MICROLEAKAGE OF ENAMEL PRESERVATION AT GINGIVAL WALL OF CLASS II RESIN COMPOSITE RESTORATIONS (NANOFILLED VS BULK-FILL)

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การรั่วซึมระดับจุลภาคของการอนุรักษ์ผนังเคลือบฟันที่บริเวณผนังด้านเหงือก ของการบูรณะโพรงฟันชนิดคลาส ทู ด้วยเรซินคอมโพสิต (นาโนฟิลล์เทียบกับบัลค์ฟิลล์)

นางสาวอรลัดดา พิสุทธิวงษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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อรลัดดา พิสุทธิวงษ์ : การรั่วซึมระดับจุลภาคของการอนุรักษ์ผนังเคลือบฟันที่บริเวณผนังด้านเหงือกของการบูรณะโพรงฟันชนิดคลาส ทู ด้วยเรซินคอมโพสิต (นาโนฟิลล์เทียบกับบัลค์ฟิลล์) (MICROLEAKAGE OF ENAMEL PRESERVATION AT GINGIVAL WALL OF CLASS II RESIN COMPOSITE RESTORATIONS (NANOFILLED VS BULK-FILL)) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทพ. เฉลิมพล ลี้ไวโรจน์, 129 หน้า.

วัตถุประสงค์ งานวิจัยครั้งนี้มีวัตถุประสงค์เพื่อทดสอบสมมติฐานที่ว่าการอนุรักษ์ผนังเคลือบฟันที่บริเวณผนังด้านเหงือก และการใช้บัลค์ฟิลล์เรซินคอมโพสิตสามารถลดการรั่วซึมระดับจุลภาคของโพรงฟันชนิดคลาส ทู เรซินคอมโพสิต

วิธีการทดลอง แบ่งฟันกรามมนุษย์ซี่ที่ 3 จำนวน 36 ซี่ เป็น 3 กลุ่มโดยวิธีสุ่ม กลุ่มละ 12 ซี่: Filtek Bulk Fill Posterior Restorative แบบแคปซูล (BFC), Filtek Bulk Fill Posterior Restorative แบบไซริงค์ (BFS) และ Filtek Z350 XT (Z350) กรอเตรียมโพรงฟันชนิดคลาส ทู (3 มม buccolingually x 2 มม mesiodistally ที่ด้านบดเคี้ยว และ 1.5 มม mesiodistally ที่ด้านคอฟัน x 4 มม axial) ทั้งสองด้าน โดยให้ผนังด้านเหงือกด้านหนึ่งอยู่ต่ำกว่ารอยต่อระหว่างเคลือบฟันกับเคลือบรากฟัน 0.5 มม (NP) ส่วนอีกด้านหนึ่งมีการอนุรักษ์ผนังเคลือบฟันขนาด 0.5 x 1 มม (EP) เหนือรอยต่อระหว่างเคลือบฟันกับเคลือบรากฟัน หลังจากบูรณะโพรงฟันและนำฟันไปเข้าเครื่องเทอร์โมไซคลิงแล้ว จึงนำฟันมาแช่สารละลายเมทิลีนบลู 0.5% นาน 24 ชั่วโมง ตัดแบ่งฟันเป็น 2 ส่วนบริเวณกลางโพรงฟัน ประเมินการรั่วซึมของสีที่ผนังด้านเหงือกโดยผู้อ่านผลการศึกษา 3 คนซึ่งถูกอำพราง โดยใช้มาตราอันดับ 0-4 ใช้สถิติทดสอบครูสคัล-วัลลิส และ การเปรียบเทียบพหุคูณ (การทดสอบดันน์) ในการเปรียบเทียบการรั่วซึมระดับจุลภาคระหว่างวัสดุบูรณะ และ ใช้สถิติทดสอบของแมน-วิทนีย์เพื่อเปรียบเทียบการรั่วซึมระดับจุลภาคระหว่างโพรงฟันด้านที่มีการอนุรักษ์ผนังเคลือบฟัน (EP) และ ด้านที่ไม่มีการอนุรักษ์ผนังเคลือบฟัน (NP) ที่ระดับนัยสำคัญ = 0.05

ผลการทดลอง สถิติทดสอบแมน-วิทนีย์แสดงผลว่าโพรงฟันด้านที่ไม่มีการอนุรักษ์ผนังเคลือบฟัน (NP) มีค่าการรั่วซุมระดับจุลภาคมากกว่า ด้านที่มีการอนุรักษ์ผนังเคลือบฟัน (EP) อย่างมีนัยสำคัญทางสถิติ สถิติทดสอบครูสคัล-วัลลิส แสดงผลว่ามีความแตกต่างของการรั่วซึมระดับจุลภาคระหว่างวัสดุบูรณะอย่างมีนัยสำคัญทางสถิติ ($P < 0.05$) โดยเมื่อเปรียบเทียบกับ Z350 ในโพรงฟันด้านที่มีการอนุรักษ์ผนังเคลือบฟัน (EP) BFC และ BFS มีค่าการรั่วซุมระดับจุลภาคน้อยกว่าอย่างมีนัยสำคัญทางสถิติ ($P = 0.001$) ($P = 0.028$) ส่วนในโพรงฟันด้านที่ไม่มีการอนุรักษ์ผนังเคลือบฟัน (NP) BFC มีค่าการรั่วซุมระดับจุลภาคน้อยกว่าอย่างมีนัยสำคัญทางสถิติ ($P = 0.001$)

สรุป การอนุรักษ์ผนังเคลือบฟันและการบูรณะด้วยบัลค์ฟิลล์ เรซินคอมโพสิต ทั้ง BFC และ BFS สามารถลดการรั่วซึมระดับจุลภาคที่ผนังด้านเหงือกของโพรงฟันชนิดคลาส ทู เรซินคอมโพสิตได้

สาขาวิชา ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม ลายมือชื่อนิสิต

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5775832232 : MAJOR ESTHETIC RESTORATIVE AND IMPLANT DENTISTRY
KEYWORDS: MICROLEAKAGE / THIN ENAMEL LAYER / GINGIVAL MARGIN / ENAMEL PRESERVED / NANOFILLED RESIN COMPOSITE / BULK-FILL RESIN COMPOSITE

ONLADDA PISUTTIWONG: MICROLEAKAGE OF ENAMEL PRESERVATION AT GINGIVAL WALL OF CLASS II RESIN COMPOSITE RESTORATIONS (NANOFILLED VS BULK-FILL). ADVISOR: ASSOC. PROF. CHALERMPOL LEEVAILOJ, 129 pp.

Objectives. This *in vitro* study tested the hypothesis that preserving a thin enamel layer at the gingival margin and using bulk-fill resin composites could minimize microleakage of class II resin composite.

Materials and Methods. Thirty-six human third molars were randomly divided into three groups of 12 specimens each: Filtek Bulk Fill Posterior Restorative in Capsules (BFC), Filtek Bulk Fill Posterior Restorative in Syringes (BFS) and Filtek Z350 XT (Z350). Teeth were prepared on two sides for a class II cavity (3 mm buccolingually x 2 mm mesiodistally at occlusal and 1.5 mm at coronal x 4 mm of axial depth) with 0.5 mm under the CEJ on one side (NP) and 0.5x1 mm of thin enamel at the gingival margin was preserved on the other side (EP). The teeth were then restored, thermocycled, immersed in 0.5% methylene blue solution for 24 hours and sectioned mesiodistally through the restorations. Dye penetration was evaluated at the gingival margin by three blinded examiners using a 0-4 ordinal scale. The Kruskal-Wallis test and Dunn test were used to compare differences in microleakage scores among the three restorative materials. Mann-Whitney U test was utilized to analyze the difference between enamel preserved (EP) and non-enamel preserved sides (NP) in the same restorative material. Tests were performed with the level of significance at a = 0.05.

Results. Mann-Whitney U test showed that the “NP” groups had significantly higher microleakage score than the “EP” groups. The Kruskal-Wallis test revealed significant differences in microleakage scores among the three restorative materials ($P < 0.05$). Compared to “Z350”, the “EP” group, “BFC” and “BFS” had significantly less microleakage score ($P = 0.001$) ($P = 0.028$). The “NE” group, “BFC” had significantly less microleakage score than “Z350” ($P = 0.001$).

Conclusions. Preserving thin layer of enamel (“EP”) and use of two bulk-fill products (“BFC” and “BFS”) reduced microleakage of class II resin composite.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature	....
		Advisor's Signature	....
Academic Year:	2017		

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CHAPTER I INTRODUCTION

Background and Rationale

Tooth-colored restorative material, resin composites are now widely used for posterior teeth restoration because of their ability to mimic the color of natural teeth and meet patient's demand in esthetic appearance.(1) Moreover, restoration using resin composite can be completed in one visit, making it convenient for both the dentist and the patient. There are numbers of clinical studies reported long-term durability of resin composite.(2-5)

The usage of adhesive material is one of the advantage of resin composite restoration, provided many benefit as following; more conservative tooth preparation, potent sealing margins of restoration, stress distributing and reinforcing weakened tooth structure.(6, 7) However, some clinical problems of restoring tooth structure with resin composite still remains such as microleakage at the gingival wall of class II resin composite restoration,(8) which might lead to post-operative hypersensitivity, secondary caries and pulpal pathology.(8-10)

Microleakage was defined as the clinical undetectable passage of bacteria, fluid, molecules, or ions between a cavity wall and the restorative material applied to it.(11) There were multiple factors that cause microleakage when restoring teeth with resin composite. One of the main cause was polymerization shrinkage of the material.(8) Other factors included the cavity configulation factor, coefficient of thermal expansion, adhesive bond strength, hygroscopic expansion and modulus of elasticity of restorative materials.

Ideally, preparation of class II resin composite restoration should preserved enamel as much as possible due to better adhesive properties. Bonding to enamel provided a better bond in comparison to dentin and cementum.(8) Leevairoj C, et al. found that the microleakage at the gingival level of class II cavites restored with resin composite was higher than at the occlusal level.(12) Characteristic of class II dental caries, when dental caries penetrated into dentin, the dental substrate was extensively damaged. It might penetrate down under the CEJ, leaving a thin layer of enamel at gingival undamaged. This unsupported enamel was normally removed in clinic for two reasons; 1) An arrangement of enamel rod at CEJ area was irregular, lacking definite form which might affect bonding efficiency.(13) 2) It might be fractured as a consequence of polymerization shrinkage stress.(14) In addition, to make a straight horizontal gingival wall, the operator might decide to grind this fine undamaged enamel out.

Current resin composites have good physical properties of hardness, flexural strength, and fracture toughness, as well as low shrinkage and low wear. However, because of the low depth of cure, conventional resin composites required the addition of multiple separate cured layers. This was called "Incremental placement" and was time consuming.(10, 15) One advantage of bulk-fill resin composites was that the dentist can restore thicker layers of material compared to conventional resin composite and allow complete polymerization to take place.(16) The placement of large increments of bulk-fill resin composite into a cavity increased the potential of creating high shrinkage stress. However, a study has shown that the mean values of polymerization stress for most of the bulk-fill products were not statistically different compared to conventional resin composites.(17) Filtek Bulk Fill Posterior Restorative in capsule and syringe type was launched onto the market with the same composition but a different application method. The key manufacturing features relate to improved polymerization shrinkage with a greater depth of cure. Testing the microleakage of this bulk-fill product in both capsule and syringe type is, therefore, of interest.

No current research has investigated the microleakage from cavities where a thin enamel layer was left at the gingival wall. Therefore, this study examined the effect of preserving a thin enamel layer at the gingival wall on the microleakage of class II resin composite restoration. In addition, the microleakage was compared between bulk-fill and conventional resin composites.

Research Questions

1. Does thin enamel preservation at gingival wall affect microleakage score of class II resin composite restoration?

2. Do the restorative materials affect microleakage score of class II resin composite restoration?

Research Objectives

1. To compare microleakage of class II resin composite restoration at gingival wall with thin enamel preservation and without thin enamel preservation.

2. To compare microleakage of class II cavity restored with Bulk-fill resin composite (capsule and syringe) and Nanofilled resin composite.

Statement of Hypotheses

Null hypotheses

1. There is no statistically significant difference in microleakage score of class II resin composite restoration between thin enamel preserved groups and non-enamel preserved groups.

2. There is no statistically significant difference in microleakage score of class II resin composite restoration using bulk-fill resin composite (capsule and syringe) and nanofilled resin composite.

Conceptual Framework

Population: Human third molars with prepared class II cavity (Thin enamel preserved side and non-enamel preserved side)

Intervention: Different restorative materials (Bulk-fill resin composite (capsule), Bulk-fill resin composite (syringe) and Nanofilled resin composite)

Outcome measurement: Microleakage score

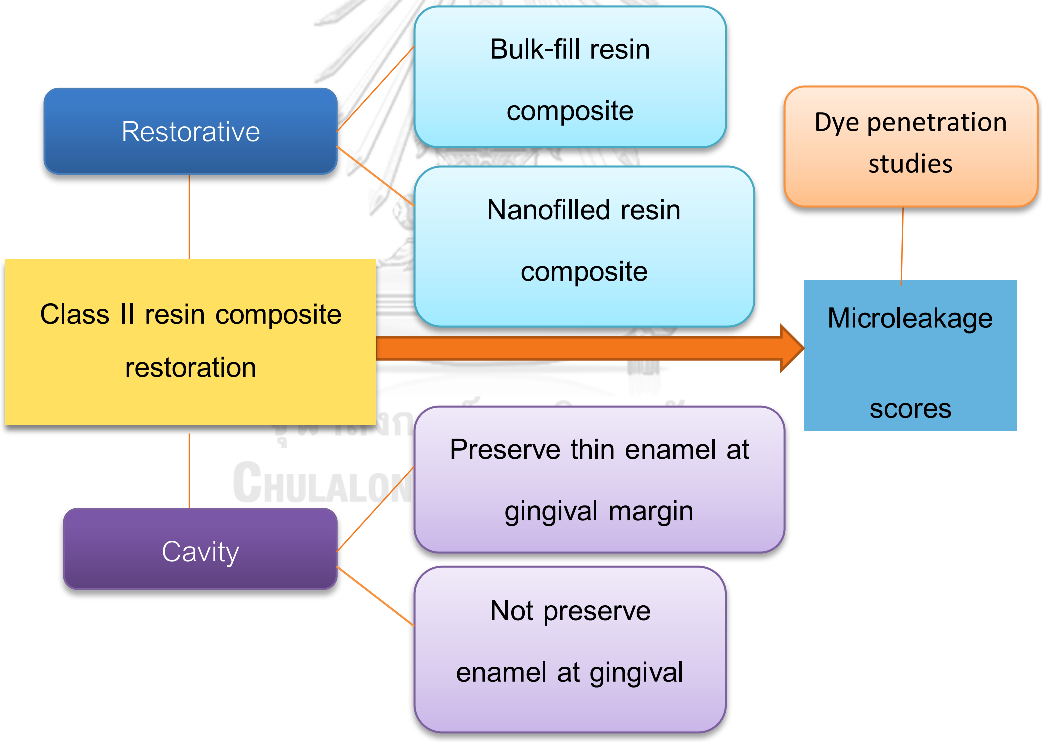


Figure 1 The conceptual framework

In this study, the procedures were performed using human third molars under well-controlled conditions in order to reduce confounding factors. All specimens were prepared and restored by one operator, then microleakage score were evaluated by 3 blinded examiners that is not the operator in the same controlled environment. The research methodology is shown in figure 2.

Keywords

- Microleakage
- Thin enamel layer
- Gingival margin
- Enamel preserved
- Nanofilled resin composite
- Bulk-fill resin composite

Assumptions

Every cavity was restored strictly according to standardized technique for each material. Therefore, microleakage score was affected only by the performance of material itself.

Operational Definition

1. Filtek Bulk Fill Posterior Restorative (3M ESPE, St. Paul, MN, USA)

- One-step placement, Bulk-fill resin composite

2. Filtek Z350 XT Universal Restorative (3M ESPE, St. Paul, MN, USA)

- Conventional nanofilled resin composite

3. Adper Scotchbond Multi-Purpose Adhesive (3M ESPE, St. Paul, MN, USA)

- 3-step total-etch adhesive system

Research Design

Randomized controlled examiner-blinded experimental study.

The Expected Benefits

Knowing the effect of preserve thin enamel at CEJ area and understanding the result of restoring teeth with Bulk-fill resin composite and conventional nanofilled resin composite materials to the preserved enamel cavity or non-enamel preserved cavity in class II resin composite restoration will be the information for the clinicians to adapt the preparation and restorative technique in order to improve the quality of, especially reducing microleakage of cavity, and to be knowledge for further study.

Study Limitations

This is an in vitro study, not a clinical study. Therefore, the results of this study may not be inferred to the clinical outcome of these products.

CHAPTER II REVIEW OF THE LITERATURES

The literatures in these following topics will be reviewed.

Resin composite

- Nanofilled resin composite
- Bulk-fill resin composite

Tooth structure

- Enamel
- Dentin
- Pulp
- Cementoenamel junction

Microleakage

- Definition
- Factors Contributing to Microleakage
    - Polymerization shrinkage
    - Modulus of elasticity
    - Coefficient of thermal expansion

- Hydroscopic expansion
- Adhesive bond strength
- Cavity configuration factor
- Thermocycling
- Bonding to tooth structure

- Measurement of microleakage
  - Dye penetration studies
  - Number of section

Review of materials

- 3M ESPE Filtek Bulk Fill Posterior Restorative
  - capsules
  - syringes
- 3M ESPE Filtek Z350 XT Universal Restorative
- 3M ESPE Adper Scotchbond Multi-Purpose Adhesive

Resin composite

- Nanofilled resin composite

Dental composite restorative materials have been available since the early 1960s. Their use in posterior teeth has been recommended for more than 40 years.(18)

Resin composites have been classified according to various characteristics. Consider the distribution and average particle size of composite's fillers, macrofilled composite, conventional dental composites with average particle sizes morethan 1 µm were very strong, However, the material was difficult to polish and impossible to retain surface smoothness.(19) To solve the problem of macrofilled composite, nanotechnology was invented. Nanotechnology is known as molecular engineering, the production of functional materials and structures in the range of 0.1 to 100 nanometers by various physical and chemical methods.(20)

Nanofilled composites consist of nanomers (5 nm to 75 nm particles) and nanocluster agglomerates as the fillers. Nanoclusters are agglomerated (0.6 µm to 1.4 µm) of primary zirconia/silica nanoparticles (5 nm to 20 nm in size) fused together at points of contact. The resulting porous structure is infiltrated with silane.(21) While the nanofilled composite gave the restoration a better finish they also achieved sufficiently competent mechanical properties to be indicated for use in the anterior and posterior teeth.(21)

- Bulk-fill resin composite

Current resin composites have good physical properties of hardness, flexural strength, and fracture toughness, as well as low shrinkage and low wear. However, because of low depth of cure, conventional resin composites require multiple separate cured layers, called “Incremental placement”. Incremental curing does not change the total volume of linear shrinkage of the composite material but it compensates some of the shrinkage by applying and curing the composite in layers.(10) The use of an incremental placement technique has been reported to reduce microleakage associated with class II resin-based composite restorations.(22) The main disadvantage of this technique is time consuming.(10, 15)

Bulk-fill resin composites were developed to reduce the number of increments required to complete a restoration. The key features from manufacturers are related to the improved polymerization shrinkage and the greater depth of cure. Both of these features allow dentists to have the confidence to place fewer and larger increments with predictability.

Regarding placing large increments of bulk-fill resin composite into a cavity, the potential for creating high shrinkage stress may occur. However, a study has shown that the mean values of polymerization stress for most of the bulk-fill products were not statistically different compared to the conventional resin composites.(17) The researchers also found that performance of bulk-fill products are all acceptable according to an international standard ISO 4049-2009 except for some products that did not achieve adequate depth of cure and hardness.(17)

Tooth structure

Teeth are composed of enamel, dentin, pulp and cementum

- Enamel

Enamel is the hardest calcified tissue in the human body. It is composed of 96% weight hydroxyapatite.(23) Enamel rod of approximately 5 μm in diameter is formed by ameloblast cell. The enamel rods emerging from dentinoenamel junction to external tooth surface.(24) Macroscopically, incremental pattern of enamel rods is exhibited on tooth surface as perikymata but microscopically, groups of enamel rods run in unique direction. Therefore, results in forming different patterns of enamel rod endings on tooth surface.(25)

The long axis of the enamel rod is generally perpendicular to the underlying dentin, the only exception is that enamel rods near the cementoenamel junction (CEJ) in permanent teeth which tilt slightly toward the root of the tooth.(26) Fernandes and Chevitarese found that the arrangement of the first 0.5 mm thickness of enamel rod at cementoenamel junction was irregular and lack of definite form.(13) This histologic alignment of the enamel rods influences the cavity preparation for several restorative materials. Unsupported enamel rods are considered as a hazard for resin composite restorations because of their brittleness.(27) Resins composite are also affected by unsupported enamel because of polymerization shrinkage during the setting period.(14)

- Dentin

Dentin forms the largest portion of the tooth structure, extending almost the full length of the tooth. Externally, dentin is covered by enamel on the anatomic crown and cementum on the anatomic root. Internally, dentin forms the walls of the pulp cavity. The composition of dentin contains a significant amount of water and organic material, mainly type I collagen.(23) The collagen structure of dentin is complex, the collagen oriented in helical-like structures forming tubules but then changing to a more radial orientation in the plane perpendicular to the tubule direction.(28)

Dentin tubules run continuously from the dentinoenamel junction to the pulp in coronal dentin, and from the cementodentin junction to the pulp canal in the root.(29) The dentin around the tubules is more highly mineralized which approximately the thickness of the tubule diameter, called the 'peritubular dentin'. Outside this zone the mineral content is lower, called the 'intertubular dentin'.(28) Near DEJ dentin tubules are widely spaced but tubule density increases near the pulp.(30) The water content of dentin near the DEJ is about 1% by volume, while the dentin near the pulp is about 22%.(31) This difference in intrinsic moisture may result in differences in bond strengths between superficial and deep dentin.

- Cementum

Cementum is a thin layer of hard dental tissue covering the anatomic roots of teeth and is formed by cells known as cementoblasts.(32) It contains a wet-weight basis 65% inorganic material, 23% organic material and 12% water.(33) The organic matrix of cementum consists predominantly of type I collagen.(34)

Cementum has been classified into cellular and acellular cementum by inclusion or non-inclusion of cementocytes. Generally, acellular cementum is thin and covers the cervical root, whereas thick cellular cementum covers the apical root.(35) The structural differences between cellular and acellular cementum are related to the faster rate of matrix formation for cellular cementum.(33) Unlike enamel and dentin, an irregular rhythm of deposition of cementum, resulting in unevenly spaced incremental lines. The appearance of incremental lines is mainly due to differences in the degree of mineralization and composition of the underlying matrix. In acellular cementum, incremental lines tend to be close together, thin and even. In cellular cementum, the lines are further apart, thicker, and more irregular.(33)

- Pulp

The pulp is circumscribed by the dentin. Anatomically, the pulp tends to lie in the center of the tooth, called the pulp cavity. It is divided into two parts, the first part is coronal pulp located in the pulp chamber at the crown portion of the tooth, including the pulp horns that are directed toward the incisal ridges and cusp tips. The second part is radicular pulp located in the pulp canals at the root portion of the tooth.(36)

Dental pulp consists of cells, nerve fibers and blood vessels embedded in a gel-like ground substance. It is surrounded by a layer of specialized cells called odontoblasts, which secrete and encase the connective tissue in a rigid hard tissue shell called dentine.(36) Immediately adjacent to the odontoblastic layer is a zone of connective tissue, which is relatively free of cells, called the “cell-free zone” that tends to disappear during periods of cellular activity in a young pulp or in older pulps where reparative dentine is being formed.(37) Deep to the odontoblastic layer is the cell-rich zone, contains fibroblasts and undifferentiated cells which sustain the population of odontoblasts by proliferation and differentiation.(38)

- Cementoenamel junction

The cementoenamel junction (CEJ) represents the anatomic limit between the crown and root surface, which defined as the area of union between the cementum and enamel at the cervical region of the tooth. In CEJ area, three types of mineralized tissues are present: Enamel, dentin and cementum.(39) There are four types of normal variation in relationships between enamel and cementum at the cervical region.

Pattern I, the cementum overlaps the enamel for a short distance, seen in 60% of all teeth. It occurs when the enamel epithelium degenerates at the cervical region thereby allowing the connective tissue consisting of cementoblasts to contact the enamel directly.(40)

Pattern II, an end-to-end approximating CEJ, cementum and enamel meet at a butt joint. It is seen in about 30% of teeth.(40)

Pattern III, the absence of contact between enamel and cementum. Therefore, the dentin is an external part of the surface of the root.(41) It is seen in 10% of teeth. This occurs when enamel epithelium in the cervical portion of the root is delayed in its separation from dentine. In this situation, the CEJ is absent.(40)

Pattern IV, the overlapping of the enamel on cementum.(42) This is observed under an optical microscope, seen in about 1.6% of teeth.(43)

Microleakage

- Definition

Microleakage might be defined as the passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material applied to it.(11) Clinically, microleakage can be identified as a dynamic phenomenon that results in two consequential manifestations known as the sensory component and the pathologic component. The compromised marginal seal can cause hypersensitivity, which was caused by hydrodynamic fluid movement through a degrading smear layer into the dentinal tubules underneath. This part was referred to as the *sensory* component of microleakage. Bacteria and their products that pass through the potential gaps along the axiopulpal floor result in recurrent caries and the subsequent pulpal pathoses was referred to as the *pathologic* component of microleakage.(44) Microleakage also results in marginal discoloration.(45) It has also been reported as one of the major causes of resin composite restoration failure.(46) The effects of bacterial leakage upon the dental pulp were well documented.(47) Therefore, prevention of bacterial access along the margins of restorations is a high priority.

- Factors Contributing to Microleakage

Several factors affect the integrity of the tooth-restoration interface and can contribute to microleakage. These factors include polymerization shrinkage, modulus of elasticity, coefficient of thermal expansion, hydroscopic expansion, adhesive bond strength, cavity configuration factor, thermocycling and bonding to tooth structure.

❖ Polymerization Shrinkage

Polymerization shrinkage is one of the most critical properties of resin based composite restorative materials.(48) It is considered as one of the major problems that limits the application of direct esthetic restorative techniques.(49) Because it can create contraction forces which might disrupt the bond to the cavity walls, leading to marginal failure and subsequent microleakage.(50)

Polymerization shrinkage of dental composites ranges between 2% and 6% by volume.(51) Resins shrink during polymerization because the monomer units of the polymer are located closer to one another than they were in the original monomer.(48) Besides volume reduction, chain growth and cross-linking during polymerization of resin composites also results in an increased elastic modulus.(52)

During polymerization, *gelation* or *gel point* is a stage in monomer conversion at which the elastic modulus of the composite increases to a level that does not allow plastic deformation or flow to compensate the reduction in volume.(51)

Total polymerization shrinkage can be divided into two components: the pre-gel and post-gel phases. During the pre-gel polymerization, the cross linking density is low and polymeric chains are able to assume new positions (flow), causing stress relief within the structure.(49) During post-gel polymerization, additional contraction produces clinically significant stresses in the composite-tooth bond and surrounding tooth structure.(51)

Post-gel polymerization stresses are not uniformly distributed along the cavity walls(53) and the bond strength between tooth and composite also varies along the bonded interface.(54) Therefore, in areas where shrinkage forces are higher than the composite-tooth bond, a gap may develop leading to bond failure and microleakage with associated postoperative sensitivity and secondary caries.(49) Polymerization contraction stresses transferred to the tooth can cause tooth deformation that results in post-operative sensitivity and may open pre- existing enamel causing microcracks.(55) Another consequence of polymerization shrinkage in composite restorations is cuspal movement.(56)

Polymerization contraction stress is mainly influenced by the composite's volumetric shrinkage and its visco-elastic behavior that is usually described in terms of elastic modulus development and flow capacity.(57)

❖ Modulus of elasticity

The elastic modulus represents the stiffness of a material within the elastic range.(58) The modulus of elasticity can influence the sealing ability of a resin composite material. During the pre-gel phase of polymerization, cross linking density is low and the resin composite is able to flow, this resin composite has a low modulus of elasticity that helps to relieve the polymerization contraction stresses.(48)

Following gel formation, there is a rapid increase in the elastic modulus of the resin composite. This results in contraction stress development but the material is rigid and resists the plastic flow to compensate the original volume. Therefore, the gap is possible formed.(48)

Volumetric shrinkage and elastic modulus are highly dependent upon the filler content of materials.(59) Composites with higher filler content will have a low resin matrix fraction that may determines the volume reduction observed during the formation of a dense cross-linked polymeric network. Conversely, materials heavily filled with filler particles present high stiffness that is also associated with high stress levels. The reduction of the materiel's flow may cause destruction of the tooth-restoration bonded interface and increase the chance of microleakage.(60) In general, the higher the volumetric contraction or the faster the material acquires elastic properties after the beginning of polymerization, the higher the stresses will be.(57)

The modulus of elasticity of enamel (33.6 GPa) and dentin (11.7 GPa) is greater than that of composites (10.5 GPa) when condense.(61) Micromovement of resin along the cavity walls as a result of non-matching modulus of elasticity may occur under stress because resin composite is more flexible, while enamel does not deform under compressive strength before fracturing. Therefore this may cause bond failure at the tooth restoration interface resulting in microleakage or fracture of the tooth surface.(61)

❖ <u>Coefficient of thermal expansion</u>

Dimensional changes of a substance in response to thermal variations are measured in terms of its Coefficient of Thermal Expansion (CTE). The restorative materials have a different coefficient of thermal expansion from that of enamel to dentin.(62)

The coefficient of thermal expansion of resin composite (14 to 50 x 10^{-6} /$^{\circ}$C)(58) is several times larger than a tooth that has been reported within a range of 11-14 x 10^{-6} /$^{\circ}$C.(63) A great difference in the coefficient of thermal expansion (CTE) between tooth and restorative material results in different dimensional changes. Expand when exposed to hot foods or beverages and contract when exposed to cold substances.(58) The different in expansion and contraction of material and tooth develops stresses at the tooth-restorative interface may lead to debonding and gap formation or cusp fracture if the bond persists in case of the tooth is not able to tolerate the changes induced by the temperature variations.(58)

❖ Hydroscopic expansion

Resin based composite restorative materials may absorb significant amounts of water when exposed to the oral environment.(64) The resin matrix has the most significant bearing on the amount and rate of hydroscopic expansion for any given resin-based composite restorative material.(65) Water sorption will cause a change in the dimension and the weight of the set material.(66)

Hirasawa et al. reported a direct correlation between the mass of absorbed water and the linear expansion of the resin composite.(67) This expansion may relieve some of the internal stresses produced during polymerization shrinkage of the restoration or may close marginal leakage gaps.(65) However, the adhesive bonds that were broken by the polymerization shrinkage will not be re-established by hydroscopic expansion.(68)

❖ Adhesive bond strength

Several factors affect the quality of the bond including the thickness of the smear layer, variations in resin penetration into the demineralized surface and stresses developed at the adhesive–dentin interface during polymerization shrinkage and function.(69)

Although a bond strength of 20 to 24 MPa is necessary to resist polymerization contraction stresses of resin composites and to prevent microleakage at the dentin-resin interface.(70) Sometimes bonding agents exhibit bond strengths to dentin higher than 20 MPa are incapable to prevent microleakage because they cannot withstand the total contraction forces generated during the polymerization reaction, leading to open margins.(71, 72)

Asmussen and Peutzfeldt found that the direction of shrinkage is directed towards the light source.(73) When the filling is cured from the occlusal, it shrinks away from the adhesive zone, damage could occur to the adhesive bond. Therefore, when the restoration is cured from the proximal, this damage may be minimized and microleakage reduced.(74)

❖ Cavity configuration factor

When a resin composite restoration is cured, it bonds to the walls and the floor of the cavity preparation. During polymerization the restorative resin shrinks and pulls the opposing walls and floor of the cavity closer together. The magnitude of this phenomenon depends upon the configuration of the cavity which is called the cavity configuration factor or C-factor.(75) The configuration factor has been defined as the ratio of the bonded surface area to the free surface area of the cavity.(76) Higher C-factors have been reported to produce higher contraction stresses by limiting the flow capacity of the resin composites.(76) Moreover, it is also being risk for bonding because the polymerization stresses may be too great to be counteracted by the bond strength of the dentin bonding agent.(77)

❖ Thermocycling

The oral environment can be replicated by water storage and thermocycling of samples. The use of thermocycling as a simulation of clinical aging is a common artificial aging technique. Thermal stresses can be pathologic in two ways. Firstly, the differential thermal changes induce mechanical stresses that can cause crack propagation through the bond interface. Secondly, the gap volume changes associated with changing gap dimensions pump pathogenic oral fluids in and out of the gaps with possible pulpal complications.(78)

There are disagreeing opinions about the influence of thermocycling on microleakage. Some authors reported the absence of any influence of thermocycling on microleakage,(79, 80) while others showed increasing of microleakage at the cementum-dentin-restoration interface after thermal stressing.(81, 82)

❖ <u>Bonding to tooth structure</u>

The basic mechanism of bonding to enamel and dentin is essentially an exchange process. Minerals removed from the hard dental tissue are replaced by resin monomers that upon *in situ* setting provide micro-mechanical interlocking in the created porosities.(83) Therefore, enamel and dentin should be properly treated to allow the full penetration of the adhesive monomers.

The acid-etch technique introduced by Buonocore permits resin composite to bond to enamel.(84) While the significant increase in bond strength values reported over the years, the occurrence of microleakage and gap formation, mostly at the dentin-composite interface, did not seem to decrease at a similar rate.(85) There is a study demonstrated that the percentage of dentinal gaps in a composite restoration placed *in vivo* may vary between 14% and 54% of the total interface, depending on the materials and techniques used.(86) Celik and Ozgunaltay also found that the gap form particularly if the restoration margin is placed in dentin or cementum.(87)

Dental enamel is composed of 96% weight hydroxyapatite (mineral), a hard solid crystalline structure, with strong intermolecular forces and a high-energy surface. Conversely, dentin contains a significant amount of water and organic material, mainly type I collagen.(23) Dentin is intrinsically humid and flexible than enamel, with low intermolecular forces and a low-energy surface. The humid and organic nature of dentin makes this hard tissue extremely difficult to bond to. While enamel bonding is reliable and easy to achieve as long as the enamel is etched with phosphoric acid.(88)

- Measurement of microleakage

Investigation of leakage has been carried out both in *in vivo* and *in vitro*, but the latter is more common. *In vitro* studies help in the selection of restorative materials and techniques and are essential for research and developmental purposes.(89) There is no direct correlation established between the results of *in vitro* tests and *in vivo* findings regarding microleakage.(89) However, it is reported that microleakage tests may be reliable parameters to predict the *in vivo* performance.(90)

In vitro experiments devide broadly into two categories; those, which use a clinically relevant model with attempts to reproduce the oral situation, and those in which the model does not represent this and is purely a test of the material's behaviour. These techniques include the use of air pressure method, penetration studies (dye penetration, chemical tracer, radioactive tracers, neutron activated analysis, bacteria's toxin and product and chemical diffusion techniques), fluid conduction studies and electronic method.(91) Dye penetration measurements on sections of restored teeth are the most common method to determine microleakage due to its simplicity and cost effectiveness.(92)

❖ Dye penetration studies

Dye penetration is a diffusion of coloured agents to demonstrate microleakage phenomenon. The results are not obtained immediately, they are semi-quantitative, and the defect is evaluated on a section (two-dimensional evaluation). In general, this method for detecting microleakage after placing a restoration in an extracted tooth, coating the unfilled parts of the tooth with a waterproof varnish, immersing in a dye solution by visual examination to establish the extent of penetration of dye around the filling.(93)

However, it is highly technique sensitive and the assessment of results requires careful standardization. The main disadvantages of this technique is usually associated with the evaluation in the studies largely depends on the observer’s interpretation. Moreover, the assessment of the restoration as a whole is difficult when viewing only individual small sections of tooth.(92, 94) There have been wide variations in choice of dye used, methylene blue solution is one of the most common tracer.(95) It is impractical to use a dye particle which has a diameter greater than that of the internal diameter of dentinal tubues (I-4 μm)(93), the recommended size of dye particle is the one that diameter equal to the bacterial size or smaller which is around 2 μm. The area of methylene blue is calculated to be approximately 0.52 nm^2, smaller than the average size of bacteria.(94) None of the concentrations and immersion times are ideal, the concentrations of dye in microleakage test are ranged between 0.5%-10%, while the time of immersion of specimens in the dye varied between 4 hours to 72 hours or more.(93)

❖ Number of section

In vitro microleakage detection around dental restorations has been extensively reviewed in the literatures.(45, 92) The most commonly applied method is the use of dyes and a single midline section through the restoration in the tooth. Microleakage is assessed on an ordinal score and expressed as linear leakage length, or a percentage of leakage length related to the total length of the measured surface line.(96) Mixson et al. found that microleakage score of one section (two-surface) and multiple-section are not statistically significant difference when compare with the whole microleakage score of teeth.(97) Microleakage at the proximal corners of the restoration are more severe than others.(97) Therefore, in one section design, midline section through the restoration in the tooth might be the way to reduce error.

Review of material

- 3M ESPE Filtek Bulk Fill Posterior Restorative
    - Capsules
    - Syringes

Product Description

3M ESPE Filtek Bulk Fill Posterior Restorative material is a visible, light-activated restorative composite optimized to create posterior restorations simpler and faster. This bulk-fill material provides excellent strength and low wear for durability. The shades are semi-translucent and low-stress curing, enabling up to a 5 mm depth of cure. With excellent polish retention, Filtek Bulk Fill Posterior Restorative is also suitable for anterior restorations that call for a semi-translucent shade. All shades are radiopaque, offered in A1, A2, A3, B1 and C2 shades.

Product Features

- Packaged in 0.4 gram syringes are dark teal green with white labels and shade designations.

- Packaged in 0.2 gram capsules are black with dark teal green caps.

Indications for Use

- Direct anterior and posterior restorations (including occlusal surfaces)
- Base/liner under direct restorations
- Core build-ups
- Splinting
- Indirect restorations including inlays, onlays and veneers
- Restorations of deciduous teeth
- Extended fissure sealing in molars and premolars
- Repair of defects in porcelain restorations, enamel and temporaries

Composition

The fillers are a combination of a non-agglomerated/non-aggregated 20 nm silica filler, a non-agglomerated/non-aggregated 4-11 nm zirconia filler, an aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4-11 nm zirconia particles) and ytterbium trifluoride filler consisting of agglomerate 100 nm particles. The inorganic filler loading is about 76.5% by weight (58.4% by volume). Filtek Bulk Fill Posterior Restorative contains AUDMA (Aromatic urethane dimethacrylate), UDMA (urethane dimethacrylate) and DDDMA (1, 12-dodecane-DMA). A high molecular weight aromatic dimethacrylate (AUDMA) decreases the number of reactive groups in the resin. This helps to moderate the volumetric shrinkage as well as the stiffness of the developing and final polymer matrix, which contribute to the development of polymerization stress. DDDMA has a hydrophobic backbone that increases its molecular mobility and compatibility with nonpolar resins, which offers a low viscosity/low volatility resin that is commonly used in biomaterials and dental applications due in part to its fast cure with low exotherm and low shrinkage. UDMA is a relatively low-viscosity, high-molecular weight monomer, which is included in the resin system to reduce the viscosity of the resin. By modifying the proportions of these high molecular weight monomers, a resin system with the properties of a sculptable bulk fill material was developed.

Benefits

- One-step placement, no additional capping layer.

- Excellent adaptation without additional expensive dispensing devices.
- Stress relief to enable up to 5 mm depth of cure.
- Excellent handling and sculptability.

○ 3M ESPE Filtek Z350 XT Universal Restorative

Product Description

3M ESPE Filtek Z350 XT Universal Restorative is a visible light-activated composite designed for use in anterior and posterior restorations. All shades are radiopaque. A dental adhesive, such as manufactured by 3M ESPE, is used to permanently bond the restoration to the tooth structure. The restorative is available in a wide variety of Dentin, Body, Enamel and Translucent shades. It is packaged in syringes.

Indications for Use

- Direct anterior and posterior restorations (including occlusal surfaces)
- Core build-ups

- Splinting
- Indirect restorations (including inlays, onlays and veneers)

Composition

The fillers are a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4-11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4-11 nm zirconia particles). The Dentin, Enamel and Body (DEB) shades have an average cluster particle size of 0.6-10 microns. The Translucent (T) shades have an average cluster particle size of 0.6-20 microns. The inorganic filler loading is about 72.5% by weight (55.6% by volume) for the translucent shades and 78.5% by weight (63.3% by volume) for all other shades. The resin system is slightly modified from the original Filtek Z250 Universal Restorative and Filtek Supreme Universal Restorative resin. Filtek Z350 XT Universal Restorative resin system consists of three major components. The majority of TEGDMA (in the Z100™ Restorative system) was replaced with a blend of UDMA (Urethane dimethacrylate) and Bis-EMA (Bisphenol A polyethethylene glycol diether dimethacrylate). UDMA and Bis-EMA resins are of higher molecular weight than TEGDMA and therefore have fewer double bonds per unit of weight. The high molecular weight materials also impact the measurable viscosity. However, the higher molecular weight of the resin results in less shrinkage, improved aging and a slightly softer resin. TEGDMA and PEGDMA are used in minor amounts to adjust the viscosity. PEGDMA was used to replace part of the TEGDMA component to moderate shrinkage in Filtek Z350 XT restorative.

<u>Benefit</u>

- Simple to Use
- Lifelike aesthetics
- Unique nanofiller technology

- 3M ESPE Adper Scotchbond Multi-Purpose Adhesive

Product Description

The Adper scotchbond multi-purpose adhesive is a versatile system for bonding. Adper scotchbond etchant etches the enamel and removes the dentinal smear layer.

Adper scotchbond multi-purpose primer facilitates the wetting of the adhesive onto the prepared tooth structure. Adper scotchbond multi-purpose adhesive is the light-cure component of the system. It bonds to etched enamel and to dentin when conditioned using the etchant and primer. It will not self cure without the addition of Adper scotchbond multi- purpose plus catalyst.

Product Features

- Etchant
- Primer bottle
- Adhesive bottle

Indications for Use

- Direct and indirect resin composite restorations
- Metal, porcelain or composite crowns, inlays and onlays
- Amalgam and self-cure resin composite restorations
- Bond orthodontic bracket to crowns

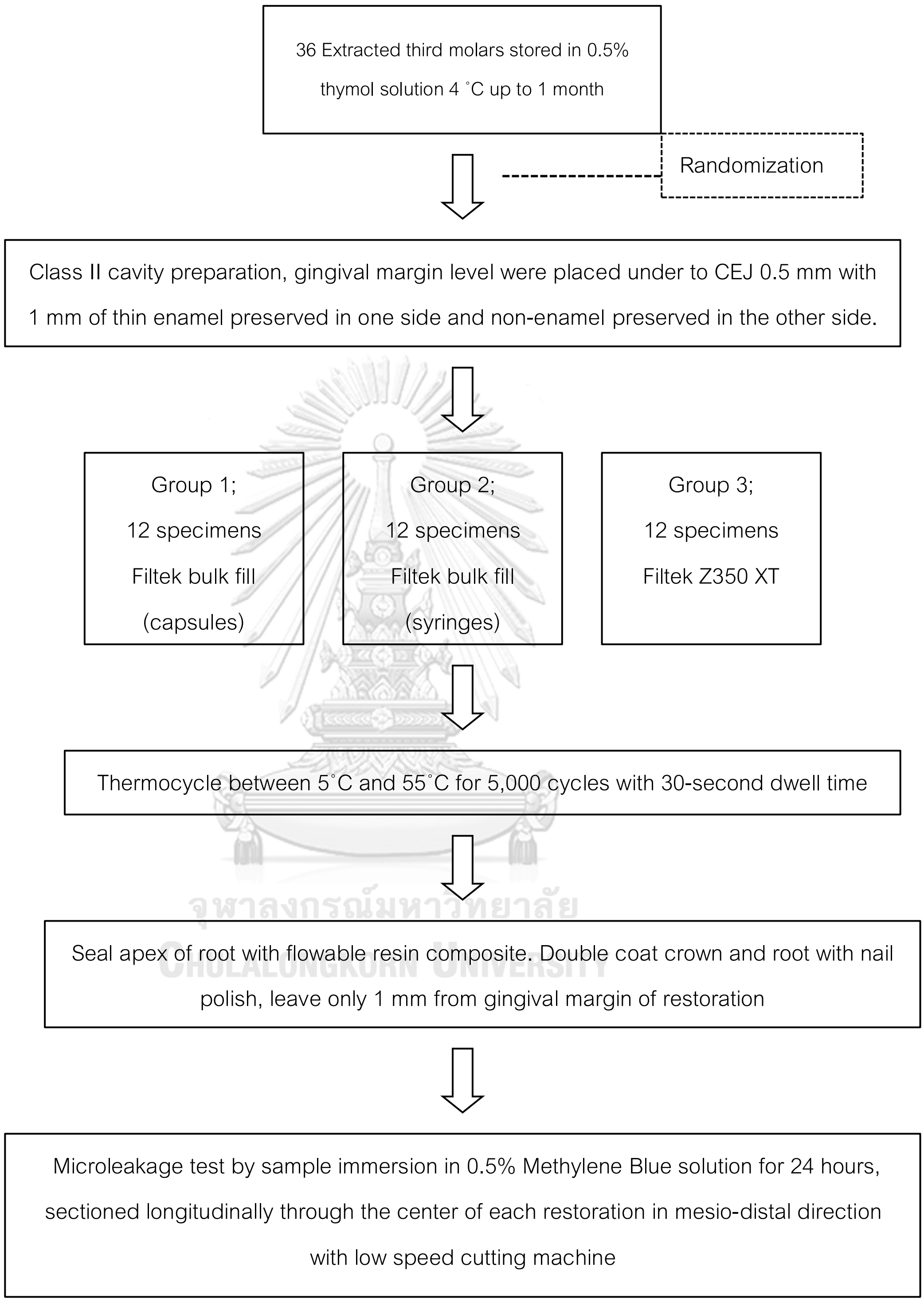
<u>Composition</u>

Adper scotchbond etchant etches the enamel and removes the dentinal smear layer in preparation for bonding. Either scotchbond 10% maleic acid etchant or 35% phosphoric acid etchant can be used. Use of an etchant is critical on both enamel and dentinal surfaces. The maleic acid etchant has a pH of approximately 1.2 while the phosphoric acid etchant has a pH of approximately 0.6.

Adper scotchbond multi-purpose primer is an aqueous solution of HEMA and a polyalkenoic acid copolymer first introduced in Vitrebond glass ionomer liner/base. Incorporation of the polyalkenoic acid into the formulation has been shown to aid in resisting the detrimental effect of moisture in a high relative humidity environment. The pH of the primer is approximately 3.3.

Adper scotchbond multi-purpose adhesive is a BIS-GMA and HEMA resin combined with a novel initiation system. A blend of amines allows for a fast, 10-second light cure as well as compatibility with the peroxide component of the catalyst resin. Thus the adhesive can be used in either a light-cure mode or, when combined with the catalyst, in self-cure or dual-cure modes. Scotchbond multi-purpose adhesive is used for all light-cure applications. When mixed with the catalyst, a dual- cure system is obtained which is indicated for bonding amalgam and self-cure composite.

CHAPTER III MATERIALS AND METHODS



Photograph samples with 20X magnification Stereomicroscope.

⇩

Dye penetration scores were evaluated at dental-restorative junction of the gingival margin by 3-blinded restorative dentists that already practiced in interpreting the microleakage score and get excellent strength of reliability.

⇩

Data collection, Data analysis and Interpretation

Figure 2 Research methodology

Materials and methods

Materials

1. Filtek Bulk Fill Posterior Restorative (shadeA2, 3M ESPE, St. Paul, MN, USA) in capsules and syringes product
2. Filtek Z350 XT Universal Restorative (shadeA2, 3M ESPE, St. Paul, MN, USA)
3. Adper Scotchbond Multi-Purpose Adhesive (3M ESPE, St. Paul, MN, USA)
4. 0.5% Methylene Blue solution
5. Premise flowable resin composite (shadeA2, Kerr, USA)

6. Red nail polish (Tenten, Thailand)

7. Clay (P-Clay, Thailand)

Equipments

1. Cylinder diamond bur (DIA TESSIN, Thailand) diameter 1.5 mm

2. Cutting tip edge diamond bur (Cross Tech, Thailand) diameter 1.0 mm

3. Carborundum disk (Miltex, Germany)

4. Digital Vernier Caliper 0.01 mm (Mitutoyo, Japan)

5. Dental loupes 2.8x magnification (Orascoptic, USA)

6. Microbrush (Kerr, USA)

7. Auto matrix (Kerr, USA)

8. 5A XTS plugger (Hu-Friedy, USA)

9. W3 composite instrument (Hu-Friedy, USA)

10. Composite dispenser gun (Kerr, USA)

11. Scalpel blade number 12 (Swann-Morton, England)

12. Light curing unit (DEMI PLUS, Kerr, WI, USA)

13. Digital dental radiometer (Demetron L.E.D. Radiometers, Kerr, USA)

14. Low speed cutting machine (Model ISOMET 1000, Buehler, USA)

15. Thermocycling Unit (Certiga, Austria)

16. Incubator (Contherm 160M, Contherm Scientific Ltd., New Zealand)

17. Stereomicroscope (ML 9300 MEIJI TECHNO, Saitama, Japan)

Methods

1. Sample description

Sample size calculation was done as the equation shown below;

$$n = \frac{\sigma^2 (Z_{\alpha/2} + Z_\beta)^2}{(\mu_1 - \mu_2)^2}$$

$$\sigma^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$$

The α and β values utilizing are 0.05 and 0.2 respectively.

$Z\alpha/2$ = 1.96 at 95 % confidence interval, Z_β = 0.84 at power of test 80%.

The value of μ_1, μ_2, n_1, n_2 and σ^2 are 1.13, 0.38, 8, 8 and 1.768, which obtained from the pilot study.

$$n = \frac{[1.96+0.84]^2(1.768)^2}{(1.13-0.38)^2}$$

$$n \approx 24$$

Pilot study was performed under a protocol approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Pilot study code: P-2015-002). The calculation showed adequate sample size of 24 sections per group, which equal to 12 teeth per group. Therefore, a randomized group of 12 specimens were created under a protocol approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Study code: HREC-DCU 2016-049). Non-carious, non-restored nor crack extracted human third molars were collected after informed consent has been obtained under a protocol approved by the Ethics Committee of the Faculty of Dentistry, were debrided and stored in a 0.5% thymol solution at 4 °C up to 1 month but not greater than 6 months following extraction. All of the samples were conditioned in distilled water at 23 ± 2 °C for a minimum of 12 hours prior to use according to ISO/TS11405: 2015.

2. Cavity preparation

All preparations were performed under dental loupes magnifications of 2.8x (Orascoptic, USA)

2.1 Class II cavity size of 3 mm in width and 1.5 mm in depth at coronal 1/3, 2 mm at occlusal1/3 were prepared parallel to tooth surface superior to CEJ 1 mm by cylinder diamond bur diameter 1.5 mm (DIA TESSIN, Thailand) in both medial and distal side of all specimens.

2.2 Cutting tip edge diamond bur diameter 1 mm (Cross Tech, Thailand) was used to deepen the cavity inferior to CEJ 0.5 mm and the side of sample, mesial or distal, was randomly picked to preserve 0.5 mm thickness, 1 mm in depth and 3 mm in width of thin enamel in one side (EP). For the opposite, thin enamel was eliminated to create straight horizontal gingival wall (NP).

2.3 The teeth were flattened parallel to occlusal surface at 3.5 mm from CEJ with carborundum disc (Miltex, Germany), measured from both mesial and distal side.

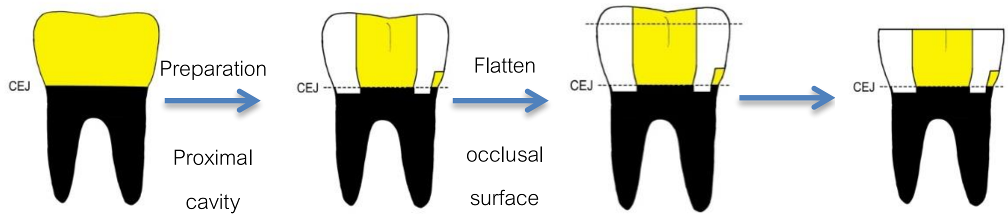


Figure 3 Preparation of samples

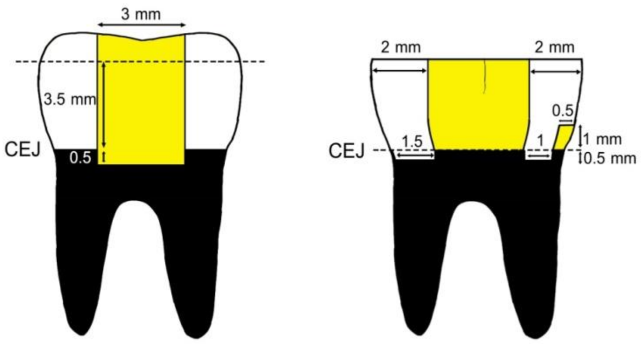


Figure 4 Dimensions of class II cavity preparation

A: Proximal cavity of non-enamel preserved side (NP)

B: Frontal view with compose of non-enamel preserved side (NP)(left) and enamel preserved side (EP)(right)

C: Proximal cavity of enamel preserved side (EP)

3. Restorative technique

In restorative procedure, the cavitated teeth were placed adjacent to the molar tooth in a clay block to replicate the clinical situation. Automatrix (Kerr, Orange, CA, USA) was used with a transparent band (5.0 mm) and wood wedge. Half of each experimental group (6 specimens) was randomly restored the “EP” side prior to “NP” side. Each first restored side was wrapped with thin aluminum foil before the second side was restored. The cavity surface was conditioned using Adper Scotchbond Multi-Purpose Adhesive (3M ESPE, St. Paul, MN, USA). The process was performed following the manufacturer’s instructions as follows: etch with 35% phosphoric acid for 15 seconds, rinse with water from triple syringe for 15 seconds, blot dry with triple syringe with air density at 2 bar pressure for 5 seconds, apply primer with microbrush 2 times for 5 seconds each, completely dry with air density at 2 bar pressure for 10 seconds, apply bonding with microbrush for 5 seconds, then light cure for 10 seconds. The position of the LED light-curing tip (DEMI PLUS, Kerr, WI, USA) was adjusted perpendicular and close to the occlusal surface of the cavity. Periodic Level Shifting (PLS) mode which is shifting of the output intensity from 1100 mW/cm^2 to a peak of 1330 mW/cm^2 in a short time for multiple times throughout the curing cycle was used. The light-curing unit was recharged and measured the intensity with Digital dental radiometer (Demetron L.E.D. Radiometers, Kerr, USA) every day before usage. Blade no.12 (Swann-Morton, Shieffield, Eng) was used to finish the restoration's margin. All preparation and restoration were performed by one operator under dental loupes at magnifications of 2.8X (Orascoptic, Middleton, WI, USA).

Group 1 (12 specimens); Filtek Bulk Fill Posterior Restorative, capsule type (BFC) (shadeA2, 3M ESPE, St. Paul, MN, USA) was placed 4 mm in one time to completely fill the cavity using a composite dispenser gun.

Group 2 (12 specimens); Filtek Bulk Fill Posterior Restorative, syringe type (BFS) (shadeA2, 3M ESPE, St. Paul, MN, USA) was placed 4 mm in one time to completely fill the cavity using a W3 Composite Instrument (Hu-Friedy, Chicaco, IL, USA). For both Group 1 and Group 2, resin composites were condensed with a 5A XTS Plugger (Hu-

Friedy, Chicaco, IL, USA) in10 times. Then, the materials were light-cured at occlusal, buccal and lingual sides for 20 seconds on each side.

Group 3 (12 specimens); Filtek Z350 XT (Z350) (shadeA2, 3M ESPE, St. Paul, MN, USA) was placed into the cavity in two layers using a W3 Composite Instrument (Hu-Friedy, Chicaco, IL, USA). The first 2 mm layer was plugged with a 5A XTS Plugger (Hu-Friedy, Chicaco, IL, USA) in 10 times and then light-cured on the occlusal side for 20 seconds. The next horizontal incremental layer was performed as the first layer and light-cured at occlusal, buccal and lingual sides for 20 seconds on each side.

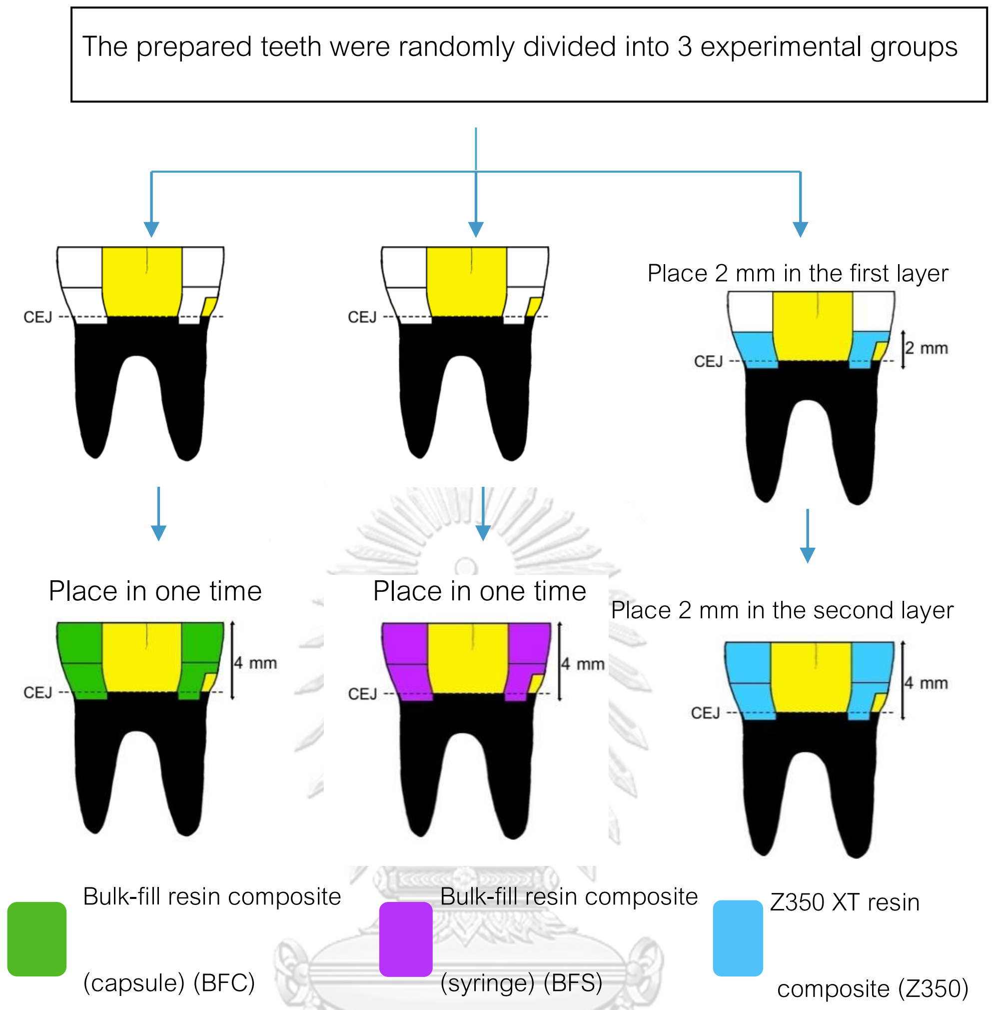


Figure 5 Restorative technique in three experimental groups

4. Specimen preparation for microleakage test

All restored specimens were thermocycled (Certiga, Unterhaching, Austria) between 5 °C and 55 °C for 5,000 cycles with 30-second dwell time to simulate clinical aging after 24 hours storage in distilled water at 37 ± 2 °C. The root tips were coated and sealed with flowable resin composite (Premise, Kerr, Orange, CA, USA). Crown and root were double coated with red nail polish, leaving only a 1 mm gingival margin of restoration. All specimens were dried for 24 hours prior to test the microleakage.

5. Microleakage test

All specimens were immersed in 0.5% methylene blue solution for 24 hours. After removing the nail polish and rinsing with water for 5 minutes, the teeth were placed into an acrylic block with the occlusal surface parallel to the ground position and sectioned mesiodistally through the restorations using a low speed cutting machine (model ISOMET 1000, Buehler, Binghamton, NY, USA).

6. Outcome Measurement

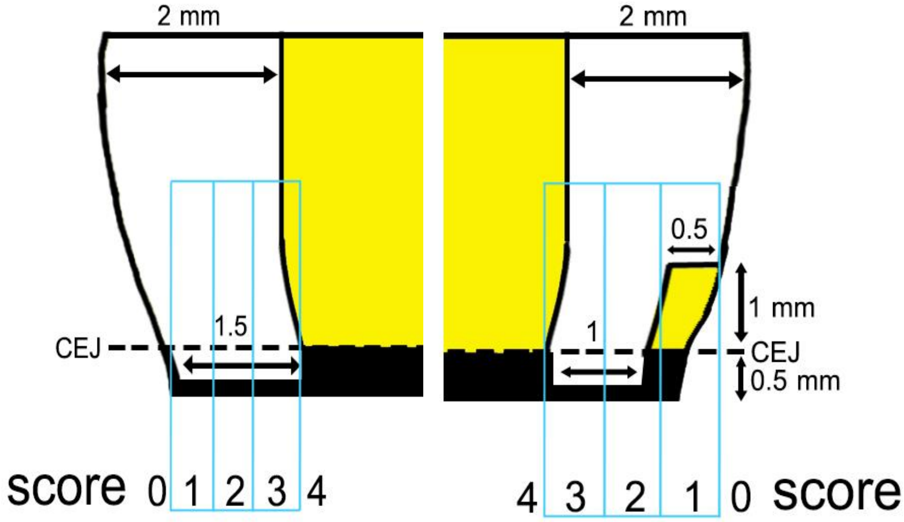


Figure 6 Scoring of microleakage

Ordinal and dichotomic data are most commonly used to evaluate microleakage.(82) The ISO/TS11405 (2015) recommends evaluating microleake in ordinal scale. The microleakage results in each study group differed only slightly; therefore, interpretation of the results was difficult. Focusing on the severity of the leakage close to the pulp, the ordinal scale split the range of microleakage scores to allow the researcher to observe the severity of the leakage more clearly and more easily compare the detailed results of each experimental group and other microleakage studies. Therefore, scoring of the microleakage in this study at the gingival margin was assessed using the following criteria as per Chuang. SF et al.(98):

0 = No dye penetration (No microleakage)

1 = Dye penetration up to one-third of the gingival wall (Mild microleakage)

2 = Dye penetration up to two-thirds of the gingival wall (Moderate microleakage)

3 = Dye penetration up to the full length of the gingival wall (Moderate microleakage)

4 = Dye penetration up to the whole length of the gingival wall and along the axial wall (Severe microleakage)

7. Data Collection and Analysis

The sectioned specimens, both buccal and lingual side, were examined at 20X magnification using a stereomicroscope (ML 9300 MEIJI TECHNO, Saitama, Japan) and standardized digital images were obtained. The images were randomly arranged with Keynote program to evaluate dye penetration at the gingival margin individually by three blinded examiners who were restorative dentists. All examiners were calibrated and had excellent strength of reliability in ICC (intraclass correlation coefficient interpretation). Timing of evaluating the scores of microleakage was 15 seconds per photo. Consensus was forced in case of disagreement occurred after the evaluation all of specimens by selecting the issue images to rediscuss the score.

All data were analyzed with statistical software (SPSS 22.0; spss). All test were performed with the level of significance at $\alpha = 0.05$. Due to the nature of microleakage score as ordinal scale, non-parametric test was utilized.

1. Kruskal-Wallis test were utilized to analyze whether there is any significant differences between 3 restorative materials, both in enamel preserved (EP) and non-enamel preserve (NP) groups. After the result showed statistical significant difference ($P < 0.05$), multiple comparison test (Dunn test) was performed to determine which pair of techniques is different.
2. Mann-Whitney u test was utilized to analyze the difference between two groups, “EP” and “NP” in the same restorative material.

CHAPTER IV RESULTS

Materials used are shown in Table 1. The number of specimens available for evaluation was 141 from 144 specimens. Three fillings were lost during the cutting procedure. The dye penetration and mode of scores at the gingival wall of class II resin composite restorations are shown in Table 2. Representative specimens of enamel preserved group and non-enamel preserved group restored with Filtek Bulk Fill (Capsules), Filtek Bulk Fill (Syringes) and Filtek Z350 XT are shown in Figure 7.

Results of Mann-Whitney U test in Table 2 showed that the "NP" group had significantly higher microleakage scores than the "EP" group for all of the three restorative materials.

The Kruskal-Wallis test revealed significant differences in microleakage scores among three restorative materials ($p<0.05$). Further analysis with Dunn test showed in Table 3 that for "EP" group, "Z350" showed statistically significant higher microleakage scores than "BFC" (P = 0.001) and "BFS" (P = 0.028). For the "NP" group, "Z350" showed statistically significant higher microleakage scores than "BFC" (P = 0.001) but no significant difference with “BFS”. “BFC” and “BFS” showed no significant difference in microleakage score between each other.

Table 1 Materials used with the manufacturer's information, composition and lot numbers

Material / Manufacturer	Composition	Lot #
Filtek Bulk Fill Posterior Restorative (capsule type) 3M ESPE, St. Paul, MN, USA	AUDMA, DDDMA, UDMA, Silica (20 nm non-agglomerated/aggregated), Zirconia (4-11 nm non=agglomerated/aggregated), Zirconia/Silica aggregated cluster (20 nm silica combined with 4-11 nm zirconia), Ytterbium trifluoride (100 nm aggregated)	N666574
Filtek Bulk Fill Posterior Restorative (syringe type) 3M ESPE, St. Paul, MN, USA	AUDMA, DDDMA, UDMA, Silica (20 nm non-agglomerated/aggregated), Zirconia (4-11 nm non=agglomerated/aggregated), Zirconia/Silica aggregated cluster (20 nm silica combined with 4-11 nm zirconia), Ytterbium trifluoride (100 nm aggregated)	N611596
Filtek Z350 XT 3M ESPE, St. Paul, MN, USA	UDMA, BIS-EMA, PEGDMA, Silica (20 nm non-agglomerated/aggregated), Zirconia (4-11 nm non=agglomerated/aggregated), Zirconia/Silica aggregated cluster (20 nm silica combined with 4-11 nm zirconia)	N652159
Adper Scotchbond Multi-Purpose Adhesive 3M ESPE, St. Paul, MN, USA	Etchant: 35% Phosphoric acid Primer: HEMA, Polyalkenoic acid copolymer Adhesive: Bis-GMA, HEMA	N616851

Abbreviations: AUDMA, AROMATIC URETHANE DIMETHACRYLATE; DDDMA, 1,12-DODECANE DIMETHYCRYLATE; UDMA, DIURETHANE DIMETHACRYLATE; BIS-EMA, BISPHENOL A ETHOXYLATE DIMETHACRYLATE; PEGDMA, POLYETHYLENE GLYCOL DIMETHACRYLATE; BISGMA, BISPHENOL A GLYCIDYL METHACRYLATE; HEMA, 2-HYDROXYETHYL METHACRYLATE

Table 2 Distribution of the microleakage score, Mode of score and Mann-Whitney U test between enamel preserved groups and non-enamel preserved groups of the three restorative materials.

Group		Microleakage score 0	1	2	3	4	Total	Mode of score	Asymp. Sig. (*P*-value)
BFC	EP	20	3	-	-	-	23	0	0.003*
	NP	11	5	1	1	5	23	0	
BFS	EP	19	-	-	-	5	24	0	0.003*
	NP	6	4	4	2	8	24	4	
Z350	EP	9	8	-	2	5	24	0	0.001*
	NP	2	2	1	3	15	23	4	

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

Abbreviations: BFC, Filtek Bulk Fill Posterior Restorative (capsule type); BFS, Filtek Bulk Fill Posterior Restorative (syringe type); Z350, Filtek Z350 XT; EP, Enamel preserved; NP, Non-enamel preserved

Table 3 Multiple comparison (Dunn test) between the three restorative materials of enamel preserved groups and non-enamel preserved groups

Group	Asymp. Sig. EP (*P*-value)	Asymp. Sig. NP (*P*-value)
BFC versus**BFS**	0.976	0.247
BFC versus**Z**350	*0.001	*0.001
BFS versus**Z**350	*0.028	0.170

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

Abbreviations: BFC, Filtek Bulk Fill Posterior Restorative (capsule type); BFS, Filtek Bulk Fill Posterior Restorative (syringe type); Z350, Filtek Z350 XT; EP, Enamel preserved; NP, Non-enamel preserved

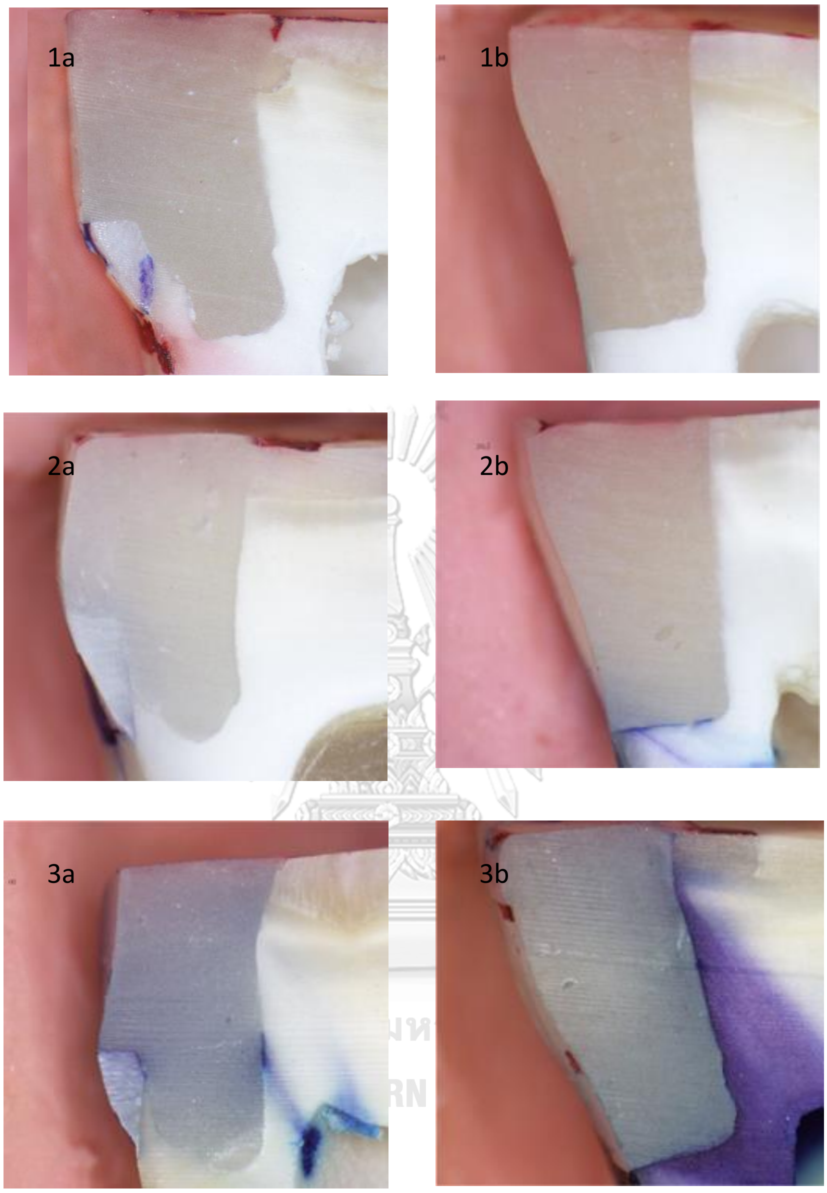


Figure 7 Representative specimen 1a, 2a and 3a showed microleakage of enamel preserved group (Score0, 0, 4) 1b, 2b and 3b showed microleakage of non-enamel preserved group (Score0, 3, 4) restored with Filtek Bulk Fill (Capsules)(1a, 1b), Filtek Bulk Fill (Syringes) (2a, 2b) and Filtek Z350 XT (3a, 3b) respectively.

CHAPTER V DISCUSSION

A microleakage test is one of the methods used to measure the quality of resin composite restoration. Many researchers used this test to measure the properties of dental restorations because of its simplicity in performing the test. The data obtained could be easily evaluated and samples were not destroyed during measurement interpretation.(99) However, there were also disadvantages to the microleakage test, the evaluation of microleakage largely depends on the observer's interpretation and the microleakages are scored from 2D image, while the restoration material is shaped in 3D. Therefore, the microleakage results might have some discrepancies from actuality.(94) According to the ISO/TS11405 (2015), many tracer solutions have been used for microleakage test. It is obviously impractical to use a dye particle which has a diameter greater than the internal diameter of the dentinal tubules (1-4 μm).(93) The recommended size of dye particle is a diameter equal to the bacterial size or smaller at around 2 μm. Considering the penetration capacity of methylene blue, its use is considered as a good tracer for microleakage test because the area of methylene blue is very small (0.52 nm^2) when compared to the mean size of a bacteria(94) and its penetration into the specimen can be easily detected by stereomicroscope. However, if the detection of a very severe nanoleakage test was required, such as analyzing of discrepancy between the depth of the demineralized zone and monomer diffusion, silver nitrate would be a better choice because of the diameter of the silver ion (0.059 nm) and its strong optical contrast.(71) Previous concentrations of methylene blue used ranged from 0.5% to 10%, while time of immersion of specimens in the dye ranged between 4 and 72 hours or more.(93) None of the concentrations are ideal but the recommended immersion time from the ISO/TS11405 (2015) is 24 hours. In this study, methylene blue at 0.5% and 24 hours immersion time was used because of its quality being high

enough for testing microleakage, ease of preparation and cost effectiveness.

In this research, two bulk-fill products (“BFC” and “BFS”) were compared with conventional resin composite (“Z350”). The products all came from the same company and contained the same type of filler in nanometric scale. “Z350” is well known and widely used in dental clinics. The manufacturer claims that “BFC” and “BFS” have 4 mm depth of cure with less polymerization shrinkage. This concurred with the results in Table 2, indicating that the majority of the specimens in “BFC” and “BFS” showed no microleakage (score 0), while less than half of “Z350” specimens showed no microleakage (score 0) or mild microleakage (score 1). The majority of “Z350” specimens showed severe microleakage (score 4).

Neither of two bulk-fill products represented others bulk-fill products in the market due to difference in compositions and properties.(16, 17, 100) It is known that the shear stresses induced by injection technique can improved marginal adaptation instead of a hand instrument.(101) Resin composite was placed into the prepared cavity by a hand instrument in “BFS” group, similarly to the conventional resin composite; while, “BFC” resin composite was dispensed through a capsule tip by a composite dispenser gun at the deepest part of prepared cavity, and then the tip was slowly withdrawn as the cavity was filled. Hence, “BFC” should perform better microleakage score than “BFS”. Nevertheless, the results showed no significant difference in microleakage score between using “BFC” and “BFS”.

One thing concerning the use of “BFC” is the diameter of the tip being 2 mm. Therefore, in small cavities with width less than 2 mm the tip may not reach till the cavity depth, and this can result in poor adaptation of restorative resin if the force to compress the thick layer of resin composite is not high enough. In this research, “BFC” still showed good results for microleakage at a gingival margin of 1.5 mm. This might be because the cavity design size at the occlusal approached 2 mm then the tip could be pushed down into the cavity.

Focusing on dental substrates, microleakage scores ranged from no leakage (0) to the highest severe leakage (4). The samples were divided into three parts by an imaginary line in the Keynote program (Figure6). In the first part (score 1), there was a difference in the distance of dye penetration because the height of the enamel in “EP” groups, making the leakage pathway to reach the second part longer than in “NP” groups. Results of microleakage distribution in Table 2 showed the scores of “EP” group were mostly 0-1 (no to mild microleakage). In contrast, the majority of microleakage scores for “NP” group were 3-4 (moderate to severe microleakage). These findings concurred with other authors who reported that leakage mostly occurred at the dentin surface.(102-104) The preservation of a thin enamel layer at the gingival wall in this research increased the leakage distance from the outside margin to the dentin. The thin enamel layer (0.5 mm) was still preserved, even without the supporting dentin due to its location being at the proximal, which is not directly subjected to occlusal stress. However, this enamel layer might become fractured as a consequence of polymerization shrinkage stress.(14) Therefore, Future research might test for microleakage combined with mechanical loading to observe how occlusal force impacts on this thin enamel layer. In this study, etch and rinse system was used which considered as a gold standard adhesive. A study has shown that different adhesive systems had an affect on microleakage scores in enamel substrate but not in dentin substrate.(105) Therefore, the results of this study may be different if other adhesive systems were used.

Dye penetration into other areas, not at the dental-restorative junction, was found in some specimens (25 pieces from 141 pieces), mostly occurred in “EP” groups at enamel-dentin junction (Figure 8), which did not affact the interpreting of microleakage score. Reasons for dye penetration in dental substrate beyond the dental-restorative junction were not determined, but may be due to the pattern of anatomical of the cementoenamel junction which absence of contact between enamel and dentin. Therefore the dentin is an external part of the tooth surface that leakage mostly occurred.

Thermocycling was a widely accepted method for *in vitro* microleakage studies.(82) A literature review concluded that 10,000 cycles corresponded approximately to 1 year of *in vivo* functioning.(78) The ISO/TS11405 (2015) suggests that a thermocycling regimen comprising of 500 cycles in water between 5 °C and 55 °C with at least 20 seconds dwell time is an appropriate artificial aging test. Here, 5,000 test cycles were used as an aging technique to simulate the intraoral temperature. Further research might evaluate results for 10,000 cycles to replicate 1 year of *in vivo* functioning and observe how the added cycles affect on microleakage of all experimental groups.

Regarding clinical implications, preserving the enamel at the gingival margin would make it easier for the dentist to build up contact or prevent moisture from sulcular fluid due to the higher margin of restorations compared to cavities without preserving. Furthermore, it would be easier for patients to perform routine cleaning when the margin of the restorative materials was not below the gingiva. Limited studies have investigated the thin enamel and further research is necessary to determine any possible disadvantages of preserving this thin enamel layer.

Figure 8 Representative specimens showed dye penetration into other areas, not at the dental-restorative junction of enamel preserved group (Score0, 0, 0) a, b and c restored with Filtek Bulk Fill (Capsules) (a), Filtek Bulk Fill (Syringes) (b) and Filtek Z350 XT (c) respectively.

CHAPTER VI CONCLUSIONS

In Conclusions, under controlled condition of this research, microleakage of class II resin composite filling occurred in all the three experimental materials “BFC”, “BFS” and “Z350” for both “EP” and “NP” groups. However, preserving thin layer of enamel (“EP”) and use of two bulk-fill products (“BFC” and “BFS”) reduced microleakage.

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APPENDIX

Appendix A. Raw data of microleakage scored by three examiners

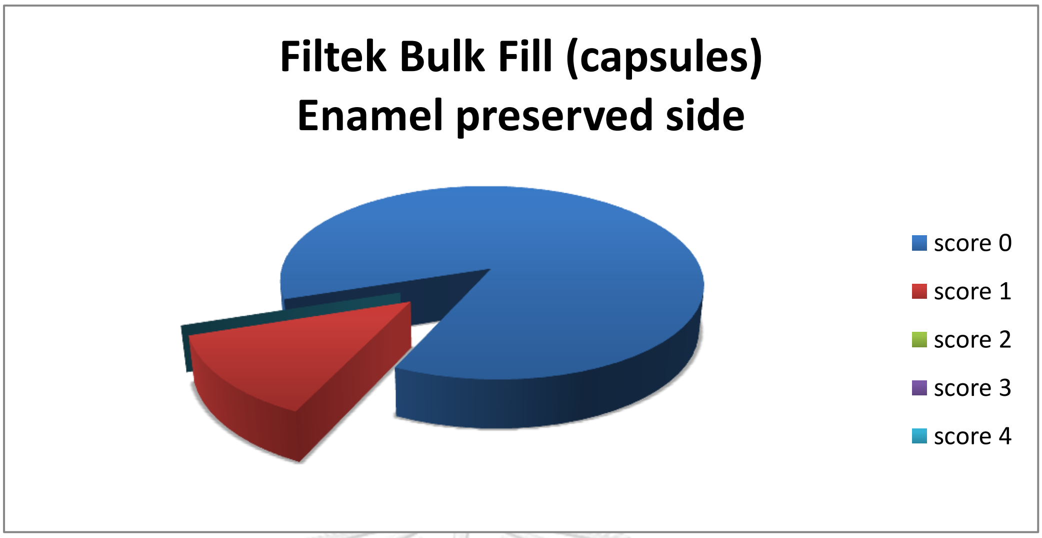
Table 4 Microleakage score of random specimens for measurement of intra-rater reliability (Intra class Correlation Coefficient)

Specimens	Examiner 1		Examiner 2		Examiner 3	
	Score1	Score 2	Score 1	Score 2	Score 1	Score 2
1	2	2	2	2	2	2
2	2	3	2	2	2	2
3	1	0	1	0	0	1
4	0	0	0	1	0	0
5	4	4	4	4	4	4
6	4	4	4	4	4	4
7	0	0	0	1	0	0
8	1	1	0	1	0	1
9	4	4	4	4	4	4
10	4	4	4	4	0	4
11	4	4	4	4	4	4
12	4	4	4	4	0	4
13	0	0	0	0	0	1

Table 5 Distribution of the microleakage score of Filtek Bulk Fill (capsules)

Group 1 Filtek Bulk Fill (capsules)	Examiner 1		Examiner 2		Examiner 3		Total score	
	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	2	0	2	0	2	0	2	0
4	2	0	3	0	3	0	3	0
5	1	0	1	0	0	0	1	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	1	0	1	0	1	0	1
10	0	1	0	1	0	1	0	1

11	0	1	0	0	0	1	0	1
12	0	1	0	0	0	1	1	0
13	4	0	4	0	4	0	4	0
14	4	0	4	0	4	0	4	0
15	1	0	1	0	1	0	1	0
16	4	0	4	0	4	0	1	0
17	4	0	4	0	4	0	4	0
18	4	0	4	0	4	0	4	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	4	0	4	0	4	0	4	0
23	1	0	1	0	1	0	1	0



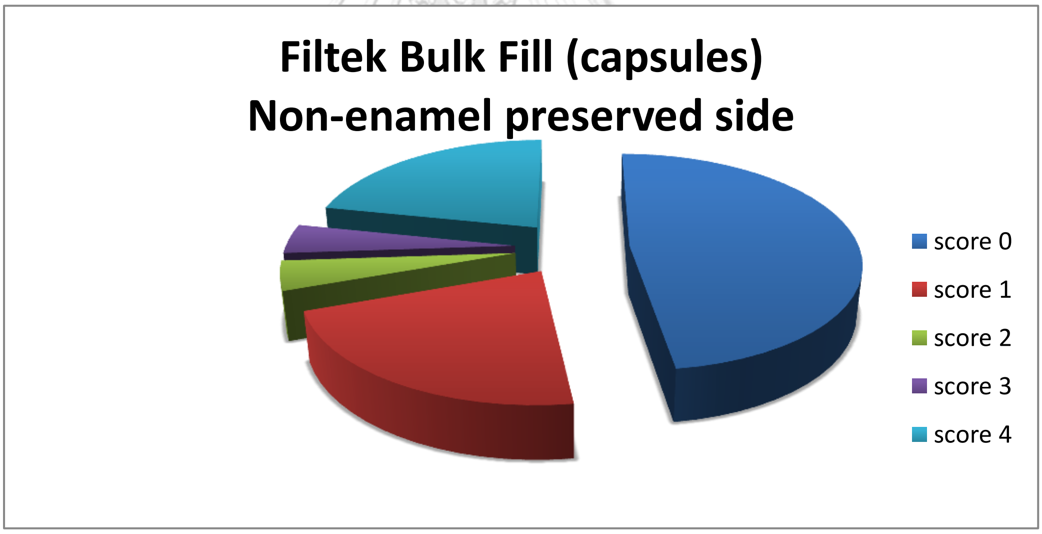
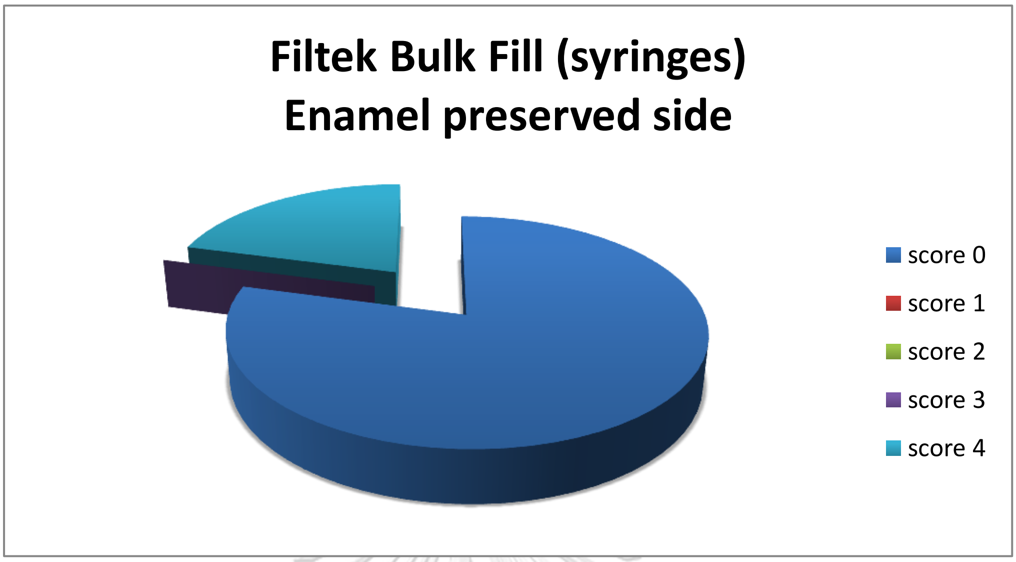


Figure 9 Distribution of the microleakage score of Filtek Bulk Fill (capsules) in enamel preserved and non-enamel preserved side.

Table 6 Distribution of the microleakage score of Filtek Bulk Fill (syringes)

Group 2 Filtek Bulk Fill (syringes)	Examiner 1		Examiner 2		Examiner 3		Total score	
	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved
1	2	0	2	0	2	0	2	0
2	2	0	2	0	2	0	2	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	4	0	4	0	4	0	4	0
6	1	4	1	4	1	4	1	4
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	4	0	4	0	4	0	4	0
10	4	0	4	0	4	0	4	0

11	4	0	4	0	4	0	4	0
12	4	0	4	0	4	0	4	0
13	0	0	0	0	0	0	0	0
14	1	0	1	0	1	0	1	0
15	3	0	3	0	3	0	3	0
16	3	0	3	0	3	0	3	0
17	4	0	4	0	4	0	4	0
18	4	0	4	0	4	0	4	0
19	2	0	1	0	2	0	2	0
20	1	0	1	0	1	0	1	0
21	2	4	1	4	2	4	2	4
22	4	4	4	4	4	4	4	4
23	1	4	1	4	0	4	1	4
24	0	4	0	4	0	4	0	4



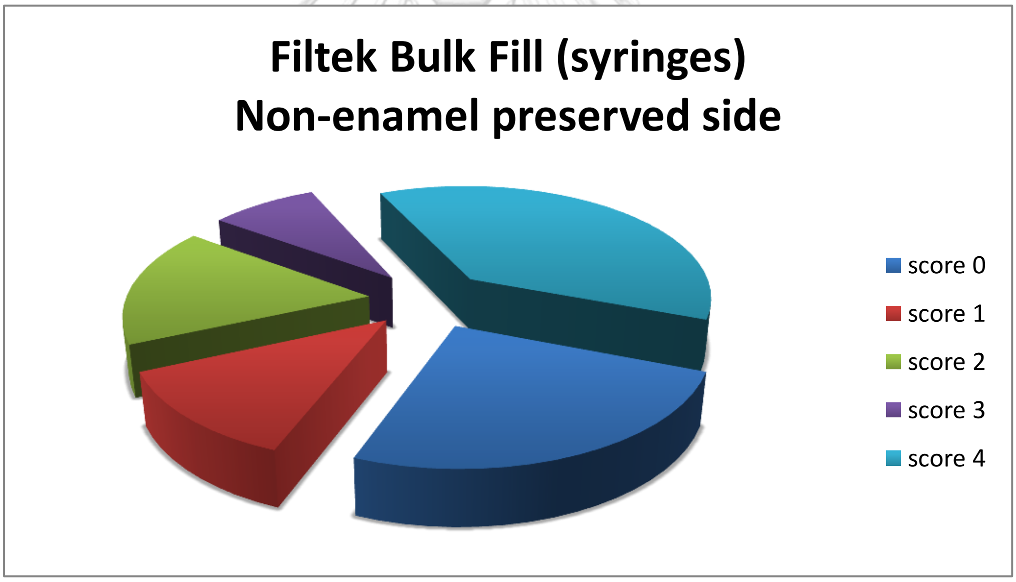
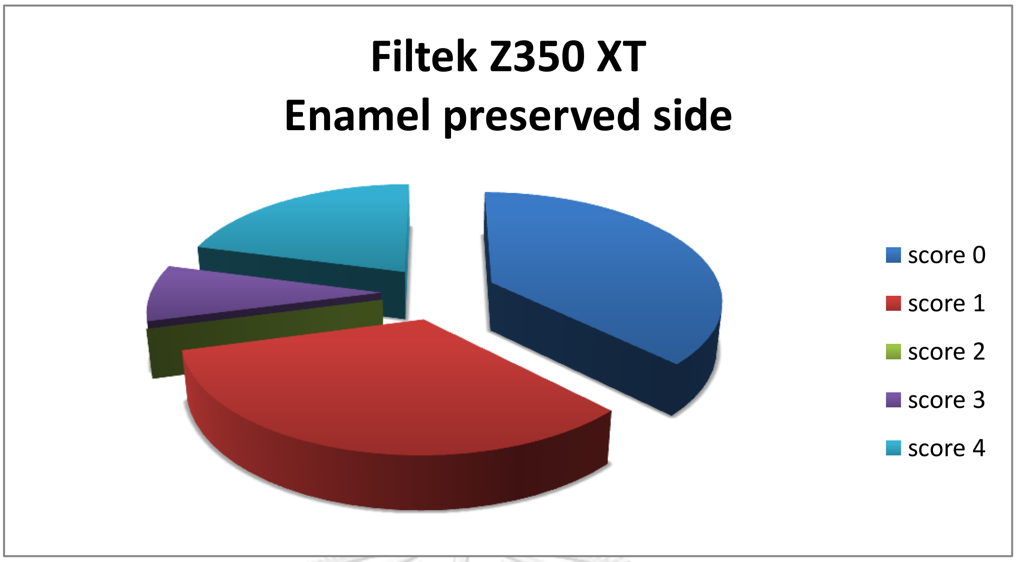


Figure 10 Distribution of the microleakage score of Filtek Bulk Fill (syringes) in enamel preserved and non-enamel preserved side.

Table 7 Distribution of the microleakage score of Filtek Z350 XT

Group 3 Filtek Z350 XT	Examiner 1		Examiner 2		Examiner 3		Total score	
	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved	Non-enamel preserved	Enamel preserved
1	3	0	3	0	3	0	3	0
2	3	0	3	0	3	0	3	0
3	4	1	4	1	4	1	4	1
4	4	1	4	1	4	1	4	1
5	1	1	1	1	1	1	1	1
6	1	0	1	1	1	1	1	1
7	4	4	4	4	4	4	4	4
8	4	4	4	4	4	4	4	4
9	4	1	4	1	4	1	4	1
10	4	1	4	1	4	1	4	1

11	3	4	3	4	3	4	3	4
12	2	4	2	4	2	4	2	4
13	4	0	4	0	4	0	4	0
14	4	0	4	1	4	1	4	1
15	4	0	4	0	4	0	4	0
16	4	0	4	0	4	0	4	0
17	0	3	0	3	0	3	0	3
18	0	3	0	3	0	3	0	3
19	4	0	4	0	4	0	4	0
20	4	0	4	1	4	1	4	1
21	4	4	4	4	4	4	4	4
22	4	0	4	0	4	0	4	0
23	4	0	4	0	4	0	4	0
24	-	0	-	0	-	0	-	0



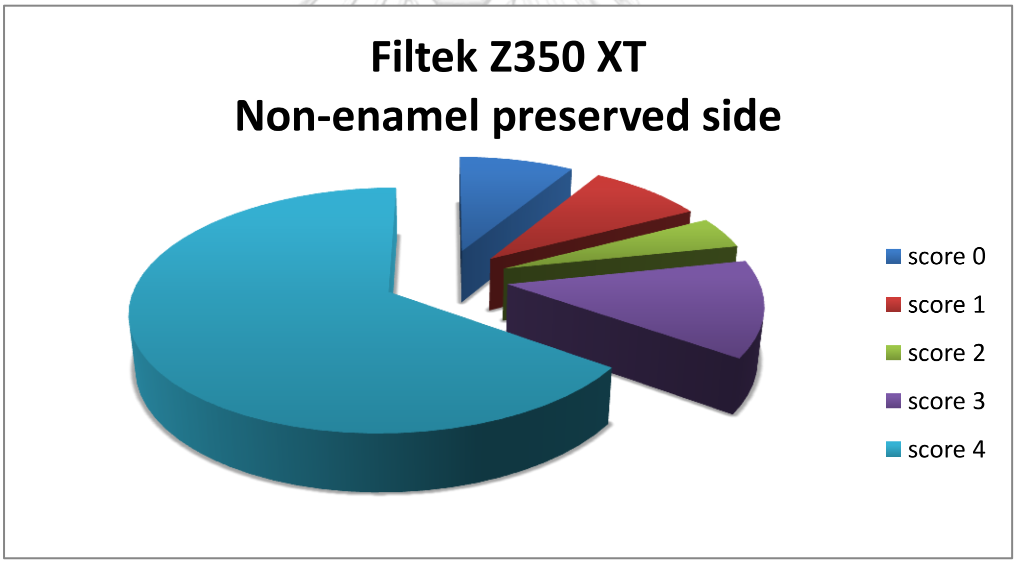
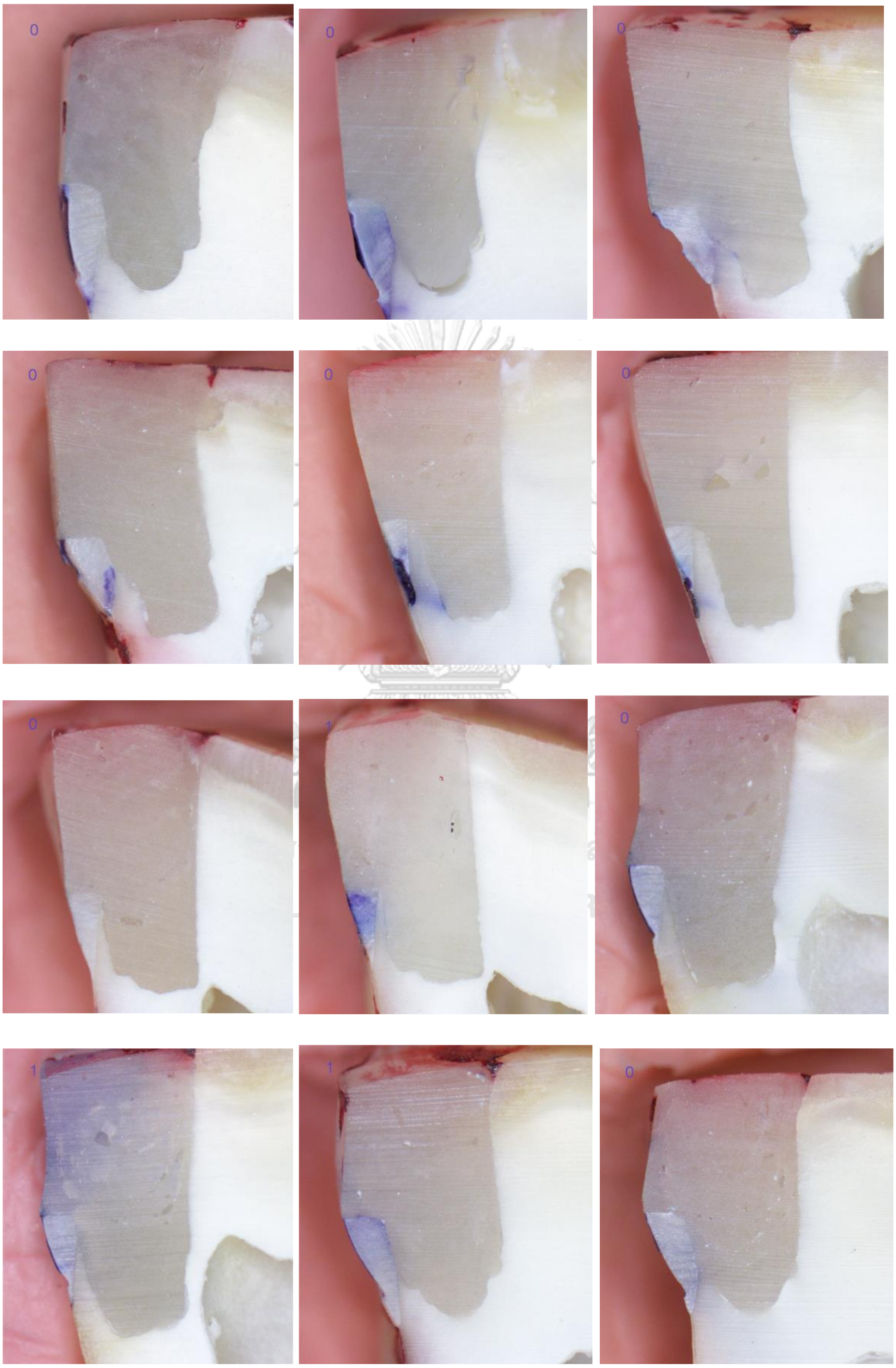


Figure 11 Distribution of the microleakage score of Filtek Z350 XT in enamel preserved and non-enamel preserved side.

Figure 12 Samples of enamel preserved group of Filtek Bulk Fill (capsules) with microleakage score at the upper left corner.



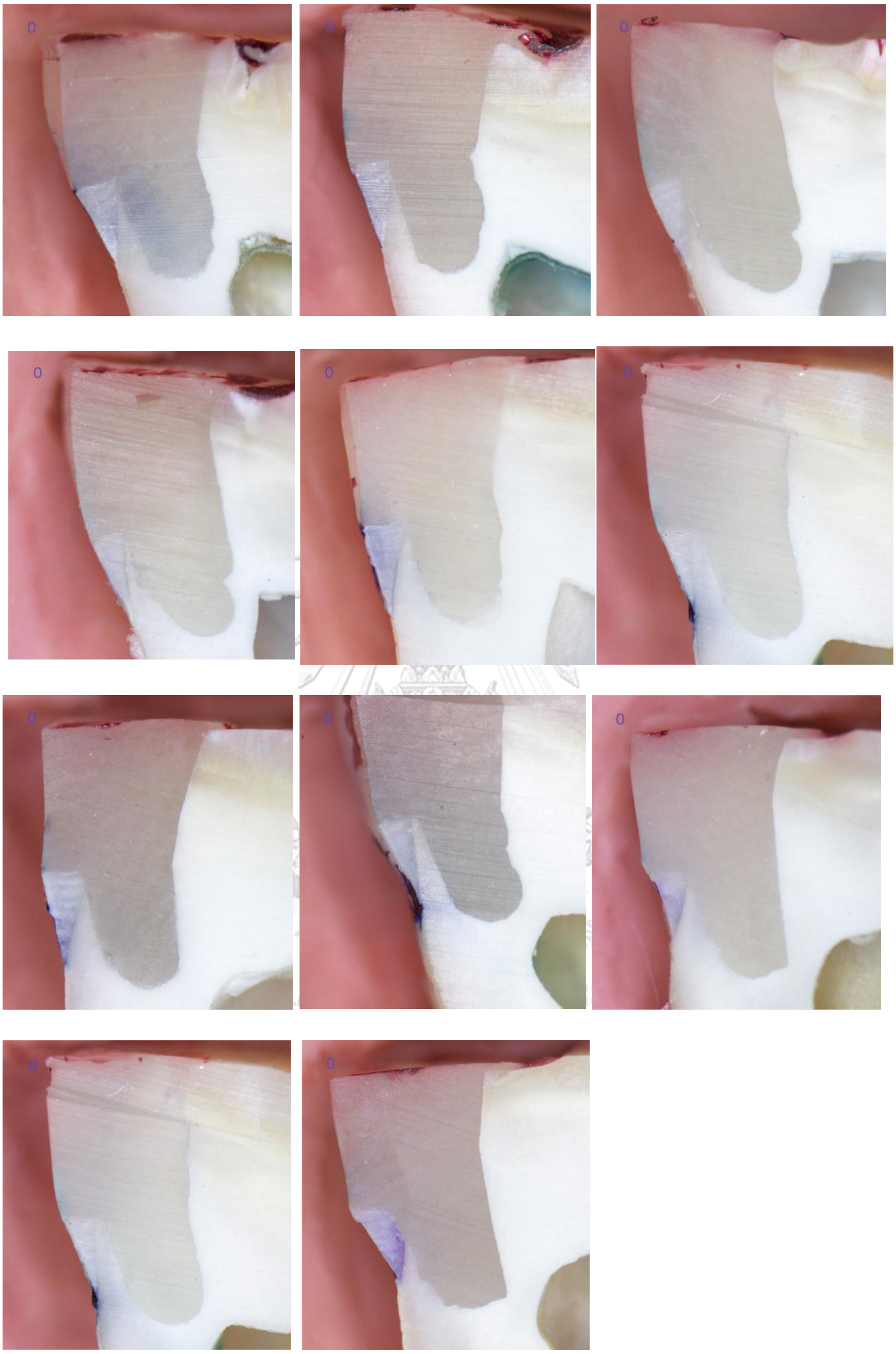
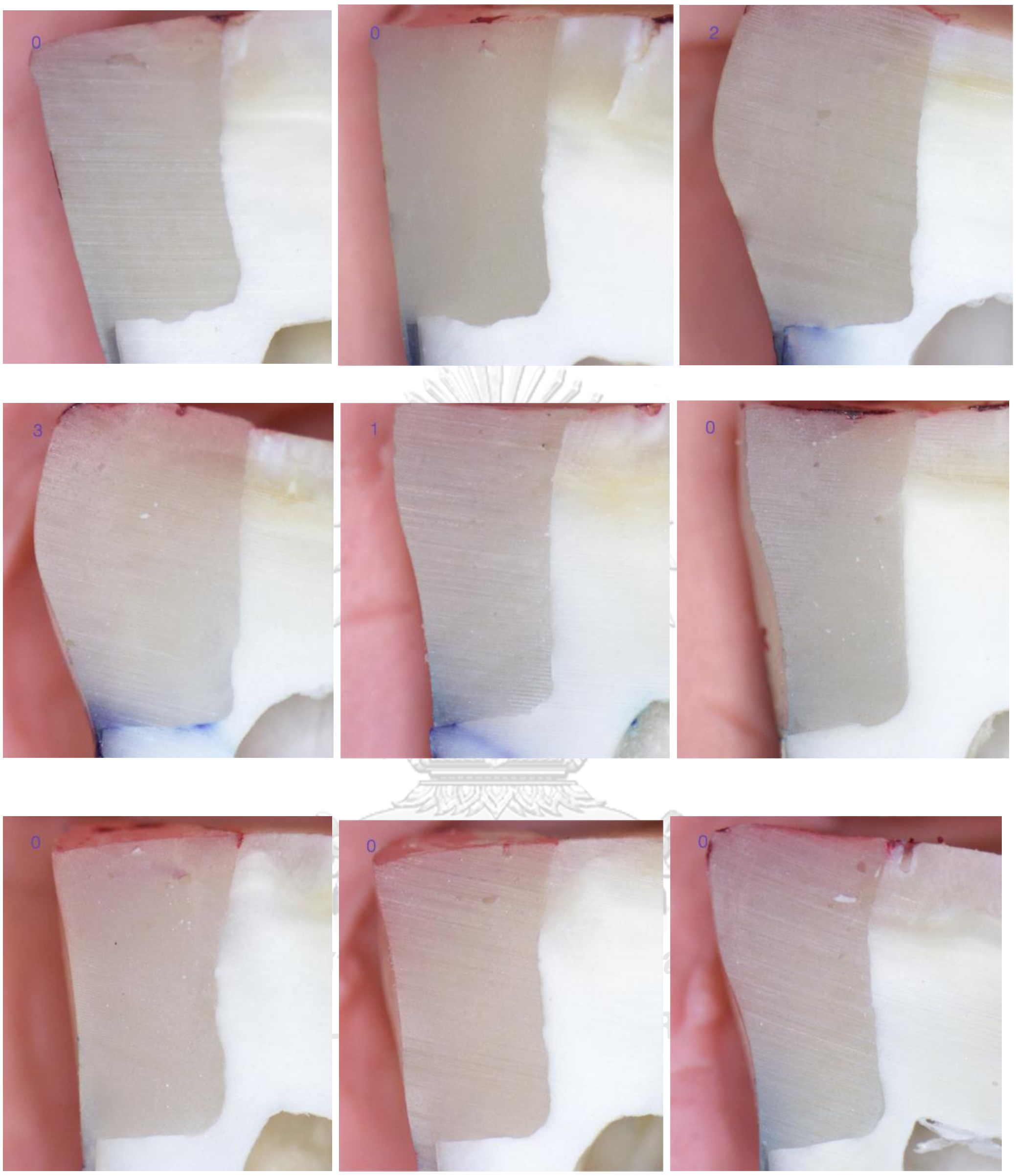


Figure 13 Samples of non-enamel preserved group of Filtek Bulk Fill (capsules) with microleakage score at the upper left corner.

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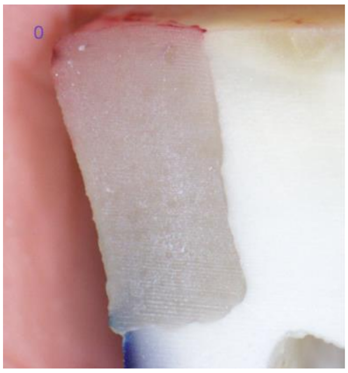
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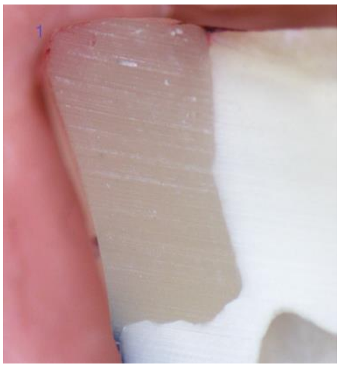
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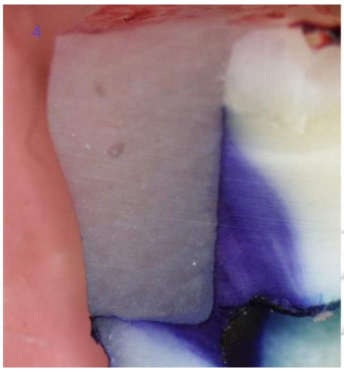
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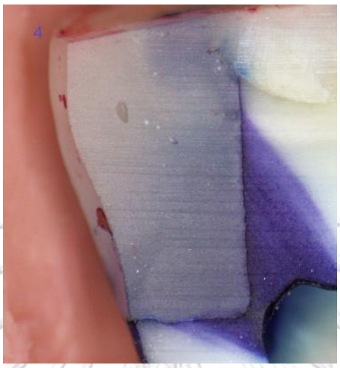
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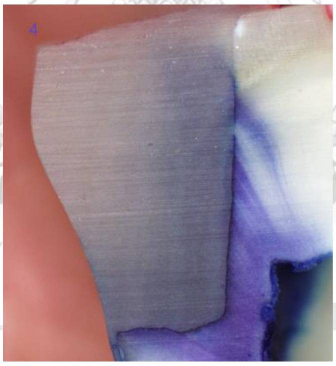
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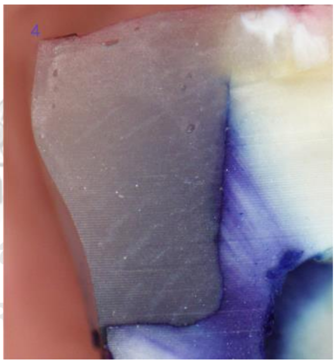
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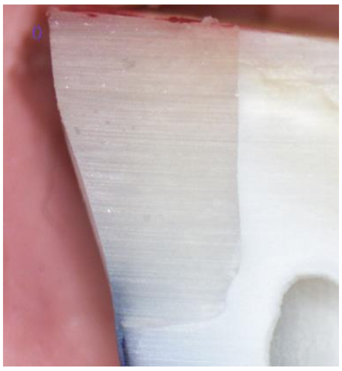
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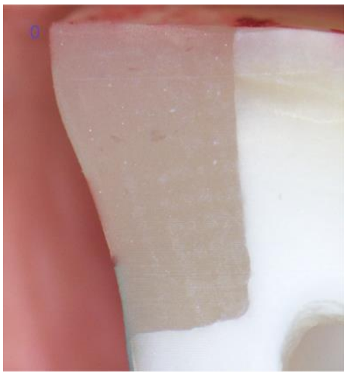
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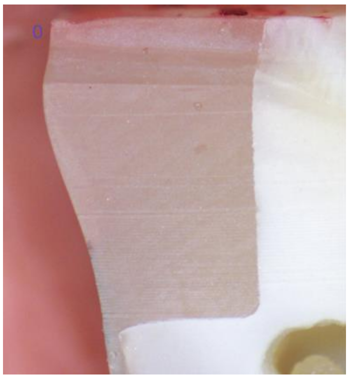
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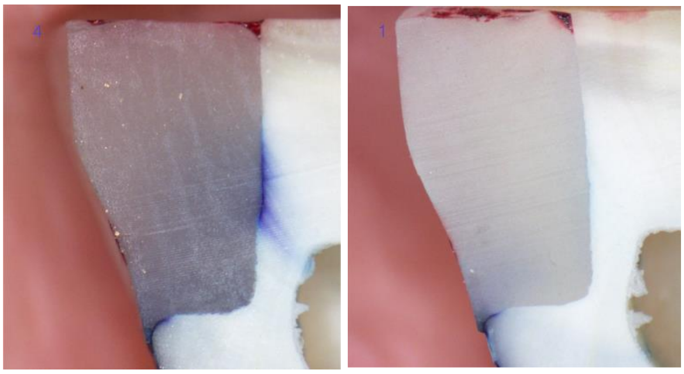
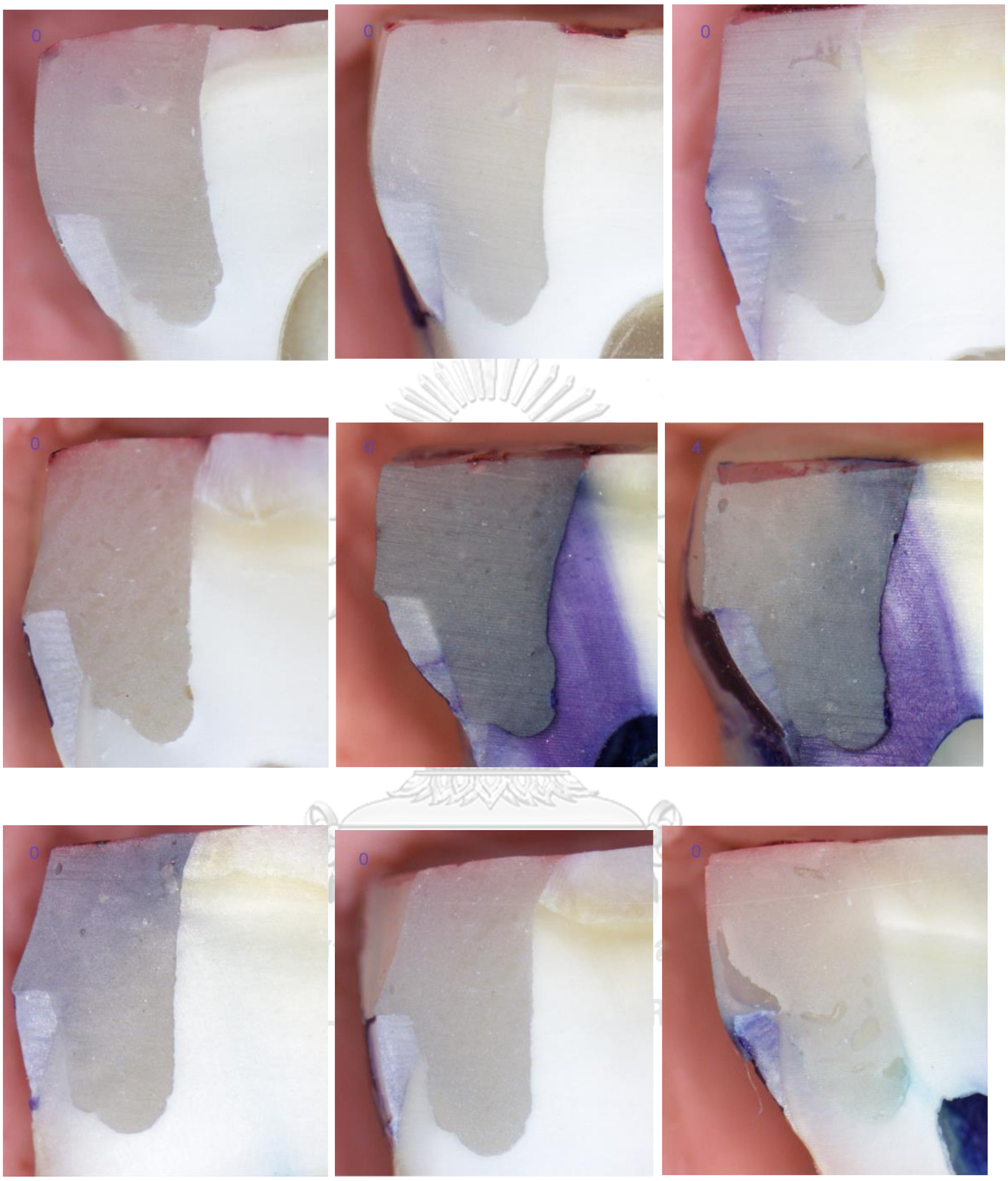
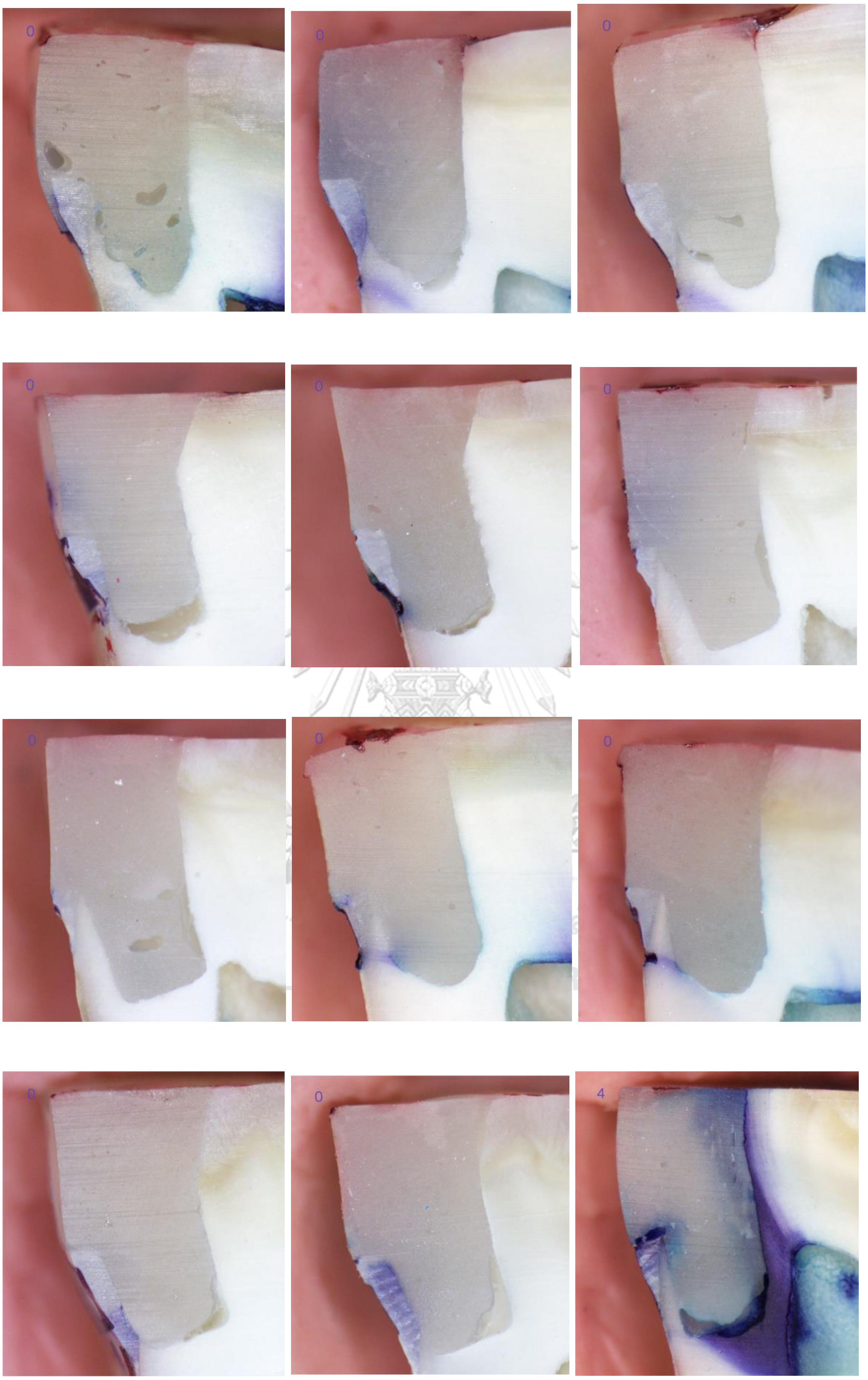


Figure 14 Samples of enamel preserved group of Filtek Bulk Fill (syringes) with microleakage score at the upper left corner.

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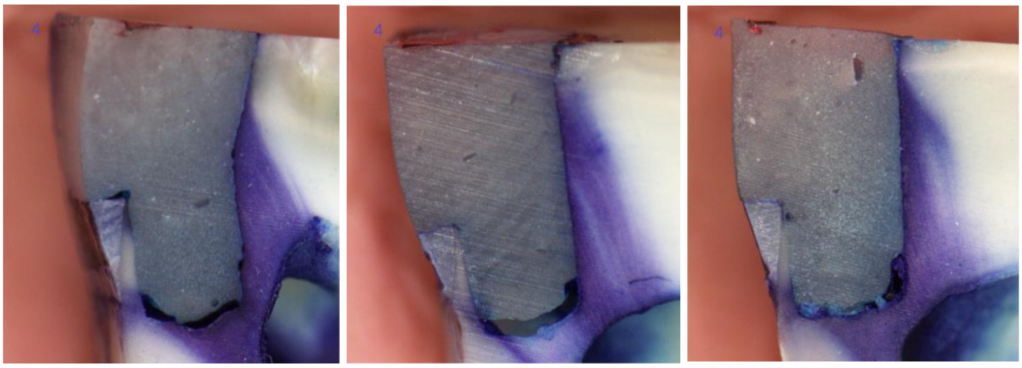
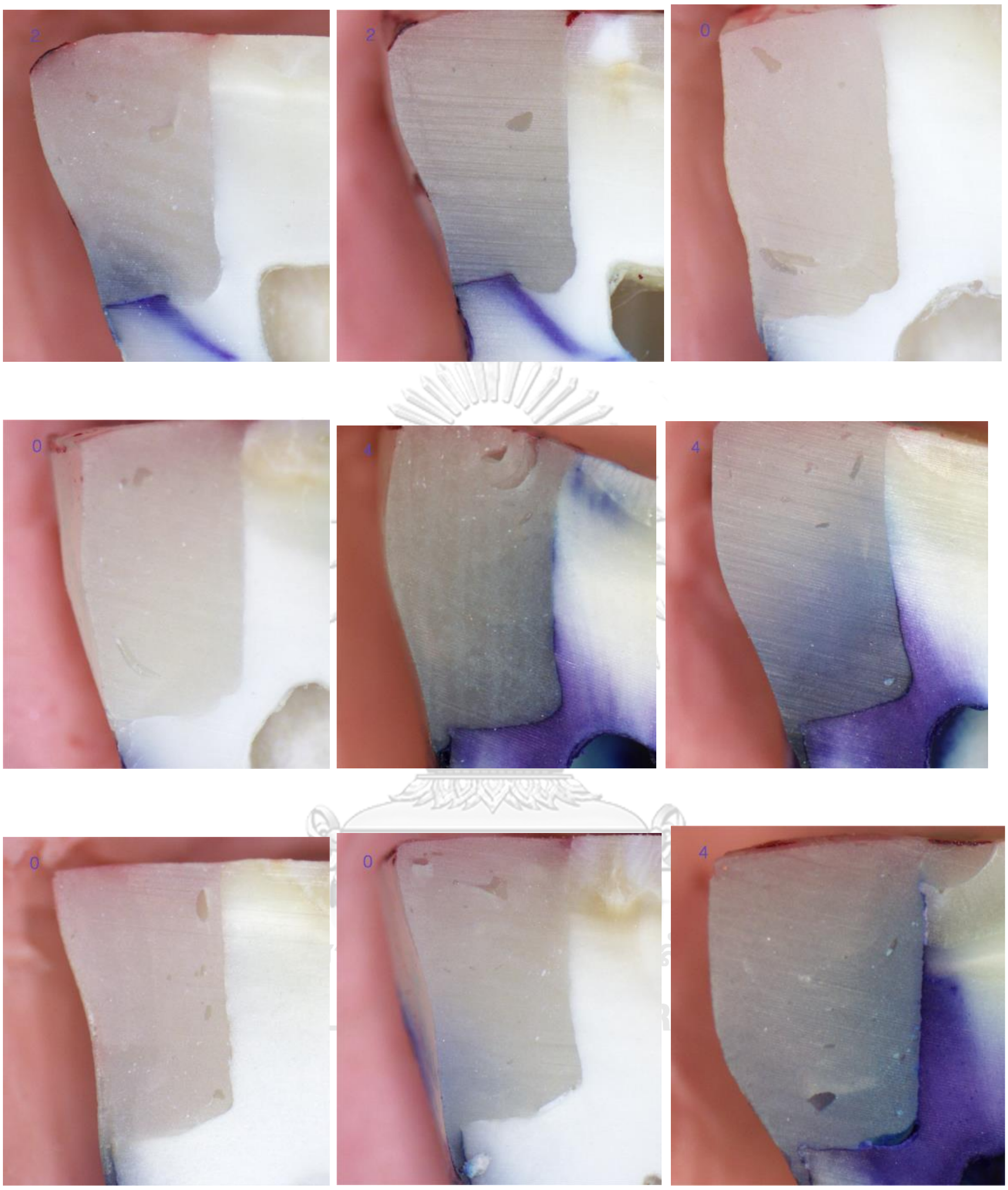
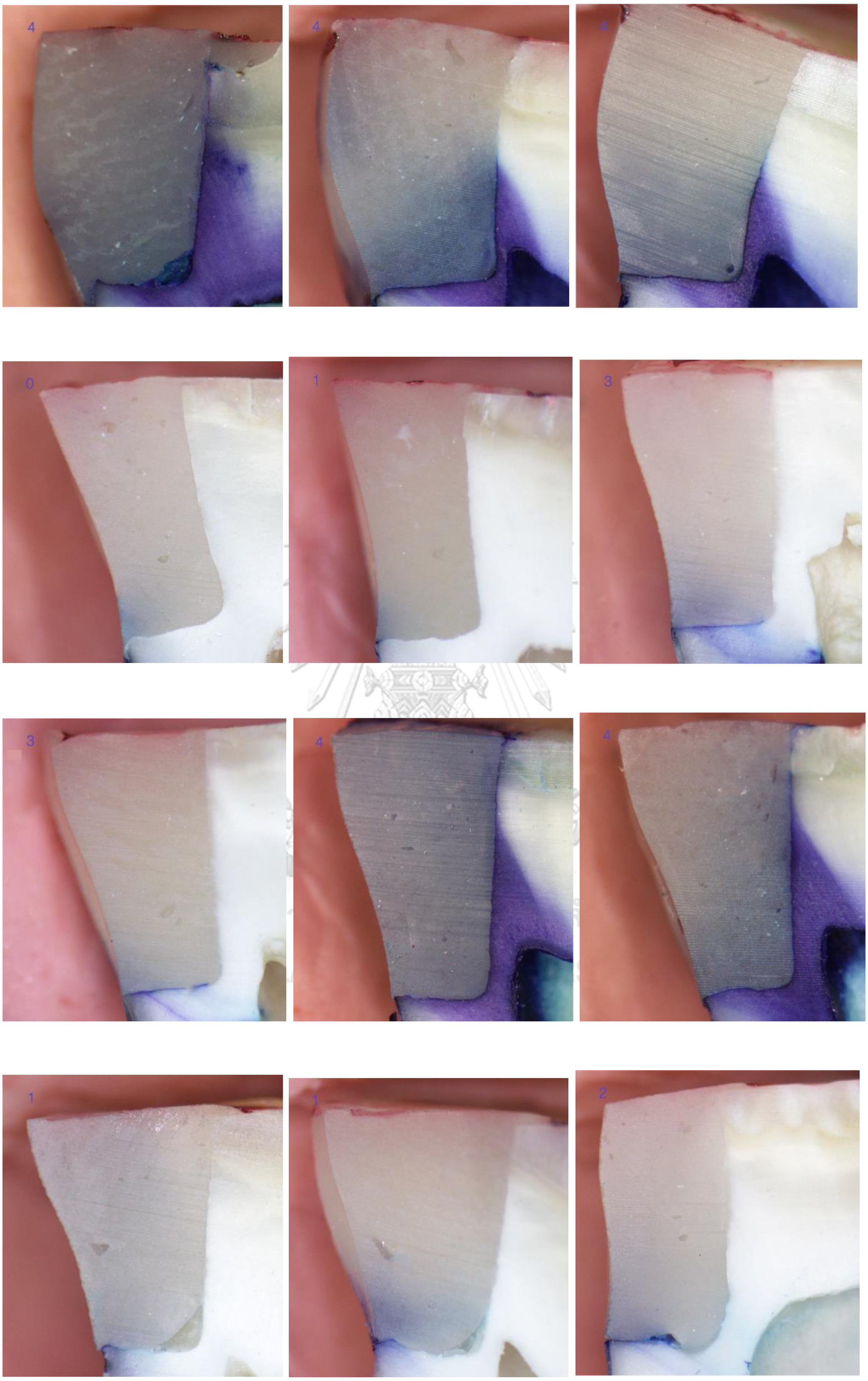


Figure 15 Samples of non-enamel preserved group of Filtek Bulk Fill (syringes) with microleakage score at the upper left corner.

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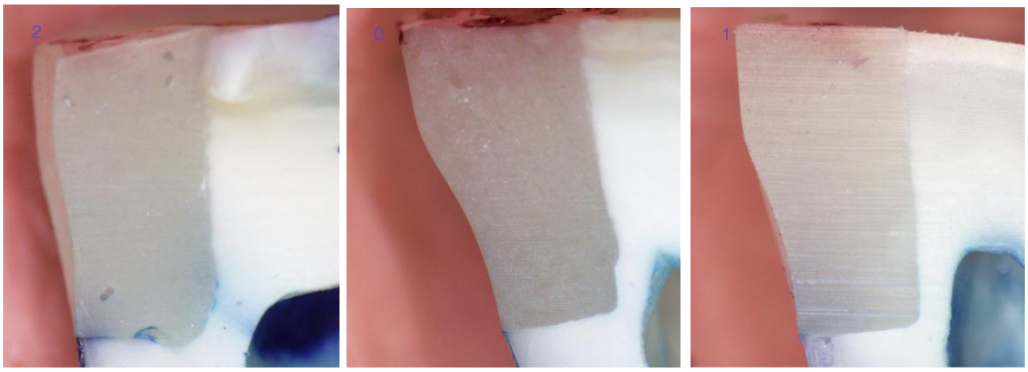
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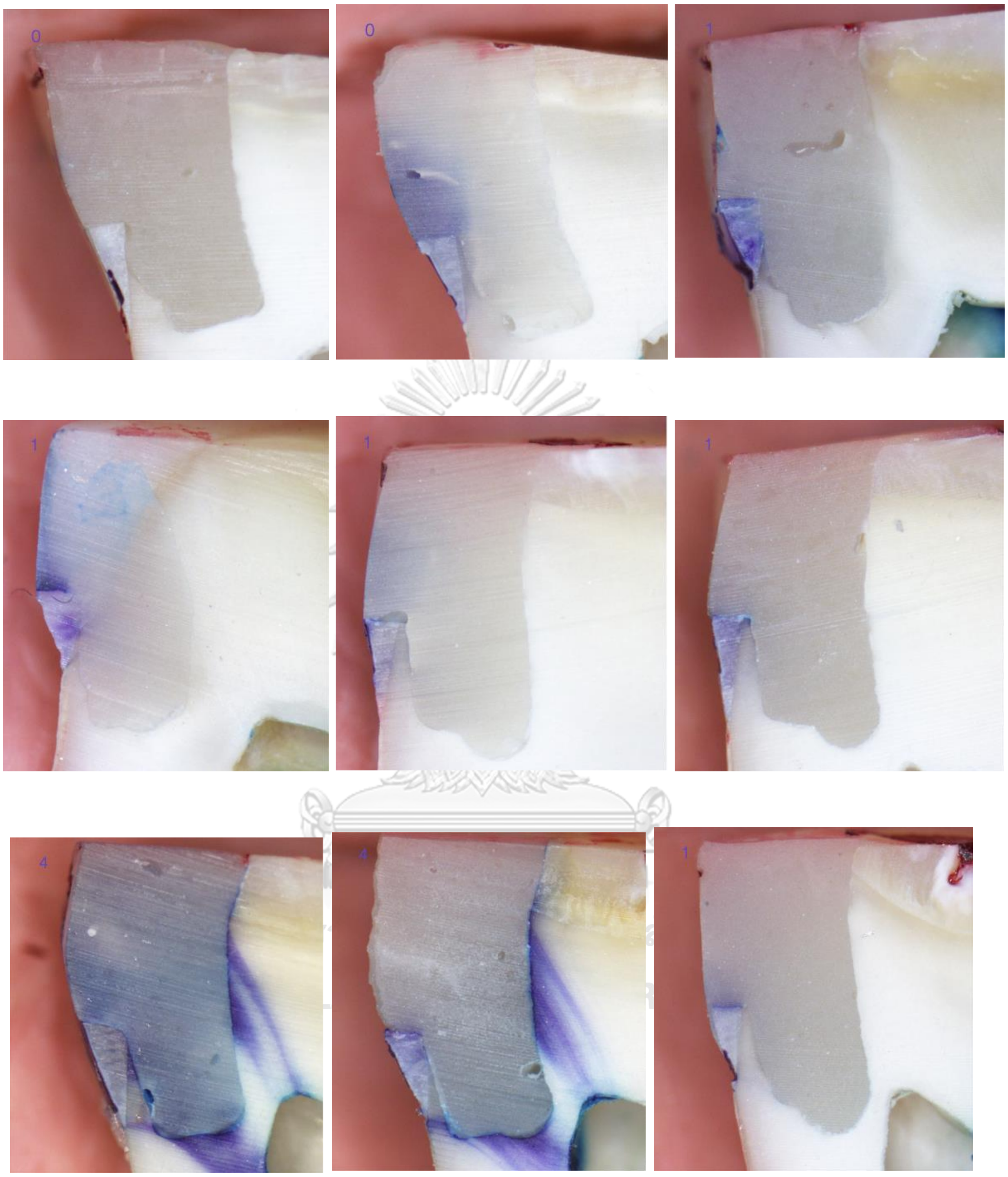
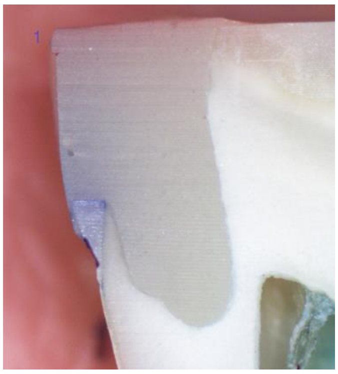
Figure 16 Samples of enamel preserved group of Filtek X350 XT with microleakage score at the upper left corner.

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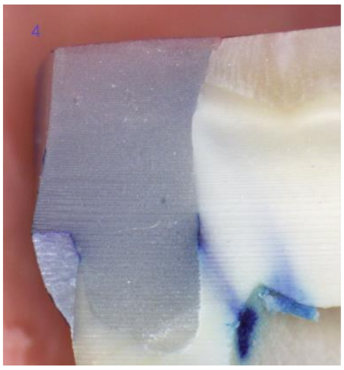
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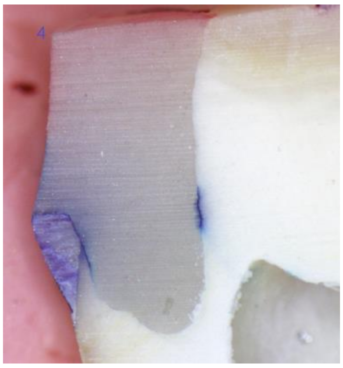
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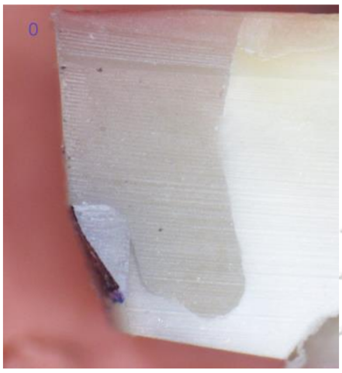
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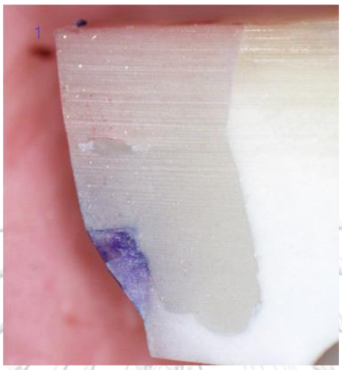
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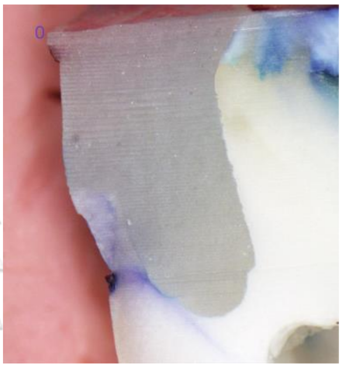
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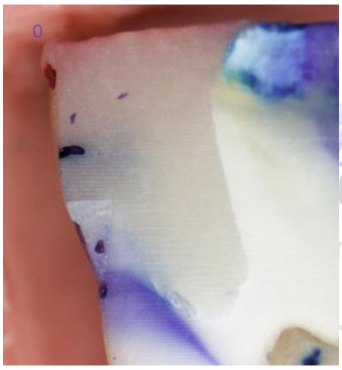
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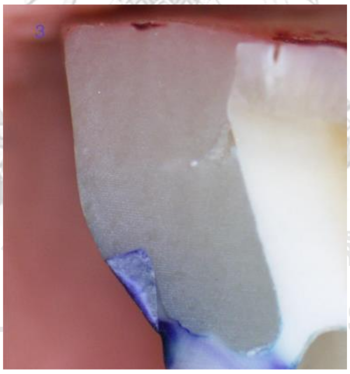
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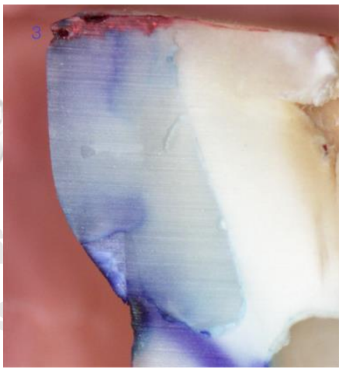
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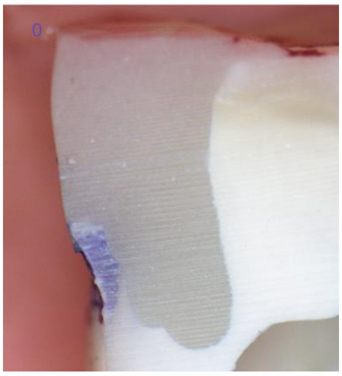
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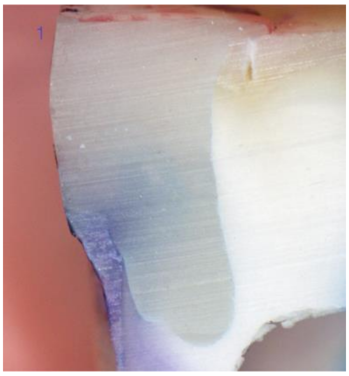
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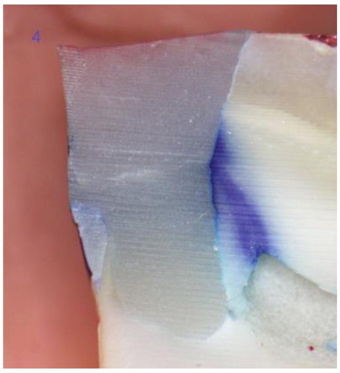
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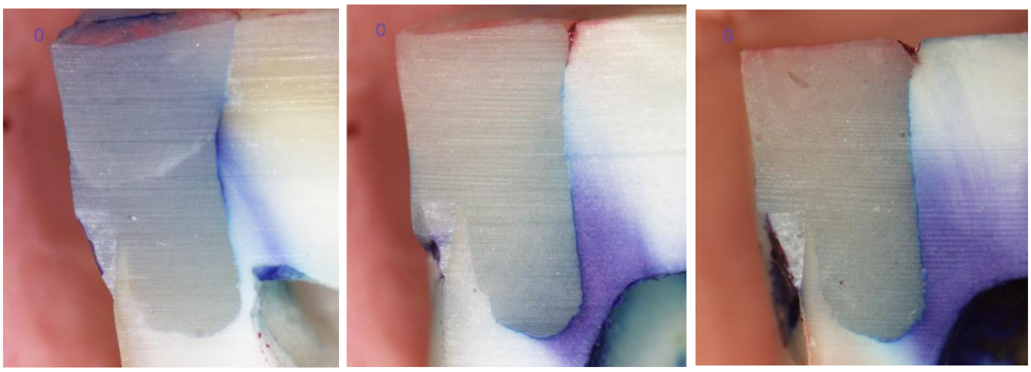
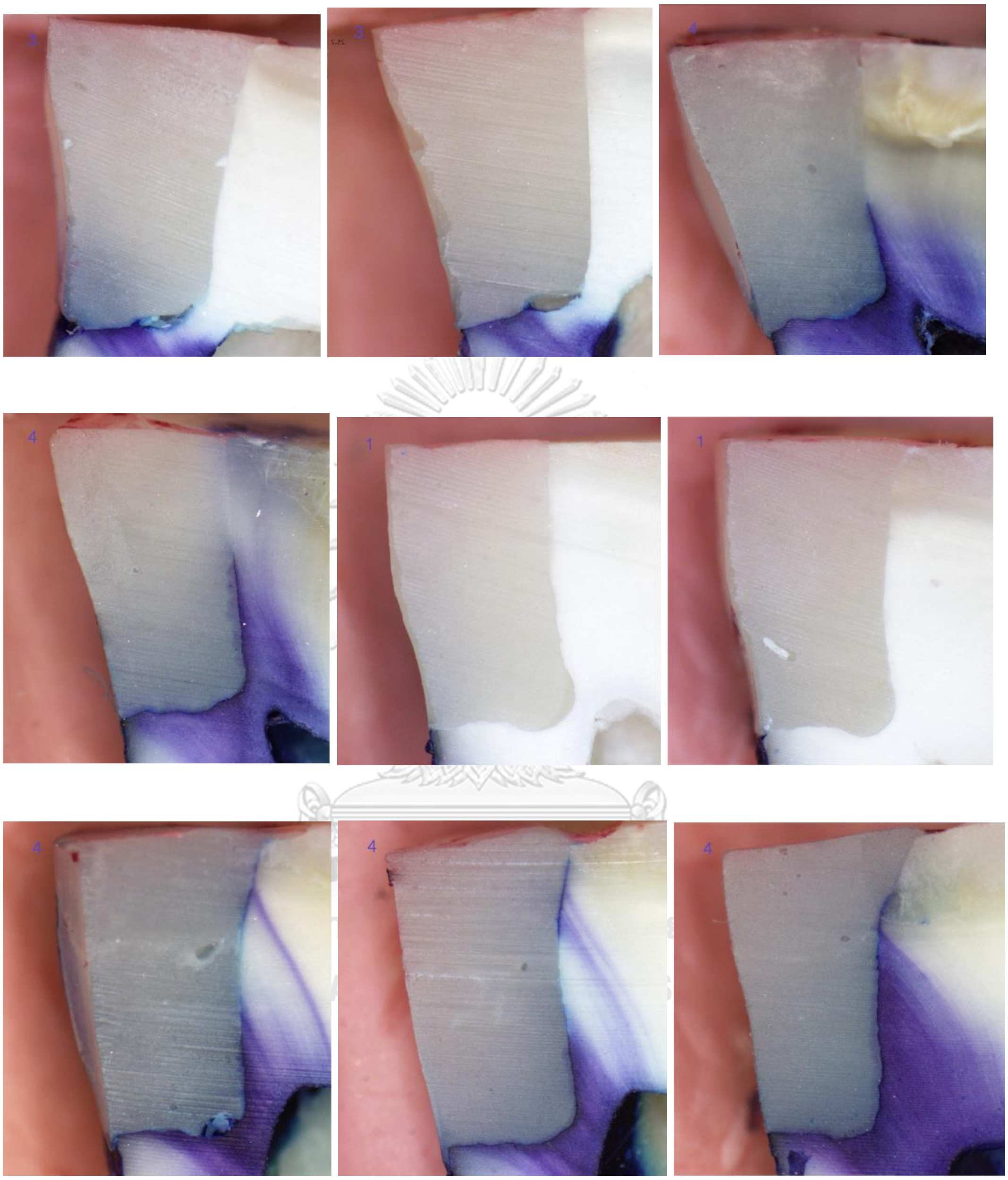
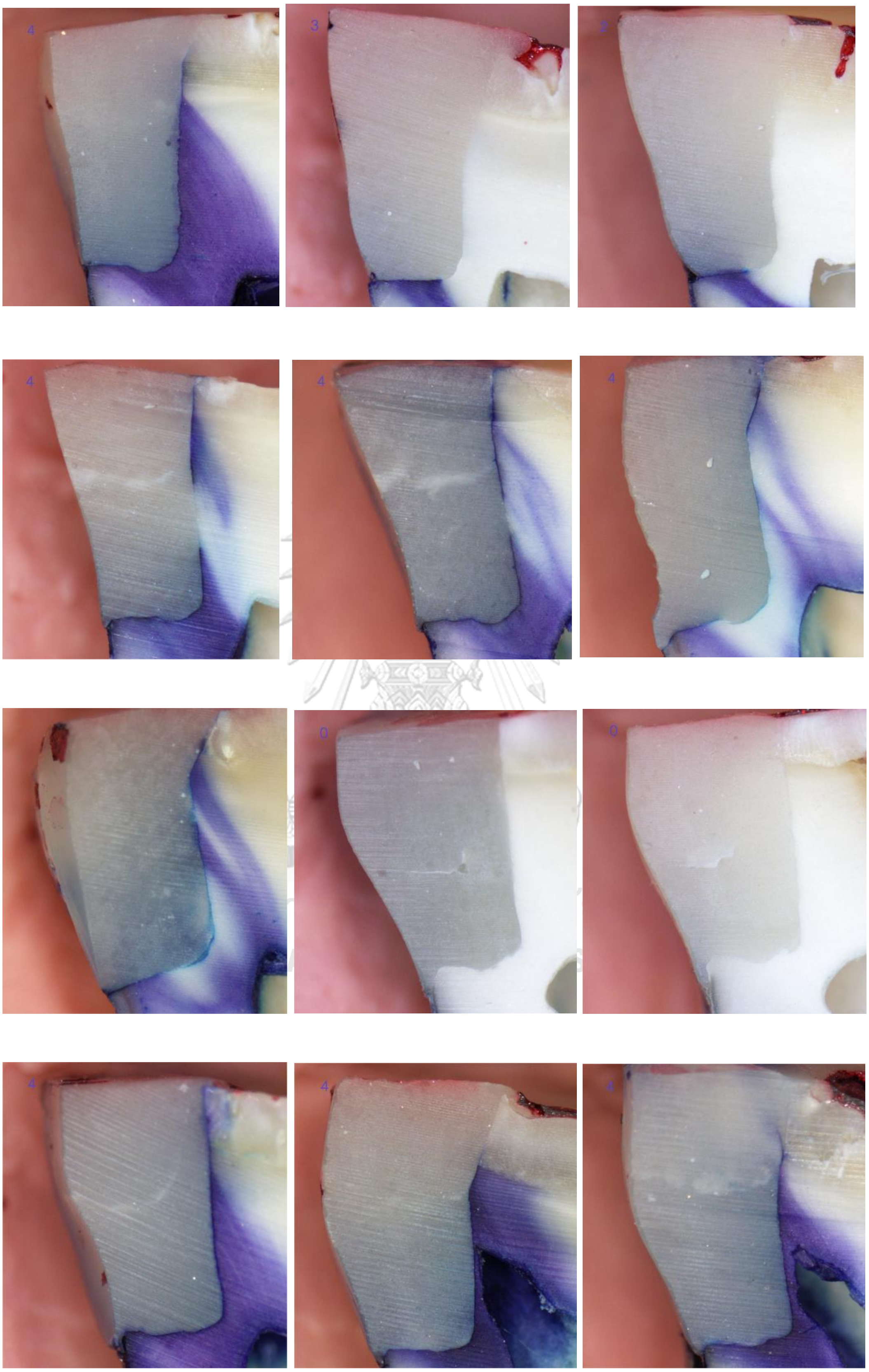
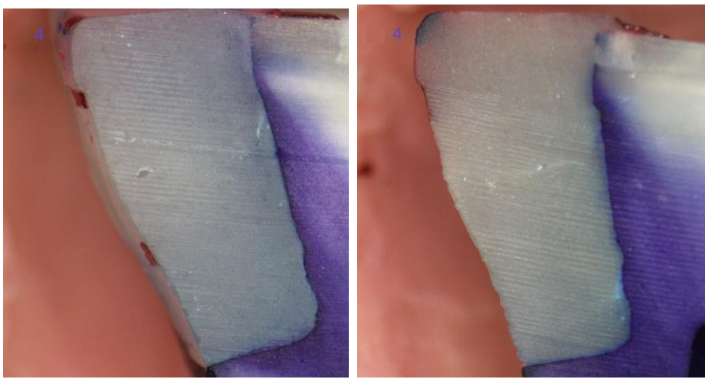


Figure 17 Samples of non-enamel preserved group of Filtek X350 XT with microleakage score at the upper left corner.







Appendix B. Statistical evaluation of three Examiners

Table 8 Intra class Correlation Coefficient (ICC)

Case Processing Summary

		N	%
Cases	Valid	13	100.0
	Excluded[a]	0	.0
	Total	13	100.0

a. Listwise deletion based on all variables in the procedure.

Intraclass Correlation Coefficient of examiner 1

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.974[a]	.918	.992	76.538	12	12	.000
Average Measures	.987[c]	.957	.996	76.538	12	12	.000

Intraclass Correlation Coefficient of examiner 2

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.950[a]	.844	.984	38.750	12	12	.000
Average Measures	.974[c]	.915	.992	38.750	12	12	.000

Intraclass Correlation Coefficient of examiner 3

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.654[a]	.187	.880	4.784	12	12	.006
Average Measures	.791[c]	.315	.936	4.784	12	12	.006

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Appendix C. Descriptive statistic of experimental groups

Table 9 Dye penetration score (Mode, Mean + s.d.)

Group		N	Mode	Mean ± s.d.
Filtek Bulk Fill (capsules)	Enamel preserved	23	0	0.13±0.34
	Non-enamel preserved	23	0	1.30 ± 1.64
Filtek Bulk Fill (syringes)	Enamel preserved	24	0	0.83±1.66
	Non-enamel preserved	24	4	2.21±1.67
Filtek Z 350 XT	Enamel preserved	24	0	1.42±1.59
	Non-enamel preserved	23	4	3.17±1.37

Appendix D Statistical comparison of microleakage of experimental groups

Table 10 Kruskal-Wallis test of enamel preserved group among three restorative materials

Ranks

Group	N	Mean Rank
Filtek Bulk Fill)capsules)	23	28.35
Filtek Bulk Fill)syringes)	24	33.25
Filtek Z 350XT	24	46.08
Total	71	

Test statistics[a,b]

	Score
Chi-Square	13.607
df	2
Asymp. Sig.	.001*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

a Kruskal-Wallis test, b Grouping Variable: GR

The Kruskal-Wallis test revealed significant differences in microleakage scores of enamel preserved group among the three restorative materials ($P < 0.05$). Further analysis with a multiple comparison test are required.

Table 11 Kruskal-Wallis test of non-enamel preserved group among three restorative materials

Ranks

Group	N	Mean Rank
Filtek Bulk Fill)capsules)	23	25.37
Filtek Bulk Fill)syringes)	24	35.19
Filtek Z 350XT	23	45.96
Total	70	

Test statistics[a,b]

	Score
Chi-Square	13.014
df	2
Asymp. Sig.	.001*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

a Kruskal-Wallis test, b Grouping Variable: GR

The Kruskal-Wallis test revealed significant differences in microleakage scores of non-enamel preserved group among the three restorative materials ($P < 0.05$). Further analysis with a multiple comparison test are required.

Table 12 Multiple comparison (Dunn test) of enamel preserved group among three restorative materials

	Test Statistic	Std. Error	Std.Test Statistic	Sig.	Adj.Sig.
BFC vs BFS	4.902	4.983	.984	.325	0.976
BFC vs Z350	17.736	4.983	3.559	.000	0.001*
BFS vs Z350	-12.833	4.930	-2.603	.009	0.028*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

Abbreviations: BFC, Filtek Bulk Fill Posterior Restorative (capsule type); BFS, Filtek Bulk Fill Posterior Restorative (syringe type); Z350, Filtek Z350 XT

Multiple comparison test revealed that the enamel preserved group, Z350 XT showed statistically significant higher microleakage scores than the Filtek Bulk Fill (capsules) (P = 0.001) and Filtek Bulk Fill (syringes) (P = 0.028). Filtek Bulk Fill (capsules) and Filtek Bulk Fill (syringes) showed no significant difference in microleakage score between each other.

Table 13 Multiple comparison (Dunn test) of non-enamel preserved group among three restorative materials

	Test Statistic	Std. Error	Std.Test Statistic	Sig.	Adj.Sig.
BFC vs BFS	-9.818	5.649	-1.738	.082	0.247
BFC vs Z350	-20.587	5.709	-3.606	.000	0.001*
BFS vs Z350	-10.769	5.649	-1.906	.057	0.170

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

Abbreviations: BFC, Filtek Bulk Fill Posterior Restorative (capsule type); BFS, Filtek Bulk Fill Posterior Restorative (syringe type); Z350, Filtek Z350 XT

Multiple comparison test revealed that non-enamel preserved group, Z350 XT showed statistically significant higher microleakage scores than the Filtek Bulk Fill (capsules) (P = 0.001) but no significant difference with the Filtek Bulk Fill (syringes). Filtek Bulk Fill (capsules) and Filtek Bulk Fill (syringes) showed no significant difference in microleakage score between each other.

Table 14 Mann-Whitney U test between enamel preserved groups and non-enamel preserved groups for Filtek Bulk Fill (capsules)

Ranks

Group	N	Mean Rank	Sum of Ranks
Enamel preserved	23	18.54	426.50
Non-enamel preserved	23	28.46	654.50
Total	46		

Test statistics[a]

	Score
Mann-Whitney U	150.500
Wilcoxson W	426.500
Z	-3.020
Asymp. Sig. (2-tailed)	.003*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

a Grouping Variable: GR

Mann-Whitney U test revealed that the non-enamel preserved group had significantly higher microleakage scores than the preserved enamel group (*P* = 0.003)

Table 15 Mann-Whitney U test between enamel preserved groups and non-enamel preserved groups for Filtek Bulk Fill (syringes)

Ranks

Group	N	Mean Rank	Sum of Ranks
Enamel preserved	24	18.94	454.50
Non-enamel preserved	24	30.06	721.50
Total	48		

Test statistics[a]

	Score
Mann-Whitney U	154.500
Wilcoxson W	454.500
Z	-3.015
Asymp. Sig. (2-tailed)	.003*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

a Grouping Variable: GR

Mann-Whitney U test revealed that the non-enamel preserved group had significantly higher microleakage scores than the preserved enamel group (*P* = 0.003)

Table 16 Mann-Whitney U test between enamel preserved groups and non-enamel preserved groups for Filtek Z350 XT

Ranks

Group	N	Mean Rank	Sum of Ranks
Enamel preserved	24	17.65	423.50
Non-enamel preserved	23	30.63	704.50
Total	47		

Test statistics[a]

	Score
Mann-Whitney U	123.500
Wilcoxson W	423.500
Z	-3.422
Asymp. Sig. (2-tailed)	.001*

Upper case asterisk indicate statistical significant difference ($p \leq 0.05$)

a Grouping Variable: GR

Mann-Whitney U test revealed that the non-enamel preserved group had significantly higher microleakage scores than the preserved enamel group (P = 0.001)

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