การศึกษาคอมโพสิตเรซินชนิดอุดเป็นก้อนในแง่ความสมบูรณ์ขอบเขตและความแนบสนิทภายในของการบูรณะโดยตรงคลาส วัน

นายรินเดช ขจรนิติกุล

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THE STUDY OF BULK FILLED COMPOSITE RESIN ON MARGINAL INTEGRITY AND INTERNAL ADAPTATION OF CLASS I DIRECT RESTORATION

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A Thesis Submitted in Partial Fulfillment of the Requirements
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การศึกษาคอมโพสิตเรซินชนิดอุดเป็นก้อน โดยส่วนใหญ่สนใจในสมบัติทางกายภาพของวัสดุ แต่การรั่วซึมบริเวณขอบของวัสดุบูรณะ ทั้งการรั่วซึมภายนอกและภายในของการใช้วัสดุในกลุ่มนี้ ยังไม่ได้รับการศึกษาและยังไม่มีข้อสรุปที่ชัดเจน การศึกษานี้มีวัตถุประสงค์ที่จะตรวจสอบการรั่วซึมบริเวณขอบ ทั้งภายนอกและภายใน ของวัสดุบูรณะคอมโพสิตเรซินชนิดอุดเป็นก้อนโดยใช้บอนดิ้ง ๓ ชนิด เปรียบเทียบกับการบูรณะโดยใช้คอมโพสิตเรซินชนิดไฮบริด

การศึกษานี้ประกอบด้วยสองการทดลองคือ การทดสอบวัดการรั่วซึมบริเวณขอบภายนอกของวัสดุบูรณะ และการทดสอบวัดการรั่วซึมบริเวณขอบภายในของวัสดุบูรณะ แต่ละการทดลองใช้ฟัน ๒๑๐ ซี่ บูรณะด้วยคอมโพสิตเรซินชนิดอุดเป็นก้อน ๕ ชนิด (ฟิลเทคบัลค์ฟิล เททริคเอ็นซีแรมบัลค์ฟิล เอ็กซ์ตราฟิล วีนัสบัลค์ฟิล และโซนิกฟิล) และคอมโพสิตเรซินชนิดไฮบริด (ฟิลเทคแซดสองห้าศูนย์) ใช้บอนดิ้ง ๓ ชนิด ได้แก่ แอดเปอร์ซิงเกิ้ลบอนด์ทู เคลียร์ฟิลเอสอีบอนด์ และซุปเปอร์บอนด์ซีแอนด์บี หลังการบูรณะ นำกลุ่มทดลองทั้งหมด แช่ในเครื่องแช่สลับอุณหภูมิร้อน เย็น จำนวน ๕,๐๐๐ รอบ จากนั้น แช่ซี่ฟันทดลองทั้งหมด ในสารละลาย ๒ เปอร์เซนต์เมทิลีนบลู เป็นเวลา ๓๐ นาที วัดการรั่วซึมบริเวณขอบภายนอกและขอบภายในวัสดุบูรณะ โดยการใช้โปรแกรมคอมพิวเตอร์ อิมเมจโปรพลัส ประเมินค่าการรั่วซึมเป็นเปอร์เซนต์

การวิเคราะห์ความแปรปรวนทางสถิติแบบจำแนกสองทาง พบความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น ๙๕ เปอร์เซนต์ ระหว่างสองปัจจัยหลักคือ บอนดิ้งและคอมโพสิตเรซินและมีอิทธิพลต่อกัน การวิเคราะห์ทางสถิติเปรียบเทียบเชิงซ้อน ทูกี้ เอชเอสดี แสดงให้เห็นว่าการใช้ซุปเปอร์บอนด์ซีแอนด์บีร่วมกับเททริคเอ็นซีแรมบัลค์ฟิล มีค่าเปอร์เซนต์ของการรั่วซึมบริเวณขอบทั้งภายนอกและภายในวัสดุบูรณะ น้อยที่สุด ชนิดของบอนดิ้งและชนิดของคอมโพสิตเรซิน มีผลต่อการรั่วซึมบริเวณขอบ ทั้งภายนอกและภายในวัสดุบูรณะ และการใช้ซุปเปอร์บอนด์ซีแอนด์บีร่วมกับเททริคเอ็นซีแรมบัลค์ฟิล จะมีการรั่วซึมบริเวณขอบ ทั้งภายนอกและภายในวัสดุบูรณะ น้อยที่สุดเมื่อบูรณะแบบคลาสวัน ที่มีขอบด้านบนวัสดุบูรณะเป็นเนื้อฟัน

ภาควิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต	....
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RINDEJ KHAJORNITIKUL: THE STUDY OF BULK FILLED COMPOSITE RESIN ON MARGINAL INTEGRITY AND INTERNAL ADAPTATION OF CLASS I DIRECT RESTORATION. ADVISOR: ASSOC. PROF. MANSUANG ARKSORNNUKIT, Ph.D., 36 pp.

Most studies of bulk fill composite resin focused on their mechanical properties. But marginal and internal leakage, one of the commonly found failures, is still inconclusive. The aim of this study was to investigate the marginal and internal leakage of bulk fill composite resin restorations by using three adhesives as bonding agent, compared to conventional hybrid composite resin.

Marginal integrity test and internal adaptation test were included in this study, 210 teeth in each test. Five bulk fill composite resins (Filtek® Bulk Fill, Tetric® N-Ceram Bulk Fill, X-trafil®, Venus® Bulk fill and SonicFill®) and a conventional hybrid composite resin (Filtek® Z250) were used in this study. Three bonding agents, Adper® single bond 2, Clearfil® SE bond and Superbond C&B®, were used as adhesive. After 5,000 cycles of thermo-cycling, all specimens were placed in 2% methylene blue dye solution for 30 minutes. Marginal and internal leakage were photographically evaluated using Image pro plus® software and reported in percentage of entire restoration margin.

Two-way ANOVA suggested that there were significant difference on 2 main factors; bonding agent and composite resin, and interaction ($p < 0.05$). Multiple comparison with Tukey HSD revealed that using Superbond C&B® with Tetric® N-Ceram Bulk Fill demonstrated the least percentage of marginal and internal leakage.Type of bonding agent and composite resin had an effect on marginal leakage and internal leakage in Class l dentine cavity. Tetric® N-Ceram Bulk Fill with Superbond C&B® as bonding agent showed the least marginal leakage and internal leakage than the others.

Department:	Prosthodontics	Student's Signature	....
Field of Study:	Prosthodontics	Advisor's Signature	....
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CONTENTS

Page

CHAPTER I

INTRODUCTION

Composite resin is the common restorative material in dentistry. Because of its tooth-colored appearance, mechanical properties and bond ability. However, several clinical failures of composite resin, such as marginal discrepancies, marginal staining, micro-leakage, de-bonding, secondary caries and postoperative sensitivity were critically considered[1].

After applying bonding agent and placing composite resin into a cavity, the development of internal contraction stress which could damage the marginal seal of the bonded restorations occurred. This may result in interfacial gap formation and cause marginal staining, postoperative sensitivity, recurrent caries or crack formation at surrounding dentine walls[2].

Since the cavity configuration (C-factor) plays an important role in stress development, especially in cavity class I. The composite resin was polymerized within five bonding surface (one at the base and four at surrounding walls) while free shrinkage will only occur at the upper surface of the restoration. The high level of stress was generated between the bonded surfaces. Many researchers have suggested the use of incremental layering techniques for placing composite resin to reduce the polymerization shrinkage stress and cusp deflection[3-5]. By using an incremental technique, the bonded/unbonded ratio would be reduced, the stress level within the cavity might be lower[2].

In contrast, it was demonstrated that the incremental filling technique increased the deformation of the restored teeth and produced higher polymerization stresses compared with bulk filling technique by using Finite Element Analysis (FEA)[6]. The cuspal flexure produced by incremental filling and bulk filling technique were not different; moreover, incremental filling technique of the composite resin did not reduce cuspal flexure of restored teeth[7].

The disadvantages of the incremental filling technique include possibility of incorporating voids or contamination between composite layers, bond failures between increments, difficulty of placement the filling material into a limited access of the conservative preparation and the increased times required to place and polymerize each layer[8]. It was also reported that it was very difficult to prove that incremental filling reduced overall shrinkage stress over single bulk filling[6].

Manufacturers have been developing a new technology and method to overcome the disadvantages of the incremental filling in terms of reducing steps and chair time. The composite resin that provided single bulk, and easy handling led to the reduction of chair time, the undesirable polymerization shrinkage, less contamination and an increase of curing depth. The manufacturers claimed that the newly developed composite resin could be applied once up to 4-5 mm without any adverse effects on the material's polymerization behavior or mechanical properties. Therefore, the material was named "bulk fill" composite resin.

Most recent studies of bulk fill composite resin focused on their mechanical properties. A study reported that X-trafil® showed the highest filler content and the highest flexural modulus, while Tetric® N-Ceram Bulk Fill showed moderate values for the flexural modulus, although having a high filler content. Due to the incorporation of prepolymerized fillers in Tetric® N-Ceram Bulk Fill, it resulted in decrease flexural modulus[9]. Some studies on depth of cure of bulk fill composite resin confirmed that the curing depth was within the manufacturers' recommendations (4 mm depth in Tetric® N-Ceram Bulk Fill and X-trafil®)[10, 11]. Another study concluded that bulk fill composite resin had a similar gap free proportion on internal interface at mid dentine and enamel walls as conventional composite resin[12]. The study about marginal adaptation of bulk fill composite resin showed that bulk fill composite resin has adequate marginal adaptation and similar to the results of conventional composite resin[13]. While another recent study about the polymerization shrinkage of bulk fill composite resin concluded that using of bulk fill composite resin are not the perfect substitutes for conventional composite resin[14].

Objectives

To investigate the marginal integrity and internal adaptation in class I dentine direct restoration using three adhesives with five bulk fill composite resins and a conventional hybrid composite resin.

Research questions

Is the bulk fill composite resin suitable for posterior teeth restorations in terms of marginal integrity and internal adaptation?

Agreement

This research was an in vitro experimental study which did not represent real intra-oral situation. The entire study was conduct within Chulalongkorn University facilities by one researcher using the same instrument.

Research limitation

1. This research are affected by confounding factors such as morphology and size of teeth.
2. This study cannot simulate real condition in oral cavity due to laboratory experimental research.

Research design

Laboratory experimental research.

Expected benefits and Applications

1. To understand marginal and internal leakage of bulk fill composite resin.
2. The result will be the useful information for dentist to have another choice of restoration technique for restore posterior teeth with composite resin.
3. The result will be the database for other forthcoming researcher about bulk fill composite resin materials.

Hypothesis

$H1_0$: Type of bonding agents had no influence on marginal leakage and internal leakage of the composite resin restoration.

$H1_a$: Type of bonding agents had influence on marginal leakage and internal leakage of the composite resin restoration.

CHAPTER II

LITERATURE REVIEW

Composite resin

Since the manufacturers development in the late 1950s, composite resin represented a class of materials widely used in restorative dentistry. Because of its bond ability, its application has been increasing in modern preventive and conservative dentistry[15]. However during the curing process, composite resin has dimensional shrinkage through a free-radical mechanism[15].

When the material was placed into a cavity and bonded to the surrounding walls, the main outcome was the development of internal contraction stress which could damage the marginal seal of the bonded restorations. These may result in interfacial gap formation and cause postoperative sensitivity, marginal staining, recurrent caries, or crack formation at surrounding walls[2]. Since the cavity configuration (C-factor) plays an important role in stress development, many researchers have suggested the use of incremental layering techniques for placing composite resin restoration to reduce the polymerization shrinkage stress and cusp deflection[3-5]. In class I cavity using a single increment, the composite resin will polymerize within the five bonding surface (one base and four surrounding walls) while free shrinkage will only occur at the upper surface, producing a very high level of stress between the bonded surfaces. However, by using an incremental technique, the bonded/unbonded ratio would be reduced, the stress level within the cavity might be lower[2].

Nevertheless the literature is still inconclusive concerning the advantage of the incremental layering technique over the effects of polymerization shrinkage[2].

The disadvantages of incremental technique include the possibility of incorporating voids or contamination between composite layers, bond failures between increments, difficulty in placement because of limited access in conservative preparations and the increased times required to place and polymerize each layer[8].

Therefore, manufacturers have been developing a new technology of composite resin and restortive method to reduce the undesirable polymerization shrinkage, and provide easy adaptation, and reduce procedure time.

Bulk fill composite resin

Bulk fill composite resin is a posterior composite resin restorative material that provides a faster, easier technique than incremental layering. It was intended to be able to apply each increment up to 4 mm to reduce steps and chair time, without any adverse effects on the material's polymerization behavior or mechanical properties. Bulk fill composite resin improved depth of cure by increase its transparency or introducing a newphotoinitiator[16].

It comprises of photoinitiator (polymerization booster) that can be quickly cured with reliable properties up to 4 mm (such as Ivocerin® in Tetric® EvoCeram Bulk fill). The manufacturer claims the new initiator allows increasing in quantum efficiency which enables the material to polymerize faster and increases the depth of cure. Some manufacturer introduces the bulk fill flowable composite resin and claims that it provides a good marginal seal and eliminates the chance of voids formation, simple dispensing and placement. Low polymerization shrinkage stress minimized the marginal discrepancies and post-operative sensitivity.

Adhesive agents

Dental adhesives are one of the key factors in success outcome in restorative dentistry. It is developed to retain the composite resins to the tooth and minimize the marginal leakage of the restorations. Bonding to enamel has been proved to be better than dentine[17]. Current adhesive systems achieve in reduced microleakage on the interface between restorations and enamel. However, marginal leakage is still detected at the dentine margin[18].

Since 1980s, Nakabayashi et al. demonstrated that 10:3 (10% citric acid and 3% ferric chloride) solution could remove the smear layer from the ground tooth surface. Ferric chloride was used to stabilize dentinal collagen during demineralization, thus the resins could infiltrate into the demineralized dentine and form the hybrid layer which prevented secondary caries[19].

Two steps etch and rinse adhesives were commonly used in dental clinic due to the manufacturer's claimed to reduce the restorative steps and chair time. Most of these adhesive systems consist of 37% phosphoric acid and bonding which ethanol was added as solvent. However, a previous study demonstrated micro-tensile bond strength of extracted teeth restored with Single bond, the 2 steps etch and rinse adhesive and it is reported that the bond strength of specimens without enamel margin showed significantly lower than that of specimens with enamel margin[20].

In early 2000s, self-etching adhesive systems were introduced in dental market. Several advantages were claimed by manufacturers such as the shortest application time, the least steps, and the least technique sensitive from drying. An acidic primer was used to prepare the tooth surface due to less aggressive to the dentinal collagen when compared to phosphoric acid. Van Meerbeek et al. concluded that self-etch adhesive preserved hydroxyapatite at the interface between adhesive resin and tooth structure to protect the collagen fibril network and retained calcium ions for chemical bonding[17].

Bulk filling technique and incremental filling technique

Several investigators attempted to examine the bonding techniques for ideal replacement of tooth structure. A previous study stimulated a dynamic process of shrinkage during polymerization using the finite element analysis to compare shrinkage stresses of different restorative techniques and reported that incremental filling technique produced higher shrinkage stress than the others[6]. In contrast, bulk filling technique with flowable composite resin showed less shrinkage stress in dentine replacement[21]. The incremental filling technique also produces higher cuspal deflection than the bulk filling technique[18]. Contrarily, many researches reported that increment application showed the best performance of bond strength and internal adaptation[22, 23]. A previous study demonstrated percentage of gap-free interface in different placement techniques, incremental filling and bulk fillng was not significant differences. The amount of gap-free margin of the dentinal pulpal floor interface was significantly lower than that of the enamel interface for bulk fill technique[12]. Therefore, the restorative technique of placing composite resin is still inconclusive.

Dye penetration method

Several methods were suggested to detect marginal leakage which was a critical signal failure of restoration Dye penetration test was selected for investigating marginal integrity and internal adaptation because it is well known to be valid tool for the determination of marginal gaps in in-vitro studies[24-26]. Most common used dye tracer is 0.5% and 2% Methylene blue[24].

The dye penetration of margin located in the dentine interface was larger than that of margin located in the enamel regardless of the adhesive system used[25].

A dye penetration time is an important factor to investigate micro-leakage of composite resin restoration. The immerse time of 30 minutes showed better correlation with the result of SEM in characteristic of leakage[24].

CHAPTER III

MATERIAL AND METHODS

The protocol of this research was approved by the Ethics Committees of Chulalongkorn University (HREC-DCU2013-014).

Specimen preparation, timing, randomize sample, testing of marginal integrity and internal adaptation are performed and controlled by the same dentist throughout the protocol using the same equipment.

Four hundred and twenty extracted human third molar teeth without dental caries or crack line, extracted less than 1 month, were collected and stored in 0 $^{\circ}$C water for 1-6 months. All teeth were cleaned using gauze and blade before specimens preparation [27].

Adhesive agents used in the study

Adhesive agents used and their compositions in the present study are showed in Table 1.

Two steps total etch adhesive system (Adper single bond 2®, 3M/ESPE, St Paul, MN, USA), was applied according to the manufacturer's instructions after etching by 37% phosphoric acid and light cured for 20 seconds using a LED curing unit, 1200 mW/cm^2 light intensity (G-light Prima ll®, GC corporation, Tokyo, Japan).

Two steps self-etch adhesive system (Clearfil SE bond®, Kuraray, NY, USA), was applied according to the manufacturer's instructions and light cure for 20 seconds using the same curing unit as mentioned above.

Self-cured resin cement (Superbond C&B®, Sun Medical, Shiga, Japan), was applied according to the manufacturer's instructions by using bulk mix technique.

Table 1 Adhesive agents used in the study

Type	Adhesive agents	Composition	Lot No.
2 steps total etch (light cured)	Adper® single bond 2	Etchant: 37% phosphoric acid Primer/Bond: Ethyl alcohol, Bis-GMA, nanofiller, HEMA, glycerol-1,3-dimethacrylate	N459009
2 steps self etch (light cured)	Clearfil® SE bond	Primer: 2-hydroxyethyl methacrylate, dl-Camphorquinone, 10-Methacryloyloxydecyl dihydrogen phosphate. Bond: bisphenol A diglycidylmethacrylate, 2-hydroxyrthyl methacrylate, dl-Camphorquinone.	081183
Resin cement Self cured	Superbond C&B®	Green activator: citric acid, ferric chloride Polymer: poly(methyl methacrylate) Monomer: methyl methacrylate, 4-META Catalyst V: TBB-O	Green activator: FV1 Polymer: FW1 Monomer: FX1 Catalyst V: FX12

Abbreviation, Bis-GMA: bisphenol A diglycidylether methacrylate, UDMA: urethane dimethacrylate, TEGDMA: triethylene glycol dimethacrylate, HEMA: 2-hydroxyethyl methacrylate, 4-META: 4-methacryloxyethyltrimellitic acid anhydride, TBB-O: Partially oxidized tri-n-butylborane.

Composite resins used in the study

Composite resins used in the present study are showed in Table 2.

Specimen preparation and procedures

The total occlusal enamel of all teeth were cut off using high speed cylindrical diamond bur (Intensiv®, Lugano-Grancia, Switzerland). Flat occlusal dentin surface were wet-ground using Silicon carbide paper (600, 800, 1000 grit) on a polishing machine (Nano 2000, Pace Technologies, Tucson, AZ, USA). Surface of specimens were inspected using stereomicroscope (CK3800, Meiji, Japan) at magnification of 25x to confirm the flat dentin surface without the exposure of pulp cavity. The Class I cavity, 3 x 3 mm in diameter with 2 mm (60 specimens) or 4 mm (360 specimens) in depth were prepared on the dentine surface using high speed cylindrical diamond bur (Intensiv®, Lugano-Grancia, Switzerland) with a stainless steel mold to control size of the cavity.

Table 2 Composite resins used in the study

Composite resins	shade	Composition	Maximum depth of cure (mm)	Lot No.
Filtek® Z250 (3M/ESPE)	A1	60% zirconia/silica filler (by volume), Bis-GMA, UDMA, Bis-EMA	2.5	N383368
Filtek® Bulk Fill (3M/ESPE)	A1	58.4% filler (by volume), Bis-GMA, UDMA, aromatic urethane dimethacrylate, Addition-fragmentation monomer	4	N634662
Tetric® N-Ceram Bulk Fill (Ivoclar vivadent)	IVW	53-55% filler (by volume), Bis-GMA, UDMA, ethyoxylated bisphenol A dimethacrylate	4	R81741
X-trafil® (VOCO)	U	70.1% filler (by volume), Bis-GMA, UDMA, TEGDMA	4	13020083
Venus® Bulk fill (Heraeus)	U	38% filler (by volume), UDMA, EBPDMA	4	010100
SonicFill® (Kerr)	A1	83.5% filler (by volume), Bis-GMA, TEGDMA, EBPDMA	5	4721714

Abbreviation, Bis-GMA: bisphenol A diglycidylether methacrylate, UDMA: urethane dimethacrylate, TEGDMA: triethylene glycol dimethacrylate, HEMA: 2-hydroxyethyl methacrylate. EBPDMA: ethoxylate bisphenol-A-dimethacrylate

All teeth were randomly separated, 210 teeth for marginal integrity test and 210 teeth for internal adaptation test. Each test was separately divided into 21 experimental groups (n=10).

Group 1 (control 2 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with Filtek® Z250 (3M/ESPE, St Paul, MN, USA).

Group 2 (control 2 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with Filtek® Z250.

Group 3 (control 2 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with Filtek® Z250.

Group 4 (control 4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with Filtek® Z250.

Group 5 (control 4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with Filtek® Z250.

Group 6 (control 4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with Filtek® Z250.

Group 7 (4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with Tetric® N Ceram bulk fill (Ivoclar vivadent, Liechtenstein).

Group 8 (4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with X-trafil® (VOCO, NY, USA).

Group 9 (4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with Filtek® Bulk fill (3M/ESPE, St Paul, MN, USA).

Group 10 (4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with Venus® Bulk fill (Heraeus, Germany).

Group 11 (4 mm depth, 10 specimens) using Adper® single bond 2 as adhesive agent, filled with SonicFill® (Kerr, USA).

Group 12 (4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with Tetric® N Ceram bulk fill.

Group 13 (4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with X-trafil®.

Group 14 (4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with Filtek® Bulk fill.

Group 15 (4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with Venus® Bulk fill.

Group 16 (4 mm depth, 10 specimens) using Clearfil® SE bond as adhesive agent, filled with SonicFill®.

Group 17 (4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with Tetric® N Ceram bulk fill.

Group 18 (4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with X-trafil®.

Group 19 (4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with Filtek® Bulk fill.

Group 20 (4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with Venus® Bulk fill.

Group 21 (4 mm depth, 10 specimens) using Superbond C&B® as adhesive agent, filled with SonicFill®.

The dentine cavities were rinsed with deionized water, slightly air-dried, and applied adhesive system following each experimental group as above. The bonded cavities were placed with composite resin from preloaded tubes by bulk-filling technique, covered with transparent matrix strip, pressed flush with glass slide, and polymerized by a light curing unit for 40 second. Then, specimens were ground using silicon carbide paper (600, 800 and 1,000 grit) on a polishing machine at 3,000 rpm. Each group of specimens was then subjected to the thermocycling (Thermocycling, KMITL, Bangkok, Thailand) between 5°C and 55°C (5,000 cycles dwelling time 30s)[24].

Test 1: Marginal integrity test

Surface of all specimens were covered with two layers of nail varnish except area of the composite resin and 1 mm beyond the margin and immersed in 2% methylene blue dye solution for 30 minutes[24], and irrigated with deionized water. All specimens were observed under a 25X magnification of stereomicroscope for evaluation of the percentage of dye-stained margins. The length of the dye-stained gap along the cavity margin was measured in millimeters from computer software (Image pro plus®, Media Cybernetics, MD, USA). Percentage of marginal leakage was calculated as described below:

Percentage of marginal leakage = [length of the dye-stained gap along the margin of restoration / length of the entire margin of restoration] x 100[28].

Table 3 Specimen groups in the study

Group	Cavity depth (mm.)	Adhesive agents			Composite resins					
		SIB	SEB	SUB	FZ	TB	XF	FB	VB	SF
1	2	/			/					
2	2		/		/					
3	2			/	/					
4	4	/			/					
5	4		/		/					
6	4			/	/					
7	4	/				/				
8	4	/					/			
9	4	/						/		
10	4	/							/	
11	4	/								/
12	4		/			/				
13	4		/				/			
14	4		/					/		
15	4		/						/	
16	4		/							/
17	4			/		/				
18	4			/			/			
19	4			/				/		
20	4			/					/	
21	4			/						/

Abbreviation, SIB: Adper® single bond 2, SEB: Clearfil® SE bond, SUB: Superbond C&B®, FZ: Filtek® Z250, TB: Tetric® N Ceram bulk fill, XF: X-trafil®, FB: Filtek® Bulk fill, VB: Venus® Bulk fill, SF: SonicFill®.

Test 2: Internal adaptation test

After thermocycling, all specimens were cut in the bucco-lingual direction using a cutting machine (ISOMET® 1000, Buehler, USA) to examine the internal adaptation. The specimens were coated, immersed, and irrigated with de-ionized water as described above. The same procedure in calculated percentage of leakage was performed for evaluating internal adaptation test[28].

Statistic analysis

The percentage of marginal leakage and internal leakage were separately analyzed by two-way analysis of variance (ANOVA) with bonding agent and composite resin as main factors, followed by Tukey's post-hoc comparisons. The significance level was set at α = 0.05

The percentage of marginal leakage and the percentage of internal leakage were analyzed by linear regression analysis.

CHAPTER IV RESULT

Marginal integrity test

Two-way ANOVA suggested that there were significant difference ($p<0.05$) on 2 main factors; bonding agent and composite resin, and interaction. Multiple comparison with Tukey HSD revealed that using Superbond C&B® with Tetric® N-Ceram Bulk Fill demonstrated the least percentage of marginal leakage, while the most leakage percentage was found in group using Adper® single bond 2 with Venus® Bulk fill and SonicFill®. The marginal leakage in all experimental groups is presented in Table 4.

All the specimen groups using Superbond C&B® as bonding agent resulted in less percentage of marginal leakage than the groups of Clearfil® SE bond and Adper® single bond 2. In the same type of composite resin specimens, group using Superbond C&B® as bonding agent resulted in less percentage of marginal leakage followed by the groups of Clearfil® SE bond and Adper® single bond 2.

Internal adaptation test

Two-way ANOVA suggested that there were significant difference ($p<0.05$) on 2 main factors; bonding agent and composite resin, and interaction. Multiple comparison with Tukey HSD revealed that using Superbond C&B® with Tetric® N-Ceram Bulk Fill demonstrated the least percentage of marginal leakage, while the most leakage percentage was found in group using Adper® single bond 2 with SonicFill®. The internal leakage in all experimental groups is presented in Table 6.

Table 4 Displayed the mean percentage of marginal leakage and standard deviation of 21 experimental groups (n=10). The same superscript letters represented groups which were not significant different ($p < 0.05$).

Composite resins	Mean percentage of marginal leakage (SD)		
	Adper® single bond 2	Clearfil® SE bond	Superbond C&B®
Filtek® Z250 (2 mm)	43.66 (2.03)^{f}	34.42 (1.68)^{d}	22.97 (1.68)^{b}
Filtek® Z250 (4 mm)	52.66 (1.45)^{i}	36.34 (1.39)^{d}	26.04 (1.08)^{c}
Filtek® Bulk Fill (4 mm)	46.28 (1.22)^{g}	54.45 (1.23)^{j}	45.61 (1.11)^{f,g}
Tetric® N-Ceram Bulk Fill (4 mm)	44.06 (1.76)^{f,g}	35.76 (1.28)^{d}	12.68 (1.23)^{a}
X-trafil® (4 mm)	51.68 (1.50)^{i}	40.87 (1.96)^{e}	22.55 (1.17)^{b}
Venus® Bulk fill (4 mm)	88.55 (1.67)^{o}	70.75 (1.29)^{n}	49.29 (1.39)^{h}
SonicFill® (4 mm)	88.34 (1.40)^{o}	62.60 (1.58)^{l}	60.21 (1.25)^{k}

Table 5 Two-way ANOVA of marginal leakage, there were significant difference ($p<0.05$) on 2 main factors; bonding agent and composite resin, and interaction.

Tests of Between-Subjects Effects

Dependent Variable:mar

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	77819.269^{a}	20	3890.963	1806.302	.000
Intercept	466493.683	1	466493.683	216560.372	.000
bonding	22157.856	2	11078.928	5143.171	.000
composite	49363.362	6	8227.227	3819.326	.000
bonding * composite	6298.051	12	524.838	243.645	.000
Error	407.126	189	2.154		
Total	544720.078	210			
Corrected Total	78226.395	209			

a. R Squared = .995 (Adjusted R Squared = .994)

All the specimen groups using Superbond C&B® as bonding agent resulted in less percentage of internal leakage than the groups of Clearfil® SE bond and Adper® single bond 2. In the same type of composite resin specimens, group using Superbond C&B® as bonding agent resulted in less percentage of internal leakage followed by the groups of Clearfil® SE bond and Adper® single bond 2.

Table 6 Displayed the mean percentage of internal leakage and standard deviation of 23 experimental groups (n=10). The same superscript letters represented groups which were not significant different ($p < 0.05$).

Composite resins	Mean percentage of internal leakage (SD) [%]		
	Adper® single bond 2	Clearfil® SE bond	Superbond C&B®
Filtek® Z250 (2 mm)	60.31 (1.00)^{e}	53.41 (1.03)^{d}	39.82 (0.99)^{c}
Filtek® Z250 (4 mm)	81.31 (1.22)^{m}	67.65 (1.26)^{h}	53.56 (0.97)^{d}
Filtek® Bulk Fill (4 mm)	71.79 (1.86)^{j}	67.48 (1.72)^{h}	60.54 (1.85)^{e}
Tetric® N-Ceram Bulk Fill (4 mm)	76.74 (1.39)^{k}	62.16 (1.32)$^{f, g}$	34.25 (0.77)^{a}
X-trafil® (4 mm)	80.57 (1.01)^{m}	63.81 (1.12)^{g}	36.63 (0.90)^{b}
Venus® Bulk fill (4 mm)	80.66 (1.05)^{m}	78.84 (0.90)^{l}	61.98 (1.25)$^{e, f}$
SonicFill® (4 mm)	88.51 (0.99)^{n}	77.50 (1.20)$^{k, l}$	63.89 (0.81)^{g}

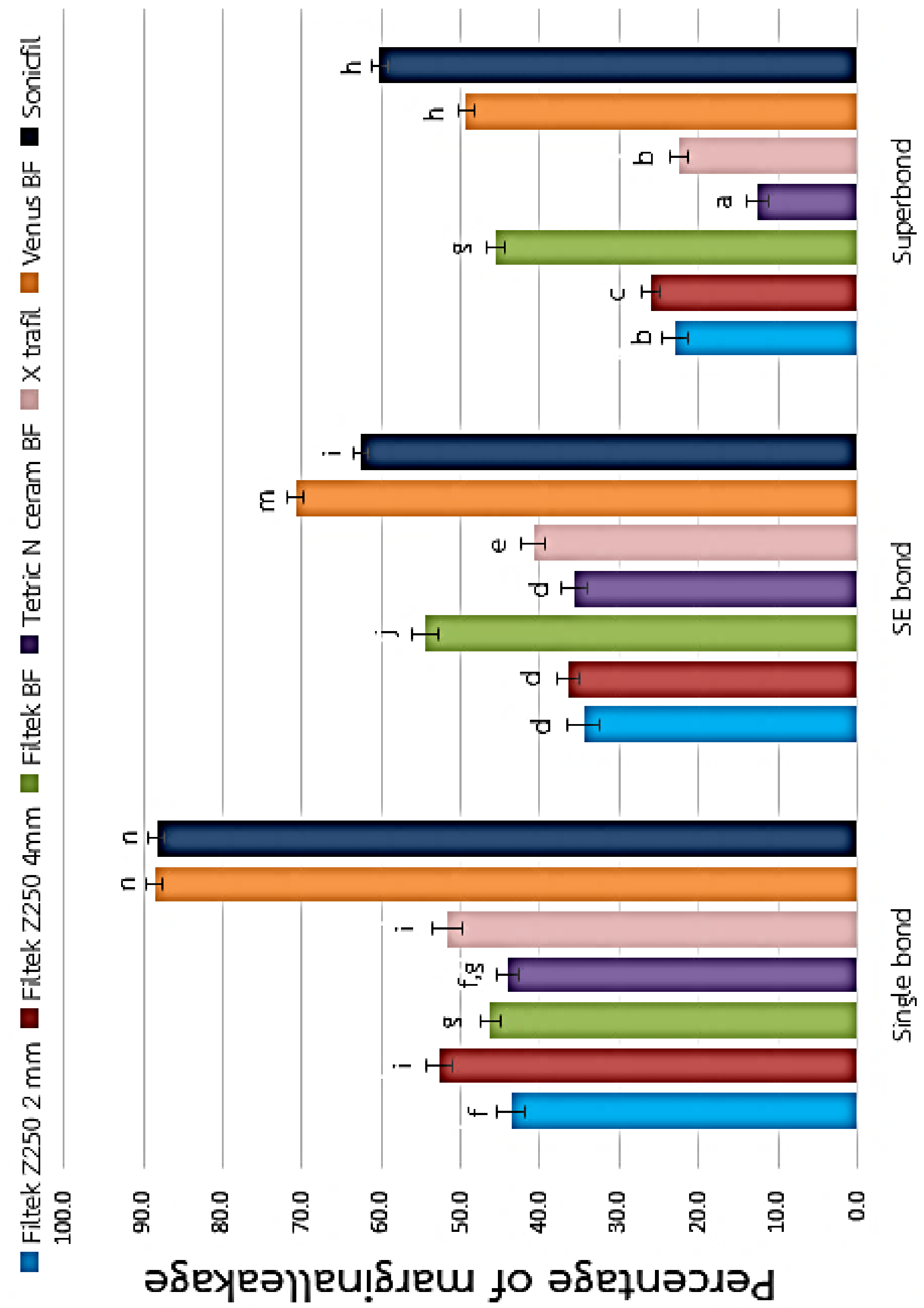
Table 7 Two-way ANOVA of internal leakage, there were significant difference ($p<0.05$) on 2 main factors; bonding agent and composite resin, and interaction.

Tests of Between-Subjects Effects

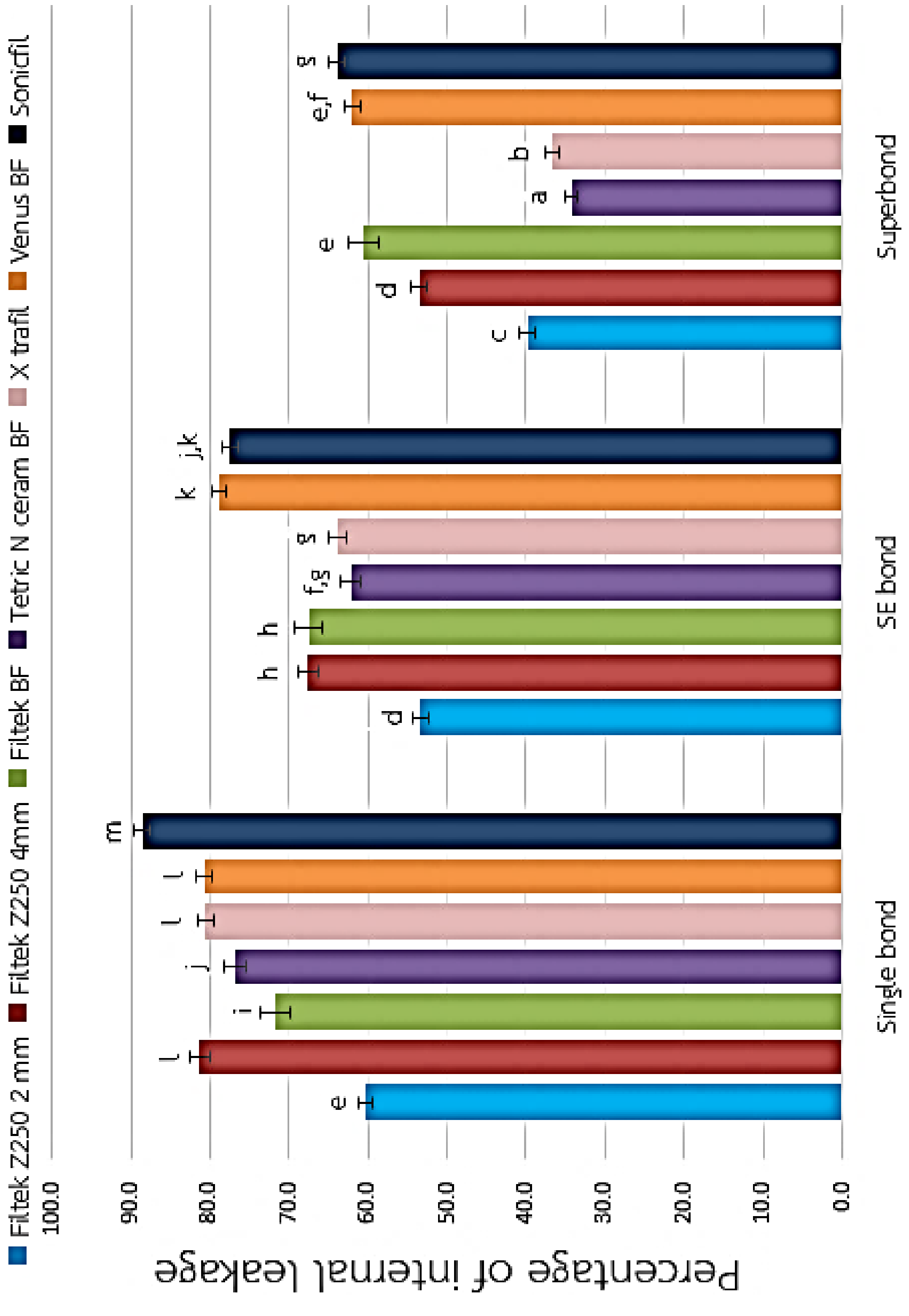
Dependent Variable:in

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	45621.914[a]	20	2281.096	1555.965	.000
Intercept	882559.316	1	882559.316	602005.271	.000
bonding	26200.177	2	13100.088	8935.742	.000
composite	14630.857	6	2438.476	1663.317	.000
bonding * composite	4790.880	12	399.240	272.327	.000
Error	277.080	189	1.466		
Total	928458.310	210			
Corrected Total	45898.994	209			

a. R Squared = .994 (Adjusted R Squared = .993)



Graph 1 Display the percentage of marginal leakage.



Graph 2 Display the percentage of internal leakage.

The linear regression analysis

Percentage of marginal leakage and percentage of internal leakage were calculated in linear regression analysis. Fig 1 demonstrated the result of linear regression analysis by slope of the regression line between percentage of marginal leakage and percentage of internal leakage. The relationship was significant (*p*<0.01), the coefficients of determination (R^2) was 0.708, the equation of the relationship is y = 34.460 + 0.644x, when y is percentage of internal leakage, x is percentage of marginal leakage.

Table 8 Linear regression analysis on percentage of marginal leakage and percentage of internal leakage.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.841[a]	.708	.706	8.03322

a. Predictors: (Constant), mar

b. Dependent Variable: in

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	34.460	1.463		23.557	.000
	mar	.644	.029	.841	22.433	.000

a. Dependent Variable: in

-

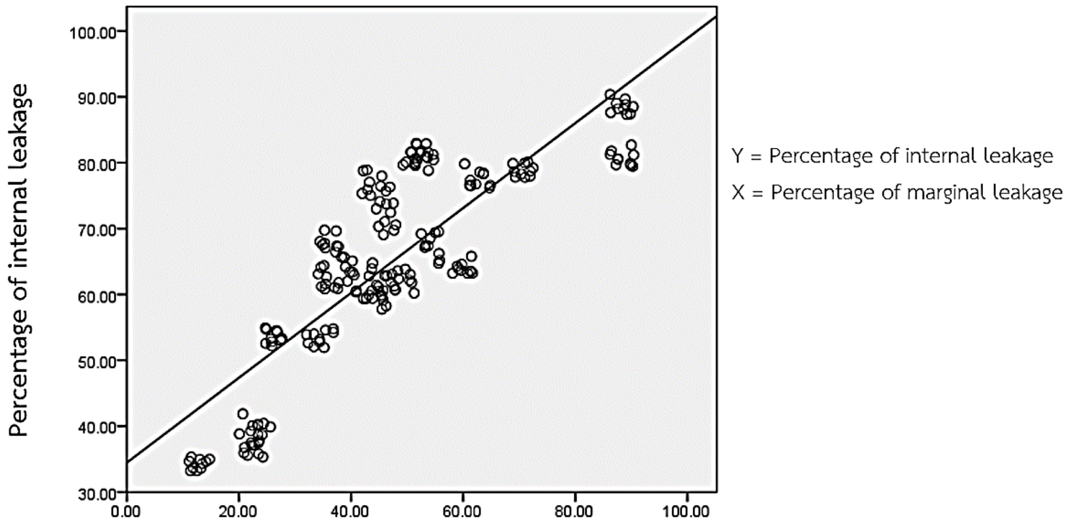


Fig. 1 Display the slope of regression line for the relationship between percentage of marginal leakage and percentage of internal leakage.

CHAPTER V

DISCUSSION

The purpose of this present study was to investigate the marginal leakage of bulk fill composite resin in class I dentine direct restoration. Two-way ANOVA demonstrated that there were significant difference on 2 main factors; bonding agent and composite resin, and interaction. Therefore, the null hypothesis that type of bonding agent had no influence on marginal leakage and internal leakage of the restoration was rejected.

The previous study claimed that the tensile force from bonding procedure around the bonding area of the restorations resulted in marginal leakage[2]. Class I cavities preparation, the highest C-factor which reflected the maximum effect of polymerization contraction was employed in order to create the extreme situation in studying such the contraction.

This present study demonstrated that the bulk fill restorative materials and the conventional composite resin with all adhesives could not provide leakage free interface of class l dentine cavity restoration. All experimental groups exhibited microleakage which could be observed as the dark blue line of 2% methylene blue along margins of restoration due to the polymerization contraction. This leakage attributed to the long-term failure of composite resin restoration clinically.

Bonding agents used in this study were not from the same manufacturer of composite resin. This study chose Adper® single bond 2 because of its widely use, Clearfil® SE bond and Superbond C&B® was chosen due to the hybridized dentine formation.

When using Adper® single bond 2 adhesive system as a bonding agent, 37% phosphoric acid etchant plays a major role in etching dentine surface prior to bonding procedures. With the demineralization effect and smear layer removal from the etchant, the mineral contents was removed from dentine. After air dried, the collagen fibril network collapsed. This prevented complete penetration of bonding agent resulting in the reduction of dentine sealing and a decrease in bond strength[29].

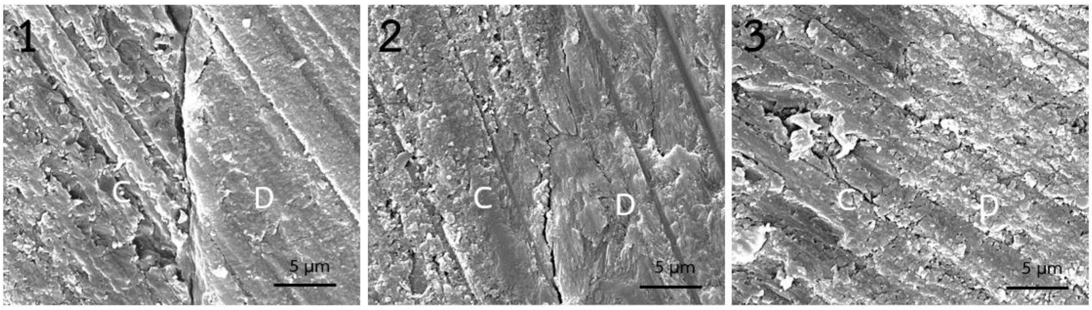


Fig. 2 Scanning electron micrographs of the bond surface of specimens (1) Adper® single bond 2 and Tetric® N-Ceram Bulk Fill (2) Clearfil® SE bond and Tetric® N-Ceram Bulk Fill (3) Superbond C&B® and Tetric® N-Ceram Bulk Fill. C = composite resin, D = dentine. Original magnification 10,000x

On the other hand, Clearfil® SE bond using self-etching primer followed by bonding agent to gain hybridization on dentin[17], while Superbond C&B® using 10:3 (10% citric acid and 3% ferric chloride) as conditioner, this process created hybridized dentine. This hybridized dentine led to better seal by not allowing water and/or dentinal fluid movement which protected both the dentine and pulpal tissues[19], and reliable to inhibit microleakage[26]. In this study, Superbond C&B® as bonding agent reduced the percentage of marginal leakage regardless of composite resin type. The finding of this present study supported the theory of hybridized dentine of the previous study[19].

In general, the polymerization shrinkage is resulted from the balance between polymerization contraction stress of composite resin and adhesive force of bonding agent[3]. When composite resin was placed into the cavity prior to polymerization of Superbond C&B® and was light activated, the composite resin shrinked directly towards the center of restoration cavity[30]. On the other hand, the self-cured resin cement was not completely polymerized and was stretched by the polymerization shrinkage, therefore, contraction stress of composite resin was compensated.

The incremental filling technique was advocated to achieve the best performance in terms of bond strength, better internal adaptation and prevention of gap formation at the cavosurface area of the composite resin restorations[22, 23]. However, the present study could not fully agree with the above findings, because gap formation along the margin of bulk fill composite resin restoration with Superbond C&B® as bonding agent was less than Filtek® Z250 group which using incremental technique.

The result of present study corresponded with other recent studies that bulk fill composite resin exhibited adequate marginal adaptation and similar to the result of the conventional composite resin[12, 13]. The marginal integrity and internal adaptation of bulk fill composite resin restoration can be improved by using Superbond C&B® as bonding agent. But the drawback was the esthetic resulted from the opacity of Superbond C&B® polymer, which showed the white line between restorations and surrounding dentine walls. However, this problem can be solved by using ivory shade polymer from the same manufacturer instead.

The light curing unit is one of the important tool for the success of composite resin restoration. Bulk fill composite resin improved depth of cure by introducing new photoinitiator or increase its transparency. Therefore, the light energy from curing unit should be adequate to achieve the optimal polymerization. To date, there is still no standard on light energy from light curing unit for bulk fill composite resin. Therefore, further study is recommended.

In consideration of direct composite resin restorations, not only type of composite resin (bulk fill or conventional) but also bonding systems should be throughly evaluated to achieve improved adaptation which led to perfect marginal integrity.

CHAPTER VI

CONCLUSIONS

Based on the limitation of this study, the following conclusions can be drawn:

1. Using Superbond C&B® as bonding agent in all composite resin tested resulted in significantly less percentage of marginal leakage and internal leakage than the Clearfil® SE bond and Adper® single bond 2 groups ($p < 0.05$).

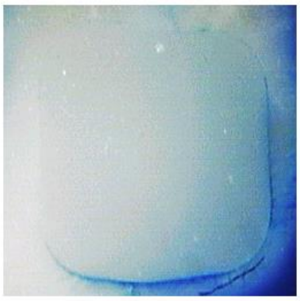
2. In groups using Superbond C&B®, Tetric® N-Ceram Bulk Fill group showed the least percentage of marginal leakage and internal leakage ($p < 0.05$).

3. In groups using Clearfil® SE bond, Filtek® Z250 group (2 mm. depth), Filtek® Z250 group (4 mm. depth) and Tetric® N-Ceram Bulk Fill group showed the least percentage of marginal leakage. Filtek® Z250 group (2 mm. depth) showed the least percentage of internal leakage ($p < 0.05$).

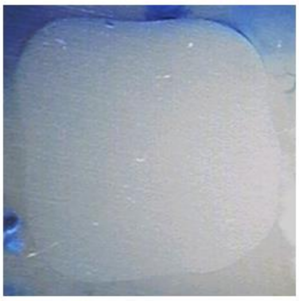
4. In groups using Adper® single bond 2, Filtek® Z250 (2 mm. depth) and Tetric® N-Ceram Bulk Fill groups showed less percentage of marginal leakage, Filtek® Z250 group (2 mm. depth) showed less percentage of internal leakage ($p < 0.05$).

APPENDIX

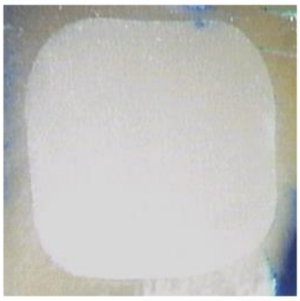
Photographs of specimen in marginal leakage test



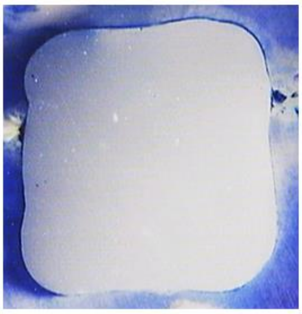
Adper® single bond 2 + Filtek® Z250 (2mm)



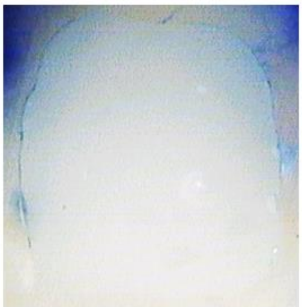
Clearfil® SE bond + Filtek® Z250 (2mm)



Superbond C&B® + Filtek® Z250 (2mm)



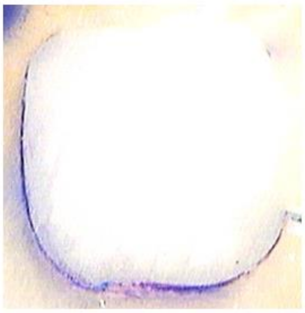
Adper® single bond 2 + Filtek® Z250 (4mm)



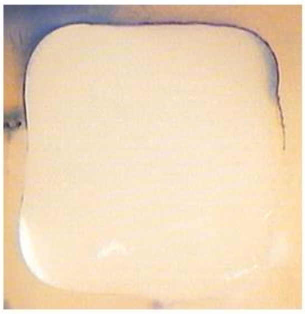
Clearfil® SE bond + Filtek® Z250 (4mm)

Superbond C&B® + Filtek® Z250 (4mm)

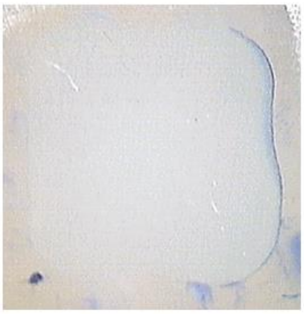
Adper® single bond 2 + Filtek® Bulk Fill (4mm)



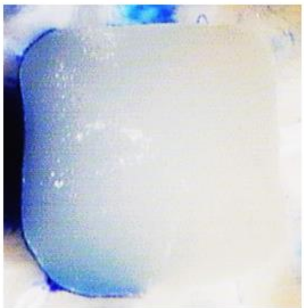
Clearfil® SE bond + Filtek® Bulk Fill (4mm)



Superbond C&B® + Filtek® Bulk Fill (4mm)



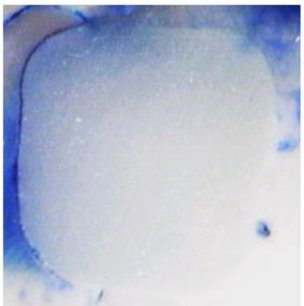
Adper® single bond 2 +
Tetric® N-Ceram Bulk Fill (4mm)



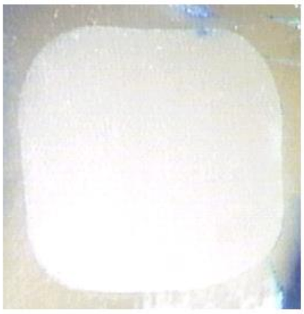
Clearfil® SE bond +
Tetric® N-Ceram Bulk Fill (4mm)

Superbond C&B® +
Tetric® N-Ceram Bulk Fill (4mm)

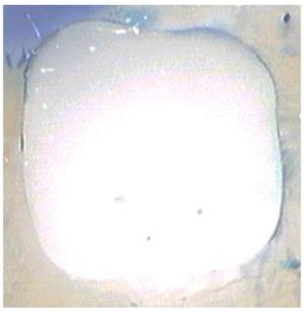
Adper® single bond 2 +
X-trafil® (4mm)



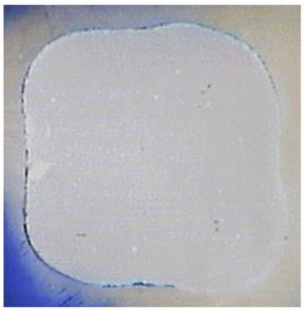
Clearfil® SE bond +
X-trafil® (4mm)



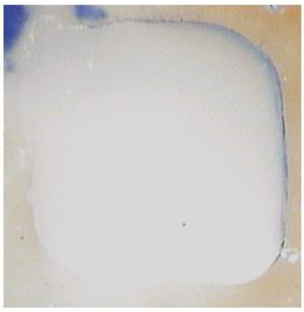
Superbond C&B® +
X-trafil® (4mm)



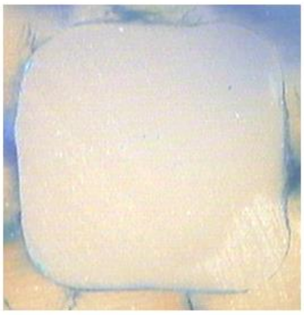
Adper® single bond 2 +
Venus® Bulk fill (4mm)



Clearfil® SE bond +
Venus® Bulk fill (4mm)



Superbond C&B® +
Venus® Bulk fill (4mm)

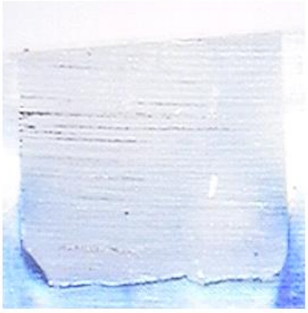


Adper® single bond 2 +
SonicFill® (4mm)

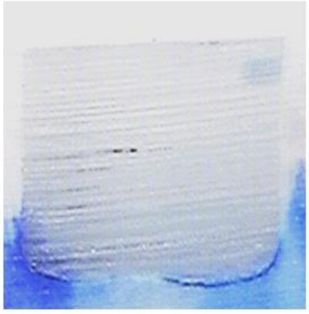
Clearfil® SE bond +
SonicFill® (4mm)

Superbond C&B® +
SonicFill® (4mm)

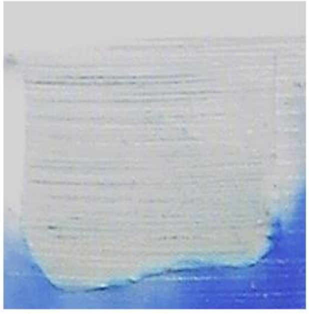
Photographs of specimen in internal leakage test



**Adper® single bond 2 +
Filtek® Z250 (2mm)**



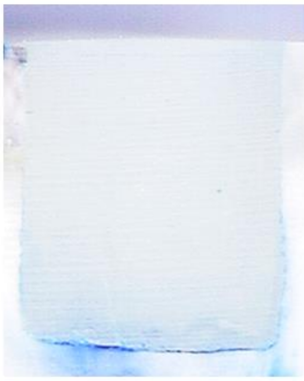
**Clearfil® SE bond +
Filtek® Z250 (2mm)**



**Superbond C&B® +
Filtek® Z250 (2mm)**

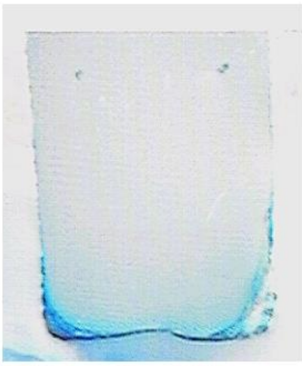
**Adper® single bond 2 +
Filtek® Z250 (4mm)**

**Clearfil® SE bond +
Filtek® Z250 (4mm)**

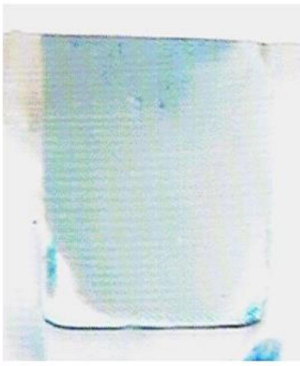


**Superbond C&B® +
Filtek® Z250 (4mm)**

**Adper® single bond 2 +
Filtek® Bulk Fill (4mm)**



**Clearfil® SE bond +
Filtek® Bulk Fill (4mm)**

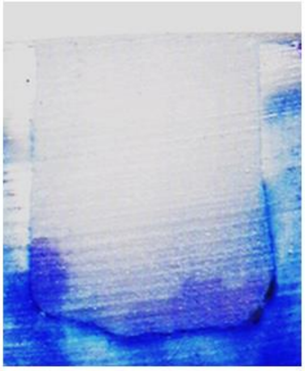


**Superbond C&B® +
Filtek® Bulk Fill (4mm)**

Adper® single bond 2 +
Tetric® N-Ceram Bulk Fill (4mm)

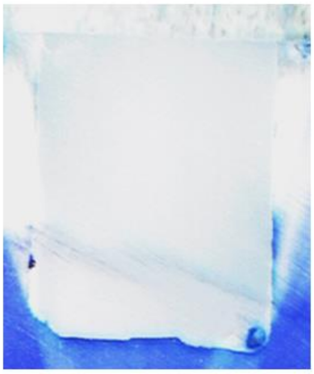
Clearfil® SE bond +
Tetric® N-Ceram Bulk Fill (4mm)

Superbond C&B® +
Tetric® N-Ceram Bulk Fill (4mm)

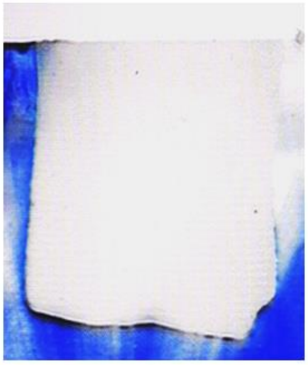


Adper® single bond 2 +
X-trafil® (4mm)

Clearfil® SE bond +
X-trafil® (4mm)



Superbond C&B® +
X-trafil® (4mm)



Adper® single bond 2 +
Venus® Bulk fill (4mm)

Clearfil® SE bond +
Venus® Bulk fill (4mm)

Superbond C&B® +
Venus® Bulk fill (4mm)

Raw data of all groups (marginal leakage)

	Adper®single bond 2 (percentage of marginal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	43.18	53.39	47.65	42.18	53.80	90.25	89.17
2	45.41	53.40	44.92	46.22	53.75	87.57	86.22
3	46.42	51.47	44.51	41.99	50.76	86.20	88.89
4	40.95	54.69	47.05	42.84	49.31	87.29	88.63
5	45.72	51.62	46.01	46.90	51.44	89.76	86.33
6	45.51	50.68	45.78	45.48	52.59	90.41	87.63
7	40.85	51.74	45.15	43.29	51.72	90.01	89.82
8	42.71	54.63	47.97	42.94	51.30	86.44	90.32
9	43.71	51.40	47.52	43.48	49.80	87.67	87.36
10	42.18	53.62	46.28	45.29	52.31	89.92	88.98
Mean	**43.66**	**52.66**	**46.28**	**44.06**	**51.68**	**88.55**	**88.34**
SD	**2.03**	**1.45**	**1.22**	**1.76**	**1.50**	**1.67**	**1.40**

	Clearfil® SE bond (percentage of marginal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	34.36	37.41	55.68	34.16	38.79	71.54	61.36
2	36.84	34.47	53.76	37.78	39.78	70.96	62.95
3	32.37	34.91	53.28	35.16	39.35	69.30	64.69
4	32.04	37.73	52.51	34.75	43.71	71.03	61.29
5	33.38	37.33	55.62	35.33	43.83	71.94	60.26
6	36.81	38.29	54.12	34.63	40.20	71.92	64.82
7	35.18	35.32	55.78	37.64	43.22	69.13	63.62
8	35.46	35.27	53.16	37.05	40.27	72.45	61.15
9	33.36	37.27	54.99	35.61	39.02	68.87	63.59
10	34.38	35.41	55.62	35.46	40.53	70.31	62.26
Mean	**34.42**	**36.34**	**54.45**	**35.76**	**40.87**	**70.75**	**62.60**
SD	**1.68**	**1.39**	**1.23**	**1.28**	**1.96**	**1.29**	**1.58**

	Superbond C&B® (percentage of marginal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	20.09	25.86	46.01	14.11	20.89	50.54	59.65
2	23.41	27.66	44.92	11.38	21.53	47.82	58.12
3	22.43	26.67	47.10	11.49	23.58	47.89	61.46
4	23.41	25.82	44.56	13.45	22.31	50.82	59.76
5	24.40	24.90	45.52	13.02	22.15	47.69	61.30
6	20.69	24.71	44.87	14.74	24.26	48.34	61.31
7	22.12	24.78	45.70	11.81	22.82	51.24	60.80
8	25.59	27.46	47.31	11.13	23.48	49.67	58.93
9	23.40	25.67	46.25	13.20	20.98	48.45	59.13
10	24.12	26.86	43.83	12.48	23.51	50.43	61.67
Mean	**22.97**	**26.04**	**45.61**	**12.68**	**22.55**	**49.29**	**60.21**
SD	**1.68**	**1.08**	**1.11**	**1.23**	**1.17**	**1.39**	**1.25**

Raw data of all groups (internal leakage)

	Adper® single bond 2 (percentage of internal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	59.93	82.88	69.76	78.78	78.83	79.45	87.31
2	59.92	80.95	70.33	75.71	81.57	80.56	90.36
3	62.83	79.57	73.00	75.34	81.61	81.26	89.68
4	60.57	80.45	72.43	78.89	79.66	79.69	88.10
5	60.59	82.95	71.05	76.30	80.64	79.88	87.62
6	59.65	81.58	69.08	77.96	81.80	81.18	88.21
7	60.34	82.78	74.11	77.04	80.24	82.68	87.43
8	59.37	81.23	70.56	75.90	79.79	81.75	88.49
9	60.56	79.95	73.85	75.03	80.08	80.54	89.01
10	59.38	80.75	73.75	76.43	81.46	79.65	88.86
Mean	**60.31**	**81.31**	**71.79**	**76.74**	**80.57**	**80.66**	**88.51**
SD	**1.00**	**1.22**	**1.86**	**1.39**	**1.01**	**1.05**	**0.99**

	Clearfil® SE bond (percentage of internal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	52.77	67.34	66.21	63.09	65.63	80.10	76.50
2	54.25	68.01	67.38	61.76	63.41	79.97	78.55
3	52.61	67.56	67.48	64.37	62.00	77.82	76.20
4	53.90	67.24	69.21	61.21	63.91	77.78	77.32
5	53.99	69.63	64.72	60.85	64.75	78.74	79.82
6	54.77	65.70	68.55	64.11	65.08	77.98	76.57
7	51.94	67.75	65.16	60.88	62.80	78.66	78.41
8	54.59	69.74	67.16	61.05	63.36	79.19	76.60
9	52.09	66.42	69.39	62.67	64.19	79.87	78.28
10	53.16	67.07	69.53	61.58	62.95	78.28	76.75
Mean	**53.41**	**67.65**	**67.48**	**62.16**	**63.81**	**78.84**	**77.50**
SD	**1.03**	**1.26**	**1.72**	**1.32**	**1.12**	**0.90**	**1.20**

	Superbond C&B® (percentage of internal leakage)						
	Filtek® Z250 (2 mm)	Filtek® Z250 (4 mm)	Filtek® Bulk Fill (4 mm)	Tetric® N-Ceram Bulk Fill (4 mm)	X-trafil® (4 mm)	Venus® Bulk fill (4 mm)	SonicFill® (4 mm)
1	38.82	52.20	62.82	34.59	35.94	63.04	63.65
2	40.20	53.31	60.49	33.22	35.57	60.71	63.23
3	40.09	54.52	61.86	35.29	37.79	60.73	65.78
4	38.68	52.82	61.43	34.32	37.10	61.82	64.58
5	40.40	54.69	57.78	34.95	37.46	61.28	63.52
6	41.86	54.91	61.16	34.97	35.33	63.61	63.51
7	39.26	52.56	59.12	33.65	37.14	60.22	63.21
8	39.89	53.03	63.07	34.66	37.46	63.81	64.29
9	40.28	53.25	58.25	33.59	36.75	62.37	63.87
10	38.68	54.30	59.42	33.23	35.79	62.16	63.25
Mean	**39.82**	**53.56**	**60.54**	**34.25**	**36.63**	**61.98**	**63.89**
SD	**0.99**	**0.97**	**1.85**	**0.77**	**0.90**	**1.25**	**0.81**

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ผลงานวิจัยในอดีต (ในระยะเวลา 5 ปี)

"การศึกษาความทนแรงดึงเฉือนระหว่างซี่ฟันเทียมเรซินอะคริลิกกับฐานฟันเทียมไนลอน"

"การศึกษานำร่องเรื่องความต้านทานการแตกหักของฟันซึ่งผ่านการรักษารากฟันที่สร้างเฟอร์รูลด้วยเรซินคอมพอสิต"