	159.36	305.06	3.15	0	0	0
8	143.26	144.05	287.31	3	0	0	0
9	144.56	143.96	288.52	3	0	0	0
10	137.77	130.21	267.98	2.98	0	0	0
Means			312.956	3.098	4.872	0.049239	1.620794
SD			36.65034	0.093903	14.05748	0.004101	0.130611

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	%leak H
1	111.55	3.21	39.05	1.123716	3.07	35.00672
2	165.19	3.12	0	0	3	0
3	152.34	2.99	85.04	1.669093	3.04	55.8225
4	169.6	3.14	50.24	0.930151	3.21	29.62264
5	142.2	3	0	0	3.19	0
6	143.62	3.01	0	0	2.98	0
7	164.49	3.12	0	0	3.15	0
8	159.46	3.1	0	0	3.07	0
9	168.03	3.13	0	0	3.06	0
10	158.4	3.1	0	0	3.16	0
Means	153.488	3.092	17.433	0.372296	3.093	12.04519
SD	17.55547	0.070679	30.26121	0.626077	3.095556	9.493905

Table 3: Dimensions of cavities, stained distances and the lining thickness of LTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	147.06	166.95	314.01	3.17	69.47	0.701315	22.1235
2	117.85	148.93	266.78	3	73.96	0.831697	27.72322
3	141.99	135.15	277.14	3.1	75.95	0.849553	27.40492
4	151.57	146.51	298.08	3.08	0	0	0
5	150.82	144.13	294.95	3.04	0	0	0
6	166.93	168.09	335.02	3.14	47.3	0.443323	14.11856
7	139.74	116.71	256.45	3.17	20.88	0.258099	8.141938
8	176.01	179.71	355.72	3.12	0	0	0
9	144.07	172	316.07	3.09	0	0	0
10	182.4	170.19	352.59	2.99	0	0	0
Means			306.681	3.09	28.756	0.308399	9.951214
SD			34.41081	0.064118	34.10564	0.264741	8.598737

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	Liner (mm)	%leak H
1	183.86	3.27	99.16	1.763588	3.04	0.44	53.93234
2	182.38	3.04	0	0	3.08	0.57	0
3	226.57	3.16	59.96	0.83627	3.08	0.47	26.46423
4	145.46	3.1	33.29	0.709467	3.2	0.58	22.88602
5	176.62	2.97	0	0	2.98	0.49	0
6	188.83	3.16	103.4	1.730361	3.17	0.51	54.75825
7	169.16	3.17	0	0	3	0.55	0
8	152.83	3.2	57.53	1.20458	3.02	0.46	37.64313
9	168.34	2.98	136.95	2.424326	3.05	0.43	81.35321
10	147.06	3.11	147.06	3.11	3.03	0.56	100
Means	174.111	3.116	63.735	1.177859	3.065	0.506	37.70372
SD	24.04081	0.096287	56.0732	1.076725	0.070907	0.513333	35.90054

Table 4: Dimensions of cavities, stained distances and the base thickness of BTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	193.38	169.31	362.69	3.18	0	0	0
2	173.79	168.18	341.97	3.15	0	0	0
3	120.34	116.47	236.81	2.89	17.46	0.21308	7.372999
4	168.07	158.15	326.22	3.04	0	0	0
5	121.89	143.61	265.5	2.98	0	0	0
6	149.08	146.09	295.17	3.01	0	0	0
7	156.14	166	322.14	3.16	44.05	0.432104	13.67418
8	172.13	152.19	324.32	3.12	0	0	0
9	185.87	145.67	331.54	3.09	31.4	0.292652	9.470954
10	149.14	139.01	288.15	2.99	0	0	0
Means			309.451	3.061	9.291	0.093784	3.051813
SD			37.87286	0.094334	16.22066	0.104204	3.390904

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	Base (mm)	%leak H
1	162.59	3.07	130.55	2.465026	3.11	1.13	80.29399
2	139.1	2.98	0	0	3.08	1.32	0
3	179.56	3.21	59.96	1.071907	3.17	1.01	33.39274
4	165.54	3.09	65.33	1.219462	3.16	1.11	39.46478
5	158.18	3.1	0	0	3.06	1.02	0
6	156.75	3.19	74.48	1.515733	3.02	1.07	47.51515
7	158.7	3.02	30.2	0.574694	3	1	19.02962
8	194.86	3.14	171.59	2.765024	3.02	1.16	88.05809
9	158.5	3	42.53	0.804984	3.08	1.14	26.83281
10	150.01	3.07	29.32	0.600043	3.1	1.09	19.54536
Means	162.379	3.087	60.396	1.101687	3.08	1.105	35.41325
SD	15.39495	0.076601	54.77291	0.934309	0.057542	1.102222	30.42651

Table 5: Dimensions of cavities and stained distances of NSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	153.12	177.07	330.19	3.1	0	0	0.0
2	146.09	136.82	282.91	3.08	51.31	0.558605	18.1
3	122.19	142.42	264.61	3	0	0	0.0
4	192.15	151.11	343.26	3.13	0	0	0.0
5	164.19	163.23	327.42	3.1	0	0	0.0
6	145.38	131.25	276.63	2.99	0	0	0.0
7	193.76	150.87	344.63	3.2	0	0	0.0
8	141.55	129.18	270.73	3	0	0	0.0
9	161.8	163.49	325.29	3.17	0	0	0.0
10	168.48	128.39	296.87	3.01	0	0	0.0
Means			306.254	3.078	5.131	0.05586	1.813651
SD			31.14879	0.075689	16.22565	0.176646	5.735268

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	%leak H
1	124.66	3.02	0	0	3.05	0
2	142.61	3.06	19.37	0.415624	2.99	13.5825
3	158.32	3	0	0	3.16	0
4	166.42	3.01	0	0	3.02	0
5	83.2	2.98	0	0	3.03	0
6	149.33	3.01	0	0	3	0
7	126.91	2.88	0	0	3.09	0
8	186.7	3.1	0	0	3.01	0
9	124.73	3	0	0	3.05	0
10	139.41	3.01	0	0	3.04	0
Means	140.229	3.007	1.937	0.041562	3.044	1.35825
SD	28.23373	0.056382	6.125332	0.131432	0.052915	1.509166

Table 6: Dimensions of cavities, stained distances and the lining thickness of LSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	182.99	173.45	356.44	3.14	0	0	0
2	180.14	170	350.14	3.11	0	0	0
3	172.46	166.74	339.2	3.08	0	0	0
4	157.38	158.39	315.77	3.06	0	0	0
5	171.71	147.17	318.88	3.04	0	0	0
6	155.05	156.65	311.7	3	0	0	0
7	148.41	152.88	301.29	3.01	50.7	0.506512	16.82764
8	184.82	178.73	363.55	3.18	0	0	0
9	164.62	124.34	288.96	3.02	0	0	0
10	154.03	156.94	310.97	3	0	0	0
Means			325.69	3.064	5.07	0.050651	1.682764
SD			25.07965	0.062574	16.03275	0.160173	5.321367

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	Liner (mm)	%leak H
1	130.34	2.99	0	0	3	0.58	0
2	144.8	3	76	1.574586	3.1	0.52	52.48619
3	173.84	2.99	13.69	0.235464	3.05	0.57	7.875058
4	140.86	3	0	0	3.07	0.58	0
5	159.3	3.09	52.86	1.025345	3.11	0.53	33.18267
6	177.62	3.05	88.7	1.523111	3.02	0.5	49.93807
7	155.55	3.02	0	0	3.03	0.48	0
8	127.95	2.89	66.19	1.49503	3.02	0.43	51.73114
9	148.05	3.01	0	0	3	0.49	0
10	162.33	3.09	114.97	2.188488	3.06	0.47	70.82486
Means	152.064	3.013	41.241	0.804202	3.046	0.515	26.6038
SD	16.8161	0.057552	43.73697	0.847424	0.03893	0.507778	29.55978

Table 7: Dimensions of cavities, stained distances and the base thickness of BSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	Leak V (pixel)	Leak V (mm)	%leak V
1	143.18	136.72	279.9	3.1	0	0	0
2	165.37	157.84	323.21	3.15	0	0	0
3	145.99	166.36	312.35	3.08	0	0	0
4	135.24	117.55	252.79	2.98	0	0	0
5	135.95	125.57	261.52	3	0	0	0
6	109.09	134.06	243.15	2.97	0	0	0
7	121.82	133.08	254.9	3	0	0	0
8	176.09	197.59	373.68	3.25	0	0	0
9	132.22	138.42	270.64	3.09	0	0	0
10	146.13	168.58	314.71	3.15	0	0	0
Means			288.685	3.077	0	0	0
SD			41.2277	0.090683	0	0	0

Tooth	H (pixel)	B-L (mm)	Leak H (pixel)	Leak H (mm)	M-D (mm)	Base (mm)	%leak H
1	143.18	3.07	0	0	3.05	0.98	0
2	147.29	3.03	0	0	3.07	1.21	0
3	157.79	3	45.04	0.856328	3.11	1.01	28.54427
4	141.07	3	47.73	1.015028	3	1.29	33.83427
5	143.36	3.1	0	0	3.09	1.03	0
6	139.9	3.14	0	0	3.04	1.12	0
7	148.16	3.02	0	0	3.06	1.1	0
8	159.13	3.1	117.79	2.294658	3	1.3	74.02124
9	145.58	3	0	0	3.02	0.99	0
10	183.07	3.07	79.57	1.334352	3.06	1.12	43.46425
Means	150.853	3.053	29.013	0.550037	3.05	1.115	17.9864
SD	13.05124	0.050122	42.2888	0.801674	0.036209	0.118439	26.01861

Table 8: Dimensions of cavities and micro-gap distances of NTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	639.4	720.2	1360.6	3.0	126.1	0.3	9.3
2	727.0	656.5	1383.6	3.1	0.0	0.0	0.0
3	644.7	575.0	1219.7	3.3	0.0	0.0	0.0
4	657.8	522.0	1179.8	3.1	0.0	0.0	0.0
5	730.6	593.6	1324.2	3.1	0.0	0.0	0.0
6	620.6	621.6	1242.2	3.2	0.0	0.0	0.0
7	693.1	664.4	1357.5	3.2	0.0	0.0	0.0
8	734.3	804.8	1539.1	3.0	0.0	0.0	0.0
9	854.6	780.7	1635.2	3.0	0.0	0.0	0.0
10	790.3	787.5	1577.8	3.0	0.0	0.0	0.0
Means			1381.97	3.098	12.614	0.028091	0.927098
SD			155.7353	0.093903	39.88897	0	0

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	%gap H
1	659.5	3.2	345.0	1.7	3.1	52.3
2	479.8	3.1	0.0	0.0	3.0	0.0
3	627.2	3.0	528.9	2.5	3.0	84.3
4	687.2	3.1	448.8	2.1	3.2	65.3
5	686.7	3.0	0.0	0.0	3.2	0.0
6	633.4	3.0	0.0	0.0	3.0	0.0
7	647.8	3.1	0.0	0.0	3.2	0.0
8	705.9	3.1	0.0	0.0	3.1	0.0
9	690.2	3.1	0.0	0.0	3.1	0.0
10	613.0	3.1	0.0	0.0	3.2	0.0
Means	643.084	3.092	132.263	0.625085	3.093	20.1933
SD	65.16457	0.070679	217.3501	1.025933	3.095556	16.62383

Table 9: Dimensions of cavities, micro-gap distances and the lining thickness of LTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	653.25	772.34	1425.59	3.17	378.19	0.840959	26.52867
2	522.03	757.34	1279.37	3	372.19	0.87275	29.09166
3	737.95	680.05	1418	3.1	454.22	0.993006	32.03244
4	607.07	816.44	1423.51	3.08	299.95	0.648992	21.07116
5	798.15	764.7	1562.85	3.04	0	0	0
6	741.14	738.1	1479.24	3.14	224.45	0.476443	15.17333
7	652.38	750.18	1402.56	3.17	20.88	0.047192	1.488706
8	788.76	709.53	1498.29	3.12	0	0	0
9	627.35	720.22	1347.57	3.09	0	0	0
10	803.13	728.08	1531.21	2.99	222.32	0.434125	14.51924
Means			1436.819	3.09	197.22	0.431347	13.99052
SD			84.95641	0.064118	179.2334	0.385834	12.59739

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	Liner (mm)	%gap H
1	824.47	3.27	114.63	0.454644	3.04	0.44	13.90348
2	789.36	3.04	0	0	3.08	0.57	0
3	728.61	3.16	340.84	1.478232	3.08	0.47	46.77948
4	569.5	3.1	0	0	3.2	0.58	0
5	671.83	2.97	0	0	2.98	0.49	0
6	764.78	3.16	764.78	3.16	3.17	0.51	100
7	169.16	3.17	0	0	3	0.55	0
8	638.38	3.2	0	0	3.02	0.46	0
9	757.95	2.98	136.95	0.538441	3.05	0.43	18.06847
10	594.37	3.11	285.57	1.494225	3.03	0.56	48.04583
Means	650.841	3.116	164.277	0.712554	3.065	0.506	22.67973
SD	189.2249	0.096287	245.9983	1.04471	0.070907	0.513333	23.65487

Table 10: Dimensions of cavities, micro-gap distances and the base thickness of BTE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	773.57	823.19	1596.76	3.18	132.03	0.262942	8.268619
2	847.49	786.52	1634.01	3.15	0	0	0
3	544.37	615.36	1159.73	2.89	290.01	0.722693	25.00668
4	756.37	747.85	1504.22	3.04	0	0	0
5	639.13	609.4	1248.53	2.98	0	0	0
6	754.33	684.18	1438.51	3.01	0	0	0
7	786.89	736.2	1523.09	3.16	231.95	0.481234	15.22891
8	742.56	717.21	1459.77	3.12	0	0	0
9	615.01	837.01	1452.02	3.09	201.2	0.428168	13.85656
10	579.12	708.16	1287.28	2.99	0	0	0
Means			1430.392	3.061	85.519	0.189504	6.236077
SD			1411.907	3.047778	80.35111	0.181344	6.010239

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	Base (mm)	%gap H
1	732.73	3.07	177.1	0.742015	3.11	1.13	24.16989
2	645.13	2.98	0	0	3.08	1.32	0
3	763.63	3.21	239.3	1.005923	3.17	1.01	31.33717
4	739.28	3.09	318.15	1.329785	3.16	1.11	43.03512
5	657.47	3.1	0	0	3.06	1.02	0
6	716.63	3.19	0	0	3.02	1.07	0
7	743.54	3.02	461.32	1.873721	3	1	62.04374
8	848.57	3.14	289.14	1.069917	3.02	1.16	34.07379
9	773.31	3	0	0	3.08	1.14	0
10	715.45	3.07	353.12	1.51524	3.1	1.09	49.35635
Means	733.574	3.087	183.813	0.75366	3.08	1.105	24.4016
SD	57.80112	0.076601	174.1927	0.715096	0.057542	1.102222	24.42735

Table 11: Dimensions of cavities and micro-gap distances of NSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	753.48	641.54	1395.02	3.1	0	0	0.0
2	675.28	783.47	1458.75	3.08	472.37	0.99736	32.4
3	743.11	675.43	1418.54	3	0	0	0.0
4	726.25	720.64	1446.89	3.13	0	0	0.0
5	774.84	717	1491.84	3.1	0	0	0.0
6	564.8	642.34	1207.14	2.99	0	0	0.0
7	705.01	796.06	1501.07	3.2	0	0	0.0
8	615.01	513.01	1128.02	3	0	0	0.0
9	850.4	753.15	1603.55	3.17	0	0	0.0
10	592.93	681.24	1274.17	3.01	0	0	0.0
Means			1392.499	3.078	47.237	0.099736	3.238183
SD			146.2645	0.075689	149.3765	0.315393	10.24003

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	%gap H
1	520.71	3.02	0	0	3.05	0
2	631.31	3.06	216.34	1.048614	2.99	34.26843
3	673.06	3	0	0	3.16	0
4	680.1	3.01	0	0	3.02	0
5	470.09	2.98	0	0	3.03	0
6	634	3.01	0	0	3	0
7	710.94	2.88	206.19	0.83527	3.09	29.00245
8	806.13	3.1	65.52	0.251959	3.01	8.127721
9	617.04	3	0	0	3.05	0
10	758.88	3.01	0	0	3.04	0
Means	650.226	3.007	48.805	0.213584	3.044	7.139859
SD	101.1915	0.056382	88.05989	0.395048	3.043333	7.933177

Table 12: Dimensions of cavities, micro-gap distances and the lining thickness of LSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	813.18	783.09	1596.27	3.14	166.33	0.327185	10.41992
2	805.26	796.2	1601.46	3.11	165.11	0.32064	10.30997
3	685	850	1535	3.08	0	0	0
4	718.64	775.83	1494.47	3.06	0	0	0
5	738.47	642.11	1380.58	3.04	0	0	0
6	749.07	724.04	1473.11	3	0	0	0
7	771.84	822	1593.84	3.01	133.66	0.25242	8.386036
8	818.68	824.43	1643.11	3.18	488.45	0.945324	29.72716
9	632.77	776.93	1409.7	3.02	0	0	0
10	848.28	636.25	1484.53	3	0	0	0
Means			1521.207	3.064	95.355	0.184557	5.884308
SD			87.54954	0.062574	156.5069	0.303059	9.56062

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	Liner (mm)	%gap H
1	639.71	2.99	0	0	3	0.58	0
2	629.21	3	273.65	1.304731	3.1	0.52	43.49104
3	173.84	2.99	158.86	2.732348	3.05	0.57	91.38288
4	589.77	3	0	0	3.07	0.58	0
5	708.05	3.09	52.86	0.230686	3.11	0.53	7.465574
6	658.85	3.05	258.07	1.194678	3.02	0.5	39.16977
7	716.63	3.02	0	0	3.03	0.48	0
8	709.04	2.89	66.19	0.269786	3.02	0.43	9.335157
9	626.23	3.01	0	0	3	0.49	0
10	663.38	3.09	365.94	1.704535	3.06	0.47	55.16295
Means	611.471	3.013	117.557	0.743676	3.046	0.515	24.60074
SD	159.2227	0.057552	137.2799	0.948461	0.03893	0.507778	27.33415

Table 13: Dimensions of cavities, micro-gap distances and the base thickness of BSE group (ImageTool)

Tooth	V1 (pixel)	V2 (pixel)	V (pixel)	Depth (mm)	gap V (pixel)	gap V (mm)	%gap V
1	558.07	552.13	1110.2	3.1	0	0	0
2	675.67	620.48	1296.15	3.15	0	0	0
3	720.22	609.12	1329.34	3.08	0	0	0
4	823.52	904.47	1727.99	2.98	0	0	0
5	526.04	577.53	1103.57	3	0	0	0
6	872.62	806.24	1678.86	2.97	0	0	0
7	868.51	794.46	1662.97	3	0	0	0
8	776.32	855.29	1631.61	3.25	0	0	0
9	817.61	690.65	1508.26	3.09	0	0	0
10	614.01	573.5	1187.51	3.15	0	0	0
Means			1423.646	3.077	0	0	0
SD			246.5428	0.090683	0	0	0

Tooth	H (pixel)	B-L (mm)	gap H (pixel)	gap H (mm)	M-D (mm)	Base (mm)	%gap H
1	569.95	3.07	0	0	3.05	0.98	0
2	558.06	3.03	0	0	3.07	1.21	0
3	570.96	3	370.41	1.946248	3.11	1.01	64.87495
4	708.98	3	47.73	0.201966	3	1.29	6.732207
5	589.43	3.1	0	0	3.09	1.03	0
6	713	3.14	312.27	1.375214	3.04	1.12	43.79663
7	637.37	3.02	84.46	0.40019	3.06	1.1	13.25133
8	761.18	3.1	371.68	1.513713	3	1.3	48.82945
9	661.1	3	0	0	3.02	0.99	0
10	609.36	3.07	295.11	1.486786	3.06	1.12	48.4295
Means	637.939	3.053	148.166	0.692412	3.05	1.115	22.59141
SD	70.76197	0.050122	166.6107	0.787934	0.036209	0.118439	25.76354

Statistical analysis in % staining of pulpal walls

Group	Count	Mean	StDev	Var	CoefVar	Min	Q1	Median	Q3	Max
NSE	10	1.36	4.30	18.45	316.23	0	0	0	0	13.58
LSE	10	26.60	27.94	780.71	105.03	0	0	20.53	51.92	70.82
BSE	10	14.60	25.93	672.29	177.56	0	0	0	32.27	74.02
NTE	10	12.05	20.46	418.70	169.88	0	0	0	30.97	55.82
LTE	10	37.7	34.9	1216.8	92.52	0	0	32.10	61.40	100
BTE	10	35.41	29.92	894.97	84.48	0	14.27	30.11	55.71	88.06

Kruskal-Wallis Test:
% Staining at pulpal walls versus adhesives and lining/base groups

Group	N	Median	AveRank	Z
NSE	10	0.000000000	18.3	-2.43
LSE	10	2.05289E+01	34.6	0.81
BSE	10	0.000000000	25.9	-0.92
NTE	10	0.000000000	25.5	-1.00
LTE	10	3.20537E+01	39.3	1.74
BTE	10	3.01128E+01	39.6	1.81
Overall	60		30.5	

H = 12.24 DF = 5 P = 0.032
H = 14.43 DF = 5 P = 0.013 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs LSE at pulpal walls

	N	Median
NSE	10	0.00
LSE	10	20.53

Point estimate for ETA1-ETA2 is -13.74
95.5 Percent CI for ETA1-ETA2 is (-51.73,0.01)
W = 78.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1124
The test is significant at 0.0899 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs BSE at pulpal walls

	N	Median
NSE	10	0.00
BSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-28.55,0.00)
W = 93.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.4057
The test is significant at 0.2343 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs NTE at pulpal walls

	N	Median
NSE	10	0.00
NTE	10	0.00

Point estimate for ETA1-ETA2 is 0.00
95.5 Percent CI for ETA1-ETA2 is (-29.63,0.01)
W = 93.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.4057
The test is significant at 0.2343 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs LTE at pulpal walls

	N	Median
NSE	10	0.00
LTE	10	32.05

Point estimate for ETA1-ETA2 is -26.46
95.5 Percent CI for ETA1-ETA2 is (-54.75,-0.01)
W = 71.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0126
The test is significant at 0.0049 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs BTE at pulpal walls

	N	Median
NSE	10	0.00
BTE	10	30.11

Point estimate for ETA1-ETA2 is -26.83
95.5 Percent CI for ETA1-ETA2 is (-47.51,-19.03)
W = 66.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0036
The test is significant at 0.0014 (adjusted for ties)

Mann-Whitney Test and CI: Group LSE vs BSE at pulpal walls

	N	Median
LSE	10	20.53
BSE	10	0.00

Point estimate for ETA1-ETA2 is 5.55
95.5 Percent CI for ETA1-ETA2 is (0.00,49.93)
W = 120.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2730
The test is significant at 0.2302 (adjusted for ties)

Mann-Whitney Test and CI: Group LSE vs NTE at pulpal walls

	N	Median
LSE	10	20.53
NTE	10	0.00

Point estimate for ETA1-ETA2 is 7.87
95.5 Percent CI for ETA1-ETA2 is (0.02,49.95)
W = 121.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2413
The test is significant at 0.1996 (adjusted for ties)

Mann-Whitney Test and CI: Group LSE vs LTE at pulpal walls

	N	Median
LSE	10	20.53
LTE	10	32.05

Point estimate for ETA1-ETA2 is -3.51
95.5 Percent CI for ETA1-ETA2 is (-46.87,23.48)
W = 95.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.4727
The test is significant at 0.4631 (adjusted for ties)

Mann-Whitney Test and CI: Group LSE vs BTE at pulpal walls

	N	Median
LSE	10	20.53
BTE	10	30.11

Point estimate for ETA1-ETA2 is -10.31
95.5 Percent CI for ETA1-ETA2 is (-35.57,23.31)
W = 98.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.6232
The test is significant at 0.6185 (adjusted for ties)

Mann-Whitney Test and CI: Group BSE vs NTE at pulpal walls

	N	Median
BSE	10	0.00
NTE	10	0.00

Point estimate for ETA1-ETA2 is 0.00
95.5 Percent CI for ETA1-ETA2 is (-6.45,18.21)
W = 105.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 1.0000
The test is significant at 1.0000 (adjusted for ties)

Mann-Whitney Test and CI: Group BSE vs LTE at pulpal walls

	N	Median
BSE	10	0.00
LTE	10	32.05

Point estimate for ETA1-ETA2 is -22.89
95.5 Percent CI for ETA1-ETA2 is (-53.91,0.01)
W = 84.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1306
The test is significant at 0.1062 (adjusted for ties)

Mann-Whitney Test and CI: Group BSE vs BTE at pulpal walls

	N	Median
BSE	10	0.00
BTE	10	30.11

Point estimate for ETA1-ETA2 is -19.55
95.5 Percent CI for ETA1-ETA2 is (-44.59,-0.01)
W = 82.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0890
The test is significant at 0.0746 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs LTE at pulpal walls

	N	Median
NTE	10	0.00
LTE	10	32.05

Point estimate for ETA1-ETA2 is -23.60
95.5 Percent CI for ETA1-ETA2 is (-53.93,-0.01)
W = 83.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0452
The test is significant at 0.0187 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs BTE at pulpal walls

	N	Median
NTE	10	0.00
BTE	10	30.11

Point estimate for ETA1-ETA2 is -19.55
95.5 Percent CI for ETA1-ETA2 is (-47.51,-0.00)
W = 81.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0757
The test is significant at 0.0625 (adjusted for ties)

Mann-Whitney Test and CI: Group LTE vs BTE at pulpal walls

	N	Median
LTE	10	32.05
BTE	10	30.11

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-26.84,34.92)
W = 107.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.9097
The test is significant at 0.9090 (adjusted for ties)

Statistical analysis in % staining of vertical walls

Group	Count	Mean	StDev	Var	CoefVar	Min	Q1	Median	Q3	Max
NSE	10	1.81	5.72	32.76	316.23	0	0	0	0	18.10
LSE	10	1.68	5.32	28.32	316.23	0	0	0	0	16.83
BSE	10	0	0	0	*	0	0	0	0	0
NTE	10	1.62	4.73	22.34	291.64	0	0	0	0.294	15.03
LTE	10	9.95	11.95	142.71	120.05	0	0	4.07	23.44	27.72
BTE	10	3.05	5.14	26.43	168.47	0	0	0	7.90	13.67

Kruskal-Wallis Test:
% Staining at vertical walls versus adhesive and lining/base groups

Group	N	Median	Ave Rank	Z
NSE	10	0	27.8	-0.55
LSE	10	0	27.7	-0.57
BSE	10	0	24.5	-1.19
NTE	10	0	30.0	-0.10
LTE	10	4.07	40.5	1.97
BTE	10	0	32.7	0.43
Overall	60		30.5	

H = 5.10 DF = 5 P = 0.404
H = 10.45 DF = 5 P = 0.063 (adjusted for ties)

Statistical analysis in % micro-gap at pulpal walls

Group	Mean	StDev	CoefVar	Min	Q1	Median	Q3	Max
NTE	20.2	33.4	165.34	0	0	0	55.60	84.30
LTE	22.7	33.1	146.04	0	0	6.95	47.10	100
BTE	24.40	23.36	95.72	0	0	27.75	44.62	62.04
NSE	7.14	13.22	185.09	0	0	0	13.35	34.27
LSE	24.60	31.47	127.90	0	0	8.40	46.41	91.38
BSE	22.59	25.76	114.04	0	0	9.99	48.53	64.87

Kruskal-Wallis Test:
Micro-gap at pulpal walls versus adhesive and lining/base group

Group	N	Median	AveRank	Z
NTE	10	0	28.0	-0.50
LTE	10	6.951738695	31.2	0.14
BTE	10	2.77535E+01	33.8	0.65
NSE	10	0	22.9	-1.51
LSE	10	8.400365931	33.5	0.60
BSE	10	9.991768256	33.6	0.61
Overall	60		30.5	

H = 3.08 DF = 5 P = 0.687
H = 3.57 DF = 5 P = 0.612 (adjusted for ties)

Statistical analysis in % micro-gap of vertical walls

Group	Mean	StDev	CoefVar	Min	Q1	Median	Q3	Max
NTE	0.93	2.94	316.23	0	0	0	0	9.30
LTE	13.99	12.94	92.46	0	0	14.85	27.17	32.03
BTE	6.24	9.00	144.30	0	0	0	14.20	25.01
NSE	3.24	10.25	316.23	0	0	0	0	32.40
LSE	5.88	9.56	162.48	0	0	0	10.34	29.73
BSE	0	0	*	0	0	0	0	0

Kruskal-Wallis Test:
Micro-gap at vertical walls versus adhesive and lining/base group

Group	N	Median	AveRank	Z
NTE	10	0	24.5	-1.19
LTE	10	1.48463E+01	43.9	2.66
BTE	10	0	33.5	0.60
NSE	10	0	25.8	-0.93
LSE	10	0	33.3	0.56
BSE	10	0	22.0	-1.69
Overall	60		30.5	

H = 10.71 DF = 5 P = 0.057
H = 16.95 DF = 5 P = 0.005 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs LTE at the vertical walls

	N	Median
NTE	10	0.00
LTE	10	14.85

Point estimate for ETA1-ETA2 is -14.52
95.5 Percent CI for ETA1-ETA2 is (-26.53,-0.00)
W = 72.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0156
The test is significant at 0.0063 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs BTE at the vertical walls

	N	Median
NTE	10	0.00
BTE	10	0.00

Point estimate for ETA1-ETA2 is 0.00
95.5 Percent CI for ETA1-ETA2 is (-13.85,0.00)
W = 89.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2413
The test is significant at 0.1236 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs NSE at the vertical walls

	N	Median
NTE	10	0.00
NSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (0.00,0.00)
W = 104.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 1.0000
The test is significant at 1.0000 (adjusted for ties)

Mann-Whitney Test and CI: Group NTE vs LSE at the vertical walls

	N	Median
NTE	10	0.00
LSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-10.31,-0.00)
W = 89.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2413
The test is significant at 0.1236 (adjusted for ties)

Mann-Whitney Test and CI: Group LTE vs BTE at the vertical walls

	N	Median
LTE	10	14.85
BTE	10	0.00

Point estimate for ETA1-ETA2 is 6.05
95.5 Percent CI for ETA1-ETA2 is (0.00,21.06)
W = 125.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1405
The test is significant at 0.1222 (adjusted for ties)

Mann-Whitney Test and CI: Group LTE vs NSE at the vertical walls

	N	Median
LTE	10	14.85
NSE	10	0.00

Point estimate for ETA1-ETA2 is 14.52
95.5 Percent CI for ETA1-ETA2 is (-0.00,26.53)
W = 131.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0494
The test is significant at 0.0265 (adjusted for ties)

Mann-Whitney Test and CI: Group LTE vs LSE at the vertical walls

	N	Median
LTE	10	14.85
LSE	10	0.00

Point estimate for ETA1-ETA2 is 5.50
95.5 Percent CI for ETA1-ETA2 is (0.00,21.08)
W = 125.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1405
The test is significant at 0.1222 (adjusted for ties)

Mann-Whitney Test and CI: Group BTE vs NSE at the vertical walls

	N	Median
BTE	10	0.00
NSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-0.01,13.86)
W = 118.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.3447
The test is significant at 0.2143 (adjusted for ties)

Mann-Whitney Test and CI: Group BTE vs LSE at the vertical walls

	N	Median
BTE	10	0.00
LSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-8.38,8.27)
W = 106.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.9698
The test is significant at 0.9660 (adjusted for ties)

Mann-Whitney Test and CI: Group NSE vs LSE at the vertical walls

	N	Median
NSE	10	0.00
LSE	10	0.00

Point estimate for ETA1-ETA2 is -0.00
95.5 Percent CI for ETA1-ETA2 is (-10.31,-0.00)
W = 92.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.3447
The test is significant at 0.2143 (adjusted for ties)

Certificate of Exemption

COE. No. MU-DT/PY-IRB 2012/010.2003

Documentary Proof of Faculty of Dentistry/Faculty of Pharmacy, Mahidol University, Institutional Review Board

Title of Project:	Internal Adaptation of Occlusal Resin Composite Restorations Lined With Thin or Thick Glass-Ionomer Lining/Base Cement
Project Number:	MU-DT/PY-IRB 2012/016.1403
Principle Investigator:	Miss Ornjira Chailert
Name of Institution:	Faculty of Dentistry
Date of Recommendation:	March 20, 2012

Faculty of Dentistry/Faculty of Pharmacy, Mahidol University, Institutional Review Board is in full compliance with International Guidelines for Human Research Protection such as Declaration of Helsinki, the Belmont Report, CIOMS Guidelines and the International Conference on Harmonization in Good Clinical Practice (ICH-GCP)

Signature of Chair:

(Associate Professor Choltacha Harnirattisai)

Chair

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