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EFFECT OF ENAMEL SURFACE TREATMENT ON TENSILE BOND STRENGTH OF REBONDED METAL ALLOYS

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Prosthodontics
Department of Prosthodontics
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การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบกำลังแรงยึดดึงระหว่างการยึดติดโลหะบนเคลือบฟันครั้งแรก และการยึดติดซ้ำ รวมทั้งศึกษาผลของการปรับสภาพผิวเคลือบฟันต่อกำลังแรงยึดดึงของการยึดติดโลหะซ้ำ นำฟันตัดล่างของวัวจำนวน 132 ซี่ ยึดในท่อพีวีซีด้วยเรซินชนิดบ่มเอง โดยให้ผิวฟันด้านริมฝีปากโผล่พ้นออกมา จากนั้นทำแบบรูปขี้ผึ้งทรงกระบอกและนำไปขึ้นรูปด้วยโลหะผสมพื้นฐาน ขัดเคลือบฟันและโลหะด้วยกระดาษซิลิกอนคาร์ไบด์ขนาด 600 กริต และพ่นทรายที่ส่วนของโลหะ จากนั้นนำโลหะมายึดติดกับส่วนของเคลือบฟันที่เตรียมไว้ โดยยึดด้วยเรซินซีเมนต์ซูเปอร์บอนด์ซีแอนด์บี (Superbond C&B) จำนวน 66 ชิ้น และพานาเวียเอฟ 2.0 (Panavia F2.0) จำนวน 66 ชิ้น ก่อนนำไปวัดค่ากำลังแรงยึดดึงและวิเคราะห์ลักษณะการล้มเหลว จากนั้นทำความสะอาดซีเมนต์ที่มองเห็นได้บนโลหะและเคลือบฟันด้วยเครื่องขูดหินน้ำลายอัลตราโซนิกส์ และพ่นทรายที่ส่วนของโลหะ จากนั้นแบ่งชิ้นตัวอย่างในแต่ละซีเมนต์เป็น 6 กลุ่ม กลุ่มละ 11 ชิ้น เพื่อปรับสภาพผิวเคลือบฟัน ได้แก่ การพ่นทราย การใช้ไฮโดรเจนเพอร์ออกไซด์ ร่วมกับโซเดียมแอสคอเบต การใช้สารเอทิลอะซิเตตในอะซิโตน การใช้สารเมทิลเมทาคริเลต การใช้สารผสมเมทิลฟอร์เมตร่วมกับเมทิลอะซิเตต และกลุ่มควบคุม จากนั้นทำการสุ่ม 1 ชิ้นตัวอย่างในแต่ละกลุ่มเพื่อศึกษาการเปลี่ยนแปลงของพื้นผิวโดยใช้กล้องจุลทรรศน์อิเล็กตรอนชนิดส่องกราด จากนั้นนำชิ้นตัวอย่างที่เหลือมายึดติดซ้ำ เพื่อนำไปวัดค่ากำลังแรงยึดดึงและวิเคราะห์ลักษณะการล้มเหลวอีกครั้ง ผลการทดลองพบว่าในกลุ่มเรซินซีเมนต์ซูเปอร์บอนด์ซีแอนด์บี การพ่นทราย การใช้สารเมทิลเมทาคริเลต และการใช้สารผสมเมทิลฟอร์เมตร่วมกับเมทิลอะซิเตต มีกำลังแรงยึดดึงสูงสุด ในกลุ่มพานาเวียเอฟ 2.0 พบว่าการปรับสภาพผิวไม่สามารถเพิ่มกำลังแรงยึดดึง สรุปได้ว่าเมื่อยึดติดครั้งแรกด้วยเรซินซีเมนต์ซูเปอร์บอนด์ซีแอนด์บี การพ่นทรายที่โลหะ ร่วมกับการปรับสภาพผิวเคลือบฟันโดยการพ่นทราย การใช้สารเมทิลเมทาคริเลต และการใช้สารผสมเมทิลฟอร์เมตร่วมกับเมทิลอะซิเตต สามารถเพิ่มค่ากำลังแรงยึดดึงของการยึดติดโลหะซ้ำ

ภาควิชา.....ทันตกรรมประดิษฐ์..... ลายมือชื่อนิสิต……………………………………………..
สาขาวิชา.....ทันตกรรมประดิษฐ์….. ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก……………........…
ปีการศึกษา……..2554……....

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ATIKOM SURINTANASARN: EFFECT OF ENAMEL SURFACE TREATMENT ON TENSILE BOND STRENGTH OF REBONDED METAL ALLOYS. ADVISOR: ASST.PROF.NIYOM THAMRONGANANSKUL, Ph.D., 95 pp.

The purpose of this study was to compare tensile bond strength between bonded and rebonded metal alloys to enamel and study the effect of different enamel surface treatments to improve tensile bond strength of rebonded metal alloys. One hundred and thirty-two bovine incisors were embedded in PVC tube using self-curing acrylic resin. Wax patterns were made and cast with base metal alloy. Teeth and metal specimens were flattened with 600-grit silicon carbide paper and metal specimens were sandblasted. Then, 66 metal specimens were cemented to the teeth with Superbond C&B and other 66 metal specimens with Panavia F2.0. The tensile bond strength was measured and mode of failure was analyzed. After debonding, visible cement was cleaned with ultrasonic scaler. Metal specimens were then sandblasted and specimens in each group of cement were divided into 6 groups of 11 each. Teeth in each group were treated with sandblasting, hydrogen peroxide with sodium ascorbate, ethyl acetate in acetone, methyl methacrylate, methyl formate-methyl acetate mixture and no treatment group. One specimen was randomly selected and inspected under SEM to determine the morphological change. Specimens were rebonded and tensile bond strength was tested and analyzed. In Superbond C&B group, high rebonding strengths were obtained when enamels were treated with sandblasting, methyl methacrylate and methyl formate- methyl acetate mixture group. In Panavia F2.0 group, no enamel surface treatments could improve rebonding strength. Combination of metal sandblasting and enamel treating with sandblasting, methyl methacrylate or methyl formate–methyl acetate mixture after Superbond C&B cementation could increase rebonding strength comparing with untreated enamel.

Department : Prosthodontics　Student’s Signature ....

Field of Study : Prosthodontics　Advisor’s Signature ....

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CHAPTER I

INTRODUCTION

Background and Significance of the problem

Resin-bonded fixed dental prostheses have been generally used as alternatives since they were mentioned by Rochette in 1973. These prostheses were attached to self-curing acrylic that provided retention from etched enamel and perforated metal retainers with silane coupling agent (Rochette, 1973). In 1982, electrolytic etching of inner metal surface was described and frequently called “The Maryland Bridge” (Livaditis and Thompson, 1982). Retainer type, cementation materials and occlusion had a relationship with the success of these prostheses (Creugers et al., 1989a; Creugers et al., 1989b). One of the benefits of resin-bonded fixed dental prostheses was that they could be rebonded in case of dislodgement. However, the study on retention ratio showed that rebonded prostheses had 74% dislodgement ratio when original bonded prostheses had 13% dislodgement ratio before 2 years (Creugers et al., 1990). Marinello et al. confirmed that rebonding often leads to repeated failures so they suggested renewing instead of multiple rebondings (Marinello et al., 1990).

The study in tensile bond strength indicated that rebond strength of all luting agents was less than that of initial bond (Williams et al., 1992). Conventional treatments of retainer such as cleaning, etching or heating and cleaning of tooth surface did not increase the bond strength of rebonded retainer compared with the initial strength level (Naifeh et al., 1988). In contrast, metal surface treatment, sandblasting or metal priming could improve bond strength in rebonding after accidental debonding (Kim and Kang, 2002). Enamel surface treatment was the alternative way to improve bond strength of rebonded metal to enamel. The purposes of this study were to compare tensile bond strength between bonded and rebonded metal to enamel and study effect of different enamel surface treatments to improve tensile bond strength of rebonded metal alloys.

Objectives

The objectives of this study were:

a. To compare the tensile bond strength between original enamel-metal alloys bonding and rebonded enamel-metal alloys bonding.

b. To evaluate the effect of enamel surface treatment on tensile bond strength of rebonded metal alloys.

Research Hypothesis

The null hypotheses are as follows:

c. There are no differences on the tensile bond strength between enamel original bonding and rebonding of metal alloys.

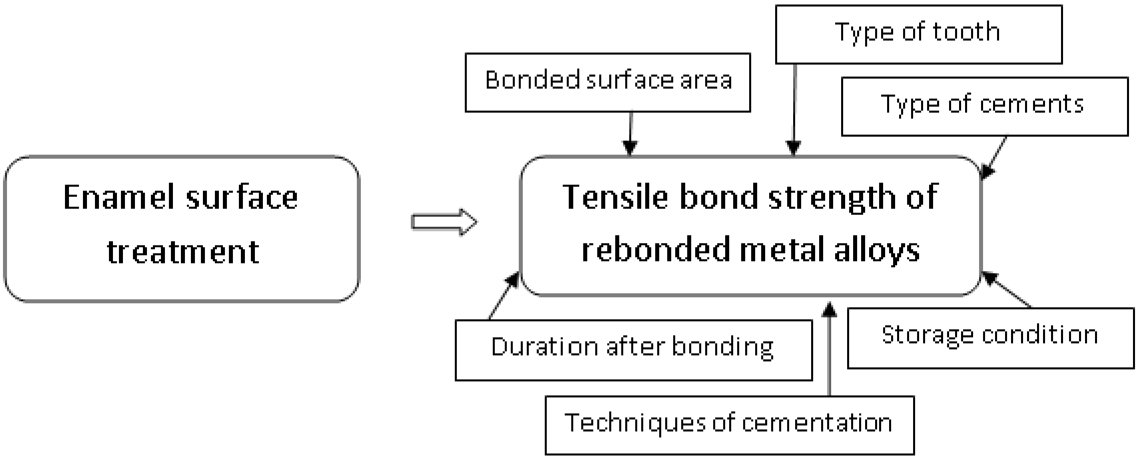
d. The enamel surface treatments have no effects on tensile bond strength of rebonded metal alloys.

The alternative hypotheses are as follows:

a. There is difference on the tensile bond strength between enamel original bonding and rebonding of metal alloys.

b. The enamel surface treatments have effects on tensile bond strength of rebonded metal alloys.

Conceptual Framework



Assumption

Prefabricated metal alloys were controlled to have same bonding area in circular shape. They were assumed to be resin-bonded prostheses in clinical situation.

Keywords

enamel, metal alloys, rebonding, resin-bonded prostheses, surface treatment, tensile bond strength

Research design

Experimental research

CHAPTER II

LITERATURE REVIEW

Concept, Theory and Relevant research

Adhesion

Adhesion is an attraction process between two dissimilar materials that can potentially bring them in direct contact by interfacial forces which may consist of valence forces or interlocking forces or both. An adhesive is the material that joins two substrates together and able to transfer a load from one to another surface.

In dentistry, bonding of resin to the components of tooth structure was described as follows (Soderholm, 1991):

1. Mechanical adhesion – Tooth conditioners have been used with the intention that conditioners would make penetration of resin easier. Formation of resin tags within tooth structure could create mechanical interlocking within tooth structure.
2. Surface precipitation – It could simplify bonding of inorganic layers to enamel but it is less significant than micro-retention from tooth conditioning.
3. Chemical bonding to the inorganic tooth structure - Most bonding agents aim to calcium ions. Due to higher inorganic structure in enamel, this method should be more effective on enamel than dentin.

4. Chemical bonding to the organic tooth structure – Bonding could also be achieved by bonding to organic structure of the tooth. It is easier to bond to dentin than to enamel because dentin contains more organic materials.

Enamel

Enamel is the most densely calcified tissue in human that has heterogeneous structure. Compositions of enamel are shown in Table 1. It consists of organic part, inorganic part and water. Inorganic part or mineral phase is made up of crystals of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) that are packed tightly in the form of prisms. These prisms are perpendicularly aligned to the surface of tooth. Because of hexagonal shape of crystals, they cannot be packed perfectly. Therefore, spaces are occupied by water and organic materials (van Noort, 2008). The bond strength of resin-enamel bonding is dependent on the orientation of the prisms. The load that applied in the direction parallel to oriented prisms results in higher bond strength (Carvalho et al., 2000). Although enamel is permeable to some substances, such as bleaching agents, enamel is normally permeable to other liquid, microorganism and toxic of microorganism (Anusavice, 2003).

Table 1. Composition of enamel (van Noort, 2008)

Composition	% by weight	% by volume
Organic part	1	2
Inorganic part	95	86
Water	4	12

Adhesion to enamel

Bonding to enamel was first described by Buonocore in 1955. The method was conditioning enamel surface with 85% phosphoric acid followed by rinsing and drying (Buonocore, 1955). Increasing the surface roughness of conditioned enamel was found in scanning electron microscope compared with unconditioned enamel (Jendresen et al., 1981). This condition allowed resin to penetrate the enamel. The extension of resin called resin tags that were approximately 6 micrometers diameter and 10-20 micrometers in length (Anusavice, 2003). Shinchi et al. found that there was no correlation between the length of the tags and the tensile bond strength (Shinchi et al., 2000). Nakabayashi and Pashley also reported that bond strength between resin and enamel relied on the cumulative cross-sectional area of the resin tags that infiltrate the etched enamel surface but there was a poor correlation between bond strength and the depth of resin penetration in etched enamel (Nakabayashi and Pashley, 1998). Retief reported that there was no difference of tensile bond strength using concentration of phosphoric acid from 10 to 50% (Retief, 1975). Bonding with 20-50% phosphoric acid provided the most retentive conditions. In addition, the more concentration of phosphoric acid, the less degree of damage to the enamel surface (Silverstone, 1974). Moreover, the total calcium dissolved was decreasing in case the concentration of phosphoric acid was more than 40% (Manson-Rahemtulla et al., 1984). One of the studies recommended using less aggressive acids or mild concentration of phosphoric acid to treat enamel surface (Shinchi et al., 2000). The diffusivity of the resin copolymers was important in the creation of resin-enamel hybrid layer (Nakabayashi and Pashley, 1998).

In conclusion, enamel etching did not only create the surface roughness and clean smear layer of bonding surface, but the surface free energy also increased after etching to improve resin infiltration and increase the retention of restoration. Tensile bond strength of resin to etched enamel was related to interfacial free energies of adhesion (Busscher et al., 1987).

Mechanism of adhesion to enamel

Substance exchange between biomaterials and tooth tissue leads to development of contemporary adhesive. They can be divided into one, two or three clinical application steps. Besides the number of application steps, Van Meerbeek classified adhesive based on the adhesion strategy in “etch and rinse”, “self-etch” and “glass-ionomer adhesive” (Van Meerbeek et al., 2003) (see Figure 1).

1. Etch and rinse approach – This strategy is still the most effective approach to achieve effective bonding to enamel. It involves at least two steps but the most conventional form consists of three steps. Tooth conditioning is the first step, followed by primer or adhesive promoter and the bonding agent. The two-step bonding combines second and third step but the conditioning step is still separated. The mechanism in this strategy is partial demineralization of hydroxyapatite crystals followed by polymerization of resin that absorbed by capillary attraction within enamel called resin tags. Resin tags can be divided into two types. Macrotags fill the space surrounding enamel prisms while microtags fill space within the etch-pits at the core of enamel prism, which could gain more retention.
2. Self-etch approach – This strategy no longer needs etch and rinse phase. It can be divided into one or two application steps. Resin infiltration occurs simultaneously with the etching process. It not only benefits for lessen application steps but also reduces a technique-sensitivity and risk of errors. However, the effects of residual smear layer and incorporating dissolved hydroxyapatite crystals are still in doubt.
3. Glass-ionomer approach – Glass-ionomer could bond to tooth structure without surface pre-treatment but weak polyalkenoic acid pre-treatment significantly improve the bond strength (Inoue et al., 2001). Thus, they can be divided into

one and two application steps. Polyalkenoic acid could increase bond strength because it removes the cutting debris and smear layer. Moreover, microporosities from demineralization appearing after step of conditioning lead to increase micromechanical interlocking.

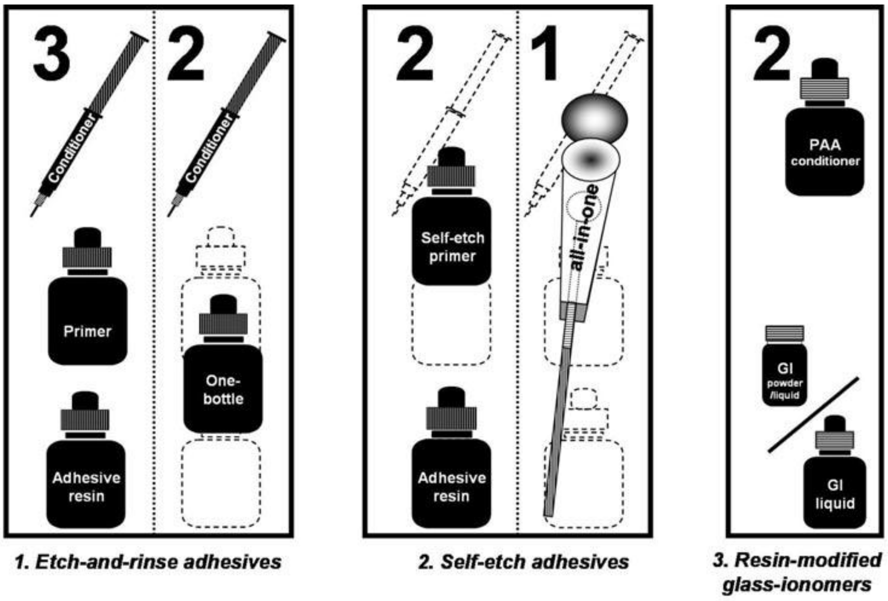


Figure 1. Classification of contemporary adhesives following adhesion strategy and number of clinical application steps (De Munck et al., 2005)

Resin-metal bonding

The development of resin-metal bonding is continually growing and dental applications are benefited much from the improvement. Resin facing on metal substructure instead of ceramic facing is one of the growths. Bonding of conventional crowns and bridges with compromised retention or minimal preparation resin-bonded bridges is widely used nowadays. The methods of bonding are followed (van Noort, 2008):

1. Macromechanical bonding – Mechanical retention between polymethyl methacrylate and metal framework was used in dental laboratories. In 1973, Rochette introduced a splint and fixed partial prosthesis without tooth reduction. It was the first time using metal bonding in dental clinic. Macromechanical bonding in this prosthesis was gained by mechanical bond with the perforated metal structure (Rochette, 1973). Many disadvantages include resin exposing and small retentive area.
2. Micromechanical bonding – Micromechanical bonding by electrolytic or acid-gel etching could overcome problems of macromechanical features. The etching process condition the surface of metal results in a pitted and grooved surface appearance. This retentive surface can strongly adhere to the resin cement without exposing of underlying resin. This technique is applicable to Ni-Cr alloy, which has a eutectic microstructure because the etching process will remove one of the phases of the alloy. Moreover, sandblasting with alumina grits, to produce the surface roughness, also increases the micromechanical bonding.
3. Chemical bonding – The composite resin cements were improved to avoid the complicated etching procedures. The adhesive promoters such as 4-META (4-methacryloxyethyl trimellitate anhydride) in Superbond C&B and MDP (10-

methacryloyloxydecyl dihydrogen phosphate) in Panavia were used to differentiate them from conventional Bis-GMA resin. These monomers can bond chemically to the oxide layer on the surface of base metals. In contrast, the surface of precious metals has a low chemical reactivity so the surface modification is required to make it enable to bond to resin cements. The familiar ways are tin plating, silica coating, tribochemical coating and using bifunctional metal primers.

Resin cements

Resin cements are luting agents that the composition is similar to the resin composite restorative materials. Some of cements are designed for general uses and some are designed for specific uses. They generally are flowable composites of low viscosity. Polymerization of resin cements can be achieved by chemical reaction, light activation or both. The variation of cement products depend on the composition, concentration and the filler contents (Anusavice, 2003). Resin cements can be classified in several systems such as the polymerization, adhesion strategy or application steps but O'Brien classified them based on the compositions as followed (O'Brien, 2008):

1. Acrylic resin cements – The powder in this system consists of polymethyl methacrylate or copolymer and benzoyl peroxide as the initiator. The liquid consists of methyl methacrylate monomer and amine accelerator. The polymerization in this system happens after polymer particles are dissolved

and softened by the monomer through peroxide-amine interaction. The reasons that this system are not used in nowadays are marginal leakage, pulpal irritation and ineffective bonding to tooth structure.

2. Adhesive resin cements – Resin cements in this system are added an adhesive promoter, 4-META (4-methacryloxyethyl trimellitate anhydride) to the methacrylate monomer. Tributyl boron, polymerization initiator, is also added to assist dentin chemical bonding. Resin cements in this group are bonded to dentin and enamel using coupling agents or adhesive promoters comprising bi-functional molecules (McCabe and Walls, 2008).
3. Dimethacrylate cements – Resin cements in this system are combinations of an aromatic dimethacrylate with monomers and fillers, which are similar to resin composite restorative materials. They usually base on Bis-GMA. These cements can be classified according to the ways of polymerization. They can be classified as chemically-cured, dual-cured and light-cured cements. Some cements contain monomer with adhesive promoters such as monomer with phosphate or carboxyl group. For example, Panavia resin cement contains phosphate group monomer, MDP, as adhesive promoter. Light-sensitive systems such as diketones and amine promoters are necessary for dual-cured and light-cured cements.

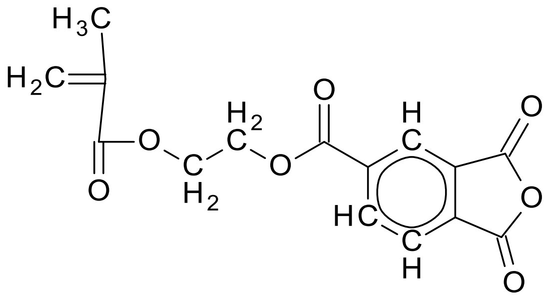


Figure 2. Chemical structure of 4-META

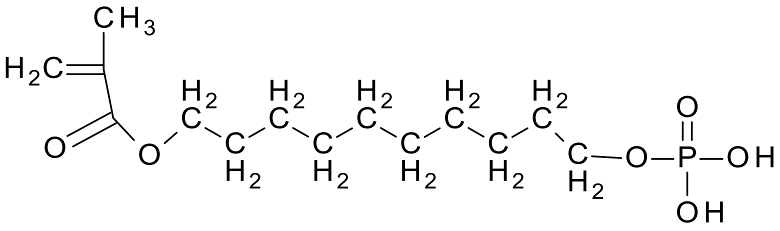


Figure 3. Chemical structure of MDP

Resin-bonded prosthesis

Resin-bonded fixed partial prosthesis was first introduced in 1973 when Rochette described a technique for fabricating a splint or fixed partial prosthesis using mechanical bonding from conditioned enamel and perforated retainers with self-curing polymethyl methacrylate without tooth reduction (Rochette, 1973). The perforated design had been widely accepted. However, this design had several disadvantages. The resin exposure through the funnel might cause the leakage between metal and resin interface and mechanical retention was limited only to the perforated area, not throughout the framework. Thus, the electrolytic etching of the inner side of cast frameworks was described to improve micromechanical retention (Livaditis and Thompson, 1982). Later, an immersion etchant technique for etching non-noble alloy was described to overcome limitations and difficult laboratory procedure of electrolytic etching (Love and Breitman, 1985). Moreover, air abrasion with aluminum oxide also increased micromechanical retention, surface area and surface-free energy (Imbery and Eshelman, 1996).

Chemical reaction between chemically reactive groups within resin cement, such as 4-META or MDP, and oxide layer on the base metal alloy becomes important role. For precious metal, chemical modifications are required because of the poor quality of bonding. Surface alteration, including tin plating, silica coating and tribochemical coating, makes the surface of metal more suitable to form a bond with resin cement. In addition, the use of bifunctional monomers in coupling agents is interesting because of simplicity and effective outcome.

There were many factors related to the success rate of resin-bonded prosthesis. Proper tooth isolation and good bonding technique enhance bond strength and increase the success rate (Eshleman et al., 1984). According to the analysis of Creugers and colleagues, retainer types, cementation materials and occlusion had a relationship with the success rate (Creugers et al., 1989a; Creugers et al., 1989b).

Rebonding of resin-bonded prosthesis

One of the advantages of resin-bonded prostheses was that they could be rebonded in case of dislodgement of restoration but the study showed that rebonded prostheses had a significantly higher dislodging rate than first bonded prostheses. Creugers et al. found that 74% of rebonded restorations had second dislodgement compared with 13% of original restorations (Creugers et al., 1990). Similarly, Marinello and colleagues published that the failure rate increased with each rebonding procedure. Failure rate of the original bonding was 21.5% but failure rate of first and second rebonding were 38.9% and 58.6%, respectively. Renewal of prostheses was recommended after multiple debonding because meticulous fit and conditioning of new framework increased the success rate (Marinello et al., 1990). Contrarily, Creugers and Kayser suggested rebonding procedure because it was a simple and inexpensive method. The renewal was recommended when clearly improper design was found (Creugers and Kayser, 1992). Besides, tensile bond strength of rebonded fixed partial prostheses was significantly less than bond strength of the original bonding (Naifeh et al., 1988; Williams et al., 1992).

According to the literature reviews of the bonding between metal and enamel, the mode of failure was classified by the interface of failure. Naifeh found that mode of failure between metal and enamel was cohesive failure in resin cement (Naifeh et al., 1988). Sen and colleagues found that the failure was predominantly at metal-resin cement interface (Sen et al., 2000). Aboush and colleagues found that the failure was cohesive failure in enamel, cohesive failure in resin cement, adhesive failure between enamel and resin cement and mixed pattern (Aboush and Jenkins, 1989). Lastly, Parsa and colleagues found mixed pattern which the test surface showed exposed enamel or metal with the island of retained cement (Parsa et al., 2003).

These studies inferred that dislodgement of resin-bonded prosthesis may leave retained cement on or within enamel surface. This effect can be found by inspection under scanning electron microscope. Tooth cleaning before rebonding did not increase the bond strength of the rebonded retainers (Naifeh et al., 1988).

Surface treatment of rebonded resin-bonded prosthesis

One of the advantages of resin-bonded prosthesis is easy rebonding but reducing of the bond strength of rebonded retainers becomes challenging problem. Kim and Kang published that sandblasting and metal priming were the effective method for metal surface treatment after debonding (Kim and Kang, 2002). This study focused on metal-resin cement interface but enamel-resin cement interface was also important. Enamel surface treatment such as sandblasting, using of hydrogen peroxide or other chemical agents may resolve the problem in this interface.

Air abrasion

Air abrasion is a pseudo-mechanical, non-rotary method of conditioning dental tissue using kinetic energy of particles to condition the tooth surface at high velocity. This technique was first described by Black as cavities preparation method (Black, 1945). According to the study of repaired resin composite restoration, surface air abrasion of the fractured restoration significantly increased the repaired bond strength. This result supported importance of micromechanical retention and increasing surface area of bonding in resin composite repair (Shahdad and Kennedy, 1998). Besides, air abrasion with aluminum oxide particles was suggested to be an ideal method of resin composite repair because it was simple, convenient and effective. This method also did not involve the use of dangerous acid in the mouth (Banerjee and Watson, 2002). The mean of repaired bond strength of resin composite was also similar to cohesive strength of resin composite (Shahdad and Kennedy, 1998).

The size of abrasive particles affected the coarseness of abraded surface. Halpern and Rouleau found that 100-μm aluminum oxide particles showed highest bond strength, followed by 50-μm and 25-μm particles (Halpern and Rouleau, 2010). On the other side, Roeder and colleagues published that aluminum oxide particle size had no influence on the bond strength (Roeder et al., 1995). Nevertheless, other studies suggested using 50-μm aluminium oxide particle for air abrasion of cured composite surface (Brosh et al., 1997; Papacchini et al., 2007a).

Other than the use of air abrasion in resin composite repair, this technique was suggested to use in enamel conditioning to increase the bond strength of orthodontic brackets and fissure sealant (Canay et al., 2000; Moslemi et al., 2010). Combination of air abrasion and acid conditioning was suggested to improve the bond strength (Canay et al., 2000; Roeder et al., 1995).

Hydrogen peroxide

Hydrogen peroxide (H_2O_2) is clear liquid. It appears colorless in solution stage. With its oxidizing properties, hydrogen peroxide is often used as bleaching agents in dental office. The mechanism of color removal has not clearly understood. The mechanism differs according to the type of staining, chemical and physical environment. In general condition, hydrogen peroxide can release free radical. Chemical equations and are as follow (Aschheim and Dale, 2001).

$$H_2O_2 \rightarrow H\cdot + \cdot OOH$$

$$H_2O_2 \rightarrow HO\cdot + \cdot OH$$

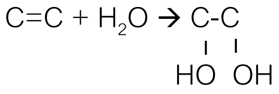
$$H_2O_2 \rightarrow H^+ + :OOH^-$$

Chemical equations of combination of free radicals and anions are as follow.

$$HOO\cdot + OH^- \rightarrow O_2^-\cdot + H_2O$$

$$HOO\cdot \rightarrow O_2^-\cdot + H^+$$

Discoloration is from the double bonds; therefore breaking double bonds usually take discoloration out. Free radicals tend to attract to double bonds and form epoxides but epoxides are unstable so they change to alcohols (Aschheim and Dale, 2001).



$$C{=}C + H_2O \rightarrow \underset{HO}{\overset{|}{C}}-\underset{OH}{\overset{|}{C}}$$

According to the study about results of hydrogen peroxide on the surface of enamel or resin composite, hydrogen peroxide slightly created surface roughness on the surface of resin composite (Turker and Biskin, 2003). However, Papacchini and colleagues found that hydrogen peroxide treated resin composite surface had no changes in surface texture and had weaker bond strength in repaired resin composite (Papacchini et al., 2007b).

On the enamel surface, Increasing in density of surface pitting was found when enamel was treated with 35% hydrogen peroxide. The pattern of morphologic alteration was heterogeneous (Spalding et al., 2003). However, the bond strength between resin and enamel was reduced after exposing to hydrogen peroxide (Stokes et al., 1992; Torneck et al., 1990). Reduction in bond strength could be caused by residual oxygen in enamel pores that could obstruct resin infiltration and inhibit polymerization (Rueggeberg and Margeson, 1990). Anyway, reduced bond strength was reversed following treatment with anti-oxidant agent, 10% sodium ascorbate. Lai suggested using at least one-third of the time of oxidizing agent application (Lai et al., 2002).

Ethyl acetate

Ethyl acetate is non-polymerizable solvent with the potential to swell and permit the diffusion of polymerizable materials. A heat-processed denture base resin surface swelled after 120 second-application of ethyl acetate and had highest three-point bending strength and shear bond strength compared with other application time and untreated group in denture base repair (Shimizu et al., 2006; Shimizu et al., 2008). Moreover, dentin surface treatment with ethyl acetate and acetone-based cleansing agent increased push-out bond strength of fiber post to root canal dentin (Demiryurek et al., 2009). However, ethyl acetate could not increase repair strength of resin composite (Azarbal et al., 1986).

Methyl acetate, methyl formate and methyl methacrylate

Vallittu and colleagues suggested using methyl methacrylate in denture base repair. They found that it could increase the bond strength of repaired acrylic resin and the surface structure of acrylic resin was dissolved after treating for 180 seconds (Vallittu et al., 1994). However, Thanyakitpisal and colleagues reported that treating with methyl formate, methyl acetate and mixture of methyl formate and methyl acetate for 15 seconds increased flexural strength of repaired acrylic denture base, as compared with using methyl methacrylate for 180 seconds and ethyl acetate (Thunyakitpisal et al., 2011).

CHAPTER III

METHODOLOGY

One hundred and thirty-three non-carious bovine mandibular incisors were collected. Teeth were extracted from bovine mandibles and rinsed with tap water to remove saliva and debris. They were then cut from their roots under water cooling with precision sectioning saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) and tried in ½”-polyvinyl chloride (PVC) tube (Elephant, Nawaplastic, Bangkok, Thailand). Additional cutting was required in case the teeth were larger than the tube and then embedded in PVC tube with self-curing acrylic resin (Fastray, Harry J. Bosworth Company, Skokie, IL, USA) with their labial surface exposed using parallel controller (Figure 4). Then, teeth were stored in 0.03% sodium azide solution at 4±2 °C. The labial surfaces of teeth were flattened using 600-grit silicon carbide paper (TOA, TOA Group, Samutprakarn, Thailand) and polishing plane controller (Figure 5) with grinder-polisher (Ecomet 250, Buehler, Lake Bluff, IL, USA). Teeth were examined that dentin was not exposed and enamel flat plane was uniform and larger than 12 mm^2 at the center of tube.

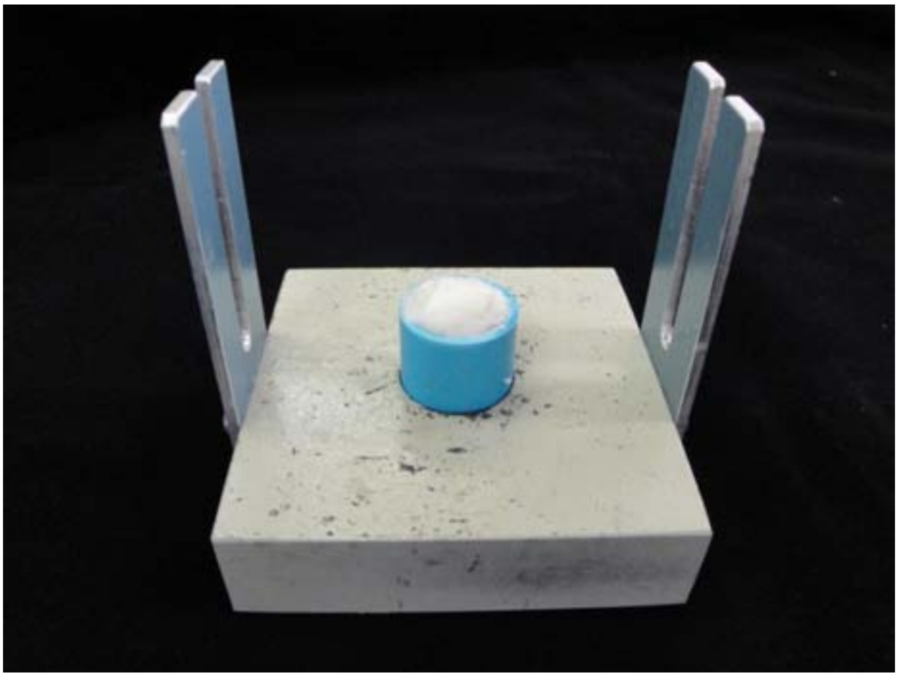


Figure 4. Tooth specimen embedded in PVC tube

with self-curing acrylic resin using parallel controller

Figure 5. Polishing plane controller of PVC tube

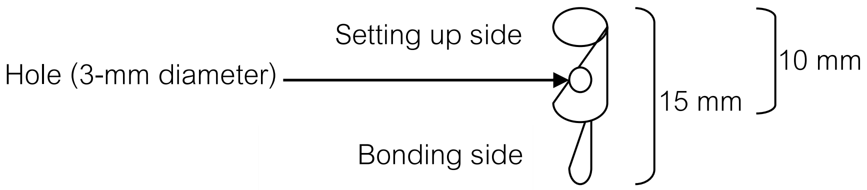


Figure 6. Metal specimen illustration

One hundred and thirty-three patterns were formed (Figure 6). The pattern consisted of a smaller plastic tube (3-mm diameter, 15-mm long), bigger plastic tube (7-mm diameter, 10-mm long) and periphery wax (Surgident, Heraeus Kulzer, Hanau, Germany) to fill-up both tubes. Parallel controller was used to control the parallel of the plastic tubes. The smaller tube was prepared for bond testing and the bigger tube was designed for setting up with testing machine. The patterns were invested and cast with base metal alloy (Argeloy N.P. (V), Argen, San Diego, CA, USA) according to the manufacturer's specification. A hole was drilled on setting up side of metal specimens by 3-mm diameter using thread cutting machine (AB Hultsfreds Mekaniska Verkstad, Hultsfreds, Rosenfors, Sweden). Then, metal specimens were flattened and polished the top and bottom sides using 220 and 600-grit silicon carbide papers with grinder-polisher (Figure 7). The polished surfaces were controlled to be perpendicular to the long axis of specimen by polishing plane controller (Figure 8-9). Then, the metal specimens were treated with sandblasting. Fifty-µm aluminum oxide particles were blasted for 10 seconds from the distance of approximately 5 mm perpendicular to the bonding surface (Papacchini et al., 2007a) using abrasion device (Dento-prep, Rønvig, Daugaard, Denmark).

Figure 7. Metal specimen with 3-mm hole on setting up side

Figure 8. Polishing plane controller of metal specimen

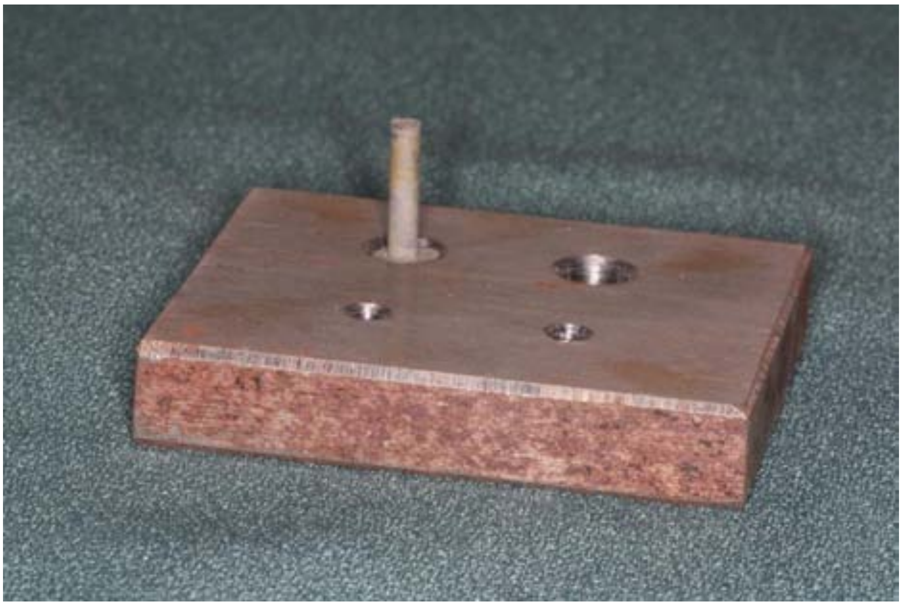


Figure 9. Polishing plane controller of metal specimen

Metal specimen and wax container in parallel controller were weighed. Modeling wax (Dentsply Ltd, Weybridge, United Kingdom) was added to the container to reach the weight of 50 grams. The setting up side of specimen was attached to the center of the wax container. The metal specimens would be cemented to the teeth according to the manufacturer's instruction.

After this step, the study was divided into 2 parts. In the first part, sixty-six specimens were cemented with polymethyl methacrylate-based adhesive resin cement (Superbond C&B, Sun Medical, Shiga, Japan). In second part, sixty-six specimens were cemented with dimethacrylate cement (Panavia F2.0, Kuraray, Osaka, Japan) using the parallel controller. The weight pressure was kept during the setting of resin cement and excess cement was carefully removed with explorer (Figure 10). After cement setting, the position of cemented area and vertical referent line on metal specimen was labeled with permanent pen and vertical referent line on tooth specimen was marked with diamond bur to confirm that rebonded specimens would be at the same position. Then, all specimens were stored in water at 37°C for 24 hours.

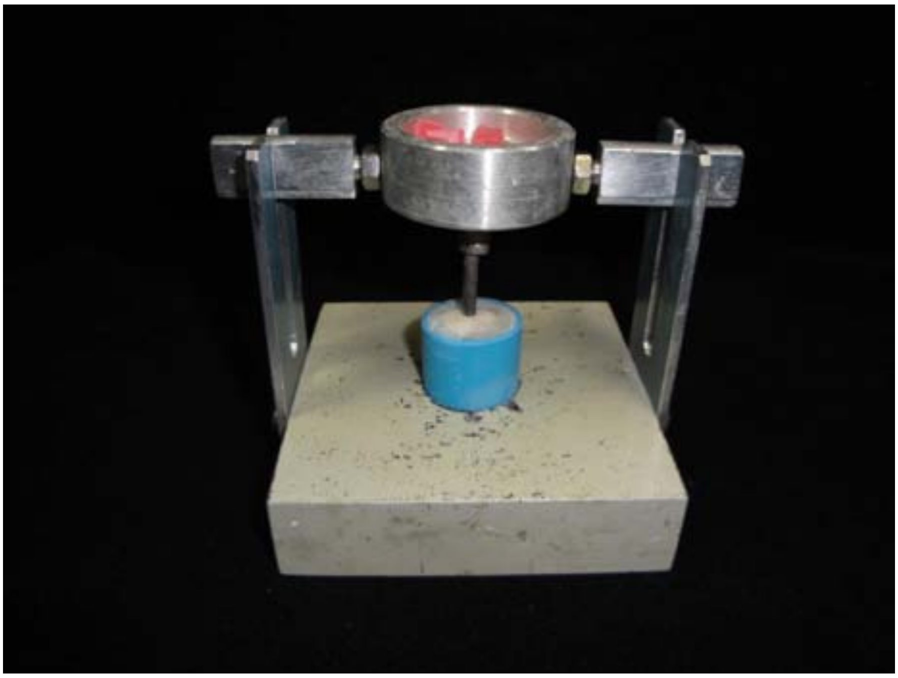


Figure 10. Metal specimen and wax container in parallel controller

For tensile testing, specimens were dried and mounted to a universal testing machine (EZ-S, Shimadzu Co., Kyoto, Japan) at the crosshead speed of 1 mm/minute and 500 N load cell. PVC tube was fixed to the clamp and metal specimens were held with 2-mm diameter metal bar. Bending or rotational forces were avoided during specimen mounting (Figure 11). The test configuration was loading in tension until failure occurring. Failure load was recorded in Newton (N) and then analyzed to Mega Pascal (MPa).

Figure 11. Specimen mounted to universal testing machine

The specimens were examined to analyze the mode of failure using stereo microscope at 15x magnification. Modes of failure were classified into 3 categories. 1.) The cohesive failure was characterized by retained resin cement covering both metal and enamel surfaces. 2.) The adhesive failure was showed by resin cement covering metal or enamel surface. 3.) Mixed failure was showed by the exposed metal or enamel with the island of resin cement.

After debonding of specimens, all visible retained resin cement was removed with ultrasonic scaler (P5 Newtron XS ultrasonic unit, Acteon Group, Mount Laurel, New Jersey, USA) at a power setting of 16. Then, the metal specimens were treated with sandblasting. Fifty-μm aluminum oxide particles are blasted for 10 seconds from the distance of approximately 5 mm perpendicular to the bonding surface using abrasion device. Specimens were cleaned with distilled water for 10 minutes in ultrasonic cleaner (Branson 5210, Branson Ultrasonic, Danbury, Utah, USA) (Kim and Kang, 2002).

The specimens of enamel were randomly divided into 6 groups of 10 for each group and received the following surface treatments:

1. Group 1: no surface treatment
2. Group 2: treated with 50-μm aluminum oxide particles for 10 seconds from the distance of approximately 5 mm perpendicular to the bonding surface. Then, rinsed with tap water for 10 seconds and dried for 10 seconds.
3. Group 3: treated with 38% hydrogen peroxide for 5 minutes and then rinsed with tap water for 30 seconds (Papacchini et al., 2007b). 10% sodium ascorbate was applied for 2 minutes. Then, rinsed with tap water for 10 seconds and dried for 10 seconds.
4. Group 4: treated with Tokuyama rebase II adhesive (Tokuyama dental corporation, Tokyo, Japan) for 120 second. Then, rinsed with tap water for 10 seconds and dried for 10 seconds.
5. Group 5: treated with methyl methacrylate (Fastray liquid, Harry J. Bosworth company, Skokie, Illinois, USA) for 60 second. Then, rinsed with tap water for 10 seconds and dried for 10 seconds.

6. Group 6: treated with mixture of methyl formate and methyl acetate solution (25:75 v/v) for 15 seconds. Then, rinsed with tap water for 10 seconds and dried for 10 seconds.

One specimen per each group was randomly selected and inspected under scanning electron microscope to determine the morphological changes.

After surface treatment, the metal specimens were rebonded to the same specimen and same position. The specimens were tested for tensile bond strength and the mode of failure as previously described.

Statistical analysis

For the normally distributed data, one-way analysis of variance (ANOVA) and Bonferroni post hoc multiple comparisons were used to perform the tensile bond strength in MPa in case of equal variances and Brown-Forsythe statistic and Tamhane's T2 post hoc multiple comparisons would be used in case of unequal variances (α=.05).

In case the data were not normally distributed, Kruskal–Wallis one-way analysis of variance would be used to perform the tensile bond strength in MPa. Post hoc multiple comparisons were used to compare between groups (α=.05).

Paired t-test was used to compare tensile bond strength between original bonding and rebonding when data was normally distributed (α=.05).

Wilcoxon signed rank test was used to compare tensile bond strength between original bonding and rebonding when data was not normally distributed (α=.05).

CHAPTER IV

RESEARCH RESULT

Part 1: Polymethyl methacrylate-based adhesive resin cement (Superbond C&B)

The data of tensile bond strengths in both original bonding and rebonding groups were normally distributed. Homogeneity of variance test showed that group variance of original bonding group are equal but the assumption of equal variances in rebonding group did not hold (p=.728 in original bonding group and p=.004 in rebonding group). Therefore, ANOVA was used to analyze in original bonding group and Brown-Forsythe statistic was used in rebonding group.

In original bonding group, the mean of tensile bond strength (MPa) and standard deviation are shown in Table 2. The bar chart and standard deviation bar are also shown in Figure 12. ANOVA revealed that the means of original bond strength are equal (p=.999).

In rebonding group, the mean of tensile bond strength (MPa) and standard deviation are shown in Table 2. The bar chart and standard deviation bar are also shown in Figure 13. Brown-Forsythe statistic revealed that the means of original bond strength are not equal (p<.001). Tamhane's T2 multiple comparison tests are also shown in Table 2.

Table 2. Mean tensile bond strength (MPa) and standard deviation in original bonding and rebonding group (Superbond C&B)

	Mean of tensile bond strength (MPa)			
	Original bonding	SD	Rebonding*	SD
Group 1: No surface treatment (C)	9.0998	1.1727	5.3872^{b}	0.8715
Group 2: Sandblasting (S)	9.2477	1.0198	8.9999^{a}	1.7022
Group 3: Hydrogen peroxide and sodium ascorbate (H)	9.2414	1.1677	3.9562^{c}	0.5796
Group 4: Ethyl acetate in acetone (EA)	9.3244	1.2000	5.1989^{b}	0.6073
Group 5: Methyl methacrylate (MMA)	9.2100	1.3350	7.7559^{a}	0.9548
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	9.2325	0.8714	7.1429^{a}	0.7314

*No significant difference ($p>0.05$) within groups denoted by the same superscript letter

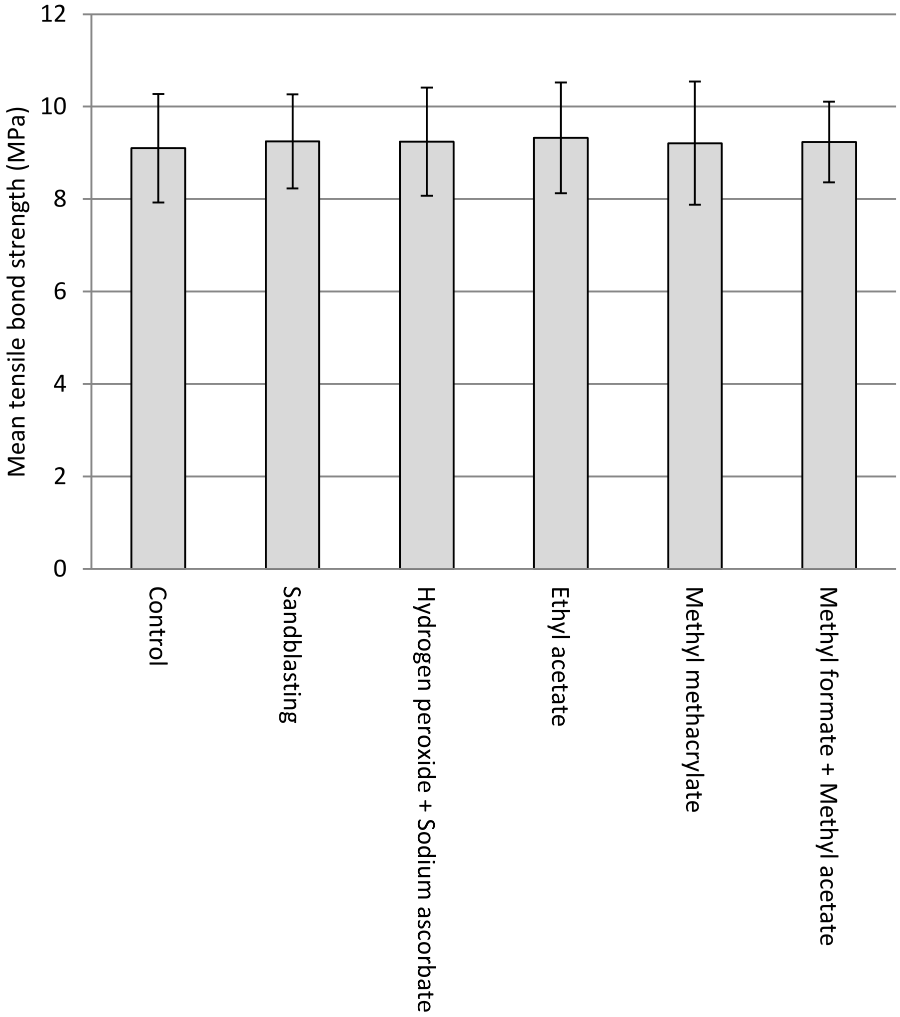


Figure 12. Mean tensile bond strength (MPa)

and standard deviation in original bonding group (Superbond C&B)

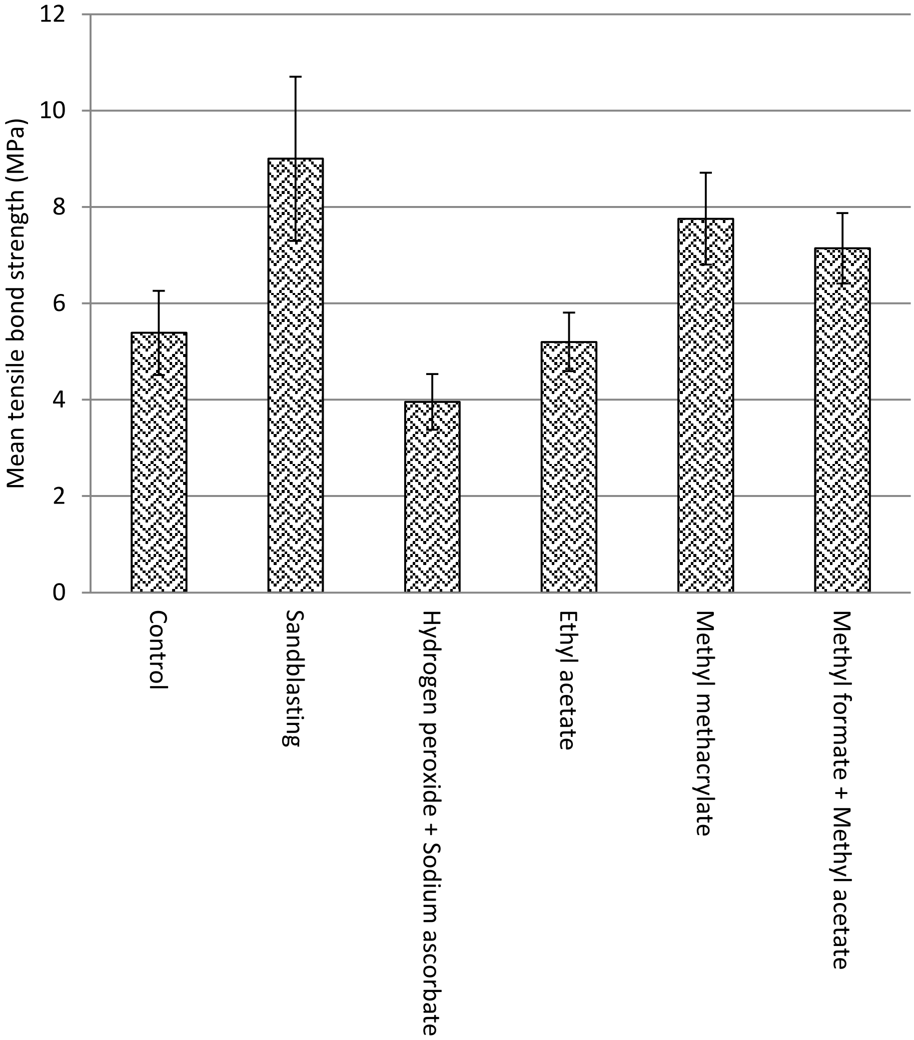


Figure 13. Mean tensile bond strength (MPa)

and standard deviation in rebonding group (Superbond C&B)

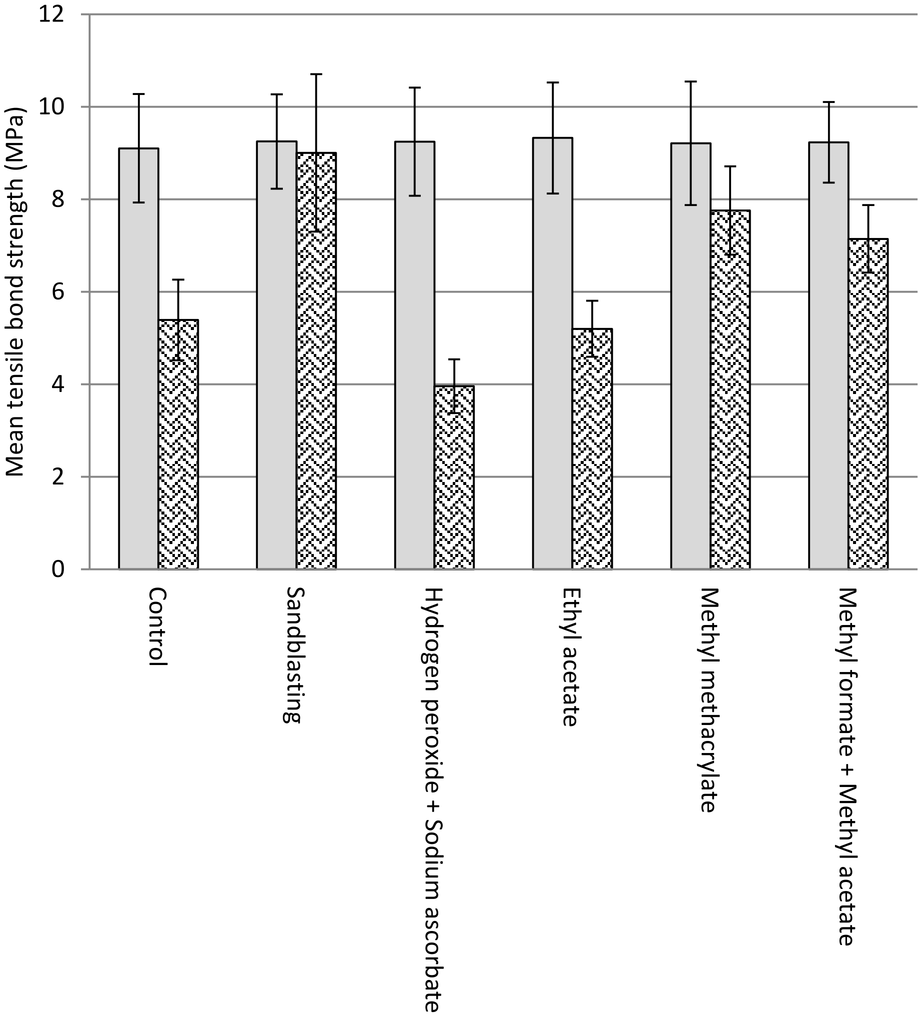


Figure 14. Mean tensile bond strength (MPa)

and standard deviation in original bonding and rebonding group (Superbond C&B)

Data of difference in tensile bond strength were normally distributed and paired t-test showed significant difference between original bonding and rebonding group in all groups except sandblasting group (p=.725).

Table 3. Mode of failure of original bonding group (Superbond C&B)

	Mode of failure				
	E	E-R	R	R-M	Mixed
Group 1: No surface treatment (C)	0	0	9	0	1
Group 2: Sandblasting (S)	0	0	9	0	1
Group 3: Hydrogen peroxide and sodium ascorbate (H)	0	0	8	0	2
Group 4: Ethyl acetate in acetone (EA)	0	0	10	0	0
Group 5: Methyl methacrylate (MMA)	0	0	8	0	2
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	0	0	9	0	1

E – Cohesive failure of enamel

E-R – Adhesive failure between enamel and resin cement

R – Cohesive failure of resin cement

R-M - Adhesive failure between metal and resin cement

Mixed – Mixed pattern of failure

Table 4. Mode of failure of rebonding group (Superbond C&B)

	Mode of failure				
	E	E-R	R	R-M	Mixed
Group 1: No surface treatment (C)	2	0	0	0	8
Group 2: Sandblasting (S)	1	0	0	0	9
Group 3: Hydrogen peroxide and sodium ascorbate (H)	2	0	0	0	8
Group 4: Ethyl acetate in acetone (EA)	0	6	0	0	4
Group 5: Methyl methacrylate (MMA)	2	0	0	0	8
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	3	0	0	0	7

E – Cohesive failure of enamel

E-R – Adhesive failure between enamel and resin cement

R – Cohesive failure of resin cement

R-M - Adhesive failure between metal and resin cement

Mixed – Mixed pattern of failure

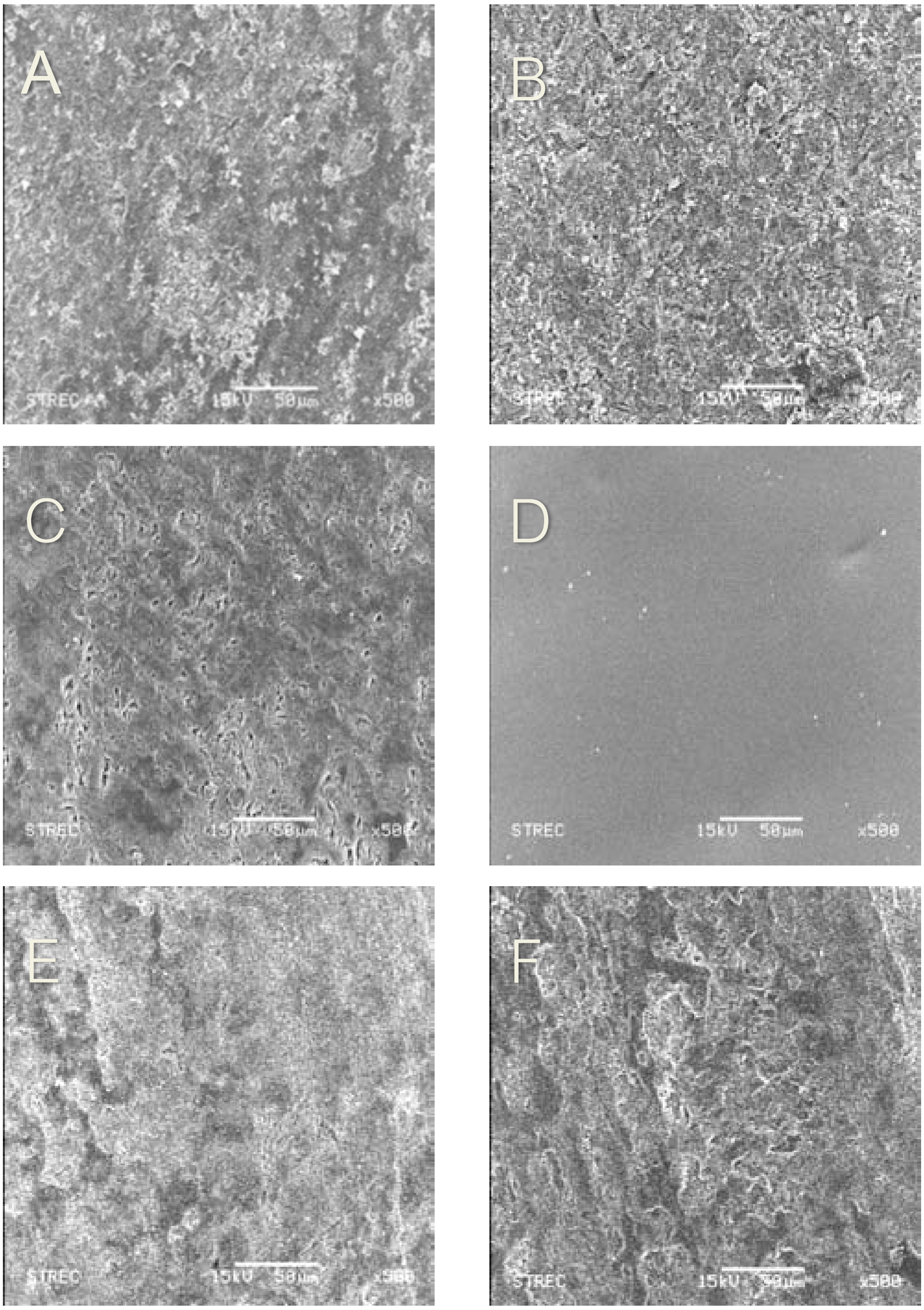

A
STREC 15kV 50µm x500
B
STREC 15kV 50µm x500
C
STREC 15kV 50µm x500
D
STREC 15kV 50µm x500
E
STREC 15kV 50µm x500
F
STREC 15kV 50µm x500

Figure 15. SEM images of morphological change of cleaned enamel after original bond testing (Superbond C&B)

A - control group,

B – surface treated with sandblasting,

C – surface treated with hydrogen peroxide and sodium ascorbate,

D – surface treated with ethyl acetate in acetone,

E – surface treated with methyl methacrylate,

F – surface treated with mixture of methyl formate and methyl acetate

Part 2: Dimethacrylate resin cements (Panavia F2.0)

The data of tensile bond strengths in both original bonding and rebonding groups were normally distributed. Homogeneity of variance test showed that group variance of original bonding group were equal but the assumption of equal variances in rebonding group did not hold (p=.162 in original bonding group and p=.028 in rebonding group). Therefore, ANOVA was used to analyze in original bonding group and Brown-Forsythe statistic was used in rebonding group.

In original bonding group, the mean of tensile bond strength (MPa) and standard deviation are shown in Table 5. The bar chart and standard deviation bar are also shown in Figure 16. ANOVA revealed that the means of original bond strength are equal (p=.996).

In rebonding group, the mean of tensile bond strength (MPa) and standard deviation are shown in Table 5. The bar chart and standard deviation bar are also shown in Figure 17. Brown-Forsythe statistic revealed that the means of original bond strength are not equal (p<.001). Tamhane's T2 multiple comparison tests are also shown in Table 5.

Table 5. Mean tensile bond strength (MPa) and standard deviation in original bonding and rebonding group (Panavia F2.0)

	Mean of tensile bond strength (MPa)			
	Original bonding	SD	Rebonding*	SD
Group 1: No surface treatment (C)	5.4937	0.9008	4.1022^{a}	0.8094
Group 2: Sandblasting (S)	5.6422	1.0649	4.0845^{a}	0.4859
Group 3: Hydrogen peroxide and sodium ascorbate (H)	5.5200	1.2601	2.1667^{b}	0.4236
Group 4: Ethyl acetate in acetone (EA)	5.4195	0.7258	2.1591^{b}	0.3394
Group 5: Methyl methacrylate (MMA)	5.4108	0.8292	4.2065^{a}	0.6214
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	5.4600	1.0432	4.0965^{a}	0.7367

*No significant difference ($p>0.05$) within groups denoted by the same superscript letter

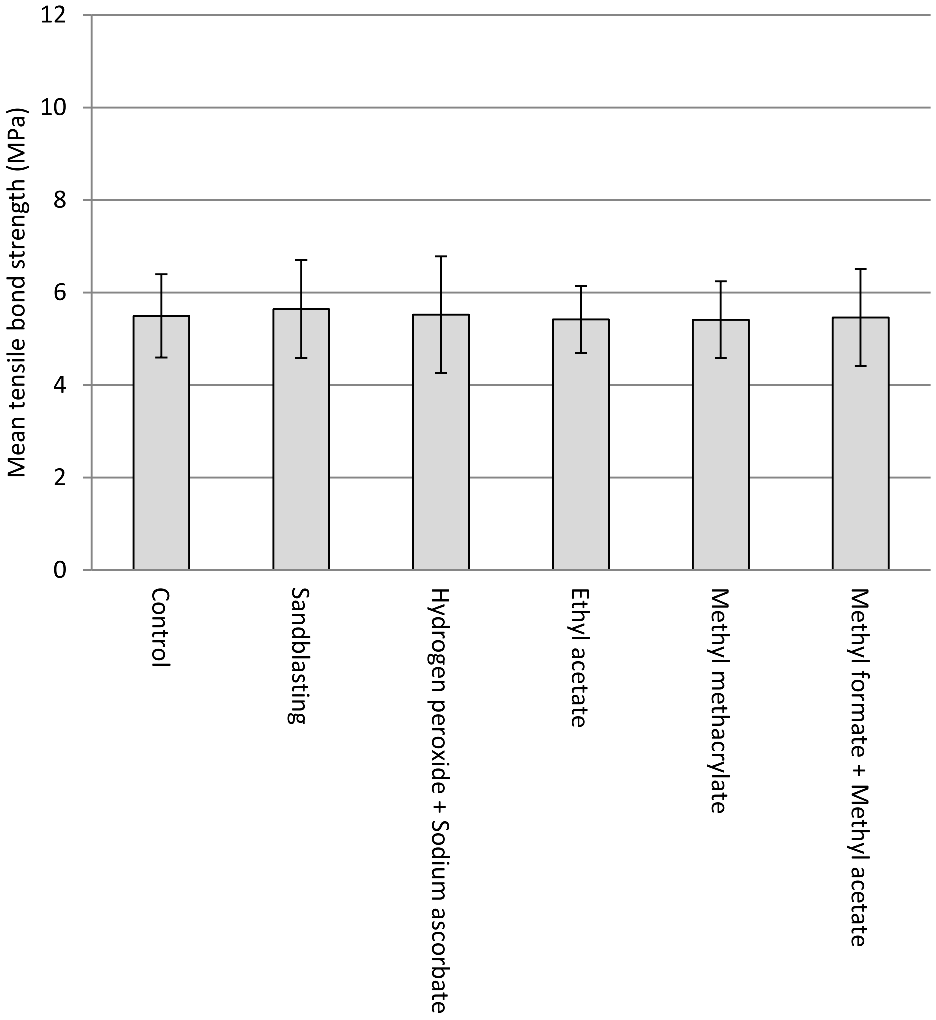


Figure 16. Mean tensile bond strength (MPa)

and standard deviation in original bonding group (Panavia F2.0)

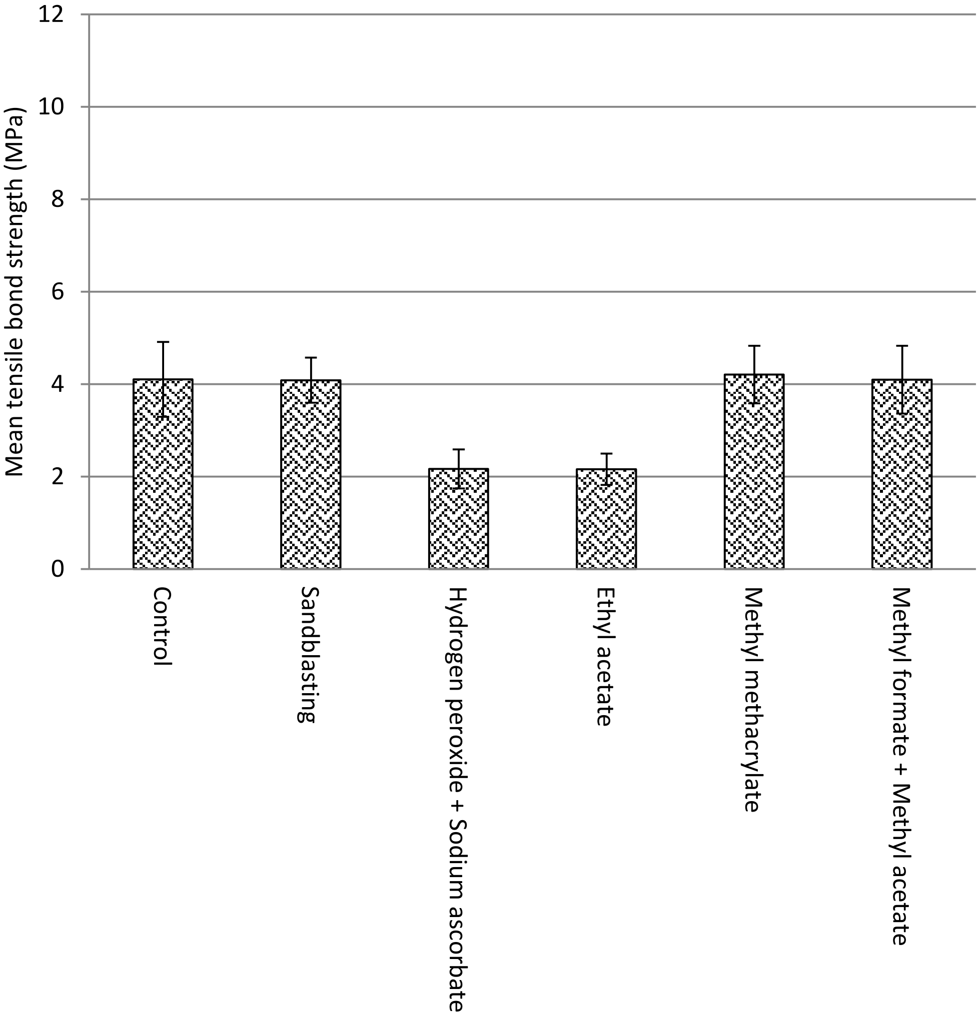


Figure 17. Mean tensile bond strength (MPa)

and standard deviation in rebonding group (Panavia F2.0)

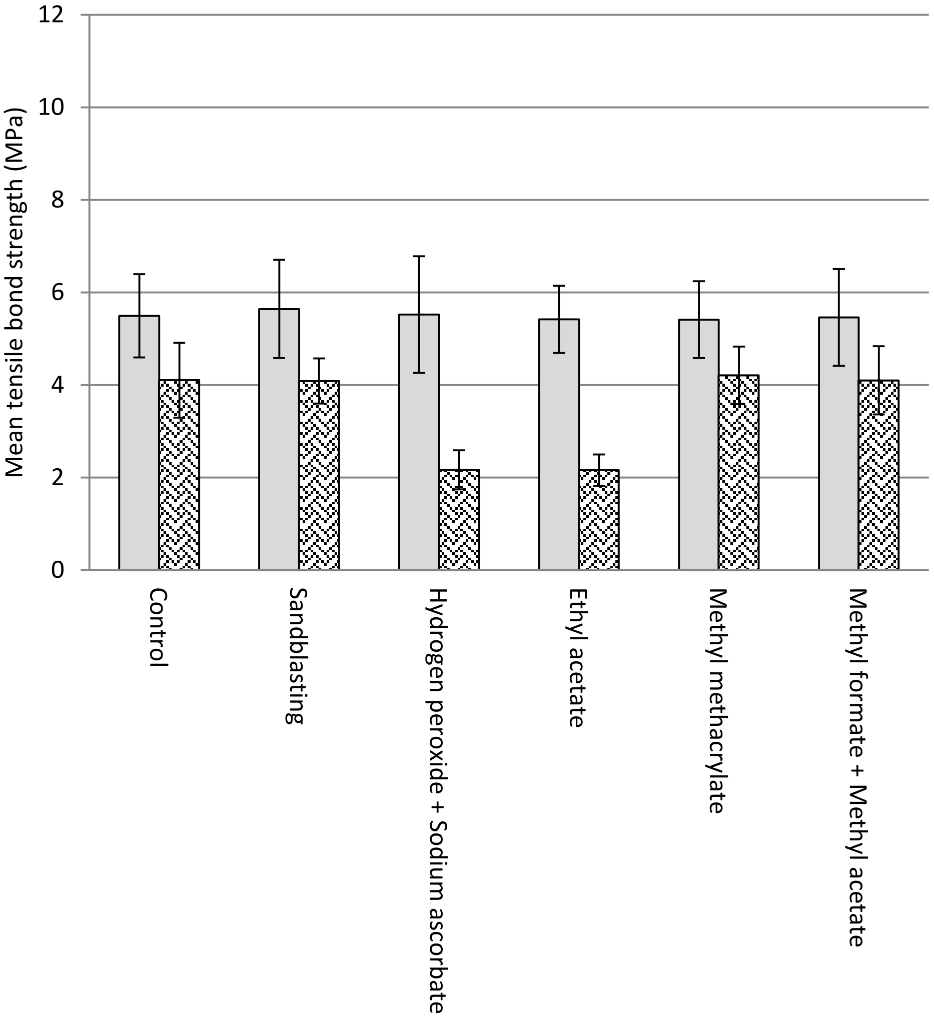


Figure 18. Mean tensile bond strength (MPa)

and standard deviation in original bonding and rebonding group (Panavia F2.0)

Data of difference in tensile bond strength were normally distributed and paired t-test showed significant difference between original bonding and rebonding group in all groups.

Table 6. Mode of failure of original bonding group

	Mode of failure				
	E	E-R	R	R-M	Mixed
Group 1: No surface treatment (C)	0	0	7	0	3
Group 2: Sandblasting (S)	0	0	10	0	0
Group 3: Hydrogen peroxide and sodium ascorbate (H)	0	0	9	0	1
Group 4: Ethyl acetate in acetone (EA)	0	0	9	0	1
Group 5: Methyl methacrylate (MMA)	0	0	9	0	1
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	0	0	8	0	2

E – Cohesive failure of enamel

E-R – Adhesive failure between enamel and resin cement

R – Cohesive failure of resin cement

R-M - Adhesive failure between metal and resin cement

Mixed – Mixed pattern of failure

Table 7. Mode of failure of rebonding group

	Mode of failure				
	E	E-R	R	R-M	Mixed
Group 1: No surface treatment (C)	0	4	3	0	3
Group 2: Sandblasting (S)	0	0	8	0	2
Group 3: Hydrogen peroxide and sodium ascorbate (H)	0	3	4	0	3
Group 4: Ethyl acetate in acetone (EA)	0	10	0	0	0
Group 5: Methyl methacrylate (MMA)	0	1	4	0	5
Group 6: Mixture of methyl formate and methyl acetate (MF+MA)	0	6	2	0	2

E – Cohesive failure of enamel

E-R – Adhesive failure between enamel and resin cement

R – Cohesive failure of resin cement

R-M - Adhesive failure between metal and resin cement

Mixed – Mixed pattern of failure

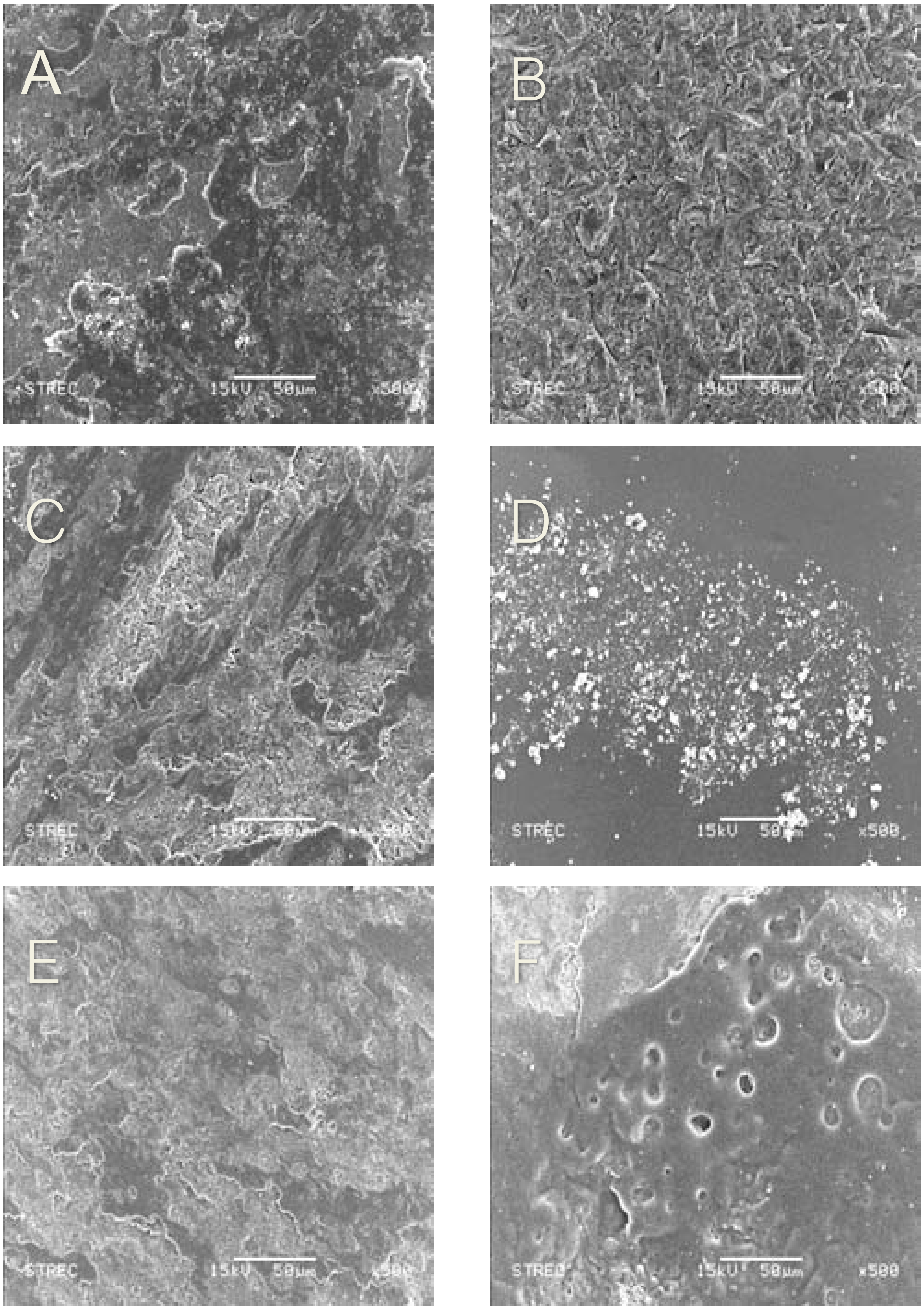

A
STREC 15kV 50µm x500
B
STREC 15kV 50µm x500
C
STREC 15kV 50µm x500
D
STREC 15kV 50µm x500
E
STREC 15kV 50µm x500
F
STREC 15kV 50µm x500

Figure 19. SEM images of morphological change of cleaned enamel after original bond testing (Panavia F2.0)

A - control group,

B – surface treated with sandblasting,

C – surface treated with hydrogen peroxide and sodium ascorbate,

D – surface treated with ethyl acetate in acetone,

E – surface treated with methyl methacrylate,

F – surface treated with mixture of methyl formate and methyl acetate

CHAPTER V

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Discussion

Bovine teeth were used in this study because the limited availability of human teeth and bovine teeth were suitable alternative (Rueggeberg, 1991). There was no difference in tensile bond strength between human and bovine enamel (Nakamichi et al., 1983). The result of this study showed difference between the bond strength of Superbond C&B and Panavia F2.0. Lower original bond strength was found in the group bonded with Panavia F2.0 which is self-etching resin cement. Smear layer that left on enamel might act as diffusion barrier (Nakabayashi and Pashley, 1998). On the contrary, smear layer was removed in acid-conditioning step when Superbond C&B was used.

In previous studies, the tensile bond strength significantly decreased in rebonding prosthesis (Naifeh et al., 1988; Williams and Dedmon, 1984; Williams et al., 1992). Replacement of prosthesis was recommended in case multiple failures were found and improvements in design were required (Creugers and Kayser, 1992). Some studies were interested in interface between metal and resin cement so metal-to-metal bonding was used to evaluate. Enamel was not used so the number of variations could be reduced (Williams et al., 1992). However, adhesive failure between enamel and resin cement was also found in other experiment (Aboush and Jenkins, 1989). Thus, bovine enamel was used in this study to imitate clinical situation and to study enamel interface.

Tensile bond strength testing was the most common rebonding test of metal alloys and there were inexact bonding diameter from 2.5-7 mm (Aboush and Jenkins, 1989; Kim and Kang, 2002; Parsa et al., 2003; Sen et al., 2000; Williams et al., 1992). Specific surface finish grit, crosshead speed, thermocycling and time prior to testing were also different in each study. In this study, 600-grit silicon carbide paper was used for enamel surface preparation because it was the most common and repeatable surface preparation method (Scherrer et al., 2010).

In rebonding procedure, Interface between resin cement and metal alloy was studies and published that sandblasting could improve bond strength (Kim and Kang, 2002). Thus, this study focused on enamel interface whether surface treatment could improve the bond strength.

The timing for each surface treatment using was selected based on the previous studies. Papacchini et al. suggested sandblasting with 50-μm aluminum oxide particles for 10 seconds from the distance of approximately 5 mm perpendicular to the bonding surface (Papacchini et al., 2007a). Hydrogen peroxide was reported that it could not improve bond strength in resin composite repair (Papacchini et al., 2007b). However, there was no study using this agent with sodium ascorbate as a reducing agent at least one-third of the time of oxidizing agent application which reported reversal of compromised bonding in bleached enamel (Lai et al., 2002).

Shimizu et al. reported that using 120-second application of ethyl acetate in denture base repair resulted in the highest bond strength comparing to other application time and untreated group (Shimizu et al., 2008). Moreover, application of a mixture of methyl formate and methyl acetate solution (25:75 v/v) for 15 seconds was also suggested in denture repair (Thunyakitpisal et al., 2011).

Vallitu et al. indicated that methyl methacrylate (MMA) could dissolve the surface of polymethyl methacrylate and increased the bond strength of repaired acrylic resin. MMA wetting for 180 seconds had the highest fracture loads compared with the shorter durations. However, scanning electron microscope images showed similarity of morphological changes in both surface wetting for 60 and 180 seconds (Vallittu et al., 1994). Moreover, 60-second treating was more practical in intraoral use. Thus, cemented enamel surface was treated for 60 seconds in this study.

In part I, the highest rebonding strength was found in enamel treated with sandblasting. Aluminum oxide blasting was seemingly suggested to be an ideal method of resin composite repair (Banerjee and Watson, 2002). Micromechanical retention from roughened and irregular topography was an important role in the repairing (Papacchini et al., 2007a). In the present study, although visible cement had been cleaned with ultrasonic scaler, residual cement on enamel surface still could be seen under scanning electron microscope. The cemented enamel surface was possibly altered the surface by sandblasting. Consequently, the bond strength was higher than control group when polymethyl methacrylate-based adhesive resin cement (Superbond C&B) was used due to increases of microretention and surface area. Whereas, sandblasting could not increase the bond strength when dimethacrylate resin cement (Panavia F2.0) was used. Smear layer might be thicker after sandblasting because aluminum oxide particles probably left on blasted enamel surface. However, the mode of failure analysis found that in rebonding group after sandblasting resulted in 80% resin cement cohesive failure. Moreover, this group was the only group that enamel – resin cement failure could not be found.

Hydrogen peroxide could create surface roughness on the surface of resin composite (Turker and Biskin, 2003). Thus, surface bonding area and micromechanical retention should increase. However, Papacchini and colleagues found that hydrogen peroxide that treated on resin composite surface had no change in surface texture and had weaker bond strength in repaired resin composite (Papacchini et al., 2007b). Ascorbic acid was suggested to use as reversal agent after tooth bleaching. This anti-oxidant agent could prevent the reduction in bond strength (Lai et al., 2002; Muraguchi et al., 2007). In this study, hydrogen peroxide was expected to increase surface roughness and sodium ascorbate was predicted to reverse the oxidizing effect of bleaching agents. Nevertheless, the results showed decreased bond strength in both groups of resin cement. In Panavia F2.0 group, the results in the present study are in agreement with previous studies which the bond strength between resin and enamel was reduced after exposing to hydrogen peroxide (Stokes et al., 1992; Torneck et al., 1990). Bond strength might decrease due to excess free radicles that hydrogen peroxide can release in general condition (Aschheim and Dale, 2001). Moreover, reversal agent could not prevent bond strength reduction in this study probably because higher concentration of hydrogen peroxide was used and residual oxygen might remain after reversal agent application. Oxygen produced by hydrogen peroxide remained not only on the surface, but also inside the enamel (Muraguchi et al., 2007). In this study, 10% sodium ascorbate was used for 10 minutes. Longer application time of anti-oxidant is probably more effective.

In Superbond C&B group, hydroxyl radical (·OH) could interfere with the resin cement polymerization (Nomoto et al., 2006). In addition, hydroxyl radical might cause localized increases in the rate of a free radical polymerization that limited termination reactions. This effect was called “Gel Effect” or “Trommsdorff-Norrish Effect” (Alger, 1997).

The high rebonding strengths in Superbend C&B, polymethyl methacrylate-based resin cement, were also found in enamel treated with methyl methacrylate and with the mixture of methyl formate and methyl acetate. Solubility parameter could be a guide to predict the miscibility of two materials. Mutual miscibility and good compatibility are found when values of solubility parameters are close or equal (Alger, 1997). The solubility parameter of polymethyl methacrylate is 18.27 $MPa^{1/2}$ while that of ethyl acetate, methyl methacrylate, methyl formate and methyl acetate are 18.6, 18.0, 20.9 and 19.6 $MPa^{1/2}$ respectively (Brandrup et al., 1999). Thus, remnant cement might be dissolved or swelled which improved rebonding strength due to increased surface roughness of remaining cement. However, there was no difference in bond strength between control group and enamel treated with Tokuyama rebase II adhesive. Moreover, this group showed 60% rebonding adhesive failure between enamel and resin cement while the majority of mode failure analysis of other surface treatments displayed mixed pattern failure. This effect might be because some components in rebase II adhesive left after treatment and coated the surface enamel. Thus, resin cement monomer could not penetrate into enamel structure and could not create proper mechanical bond.

The mode of failure analysis in Superbond C&B group showed 16.67% of rebonded specimens had cohesive failure of enamel. This effect occurred in rebonding groups but did not occur in original bonding group. They might happen because of microcrack in the first bond testing. This suggested that first bonding was important to prevent debonding of prostheses that could also prevent the microcrack of enamel.

The result of this study might be applied in case an orthodontic bracket is debonded and the bracket is planned to rebond to the cemented enamel because it is also the enamel-metal bonding.

Finally, this study was a preliminary *in vitro* study so further clinical study is required to confirm the effect of various enamel surface treatments.

General Conclusion

Combination of metal sandblasting and enamel treating with sandblasting, methyl methacrylate or methyl formate–methyl acetate mixture after Superbond C&B cementation could increase rebonding strength comparing with untreated enamel.

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Appendix

The recommended airborne exposure limit (8 hours)

Methyl methacrylate	50 ppm
Ethyl acetate	400 ppm
Methyl acetate	200 ppm
Methyl formate	100 ppm

New Jersey Department of Health and Senior Services:

Hazardous Substance Fact Sheet

Tensile bond strength (MPa) in part I (Superbond C&B)

Enamel surface treatment	Number	Original bonding strength (MPa)	Rebonded strength (MPa)
No	1	10.0551	6.0592
No	2	10.2602	4.2894
No	3	7.7505	4.2098
No	4	9.4439	7.0980
No	5	7.3243	5.8933
No	6	8.7606	5.1538

No	7	9.2558	4.8429
No	8	9.9408	5.0611
No	9	10.5491	5.7596
No	10	7.6578	5.5046
Sandblasting	1	8.9445	8.9509
Sandblasting	2	8.3539	7.7250
Sandblasting	3	9.8542	8.0228
Sandblasting	4	10.3062	7.1659
Sandblasting	5	7.5921	11.7775
Sandblasting	6	10.5014	10.8897
Sandblasting	7	8.6962	11.1090
Sandblasting	8	8.1753	7.1160
Sandblasting	9	10.0409	9.1496
Sandblasting	10	10.0126	8.0921
H_2O_2	1	8.9799	4.4104
H_2O_2	2	10.2637	3.9209
H_2O_2	3	8.6895	3.2103
H_2O_2	4	7.7887	3.3076
H_2O_2	5	11.0312	3.1131
H_2O_2	6	9.7017	4.8245

H_2O_2	7	8.2761	3.9230
H_2O_2	8	8.9091	4.3644
H_2O_2	9	7.9305	4.3863
H_2O_2	10	10.8438	4.1020
Ethyl acetate	1	9.1284	4.1529
Ethyl acetate	2	8.1682	5.3833
Ethyl acetate	3	8.9516	4.8617
Ethyl acetate	4	10.0869	5.9011
Ethyl acetate	5	9.9949	4.3633
Ethyl acetate	6	10.6888	5.2850
Ethyl acetate	7	11.3248	5.9924
Ethyl acetate	8	8.4964	5.0763
Ethyl acetate	9	7.3813	5.3013
Ethyl acetate	10	9.0223	5.6719
Methyl methacrylate	1	8.8738	7.8690
Methyl methacrylate	2	7.2928	6.3570
Methyl methacrylate	3	10.7660	7.1726
Methyl methacrylate	4	8.4706	7.9104
Methyl methacrylate	5	11.5228	6.8698
Methyl methacrylate	6	10.3380	7.5698

Methyl methacrylate	7	8.6934	9.8004
Methyl methacrylate	8	7.7215	7.3936
Methyl methacrylate	9	8.9106	8.0536
Methyl methacrylate	10	9.5104	8.5625
Methyl formate and methyl acetate	1	10.7730	7.3445
Methyl formate and methyl acetate	2	9.1836	7.5560
Methyl formate and methyl acetate	3	8.0699	7.3445
Methyl formate and methyl acetate	4	8.1300	8.0978
Methyl formate and methyl acetate	5	9.0612	6.2849
Methyl formate and methyl acetate	6	8.7358	7.8096
Methyl formate and methyl acetate	7	10.1293	7.6165
Methyl formate and methyl acetate	8	8.8844	5.9103
Methyl formate and methyl acetate	9	9.2978	6.2909
Methyl formate and methyl acetate	10	10.0604	7.1744

Tensile bond strength (MPa) in part II (Panavia F2.0)

Enamel surface treatment	Number	Original bonding strength (MPa)	Rebonded strength (MPa)
No	1	5.00595	3.78046

No	2	7.05999	4.4666
No	3	4.95785	3.44022
No	4	5.05971	5.75115
No	5	5.42046	3.69133
No	6	5.05936	3.12333
No	7	5.14495	4.86767
No	8	6.9098	3.33624
No	9	4.26712	4.54582
No	10	6.05178	4.01955
Sandblasting	1	6.63853	5.16582
Sandblasting	2	7.05976	3.55658
Sandblasting	3	5.22771	4.14086
Sandblasting	4	5.35468	3.65915
Sandblasting	5	6.94269	4.15713
Sandblasting	6	4.25297	3.92936
Sandblasting	7	4.1925	4.32689
Sandblasting	8	4.99782	3.56649
Sandblasting	9	6.46912	3.92512
Sandblasting	10	5.28607	4.41779
H_2O_2	1	7.50646	1.58483

H_2O_2	2	5.42789	1.99121
H_2O_2	3	4.16668	2.16663
H_2O_2	4	4.14121	2.49909
H_2O_2	5	4.35696	1.55618
H_2O_2	6	6.22791	2.15602
H_2O_2	7	4.92956	2.84251
H_2O_2	8	6.86453	2.63313
H_2O_2	9	6.89601	1.91516
H_2O_2	10	4.68269	2.3226
Ethyl acetate	1	5.16405	2.69502
Ethyl acetate	2	5.05582	2.19846
Ethyl acetate	3	5.6599	2.07361
Ethyl acetate	4	7.05269	2.29643
Ethyl acetate	5	5.25105	1.7309
Ethyl acetate	6	5.19517	2.16026
Ethyl acetate	7	4.18189	2.14435
Ethyl acetate	8	5.5683	2.02693
Ethyl acetate	9	5.24964	2.64197
Ethyl acetate	10	5.81623	1.62303
Methyl methacrylate	1	4.17375	4.26323

Methyl methacrylate	2	5.20083	4.15324
Methyl methacrylate	3	5.62135	3.34756
Methyl methacrylate	4	5.53718	4.75767
Methyl methacrylate	5	4.66147	4.26606
Methyl methacrylate	6	6.51368	4.58366
Methyl methacrylate	7	6.41288	2.94896
Methyl methacrylate	8	5.00454	4.58472
Methyl methacrylate	9	4.59887	4.20735
Methyl methacrylate	10	6.38388	4.9529
Methyl formate and methyl acetate	1	5.14636	3.15091
Methyl formate and methyl acetate	2	5.28819	4.76687
Methyl formate and methyl acetate	3	7.26242	4.68588
Methyl formate and methyl acetate	4	4.40435	3.26126
Methyl formate and methyl acetate	5	4.20028	4.52248
Methyl formate and methyl acetate	6	6.11721	3.97251
Methyl formate and methyl acetate	7	4.55148	4.75979
Methyl formate and methyl acetate	8	6.97771	3.63333
Methyl formate and methyl acetate	9	5.08058	5.01267
Methyl formate and methyl acetate	10	5.57149	3.19901

Mode of failure in part I (Superbond C&B)

Enamel surface treatment	Number	Mode of failure	
		Original bonding	Rebonding
No	1	Mixed	Mixed
No	2	R	Mixed
No	3	R	Mixed
No	4	R	Mixed
No	5	R	E
No	6	R	E
No	7	R	Mixed
No	8	R	Mixed
No	9	R	Mixed
No	10	R	Mixed
Sandblasting	1	R	Mixed
Sandblasting	2	R	Mixed
Sandblasting	3	Mixed	Mixed
Sandblasting	4	R	Mixed
Sandblasting	5	R	E
Sandblasting	6	R	Mixed
Sandblasting	7	R	Mixed

Sandblasting	8	R	Mixed
Sandblasting	9	R	Mixed
Sandblasting	10	R	Mixed
H_2O_2	1	R	Mixed
H_2O_2	2	R	Mixed
H_2O_2	3	R	Mixed
H_2O_2	4	R	Mixed
H_2O_2	5	R	Mixed
H_2O_2	6	R	Mixed
H_2O_2	7	Mixed	E
H_2O_2	8	Mixed	E
H_2O_2	9	R	Mixed
H_2O_2	10	R	Mixed
Ethyl acetate	1	R	Mixed
Ethyl acetate	2	R	E-R
Ethyl acetate	3	R	E-R
Ethyl acetate	4	R	E-R
Ethyl acetate	5	R	E-R
Ethyl acetate	6	R	E-R
Ethyl acetate	7	R	E-R

Ethyl acetate	8	R	Mixed
Ethyl acetate	9	R	Mixed
Ethyl acetate	10	R	Mixed
Methyl methacrylate	1	R	Mixed
Methyl methacrylate	2	R	Mixed
Methyl methacrylate	3	R	Mixed
Methyl methacrylate	4	R	E
Methyl methacrylate	5	Mixed	Mixed
Methyl methacrylate	6	R	Mixed
Methyl methacrylate	7	R	E
Methyl methacrylate	8	Mixed	Mixed
Methyl methacrylate	9	R	Mixed
Methyl methacrylate	10	R	Mixed
Methyl formate and methyl acetate	1	R	Mixed
Methyl formate and methyl acetate	2	R	E
Methyl formate and methyl acetate	3	R	E
Methyl formate and methyl acetate	4	R	Mixed
Methyl formate and methyl acetate	5	R	Mixed
Methyl formate and methyl acetate	6	R	Mixed
Methyl formate and methyl acetate	7	Mixed	Mixed

Methyl formate and methyl acetate	8	R	E
Methyl formate and methyl acetate	9	R	Mixed
Methyl formate and methyl acetate	10	R	Mixed

Mode of failure in part II (Panavia F2.0)

Enamel surface treatment	Number	Mode of failure	
		Original bonding	Rebonding
No	1	R	E-R
No	2	R	E-R
No	3	R	Mixed
No	4	R	R
No	5	R	Mixed
No	6	R	E-R
No	7	R	E-R
No	8	Mixed	R
No	9	Mixed	Mixed
No	10	R	R
Sandblasting	1	R	R
Sandblasting	2	R	R

Sandblasting	3	R	R
Sandblasting	4	R	Mixed
Sandblasting	5	R	R
Sandblasting	6	R	R
Sandblasting	7	R	Mixed
Sandblasting	8	R	R
Sandblasting	9	R	R
Sandblasting	10	R	R
H_2O_2	1	MIxed	E-R
H_2O_2	2	R	E-R
H_2O_2	3	R	Mixed
H_2O_2	4	R	Mixed
H_2O_2	5	R	R
H_2O_2	6	R	R
H_2O_2	7	R	R
H_2O_2	8	R	Mixed
H_2O_2	9	R	R
H_2O_2	10	R	E-R
Ethyl acetate	1	R	E-R
Ethyl acetate	2	Mixed	E-R

Ethyl acetate	3	R	E-R
Ethyl acetate	4	R	E-R
Ethyl acetate	5	R	E-R
Ethyl acetate	6	R	E-R
Ethyl acetate	7	R	E-R
Ethyl acetate	8	R	E-R
Ethyl acetate	9	R	E-R
Ethyl acetate	10	R	E-R
Methyl methacrylate	1	R	R
Methyl methacrylate	2	R	E-R
Methyl methacrylate	3	R	Mixed
Methyl methacrylate	4	R	Mixed
Methyl methacrylate	5	R	Mixed
Methyl methacrylate	6	R	R
Methyl methacrylate	7	R	Mixed
Methyl methacrylate	8	R	R
Methyl methacrylate	9	Mixed	R
Methyl methacrylate	10	R	Mixed
Methyl formate and methyl acetate	1	R	E-R
Methyl formate and methyl acetate	2	Mixed	Mixed

Methyl formate and methyl acetate	3	Mixed	Mixed
Methyl formate and methyl acetate	4	R	E-R
Methyl formate and methyl acetate	5	R	R
Methyl formate and methyl acetate	6	R	R
Methyl formate and methyl acetate	7	R	E-R
Methyl formate and methyl acetate	8	R	E-R
Methyl formate and methyl acetate	9	R	E-R
Methyl formate and methyl acetate	10	R	E-R

Part I

One-Sample Kolmogorov-Smirnov Test

Group			Before	After
Control group	N		10	10
	Normal Parameters[a,,b]	Mean	9.099814	5.387184
		Std. Deviation	1.1727029	.8714858
	Most Extreme Differences	Absolute	.175	.120
		Positive	.175	.120
		Negative	-.163	-.088
	Kolmogorov-Smirnov Z		.554	.380
	Asymp. Sig. (2-tailed)		.919	.999
Sandblasting	N		10	10
	Normal Parameters[a,,b]	Mean	9.247720	8.999857
		Std. Deviation	1.0198325	1.7021654
	Most Extreme Differences	Absolute	.224	.203
		Positive	.117	.203
		Negative	-.224	-.167
	Kolmogorov-Smirnov Z		.708	.642
	Asymp. Sig. (2-tailed)		.697	.804
Hydrogen peroxide	N		10	10
	Normal Parameters[a,,b]	Mean	9.241422	3.956237
		Std. Deviation	1.1677197	.5795904
	Most Extreme Differences	Absolute	.189	.176
		Positive	.189	.168
		Negative	-.115	-.176
	Kolmogorov-Smirnov Z		.596	.556
	Asymp. Sig. (2-tailed)		.869	.917

a. Test distribution is Normal.

b. Calculated from data.

One-Sample Kolmogorov-Smirnov Test

Group			Before	After
Ethyl acetate	N		10	10
	Normal Parameters[a,,b]	Mean	9.324360	5.198921
		Std. Deviation	1.2000497	.6073125
	Most Extreme Differences	Absolute	.165	.156
		Positive	.165	.116
		Negative	-.112	-.156
	Kolmogorov-Smirnov Z		.521	.494
	Asymp. Sig. (2-tailed)		.949	.967
MMA	N		10	10
	Normal Parameters[a,,b]	Mean	9.209981	7.755870
		Std. Deviation	1.3350131	.9547619
	Most Extreme Differences	Absolute	.189	.178
		Positive	.189	.178
		Negative	-.101	-.084
	Kolmogorov-Smirnov Z		.597	.562
	Asymp. Sig. (2-tailed)		.868	.911
MF+MA	N		10	10
	Normal Parameters[a,,b]	Mean	9.232538	7.142911
		Std. Deviation	.8713883	.7314292
	Most Extreme Differences	Absolute	.170	.217
		Positive	.170	.178
		Negative	-.129	-.217
	Kolmogorov-Smirnov Z		.538	.687
	Asymp. Sig. (2-tailed)		.934	.733

a. Test distribution is Normal.

b. Calculated from data.

Descriptives

Before

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Control group	10	9.099814	1.1727029	.3708412	8.260913	9.938715	7.3243	10.5491
Sandblasting	10	9.247720	1.0198325	.3224994	8.518176	9.977264	7.5921	10.5014
Hydrogen peroxide	10	9.241422	1.1677197	.3692654	8.406086	10.076758	7.7887	11.0312
Ethyl acetate	10	9.324360	1.2000497	.3794890	8.465896	10.182824	7.3813	11.3248
MMA	10	9.209981	1.3350131	.4221682	8.254970	10.164992	7.2928	11.5228
MF+MA	10	9.232538	.8713883	.2755572	8.609184	9.855892	8.0699	10.7730
Total	60	9.225973	1.0901024	.1407316	8.944369	9.507576	7.2928	11.5228

Test of Homogeneity of Variances

Before

Levene Statistic	df1	df2	Sig.
.562	5	54	.728

ANOVA

Before

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.266	5	.053	.041	.999
Within Groups	69.845	54	1.293		
Total	70.111	59			

Test of Homogeneity of Variances

After

Levene Statistic	df1	df2	Sig.
3.987	5	54	.004

Robust Tests of Equality of Means

After

	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	36.341	5	29.370	.000

a. Asymptotically F distributed.

Multiple Comparisons

After

Tamhane

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Control group	Sandblasting	-3.6126730*	.6047193	.001	-5.758173	-1.467173
	Hydrogen peroxide	1.4309470*	.3309702	.008	.290521	2.571373
	Ethyl acetate	.1882630	.3359041	1.000	-.964019	1.340545
	MMA	-2.3686860*	.4087857	.000	-3.747821	-.989551
	MF+MA	-1.7557270*	.3597883	.002	-2.973494	-.537960
Sandblasting	Control group	3.6126730*	.6047193	.001	1.467173	5.758173
	Hydrogen peroxide	5.0436200*	.5686205	.000	2.934348	7.152892
	Ethyl acetate	3.8009360*	.5715064	.000	1.690397	5.911475
	MMA	1.2439870	.6171659	.625	-.922354	3.410328
	MF+MA	1.8569460	.5858631	.112	-.264477	3.978369
Hydrogen peroxide	Control group	-1.4309470*	.3309702	.008	-2.571373	-.290521
	Sandblasting	-5.0436200*	.5686205	.000	-7.152892	-2.934348
	Ethyl acetate	-1.2426840*	.2654720	.003	-2.137506	-.347862
	MMA	-3.7996330*	.3531990	.000	-5.028366	-2.570900
	MF+MA	-3.1866740*	.2951125	.000	-4.188836	-2.184512
Ethyl acetate	Control group	-.1882630	.3359041	1.000	-1.340545	.964019
	Sandblasting	-3.8009360*	.5715064	.000	-5.911475	-1.690397
	Hydrogen peroxide	1.2426840*	.2654720	.003	.347862	2.137506
	MMA	-2.5569490*	.3578266	.000	-3.795535	-1.318363
	MF+MA	-1.9439900*	.3006355	.000	-2.962107	-.925873
MMA	Control group	2.3686860*	.4087857	.000	.989551	3.747821
	Sandblasting	-1.2439870	.6171659	.625	-3.410328	.922354
	Hydrogen peroxide	3.7996330*	.3531990	.000	2.570900	5.028366
	Ethyl acetate	2.5569490*	.3578266	.000	1.318363	3.795535
	MF+MA	.6129590	.3803366	.866	-.681607	1.907525

MF+MA	Control group	1.7557270*	.3597883	.002	.537960	2.973494
	Sandblasting	-1.8569460	.5858631	.112	-3.978369	.264477
	Hydrogen peroxide	3.1866740*	.2951125	.000	2.184512	4.188836
	Ethyl acetate	1.9439900*	.3006355	.000	.925873	2.962107
	MMA	-.6129590	.3803366	.866	-1.907525	.681607

*. The mean difference is significant at the 0.05 level.

Paired Samples Test

Group			Paired Differences					t	df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
			Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Control group	Pair 1	Before - After	3.7126300	1.4038809	.4439461	2.7083541	4.7169059	8.363	9	.000
Sandblasting	Pair 1	Before - After	.2478630	2.1625974	.6838734	-1.2991660	1.7948920	.362	9	.725
Hydrogen peroxide	Pair 1	Before - After	5.2851850	1.3326577	.4214234	4.3318591	6.2385109	12.541	9	.000
Ethyl acetate	Pair 1	Before - After	4.1254390	1.2095245	.3824852	3.2601973	4.9906807	10.786	9	.000
MMA	Pair 1	Before - After	1.4541110	1.7077094	.5400251	.2324893	2.6757327	2.693	9	.025
MF+MA	Pair 1	Before - After	2.0896270	1.1720072	.3706212	1.2512235	2.9280305	5.638	9	.000

Part II

One-Sample Kolmogorov-Smirnov Test

Group			Before	After
Control group	N		10	10
	Normal Parameters[a,,b]	Mean	5.493697	4.102237
		Std. Deviation	.9008379	.8094461
	Most Extreme Differences	Absolute	.251	.155
		Positive	.251	.155
		Negative	-.176	-.113
	Kolmogorov-Smirnov Z		.793	.489
	Asymp. Sig. (2-tailed)		.556	.971
Sandblasting	N		10	10
	Normal Parameters[a,,b]	Mean	5.642185	4.084519
		Std. Deviation	1.0648597	.4859088
	Most Extreme Differences	Absolute	.206	.146
		Positive	.206	.146
		Negative	-.181	-.139
	Kolmogorov-Smirnov Z		.653	.463
	Asymp. Sig. (2-tailed)		.788	.983
Hydrogen peroxide	N		10	10
	Normal Parameters[a,,b]	Mean	5.519990	2.166736
		Std. Deviation	1.2601462	.4235504
	Most Extreme Differences	Absolute	.180	.115
		Positive	.180	.115
		Negative	-.157	-.090
	Kolmogorov-Smirnov Z		.570	.364
	Asymp. Sig. (2-tailed)		.901	.999

a. Test distribution is Normal.

b. Calculated from data.

One-Sample Kolmogorov-Smirnov Test

Group			Before	After
Ethyl acetate	N		10	10
	Normal Parameters[a,,b]	Mean	5.419474	2.159096
		Std. Deviation	.7258241	.3393630
	Most Extreme Differences	Absolute	.208	.154
		Positive	.192	.154
		Negative	-.208	-.148
	Kolmogorov-Smirnov Z		.658	.486
	Asymp. Sig. (2-tailed)		.779	.972
MMA	N		10	10
	Normal Parameters[a,,b]	Mean	5.410843	4.206535
		Std. Deviation	.8291796	.6213774
	Most Extreme Differences	Absolute	.180	.266
		Positive	.117	.117
		Negative	-.180	-.266
	Kolmogorov-Smirnov Z		.568	.841
	Asymp. Sig. (2-tailed)		.903	.480
MF+MA	N		10	10
	Normal Parameters[a,,b]	Mean	5.460007	4.096471
		Std. Deviation	1.0432356	.7367119
	Most Extreme Differences	Absolute	.165	.218
		Positive	.165	.172
		Negative	-.127	-.218
	Kolmogorov-Smirnov Z		.523	.691
	Asymp. Sig. (2-tailed)		.947	.726

a. Test distribution is Normal.

b. Calculated from data.

Descriptives

Before

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Control group	10	5.493697	.9008379	.2848699	4.849276	6.138118	4.2671	7.0600
Sandblasting	10	5.642185	1.0648597	.3367382	4.880430	6.403940	4.1925	7.0598
Hydrogen peroxide	10	5.519990	1.2601462	.3984932	4.618536	6.421444	4.1412	7.5065
Ethyl acetate	10	5.419474	.7258241	.2295257	4.900251	5.938697	4.1819	7.0527
MMA	10	5.410843	.8291796	.2622096	4.817684	6.004002	4.1738	6.5137
MF+MA	10	5.460007	1.0432356	.3299001	4.713721	6.206293	4.2003	7.2624
Total	60	5.491033	.9467786	.1222286	5.246454	5.735612	4.1412	7.5065

Test of Homogeneity of Variances

Before

Levene Statistic	df1	df2	Sig.
1.654	5	54	.162

ANOVA

Before

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.362	5	.072	.074	.996
Within Groups	52.525	54	.973		
Total	52.887	59			

Test of Homogeneity of Variances

After

Levene Statistic	df1	df2	Sig.
2.734	5	54	.028

Robust Tests of Equality of Means

After

	Statistic[a]	df1	df2	Sig.
Brown-Forsythe	29.106	5	41.317	.000

a. Asymptotically F distributed.

Multiple Comparisons

After

Tamhane

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Control group	Sandblasting	.0177180	.2985482	1.000	-1.022178	1.057614
	Hydrogen peroxide	1.9355010*	.2888941	.000	.913159	2.957843
	Ethyl acetate	1.9431410*	.2775554	.000	.935332	2.950950
	MMA	-.1042980	.3226938	1.000	-1.202500	.993904
	MF+MA	.0057660	.3461138	1.000	-1.162022	1.173554
Sandblasting	Control group	-.0177180	.2985482	1.000	-1.057614	1.022178
	Hydrogen peroxide	1.9177830*	.2038387	.000	1.229028	2.606538
	Ethyl acetate	1.9254230*	.1874232	.000	1.282618	2.568228
	MMA	-.1220160	.2494428	1.000	-.969832	.725800
	MF+MA	-.0119520	.2790792	1.000	-.974372	.950468
Hydrogen peroxide	Control group	-1.9355010*	.2888941	.000	-2.957843	-.913159
	Sandblasting	-1.9177830*	.2038387	.000	-2.606538	-1.229028
	Ethyl acetate	.0076400	.1716281	1.000	-.574778	.590058
	MMA	-2.0397990*	.2378035	.000	-2.857243	-1.222355
	MF+MA	-1.9297350*	.2687265	.000	-2.870329	-.989141
Ethyl acetate	Control group	-1.9431410*	.2775554	.000	-2.950950	-.935332
	Sandblasting	-1.9254230*	.1874232	.000	-2.568228	-1.282618
	Hydrogen peroxide	-.0076400	.1716281	1.000	-.590058	.574778
	MMA	-2.0474390*	.2238922	.000	-2.835776	-1.259102
	MF+MA	-1.9373750*	.2564979	.000	-2.858788	-1.015962
MMA	Control group	.1042980	.3226938	1.000	-.993904	1.202500
	Sandblasting	.1220160	.2494428	1.000	-.725800	.969832
	Hydrogen peroxide	2.0397990*	.2378035	.000	1.222355	2.857243
	Ethyl acetate	2.0474390*	.2238922	.000	1.259102	2.835776

	MF+MA	.1100640	.3047711	1.000	-.921236	1.141364
MF+MA	Control group	-.0057660	.3461138	1.000	-1.173554	1.162022
	Sandblasting	.0119520	.2790792	1.000	-.950468	.974372
	Hydrogen peroxide	1.9297350*	.2687265	.000	.989141	2.870329
	Ethyl acetate	1.9373750*	.2564979	.000	1.015962	2.858788
	MMA	-.1100640	.3047711	1.000	-1.141364	.921236

*. The mean difference is significant at the 0.05 level.

Paired Samples Test

			Paired Differences							
						95% Confidence Interval of the Difference				
Group			Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Control group	Pair 1	Before - After	1.3914600	1.3097976	.4141944	.4544872	2.3284328	3.359	9	.008
Sandblasting	Pair 1	Before - After	1.5576660	1.1250016	.3557567	.7528884	2.3624436	4.378	9	.002
Hydrogen peroxide	Pair 1	Before - After	3.3532540	1.4218211	.4496193	2.3361444	4.3703636	7.458	9	.000
Ethyl acetate	Pair 1	Before - After	3.2603780	.8247106	.2607964	2.6704156	3.8503404	12.502	9	.000
MMA	Pair 1	Before - After	1.2043080	1.0871440	.3437851	.4266120	1.9820040	3.503	9	.007
MF+MA	Pair 1	Before - After	1.3635360	1.2983579	.4105768	.4347467	2.2923253	3.321	9	.009

Biography

Atikom Surintanasarn, a son of Mr.Pravit Surintanasarn and Ms.Kandarat Benjapolsirijit, was born on October 12, 1984 in Bangkok, Thailand. He graduated his elementary education from Saint Dominic School in 1996 and high school education from Triamudomsuksa Pattanakarn School in 2002. He received degree of Doctor of Dental Surgery (D.D.S.) from Chulalongkorn University in 2008. After graduation, He worked as a general dentist at Proprathapchang Hospital, Ministry of Public Health and became a head of dental department and a member of hospital executive board on October, 2009.