การทดสอบความต้านทานทางไฟฟ้าของซีเมนต์เชื่อมยึดทางทันตกรรมโดยวิธีการวัดอิมพีแดนซ์และหาความสัมพันธ์ระหว่างจำนวนรูพรุนและการละลายน้ำ

นางสาวญาณินี โกไศยกานนท์

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ELECTRICAL RESISTANCE OF DENTAL LUTING CEMENTS INVESTIGATED BY IMPEDANCE METHODOLOGY RELATED TO THEIR POROSITIES AND SOLUBILITY

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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
Faculty of Dentistry
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Thesis Title	ELECTRICAL RESISTANCE OF DENTAL LUTING CEMENTS INVESTIGATED BY IMPEDANCE METHODOLOGY RELATED TO THEIR POROSITIES AND SOLUBILITY
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ญาณินี โกไศยกานนท์ : การทดสอบความต้านทานทางไฟฟ้าของซีเมนต์เชื่อมยึดทางทันตกรรมโดยวิธีการวัดอิมพีแดนซ์และหาความสัมพันธ์ระหว่างจำนวนรูพรุนและการละลายน้ำ (ELECTRICAL RESISTANCE OF DENTAL LUTING CEMENTS INVESTIGATED BY IMPEDANCE METHODOLOGY RELATED TO THEIR POROSITIES AND SOLUBILITY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ทพ. ดร.วิริทธิ์พล ศรีมณีพงศ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: รศ. ดร.มานะ ศรียุทธศักดิ์, 63 หน้า.

ความต้านทานทางไฟฟ้าเป็นคุณสมบัติทางกายภาพของซีเมนต์ทางทันตกรรม การศึกษาส่วนใหญ่เกี่ยวกับซีเมนต์ทางทันตกรรมมุ่งเน้นไปในเรื่องของสมบัติเชิงกล การละลาย และการเชื่อมยึด มีการศึกษาเพียงไม่กี่งานที่ให้ความสนใจเกี่ยวกับความเป็นฉนวนของซีเมนต์ทางทันตกรรมจึงเป็นที่มาของการศึกษาครั้งนี้ โดยการศึกษานี้จะใช้ซีเมนต์ทางทันตกรรม 5 ชนิด คือ ซิงค์ฟอสเฟต (Hybond) กลาสไอโอโนเมอร์ (Fuji II) โพลีเมอร์ซีเมนต์ (Rely X Unicem, Rely-XTM U-100 และ Superbond C&B) ชิ้นงานทั้งหมดจะถูกนำไปวัดจำนวนรูพรุนโดยเครื่องไมโครคอมพิวเทตโทโมกราฟฟี่ (Micro computed tomography) หลังจากนั้นจะนำมาวัดความต้านทานทางไฟฟ้าโดยวิธีอิมพีแดนซ์ น้ำหนักของชิ้นงานจะถูกชั่งก่อนและหลังการวัดค่าความต้านทานไฟฟ้าเพื่อหาการละลายของซีเมนต์ทางทันตกรรม นำข้อมูลที่ได้มาวิเคราะห์ทางสถิติด้วยการวิเคราะห์ความแตกต่างโดยค่า t (independent t-test) และวิเคราะห์ความแปรปรวนทางเดียว (one-way ANOVA) ผลการทดลองพบว่า ค่าความต้านทานของกลุ่มโพลีเมอร์ซีเมนต์มีค่าสูงกว่า 2000 $\times 10^6$ โอห์ม ขณะที่กลุ่มซิงค์ฟอสเฟตและกลาสไอโอโนเมอร์ซีเมนต์มีค่า 0.017×10^6 และ 0.003×10^6 โอห์ม ตามลำดับ นอกจากนี้ พบว่า จำนวนรูพรุนของ Superbond C&B มีค่าสูงสุดและแตกต่างจากกลุ่มอื่นอย่างมีนัยสำคัญ ขณะที่การละลายน้ำจะพบในกลุ่มซิงค์ฟอสเฟตและกลาสไอโอโนเมอร์เท่านั้น โดยเมื่อนำค่าความต้านทานไฟฟ้า จำนวนรูพรุน และการละลายน้ำมาหาความสัมพันธ์ทางสถิติพบว่าค่าความต้านทานไฟฟ้าไม่สัมพันธ์กับจำนวนรูพรุนและการละลายน้ำ จึงสรุปได้ว่า ค่าความต้านทานไฟฟ้าขึ้นกับส่วนประกอบทางเคมีและปฏิกริยาแข็งตัวของซีเมนต์แต่ละชนิดและอาจขึ้นกับลักษณะการเชื่อมต่อทางกายภาพของรูภายในวัตถุ

ภาควิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต .....
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KEYWORDS: RESISTANCE / DENTAL LUTING CEMENTS / POROSITY / SOLUBILITY / IMPEDANCE METHODOLOGY

YANINEE KOSAIYAKANON: ELECTRICAL RESISTANCE OF DENTAL LUTING CEMENTS INVESTIGATED BY IMPEDANCE METHODOLOGY RELATED TO THEIR POROSITIES AND SOLUBILITY. ADVISOR: ASST. PROF. VIRITPON SRIMANEEPONG, Ph.D., CO-ADVISOR: ASSOC. PROF. MANA SRIYUDTHSAK, P.Eng., 63 pp.

The electrical resistance property of dental cement is one of important physical properties. Most previous studies aimed to investigate the mechanical properties, solubility and especially bonding property. Few studied on physical property of electrical insulation of dental cement. Therefore, investigating the electrical resistance of dental luting cements and the relation among the electrical resistance, the porosities and the solubility of dental luting cements are interesting to study. Five types of dental luting cements were used including Hybond, Fuji II, Rely-X Unicem, Rely-XTM U-100 and Superbond C&B. The electrical resistance of dental luting cements was then investigated by the impedance methodology. The porosities of all specimens were observed by micro CT scan before impedance test. The solubility of luting cement was calculated from weight of specimens before and after impedance test. All data was statistically analyzed with independent t-test and one-way ANOVA at p-value of 0.05. It was found that the electrical resistance of resin luting cements including both types of Rely-X and Superbond C&B is higher than 2000 $\times 10^6$ Ω. However, the electrical resistance of zinc phosphate cements were higher than glass ionomer cements, 0.017×10^6 and 0.003×10^6, respectively. Additionally, the mean porosity of Superbond C&B was significantly higher than the other four types of luting cements. Both zinc phosphate and glass ionomer cements showed the solubility but were not significant. This study also found no correlation among the electrical resistance, the porosities and the solubility regardless of dental luting cements. Within the limitation of this study, it can be concluded that electrical resistance of dental luting cement is related to the chemical composition and setting reaction but do not relate to amount of porosity and degree of solubility. The electrical resistance related to the pores inside the dental luting cements.

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

INTRODUCTION

Background and rationale

Dentin hypersensitivity sometimes could be an annoyance for both patient and practitioner due to non-specific and multi-factorial etiology, which it is not fully understood. This problem is not dental pathology but commonly happens. Dentine hypersensitivity could be defined as sharp shooting localized pain in response to stimuli such as temperature, evaporation (air blow), osmotic, tactile (mechanic), and chemical stimuli like acid or sweets (2, 3). The etiologies of the dentine hypersensitivity may come from tooth brushing, periodontal diseases, caries, tooth wear, prosthodontics treatments or even from oral galvanism (4). The mechanism of the dentine hypersensitivity can be explained by the hydrodynamic theory (5-8), however, this could not be applied to the phenomenon of oral galvanism (9). Even though occurrence of oral galvanism might be less than other kinds of tooth hypersensitivity, it still occasionally happens in dental practice. Pain caused from oral galvanism is thought to be induced by short-circuit resulting from different potential between dissimilar metals when come to contact or from eating utensils or dental prostheses. This leads patients have an experience of pain (or hypersensitivity). The first report of oral galvanism appeared in 1754, by Sulzer (10). Galvanism is a kind of electrochemical reaction, therefore, it sometimes cause some burning or tingling sensation in some patients apart from hypersensitivity (11, 12). Electrogalvanism or galvanic currents has long been recognized as a potential source of discomfort for patients. It is known that when two different metallic materials with different potentials contact each other, the cell is short-circuited and the current flow would occur. Consequently, the ion capable of conducting electricity can migrate through margins of restorations to dentin and stimulate the pulpal tissue leading galvanic pain. Some studies have claimed that large current might flow through metallic restorations (13). Oral galvanism found in patients who had dissimilar metal restorations were reported (14, 15). From the perspective, dental cement is thought

to be insulator to impede ionic conduction. This would prevent the galvanic current and lessen the possibility of hypersensitivity (15). The dental cement is classified into two types including water-based and polymer-based dental cements. The electrical resistance property of dental cement is one of important physical properties. Most previous studies aimed to investigate the mechanical properties, solubility and especially bonding property (16-19). Few studied on physical property of electrical insulation of dental cement (20, 21). The impedance methodology has been used to measure the dentin permeability (22), the microleakage of composite resin (23) and the insulation of three luting cements including glass ionomer, resin modified-glass ionomer and calcium silicate cement (24). Therefore in this study, the different kinds of water-based and polymer-based dental cements used as luting agents are selected and the electrical resistance property of these dental luting cements is investigated by the impedance method. This property is also observed in relation to their porosities and solubility of dental luting cements.

Objective

To investigate the electrical resistance of dental luting cements and the relation among the electrical resistance, the porosities and the solubility of dental luting cements.

Hypothesis

Null hypothesis 1 (H_{01}): the electrical resistance of dental luting cements are not different at 95% confident level.

Alternative hypothesis 1 (H_{a1}): the electrical resistance of dental luting cements are different at 95% confident level.

Null hypothesis 2 (H_{02}): the correlation between electrical resistance and porosity of dental luting cements are not different at 95% confident level.

Alternative hypothesis 2 (H_{a2}): the correlation between electrical resistance and porosity of dental luting cements are different at 95% confident level.

Null hypothesis 3 (H_{03}): the solubility of dental luting cements are not different at 95% confident level.

Alternative hypothesis 3 (H_{a3}): the solubility of dental luting cements are different at 95% confident level.

Null hypothesis 4 (H_{04}): the electrical resistance, the porosity and the solubility are correlation.

Alternative Hypothesis 4 (H_{a4}): the electrical resistance, the porosity and the solubility are not correlation.

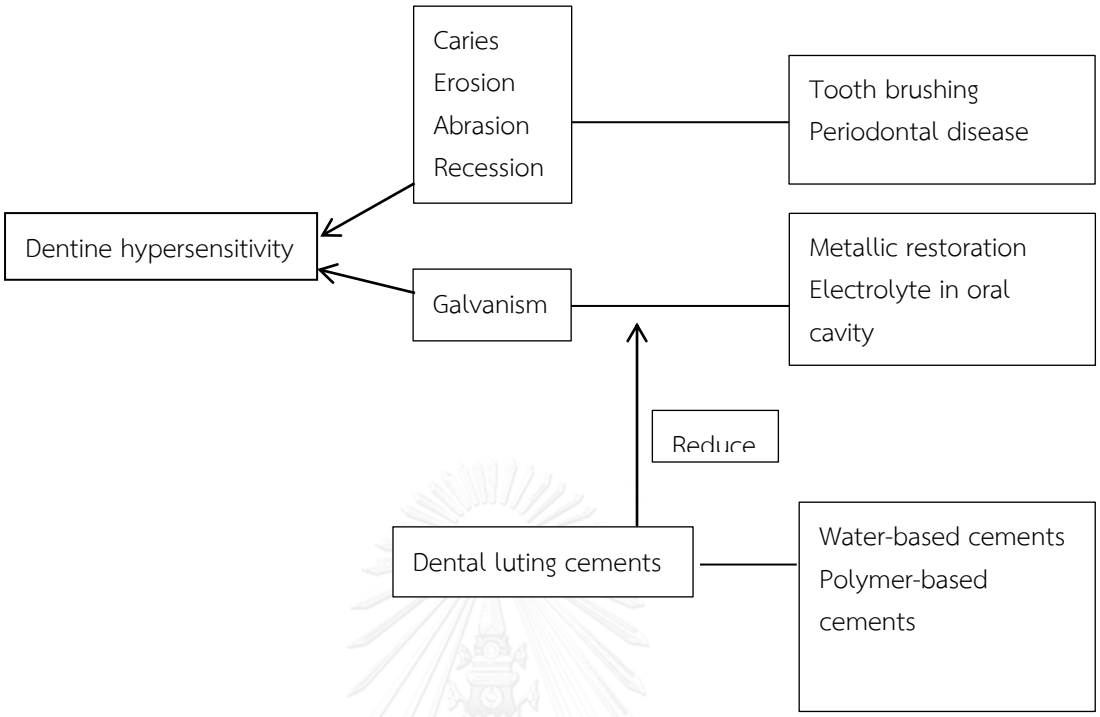
Scope of the research

1. The mixed cements are prepared as the manufacturer's description.
2. This research is an in vitro study.
3. Five types of dental luting cements including Hybond, Fuji II, Rely-X Unicem, Rely-X™ U-100 and Superbond C&B.
4. Electrical resistance is measured in wet condition.
5. The micro-CT is used to measure the porosity.

Limitation

The diameter and thickness of specimen is 12mm x 1mm. The specimens are designed to the fracture resistance as recommended ISO 4049 and the previous study. Potassium chloride (KCl) 0.1 M is the electrolyte because this electrolyte is ionized 100% at 20°C. The study divides into the measurement of porosity of dental luting cements, the electrical resistance of dental luting cements and the solubility of dental luting cements. All data are compared the different and find out the correlation of porosity, electrical resistance and solubility among the dental luting cements.

Conceptual framework



Keywords

Dental luting cements

Solubility

Porosity

Resistance

Impedance methodology

Expected benefits

1. To be able to use the luting cement to reduce the possibility of dentine hypersensitivity for galvanism.
2. To understand which components of dental luting cements perform as the insulating property. To improve its property of the commercial luting cement

CHAPTER II

LITERATURE REVIEW

The definition, signs and symptoms, etiologies and epidermiologies of dentin hypersensitivity

Nowadays, many patients suffer from dentin hypersensitivity. The definition of dentin hypersensitivity is the loss of enamel bring about to the exposed dentin, characterized by short or transient sharp pain arising from exposed dentin in response to an array of stimuli (25).

The etiologies are caries, periodontal disease, tooth wear, recession, prosthodontics restorations (3). Dentin hypersensitivity is triggered from thermal, evaporation, tactile, osmotic (26) and galvanism (9).

Theories of dentin hypersensitivity (27)

1. Dentinal receptor mechanism: odontoblasts and processes are the receptors of the mechanism.
2. The nerves are the pain receptors, which are in the pulp not the dentin.

2.1 Hydrodynamic mechanism: the triggers contact the dentin, cause the dentinal fluid movement. This movement activate the nerve axons which innervate with the odontoblast processes in the predentin layer (5).

2.2 Modulation of nerves impulses by polypeptides: the triggers contact the dentin then odontoblasts release polypeptides (kinin and substances P) to modulate the nerve axon in the pulp.

Corrosion (1)

The corrosion is the electrochemical reaction of the metal which occurs in the different environment such as rough metal surface, pH of food and the amounts of electrolyte. These factors affect to the corroded metal and reduce the strength. Types of corrosion are divided into

1. Chemical corrosion: this corrosion is the reaction between metal and nonmetal which is occurred by oxidation, halogenation or sulfurization. No liquid are involved in this type or called " dry corrosion"

2. Electrolytic or electrochemical corrosion or wet corrosion: the water or electrolyte are involved in type. The reactions of electrochemical corrosion are described as

Oxidation reaction: the anode reduced the electron as the equation.

(1) $M^0 \longrightarrow M^+ + e^-$

Reduction reaction: the cathode oxidized the electron from the anode as the equation.

(2) $M^+ + e^- \longrightarrow M^0$

$2H^+ + 2e^- \longrightarrow H_2$

$2H_2O + O_2 + 4e^- \longrightarrow 4(OH)^-$

The electrochemical corrosion is divided into

2.1 galvanic corrosion or dissimilar metals: this corrosion occurs when the dissimilar metals are in contact. This combination of dissimilar metals produces electrogalvanism or galvanic currents. The electron will be released to the oral fluid which brings to the pain or galvanic shock. For example, the insertion of the gold crown with the existing amalgam restoration on the opposing tooth leading to tingling and burning sensation. Furthermore, single metal can produce galvanic currents because the electrolytes are different.

2.2 stress corrosion: this type of corrosion occurs where the rough surface of metal presents. For example, insertion of removable partial denture causes the stress at the wire. This area contact to oral fluid brings about to corrosion.

2.3 concentration cell corrosion or crevice corrosion: This situation occurs when there are the variations of the electrolytes in oral fluids. For example, the different concentration of oxygen presents between the occlusal surface and the deep pit of restoration. The upper surface performs the cathode while the lower one is the anode then the electron movement occurs in this area.

Mostly, the electrochemical corrosion do not find alone. It must be accompanied by two or more. To prevent corrosion, it may change the metal restoration to the nonmetallic restoration or similar metal such as noble-noble

restoration or resin composite filling, respectively. Apply varnish (silver nitrate precipitates on the electrode alters the electromotive force of alloy and alters the potential (13) or polishing the restoration surface should be done to reduce corrosion.

The hypothesis of pain due to electrolytic action (galvanism)

Mumford (9) interested in the factors which affected to the electromotive force (E.M.F.) in the oral cavity. The investigation of electrodes (22 gold-17 gold, 22 gold-amalgam and 17 gold-amalgam) and electrolytes (saliva, blood and serum) was observed. They believed that the dentinal fluid is produced from blood serum. The resultant of E.M.F. depends on type of electrolytes, electrodes and body temperature but not depends on the distance of electrodes and cross sectional of dentinal tubule. If the different electrodes remain the E.M.F. is high as shown in Table 1.

Table 1 Comparison of E.M.F.'s in millivolts (9)

Electrolyte	22 old and amalgam	17 gold and amalgam	22 gold and 17 gold
Saliva	470	575	119
Serum	470	545	120
Blood	412	464	40

When the electrodes are in contact, the short circuit occurs giving a current. The electromotive force (E.M.F.) of electrodes, saliva and electrolytes in dentin and pulp are developed. The tooth endures 0.5-50 microamperes, the larger current flows along the dentinal tubules and causes pain. E.M.F. occurs around the electrodes then pass through the dentinal tubule by dentinal fluid to stimulate the nerve directly. This current could cause a brief sharp pain (9).

The conditions of oral environment which cause galvanism are (12).

1. Single electrode (Figure 1). E.M.F. of this group causes from the difference between electromotive of saliva and bone fluid. This causes the ion across the boundary between two electrolytes. The E.M.F. of this is small and unobvious to cause pain or explain that single metal restoration produces galvanic currents due to the different oxygen or electrolytes in oral fluid.

Figure 1 The schematic of single electrode (13).

2. Electrodes remaining separated (Figure 2). The dissimilar metal restorations are in the same arch but not contact each other. In this case, electromotive of saliva is equal to electromotive of bone fluid so the pain causes from the different electrodes. This pain seems unlikely because the resistance of gingiva presents to fall the E.M.F.

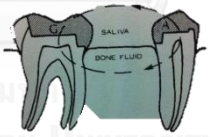


Figure 2 The schematic of Electrodes remaining separated (13).

3. Electrodes remaining in contact (Figure 3). The dissimilar metal restorations are in contact to the adjacent teeth. This condition was proved by Meyer R. which separate the adjacent teeth with elastic band and then change amalgam to resin composite cause the pain disappeared (28).

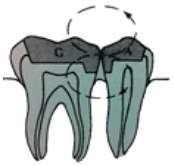


Figure 3 The schematic of Electrodes remaining in contact (13).

4. Electrodes with intermittent contacts (Figure 4). This case causes pain mostly because the short circuit occurs between two electrodes. The dissimilar metal restorations are in contact to the opposing teeth.

Figure 4 The schematic of Electrodes with intermittent contacts (13).

Biologic effects of oral galvanism (14)

If the density of electrical current is more than 1.3 μA/mm^3. This current activate the nervous system directly affect to muscles and glands. The symptoms are usually burning mouth, oral pain and tingling, salty taste and leukoplakia (shown at the soft tissue near the metallic restoration or called “electrogalvanic white lesion”)

The types of dental luting cements (29)

1. Water-based cements: zinc phosphate, zinc polycarboxylate, glass ionomer, resin-modified glass ionomer

Zinc phosphate cement is composed of zinc oxide and phosphoric acid. The setting reaction is acid-base reaction. The newly formed zinc phosphate composes of the hydrated zinc phosphate and matrix when the set cement is porous and soluble.

Zinc polycarboxylate is formed by zinc oxide and polyacrylic acid. The set cement has cores of zinc oxide within zinc polyacrylic matrix binding to the

unreacted zinc oxide. The present of stannous fluoride and magnesium oxide increases the solubility of cement.

Glass ionomer is composed by silica, alumina, calcium fluoride (CaF2), sodium fluoride (NaF) and/or aluminum phosphate (AlPO4). The liquid is polyacrylic acid. The setting reaction is acid-base reaction. The calcium ion which is hydrolyzed in the final setting can bind to the tooth structure and some fluoride will prevent the occurrence of carious lesion.

Resin-modified glass ionomer is composed of the acid-base and polymerization reaction. The powder is fluoroaluminosilicate like conventional glass ionomer. The liquid contains polyacrylic acid, 2-hydroxyethyl methacrylate (HEMA) and water. The setting reaction is divided into two phases. First, the initial is caused from light-cured or self-cured polymerization. The final setting is acid-base reaction which is slower than the conventional glass ionomer because the water presents lower.

2. Polymer-based cements: the organic matrix contains dimethacrylate monomers and high molecular weight molecules of monomers for example bisphenol-A glycidyl dimethacrylate (Bis-GMA), urethane dimethacrylate (UDMA) and ethoxylated Bis-GMA (Bis-EMA). These oligomers combine with ethylene glycol dimethacrylates (DEGDMA) and ethylene glycol trimethacrylates (TEGDMA) to achieve the high degree of conversion. The fillers vary from 30%-60% by volume. These fillers contain silanated glasses. The size ranges from 0.5μm to 8μm. Pigments and opacifiers are present in the paste. The resin cements are divided as recommendation of ISO into class1-self cured materials, class2-light cured materials and class3- dual cured materials. The setting reaction is polymerization. The sorption and solubility is much lower than the water-based cements.

1) Class 1-self cured: This is no waste time to prepare. No intermediate bonding process. Some adhesive resin cements contain 4-methacryloxyethyl-trimellitic anhydride (4-META), methylmethacrylate (MMA) and tri-n-butylborane (TBB) or 10-methacryloyoxydecyl dihydrogen phosphate (MDP) combines with phosphoric acid ester with Bis-GMA.

2) Class 2-light cured: this type is initiated by the photo-initiators like camphoquinone to access the cement will be fully cured.

3) Class 3-dual-cured: these combine with light-cured and self-cured which the practitioners will not worry about the light penetration into the inaccessible area.

3. Oil-based cements: zinc oxide noneugenol and eugenol

The powder is zinc oxide and the liquid is eugenol or oil of clove. This cement is widely used for temporary cement.

Table 2 Reactions and typical properties of dental luting cements (1).

Cement	Setting time	Film thickness (μm)	Compressive strength (MPa)	Bond strength to dentin (MPa)	Setting reaction
Zinc phosphate	5.5	25	70	-	Acid-base
Zinc polycarboxylate	6	25	70	-	Acid-base
Glass ionomer	7	25	70	-	Acid-base
Resin cement	2-4	40	180-265	18-30	Polymerization
Zinc oxide eugenol	4-10	-	2-14	0	-
Zinc oxide noneugenol	4-10	-	2.7-4.8	0	-

The previous studies interested in mechanical and biological properties. The one study which investigated in the insulation of three luting cements (24). This recommended the impedance methodology to measure the resistance of dental luting cements.

Impedance methodology

The measurement of electrochemical reaction are widely used in engineering by electrical conductivity, diffusion and permeability of Portland cement (30). This study found out that the electrical conductivity depended on porosity of specimen. The principle of impedance methodology is the two electrodes soak in the electrolyte and the circuit connects to frequency response analyzer, potentiostat or insulation tester (Figure 5). In this present time, the impedance method is applied to the dentistry for measurement the microleakage of composite resin (23) and dentin permeability (31). The advantages are

1. Non-destructive technique
2. The value detects immediately because the ionic conduction occurs easily.
3. No disturbance of the dentin's charge
4. The potential can specify as a requirement.

The disadvantage is that could not imitate like the oral environment.

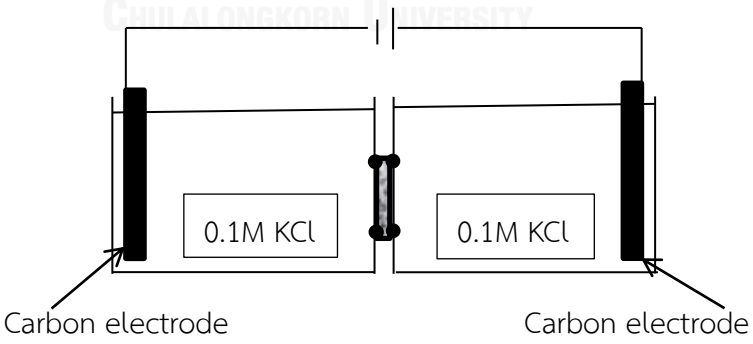


Figure 5 The impedance methodology

Electrical potential of a metallic restoration or EPR

The former method to measure the electric current in oral cavity directly. The probe (Ag/AgCl) is covered by wax to protect the gold tip with the electrolyte. This tip contacts to the metallic restoration and the other one soaks in the saliva as the reference (Figure 6). The voltmeter indicates the potential of metallic restoration. The average potential is between the metal and saliva. The advantages are the average potential of metal and suits for in vivo study. The disadvantages are

1. Patient suffers from the activated area.
2. Isolating area is difficult.
3. The potential depends on the threshold of patient.
4. Thin oxide layer on the metallic restoration causes poor electrical currents.

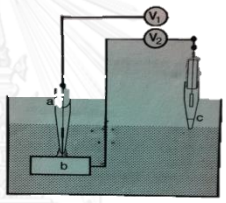


Figure 6 The schematic of electrical potential of a metallic restoration a, probe; b, tested alloy; c, reference electrode.

Porosity measurements (32)

1. Gas sorption: this method is widely used for micropore and mesopore sizes. The specimen is evacuated for degassing in order to remove moisture. After that, the evacuated specimen will be transferred to the sorption chamber and then is pressed with the pressure to absorb the gas. Until the saturated stage, the gas is desorbed, then the absorbed gas in the specimen is recorded in term of distribution curves.

2. Liquid intrusion: the same manner as gas sorption but changing the gas to liquid or called “mercury porosimetry” this method is suitable for analyzing the pore size 4nm to 60μm.

3. Microscopy: this method require the thin cross-sections of specimen as much as possible for optical or electron microscopy. The result is reported by the software analyzing program and gives the two dimensional image. The mesopores are suitable for this method.

4. Light, x-ray, and neutron scattering: this technique requires no pretreatment of the specimen contrast to the gas sorption technique. The advantage is non-destructive method which specimen will not be damaged. The pore size, which is between 1-1000 nm can be analyzed. Micro computed tomography (micro-CT) is one of this technique which x-ray is used for scattering. The image is transported into three dimensions. There are two systems of micro-CT. First, the x-ray source and background rotated around the object. The other is the x-ray source and background are settled and the object rotates.

CHAPTER III

METHODOLOGY

Target population

Water-based and polymer-based dental luting cements

Sample

1. Water-based cement: zinc phosphate (Hybond, Shofu Incorporation, Japan) 10 specimens, glass ionomer (Fuji II, GC Corporation, Japan) 10 specimens.
2. Polymer-based cement: Dual cured resin cement (Rely- X Unicem and Rely-X™U-100, 3M ESPE, USA) 20 specimens and self-cured resin cement (Superbond C&B, Sunmedical, Japan) 10 specimens.

Table 3 Composition of the dental luting cements used in this study

Material	Powder	Liquid	Manufacturer
Hybond (Zinc phosphate cement) Lot number 071301	Zinc oxide, Magnesium oxide	Phosphoric acid:water 2:1	Shofu Incorporation, Japan
Fuji II (Glass Ionomer cement) Lot number 1309201	Fluoroaluminosilicate glass	40%-50% polyacrylic acid, Tartaric acid, Itaconic, maleic or tricarboxylic acids	GC Corporation, Japan
Rely–X™ Unicem (Automix resin cement) Lot number 530044	Alkaline (basic) fillers, Silanate fillers, Initiator components and pigments	Methacrylate, Triethylene glycol dimethacrylate (TEGDMA), Bisphenol A diglycidyl methacrylate (Bis-GMA), Initiator components and Stabilizers	3M ESPE, USA

Table 3 Composition of the dental luting cements used in this study (continued)

Material	Powder	Liquid	Manufacturer
Rely-X U-100 (Hand-mix resin cement) Lot number 530252	Glass powder, Silane treated silica, Sodium persulfate, Cupric acetate and Calcium hydroxide	Methacrylate, Triethylene glycol dimethacrylate (TEGDMA), Bisphenol A diglycidyl methacrylate (Bis-GMA), Initiator components and Stabilizers	3M ESPE, USA
Superbond C&B (Self-cured resin cement) Lot number KF1 2014-02	Polymethylmethacrylate (PMMA) and pigments	Tri-n-butyl borane (TBB), Acetone 4-methacryloyloxyethyl trimellitate anhydride (4-META) and methyl methacrylate (MMA)	Sun Medical, Japan

Instruments

1. Spatula and glass slab
2. PTFE mold
3. Plastic wrap
4. Light cure unit
5. Amalgamator
6. Digital insulation tester (MY4O, Yokogawa, Japan)
7. Micro computed tomography (Skyscan 1173 Micro-CT, Belgium)
8. Digital scaler 'Sartorius BP110S' (Sartorius, Germany)
9. Carbon electrodes
10. Incubator
11. Pipette
12. Dental luting cements (zinc phosphate: Hybond, Shofu Incorporation, Japan, glass ionomer: Fuji II, GC Corporation, Japan, resin cements: Rely- X Unicem and Rely-X™U-100, 3M ESPE, USA, Superbond C&B, Sunmedical, Japan)
13. 0.1 M potassium chloride

Sample preparation and investigation of porosity

Ten disk specimens of each dental luting cement were prepared in a PTFE mold with the size of 12 mm in diameter and 1 mm thick This method is modified from ISO 4049 (33) and their manufacturer's instructions. Before impedance test, all specimens were weighed and investigated for percentage of porosity using micro computed tomography (Skyscan 1173 Micro-CT, Belgium). The system consisted of a sealed x-ray tube operated at 50 kilovolt and the x-ray source made power of 40 watt. An object manipulation was used to move the specimen in two dimension and with rotational movement. Then raw data was investigated by 3D reconstruction to evaluate the porosity. The measurement was carried out with 30 micron per slide and 669 slides per one specimen. All specimens were calculated into percentage of porosity.

Figure 7 The specimen size 12 mm in diameter and 1 mm thick

Figure 8 Micro computed tomography (Skyscan 1173 Micro-CT, Belgium)

Impedance test for Electrical resistance

Each specimen was secured with O-ring between two electrochemical chambers of which had a hole 10 mm in diameter. Each chamber contained 0.1 molar potassium chloride solution and ionized 100% at 37°C following the recommendation of National Institute of Standards Technology (NIST). The carbon electrodes in both chambers were connected to the digital insulation tester (MY4O, Yokogawa, Japan). The schematic diagram of experimental setup is shown in Figure 9. The insulation tester was operated under voltage of 125 volt for the water-based cements and 1,000 volt for the polymer-based cements. The electrical resistance of dental luting cement was measured in term of impedance value.

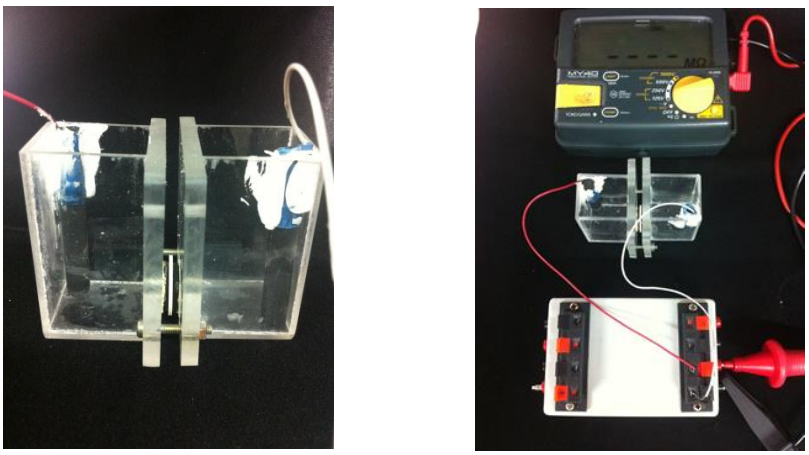


Figure 9 Schematic diagram of electrical equivalent circuit setup

The solubility of the dental luting cements

Before impedance test, all specimens were weighed as a mass (m1) using the 'Sartorius BP110S' digital scaler (Sartorius; Germany). After impedance test, the tested specimens were weighed as a mass (m2) after reconditioning in a desiccator and incubator at 37° C modified from ISO4049:2009. (REF) The solubility (Wsl) was calculated as the following equation:

$$W_{sl} = (m_1-m_2)/V$$

When W_{sl} is the solubility in water (μg/mm^3), m_1 is the mass (μg), prior to immersion, m_2 is the mass (μg), after immersion; V is the volume of the specimens (mm^3).

Figure 10 The 'Sartorius BP110S' digital scaler (Sartorius; Germany).

Statistical analysis

SPSS statistical analysis software (SPSS Statistics Version 20, Cary, USA Copyright IBM Corporation) was used to analyze the data. Independent T-test with comparison was used to analyze electrical resistance between Zinc Phosphate and Glass Ionomer cements. The relationship among electrical resistance, porosities and solubility of all groups were analyzed using one-way analysis of variance (ANOVA) followed by Spearman correlation. Significance level was set at α=0.05.

CHAPTER IV

RESULTS

Results of porosity

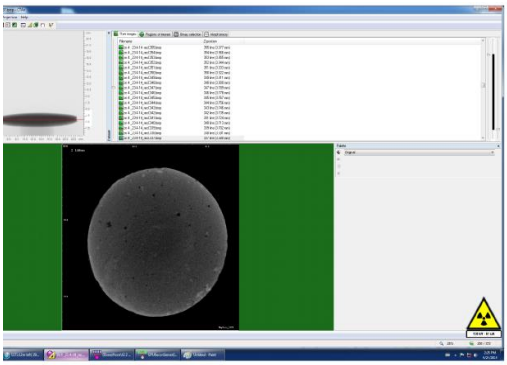
For characteristic of porosity, it was found that among cements in this study, Superbond C&B had the highest mean percentage of porosities (Table 4). The samples of photos of porosity of each dental luting cements were shown in Figure 11.

Table 4 The porosity of dental luting cements in this study.

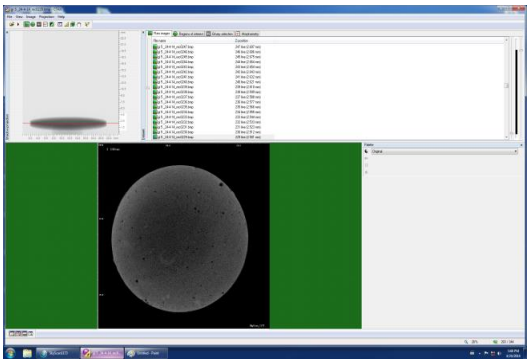
Materials	Mean of porosities [%] [s.d.]
Zinc phosphate	40.59 [15.98]
Glass ionomer	47.73 [4.68]
Rely-X Unicem	41.19 [9.01]
Rely-X™ U-100	39.49 [7.46]
Superbond C&B	76.59* [6.58]

* Significant differences (α =0.05)

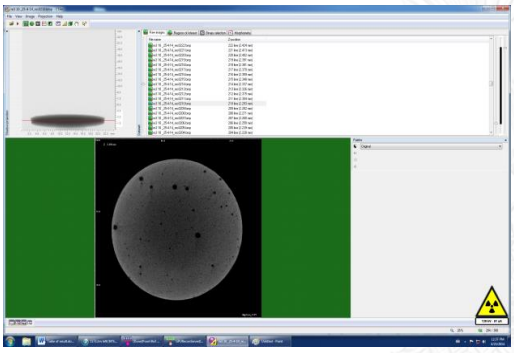
a. Hybond



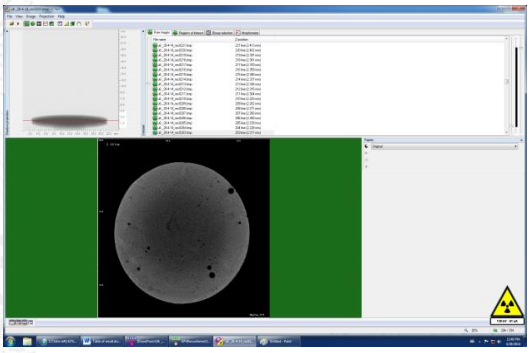
b. Fuji II



c. Rely-X Unicem



d. Rely-X™ U-100



e. Superbond C&B

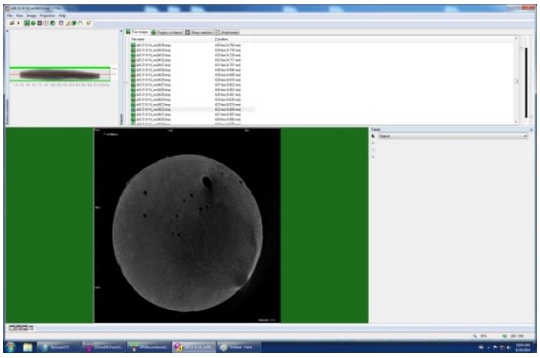


Figure 11 The porosities of zinc phosphate, glass ionomer and 3 types of resin cement.
a) Hybond, b) Fuji II, c) Rely-X Unicem, d) Rely-X™ U-100 and e) Superbond C&B

Results of electrical resistance

This study showed that the mean values of electrical resistance of zinc phosphate cement was significantly higher than those of electrical resistance of glass ionomer cement (α <0.05). Both of the values of electrical resistance of zinc phosphate and glass ionomer dramatically decreased and became less than 10% of the initial value within 1 day. However, this gradually decreased to less than 1% of the initial value after 30 days (as shown in Table 5 and Figure 12). Figure 2 also shows the tendency of decreased electrical resistance for both cement types. On the other hand, the electrical resistance of resin cements including Rely-X Unicem, Rely-X™ U-100 and Superbond C&B, were higher than limitation of measurement (2000×10^6 Ω).

Table 5 The means of the electrical resistance of dental luting cements from day0 to day30.

Day	Means of Electrical Resistance [s.d.] [x10^6 Ω]				
	Zinc phosphate	Glass ionomer	Rely-X Unicem	Rely-X™ U-100	Superbond C&B
0	3.244 [2.873]	0.439 [0.196]	>2000	>2000	>2000
1	0.046 [0.028]	0.044 [0.082]	>2000	>2000	>2000
3	0.027 [0.018]	0.011 [0.004]	>2000	>2000	>2000
7	0.018 [0.008]	0.006 [0.002]	>2000	>2000	>2000
14	0.016 [0.008]	0.005 [0.002]	>2000	>2000	>2000
21	0.016 [0.006]	0.004 [0.001]	>2000	>2000	>2000
30	0.017 [0.008]	0.004 [0.001]	>2000	>2000	>2000

Note: The insulation tester (MY4O) has a maximum measuring limit at 2000x 10^6 Ω.

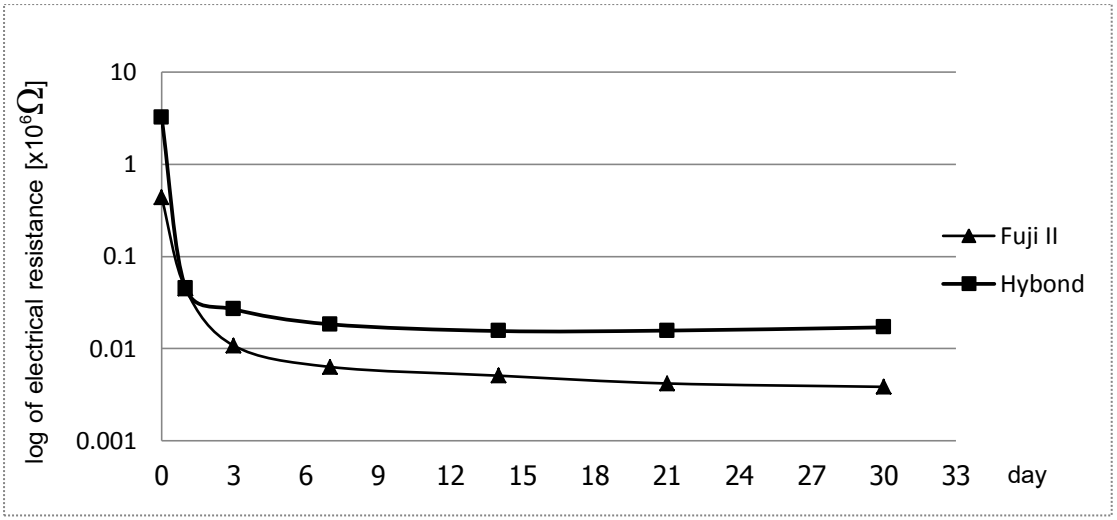


Figure 12 The mean values of electrical resistance of Hybond and Fujii II at day0, day1, day3, day7, day14, day21 and day30

Results of solubility

In an aspect of solubility, zinc phosphate (Hybond) and glass ionomer cements (Fuji II) exhibited higher solubility than the other three groups of polymer-based cements (Rely-X Unicem, Rely-X™ U-100 and Superbond C&B) , but they showed no statistically significant difference (Table 6). The correlation is displayed on Table 7.

Table 6 The solubility of dental luting cements in this study.

Materials	Mean of weight before [s.d.] [g]	Mean of weight after [s.d.] [g]	Mean of weight loss [s.d.] [g]	Mean of solubility [s.d.] [$\mu g/mm^3$]
Zinc phosphate	1.020 [0.080]	0.990 [0.080]	0.030 [0.030]	394.904 [391.258]
Glass ionomer	0.660 [0.040]	0.640 [0.040]	0.030 [0.020]	298.089 [222.126]
Rely-X Unicem	0.790 [0.030]	0.790 [0.030]	-	0
Rely™ U-100	0.660 [0.020]	0.660 [0.020]	-	0
Superbond C&B	0.560 [0.020]	0.560 [0.020]	-	0

- = unchanging of weight after immersion

Table 7 The correlation among the mean electrical resistance and the porosity on day0, the electrical resistance and the solubility on day30.

Materials	Correlations between electrical resistance and porosity on day 0 [Sig.=0.05]	Correlations between electrical resistance and solubility on day 30 [Sig.=0.05]
Zinc phosphate	0.162	0.412
Glass ionomer	0.763	0.01*
Rely-X Unicem	NAP	NAP
Rely™ U-100	NAP	NAP
Superbond C&B	NAP	NAP

* Significant differences (α =0.05)

The correlation between electrical resistance and porosities of dental luting cements were shown in Figure 13. Additionally, no correlation could be found between the electrical resistance and porosities on day0. Furthermore, the electrical resistance and solubility of each type of cements did not correlated on day30 except for glass ionomer (Figure 14).

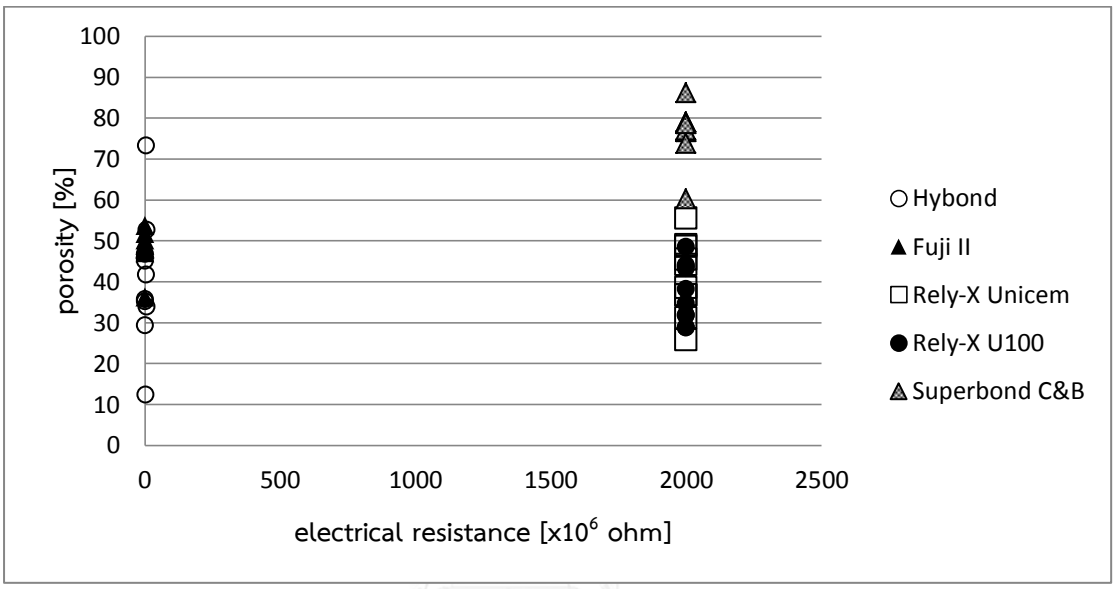


Figure 13 The correlation between electrical resistance and porosities of dental luting cements on day0

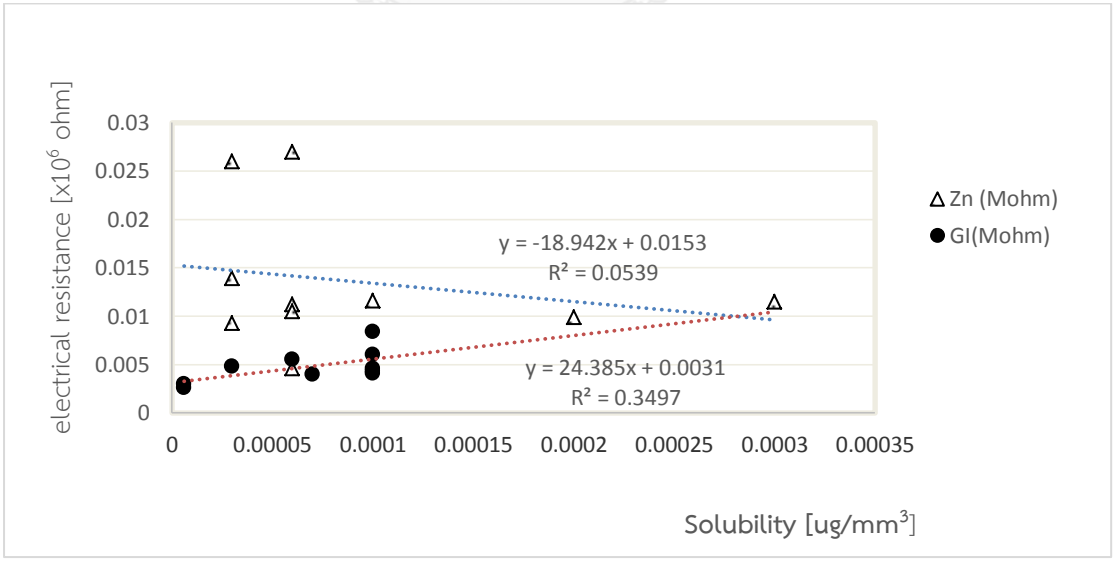


Figure 14 The correlation between electrical resistance and solubility of dental luting cements on day30

CHAPTER V

DISCUSSION AND CONCLUSION

Discussion

The property of the electrical resistance

Between water-based and polymer-based cements in the present study, it is found that the solubility of zinc phosphate and glass ionomer could be measured unlike polymer-based cement groups. However, this does not mean that the latter groups show no weight loss because this study was observed only 30 days. For property of electrical resistance, it was found that the polymer-based luting cements showed much higher electrical resistance than water-based luting cements. This finding could be the reason of different chemical composition and setting reaction. Zinc phosphate and glass ionomer cements are acid-base setting reaction typed cement while the setting reaction of polymer-based cement is polymerization. After setting reaction of zinc phosphate cement, there will be some free acid left on the surface of the cement. The remaining free acid of zinc phosphate would increase the electrical conductivity. This will contribute to lower resistance. While, Calcium ion in glass ionomer was hydrolyzed in the final setting (34). This Calcium ion dissolved in the electrolyte so the increasing of the electrical conductivity could be detected. This conformed to the previous study which found that the electrical conductivity depended on the amount of the electron from the acid-base reaction (35). In addition, the mean electrical resistance of zinc phosphate cement was higher than glass ionomer, regardless of date of measurement. In the final setting of both cements, zinc ion from zinc phosphate cement and calcium ion from glass ionomer cement were released in the solution. When comparing standard standard potential (E^0) of zinc ion ($E^{0}_{Zn^{+}}$ = -0.76) and E^0 of calcium ion ($E^{0}_{Ca^{2+}}$ = -2.87), it found that $E^{0}_{Ca^{2+}}$ was higher than $E^{0}_{Zn^{+}}$. Therefore, glass ionomer cement could provide more electrical conductivity than zinc phosphate cement. Among polymer-based (resin) cements, Rely-X Unicem and Rely-X™ U-100 were dual cured and self-adhesive resin cement. Both of them have similar basic composition but are different in mixing manipulation. For setting reaction of these resin cements, there was not any free radical in the termination phase of polymerization. It becomes the densely cross-linkage polymer (36). The same as Superbond C&B is self –cured and total etch resin cement. This cement was initiated by chemical initiator. When the polymerization of polymer-

based cement completes, the polymerized structure will have less solubility. The complexity of polymerization could be a hurdle for electrolyte to penetrate and led to higher electrical resistance of polymer-based cements than water-based cements. In addition, different mixing technique (between Rely-X Unicem and Rely-X™U-100) was aimed to be observed in this study. It was found that the mixing technique did not affect the amount of porosity and solubility. This could not apply to the manipulation technique of Superbond C&B which have powder and liquid.

The porosity of dental luting cements

To compare the porosity among all dental luting cements, the present study showed that Superbond C&B had the highest porosity and differed from the others significantly. The results of this study was confirmed by Malkoc MA. et al (37), who also demonstrated that Superbond C&B had the highest porosity. They claimed that hand mixing technique caused air inclusion the material easily, while the automatic mixing avoided these inclusions. In this study, Superbond C&B, Rely-X U100, Hybond and Fuji II were hand mixing technique but the preparation of cement was different. Due to the difference in preparation resulted in the percentage of porosity.

The solubility of dental luting cements

The result of solubility of dental luting cements showed that solubility of zinc phosphate and glass ionomer were higher than polymer-based cement. This conformed to the study by Ghanim A (38), which explained the solubility of water-based cements correlated to the microviods. Water would diffuse to these pores and then reacted with hydrophilic groups of polar molecules in the material to dissolve the water-based cements. Saleem M. and Ulhaq I. (39) found that glass ionomer was more soluble than zinc phosphate at lower pH values because glass ionomer was hydrolysed easily. This finding confirms that the pH values affect to the solubility but the present study found that the solubility of zinc phosphate and glass ionomer were not different because this in vitro study was static solubility and did not simulate the pH and temperature changes like the oral cavity. Yoshida K., Tanagawa M and Atsuta M.(40) claimed that the solubility of zinc phosphate was higher than glass ionomer because zinc and magnesium were leached from zinc phosphate easier than aluminium and silicon from glass ionomer. No matter the results of the solubility are, the solubility will affect the mechanical properties of dental luting cements therefore, the practitioners should be aware. While the solubility of

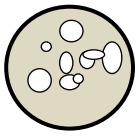
polymer-based cements could not be detected in this study This could be due to the final setting of polymer-based cement did not present the pendant hydroxyl groups to form hydrogen bond with water and had densely cross-linking so the water could not dissolve (17). But there was one study claimed that the factors which affected to the solubility of polymer-based cement depended on the monomer conversion rate, residual monomer, resin matrix and a lower rate of polymerization (41). Even though, the polymer-based cement had less soluble than water-based cement, the voids or porosities must be avoided to reduce the occurrence of solubility because the oxygen trapped in the voids inhibited polymerization (17).

The correlation among electrical resistance, porosity and solubility

There was no correlation between the electrical resistance, porosity and solubility of dental luting cements except in the last day of experiment that electrical resistance of glass ionomer correlated to the solubility. This implies that the electrical resistance of dental luting cements depended on the composition and reaction of setting cement regardless of amount of porosities. The conductive model could be explained why the electrical resistances do not relate to the porosity as shown in Figure 13. The result showed that no correlation between the value of electrical resistance and the porosity of dental luting cements. It might be 3 pathways of the penetration of the electrolyte as shown in Figure 15. First, there were many porosities but the values of electrical resistance were high. This condition happened because there were many porosities but these were little connected way. So the electrolyte could not penetrate the samples, the values of the electrical resistance were high like Superbond C&B (Figure 15A). Second, there were less porosities and the values of electrical resistance were low. These porosities connected very well so the values of the electrical resistance were low as shown in Hybond and Fuji II (Figure 15B). Third, there was a few porosities and the values of the electrical resistance were high. There were less porosities and did not connect. So the electrolyte penetrated hardly then the values of electrical resistance were high as shown in Rely-X Unicem and Rely X^{TM}U-100 (Figure 15C). In the Table 7 showed that the electrical resistance of glass ionomer correlated with the solubility on the last day and the solubility of Hybond and Fuji II were not different in this study. There were some studies which found out that the solubility of glass ionomer was greater (39). Some found that the solubility of zinc phosphate was more (40). The factors which affected to the results were time of dissolution, the type and pH of media. Even though, the correlation among the electrical resistance, porosity and

solubility do not relate, the mixing technique must be caution because if there were many porosities at the marginal restoration which exposed to oral fluids (29). The oral fluids would penetrate through these porosities to react with hydrophilic groups of dental luting cements, the water solubility occurred, leading to the marginal leakage. Furthermore, the electrical resistance decreased with the increasing time except polymer-based cements so the patient could percept the hypersensitivity from galvanic by this pathway (9).

A. Superbond C&B



B. Hybond, Fuji II

C. Rely X Unicem and Rely-X™ U-100

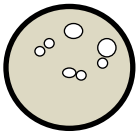


Figure 15 The conductive pathway

Conclusions

Mean electrical resistance of zinc phosphate cement was significantly higher than that of glass ionomer cement while all polymer-based luting cements show very high electrical resistance but could not be measured due to over limitation of measurement. Within the limitation of this study, it can be concluded that electrical resistance of dental luting cement related to chemical composition and setting reaction but do not relate to amount of porosity and degree of solubility. Model of pore connection were proposed to explain the relation of electrical resistance and porosity. It is believe that the connectivity of pore may play an important role to the electrical resistance than the density of pore. Moreover, the decreasing of electrical resistance was opposed to the increasing time except polymer-based cement.

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APPENDIX

Table 8 The result of percent porosities of dental luting cements.

Type of sample / No. sample	Zinc Phosphate	Glass Ionomer	Rely X Unicem	Rely X™ U-100	Superbond C&B
1	46.78	48.17	48.67	28.83	76.62
2	29.27	47.05	49.02	48.47	86.19
3	33.87	53.67	44.17	31.85	78.97
4	52.69	36.22	38.56	43.27	79.03
5	73.29	51.81	36.80	44.11	78.67
6	45.15	48.94	55.48	43.84	76.72
7	12.40	47.91	25.84	38.21	77.05
8	35.67	50.16	36.73	34.65	78.65
9	35.13	47.81	45.44	31.76	60.18
10	41.71	45.59	31.20	49.96	73.84
Mean	40.60	47.73	41.19	39.50	76.59

Table 9 The result of electrical resistance of dental luting cement at day0, 1, 3, 7, 14, 21 and 30.

1. The mean electrical resistances of zinc phosphate cement

No. specimen		1	2	3	4	5	6	7	8	9	10
Time [day]	Mean [x$10^6\Omega$]										
0		1.871	0.103	7.16	7.68	5.84	1.565	3.518	0.572	0.0725	4.06
1		0.0125	0.0618	0.0765	0.0753	0.0305	0.0164	0.0899	0.0463	0.0229	0.023
3		0.0113	0.0274	0.025	0.0377	0.0208	0.013	0.0698	0.0368	0.0125	0.0134
7		0.011	0.0218	0.0165	0.0245	0.0145	0.0115	0.0282	0.0324	0.011	0.0121
14		0.0078	0.0169	0.0122	0.022	0.0106	0.0122	0.0183	0.034	0.012	0.0091
21		0.0083	0.0235	0.0109	0.0258	0.0099	0.0143	0.0214	0.02	0.012	0.0107
30		0.0099	0.027	0.0111	0.0288	0.0094	0.0135	0.0219	0.025	0.012	0.0114

Table 10 The mean electrical resistances of glass ionomer cement

No.specimen		1	2	3	4	5	6	7	8	9	10
Time [day]	Mean [$x10^6$ Ω]										
0		0.45	0.1202	0.1602	0.647	0.643	0.3153	0.427	0.394	0.629	0.601
1		0.0175	0.0208	0.0164	0.0248	0.0134	0.0116	0.0125	0.02	0.0313	0.2763
3		0.0112	0.0155	0.0077	0.0123	0.0098	0.0057	0.0101	0.0129	0.0169	0.0055
7		0.0059	0.0097	0.0046	0.0073	0.0058	0.0049	0.0044	0.0072	0.0085	0.0049
14		0.005	0.0088	0.0037	0.0056	0.0043	0.0031	0.0039	0.005	0.0072	0.0042
21		0.0045	0.0049	0.0052	0.005	0.0036	0.003	0.0034	0.0043	0.0048	0.0031
30		0.0037	0.0048	0.0046	0.0047	0.0027	0.003	0.004	0.004	0.0043	0.0026

Table 11 The electrical resistance of Rely-X Unicem, Rely-X™ U-100 and Superbond C&B

No.specimen		1	2	3	4	5	6	7	8	9	10
Time [day]	Mean [$x10^6$ Ω]										
0		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
1		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
3		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
7		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
14		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
21		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
30		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000

Table 12 The electrical resistance of Rely- X™ Unicem

No.specimen		1	2	3	4	5	6	7	8	9	10
Time [day]	Mean [x10^6 Ω]										
0		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
1		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
3		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
7		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
14		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
21		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
30		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000

Table 13 The electrical resistance of Superbond C&B

No.specimen		1	2	3	4	5	6	7	8	9	10
Time [day]	Mean [$x10^6$ Ω]										
0		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
1		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
3		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
7		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
14		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
21		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000
30		>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000	>2000

Table 14 The result of weight before immersion, weight after immersion and the solubility of dental luting cements

1. The weight before immersion, the weight after immersion and the solubility of zinc phosphate

No.specimen	Weight before immersion [g]	Weight after immersion [g]	Weight loss [g]	Solubility [μg/mm^3]
1	0.980	0.910	0.070	891.720
2	1.020	1.000	0.020	254.777
3	1.020	0.980	0.040	509.554
4	0.930	0.920	0.010	127.389
5	0.910	0.900	0.010	127.389
6	0.940	0.920	0.020	254.777
7	1.060	1.050	0.010	127.389
8	1.160	1.150	0.010	127.389
9	1.080	1.060	0.020	254.777
10	1.090	0.990	0.10	1273.853

2. The weight before immersion, the weight after immersion and the solubility of glass ionomer

No.specimen	Weight before immersion [g]	Weight after immersion [g]	Weight loss [g]	Solubility [μg/mm^3]
1	0.65	0.644	0.006	76.433
2	0.62	0.608	0.012	152.866
3	0.64	0.598	0.042	535.032
4	0.76	0.728	0.032	407.643
5	0.68	0.628	0.052	662.420
6	0.64	0.638	0.002	25.478
7	0.67	0.638	0.032	407.643
8	0.61	0.588	0.022	280.255
9	0.67	0.638	0.032	407.643
10	0.65	0.648	0.002	25.478

3. The weight before immersion, the weight after immersion and the solubility of Rely-X™ Unicem

No.specimen	Weight before immersion [g]	Weight after immersion [g]	Weight loss [g]	Solubility [μg/mm^3]
1	0.790	0.790	0	0
2	0.790	0.790	0	0
3	0.810	0.810	0	0
4	0.830	0.830	0	0
5	0.820	0.820	0	0
6	0.810	0.810	0	0
7	0.790	0.790	0	0
8	0.750	0.750	0	0
9	0.780	0.780	0	0
10	0.720	0.720	0	0

4. The weight before immersion, the weight after immersion and the solubility of Rely-X U100

No.specimen	Weight before immersion [g]	Weight after immersion [g]	Weight loss [g]	Solubility [μg/mm^3]
1	0.670	0.670	0	0
2	0.670	0.670	0	0
3	0.670	0.670	0	0
4	0.640	0.640	0	0
5	0.680	0.680	0	0
6	0.680	0.680	0	0
7	0.670	0.670	0	0
8	0.640	0.640	0	0
9	0.630	0.630	0	0
10	0.620	0.620	0	0

5. The weight before immersion, the weight after immersion and the solubility of Superbond C&B

No.specimen	Weight before immersion [g]	Weight after immersion [g]	Weight loss [g]	Solubility [μg/mm^3]
1	0.570	0.570	0	0
2	0.570	0.570	0	0
3	0.580	0.580	0	0
4	0.530	0.530	0	0
5	0.610	0.610	0	0
6	0.560	0.560	0	0
7	0.560	0.560	0	0
8	0.540	0.540	0	0
9	0.540	0.540	0	0
10	0.580	0.580	0	0

Table 15 The result of statistics of electrical resistance, porosity and solubility

.

1. Comparison of electrical resistance between zinc phosphate and glass ionomer

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
resistanceday0	1	10	3.244150	2.8725008	.9083645
	2	10	.438670	.1955555	.0618401

Independent t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
resistanceday0	Equal variances assumed	27.824	.000	3.081	18	.006	2.8054800	.9104671	.8926597	4.7183003
	Equal variances not assumed			3.081	9.083	.013	2.8054800	.9104671	.7487402	4.8622198

2. Comparison of porosity among five groups of dental luting cement

Report

porosity

group	Mean	N	Std. Deviation
1	40.5962320	10	15.97960250
2	47.7337710	10	4.67835788
3	41.1910140	10	9.00675883
4	39.4964570	10	7.46454203
5	76.5914810	10	6.57883162
Total	49.1217910	50	16.88110322

ANOVA

porosity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9847.399	4	2461.850	26.914	.000
Within Groups	4116.212	45	91.471		
Total	13963.611	49			

Multiple Comparisons

Dependent Variable: porosity

Tukey HSD

(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-7.13753900	4.27718060	.463	-19.2909337	5.0158557
	3	-.59478200	4.27718060	1.000	-12.7481767	11.5586127
	4	1.09977500	4.27718060	.999	-11.0536197	13.2531697
	5	-35.99524900*	4.27718060	.000	-48.1486437	-23.8418543
2	1	7.13753900	4.27718060	.463	-5.0158557	19.2909337
	3	6.54275700	4.27718060	.549	-5.6106377	18.6961517
	4	8.23731400	4.27718060	.319	-3.9160807	20.3907087
	5	-28.85771000*	4.27718060	.000	-41.0111047	-16.7043153
3	1	.59478200	4.27718060	1.000	-11.5586127	12.7481767
	2	-6.54275700	4.27718060	.549	-18.6961517	5.6106377
	4	1.69455700	4.27718060	.995	-10.4588377	13.8479517
	5	-35.40046700*	4.27718060	.000	-47.5538617	-23.2470723
4	1	-1.09977500	4.27718060	.999	-13.2531697	11.0536197
	2	-8.23731400	4.27718060	.319	-20.3907087	3.9160807
	3	-1.69455700	4.27718060	.995	-13.8479517	10.4588377
	5	-37.09502400*	4.27718060	.000	-49.2484187	-24.9416293
5	1	35.99524900*	4.27718060	.000	23.8418543	48.1486437
	2	28.85771000*	4.27718060	.000	16.7043153	41.0111047
	3	35.40046700*	4.27718060	.000	23.2470723	47.5538617
	4	37.09502400*	4.27718060	.000	24.9416293	49.2484187

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

Porosity

Tukey HSD

group	N	Subset for alpha = 0.05	
		1	2
4	10	39.4964570	
1	10	40.5962320	
3	10	41.1910140	
2	10	47.7337710	
5	10		76.5914810
Sig.		.319	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

3. Mean and s.d. of weight before immersion in 5 groups of dental luting cements

Report

w1

group	Mean	N	Std. Deviation
1	1019000.000	10	80201.1360
2	659000.000	10	41753.2434
3	789000.000	10	33149.4930
4	657000.000	10	22135.9436
5	564000.000	10	23664.3191
Total	737600.000	50	165326.6402

4. Mean and s.d. of weight after immersion in zinc phosphate and glass ionomer (the weight of polymer-based cements did not change)

Report

w2

group	Mean	N	Std. Deviation
1	988000.000	10	80663.9118
2	635600.000	10	38410.6467
Total	811800.000	20	190948.7669

5. Mean and s.d. of weight loss in zinc phosphate and glass ionomer

Report

w3

group	Mean	N	Std. Deviation
1	31000.000	10	30713.7320
2	23400.000	10	17436.8703
Total	27200.000	20	24618.3500

6. Mean and s.d. of solubility in zinc phosphate and glass ionomer

Report

solubility

group	Mean	N	Std. Deviation
1	394.904410	10	391.2577312
2	298.089160	10	222.1257386
Total	346.496785	20	313.6095517

7. Comparison of solubility between zinc phosphate and glass ionomer

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
solubility	Equal variances assumed	1.926	.182	.680	18	.505	96.8152500	142.2752459	-202.0939499	395.7244499
	Equal variances not assumed			.680	14.256	.507	96.8152500	142.2752459	-207.8223265	401.4528265

8. Correlation between electrical resistance day 0 and porosity

Zinc phosphate

Correlations

			resistanceday0	porosity
Spearman's rho	resistanceday0	Correlation Coefficient	1.000	.014
		Sig. (2-tailed)	.	.955
		N	20	20
	porosity	Correlation Coefficient	.014	1.000
		Sig. (2-tailed)	.955	.
		N	20	50

Glass ionomer

Correlations

			resistanceday0	porosity
Spearman's rho	resistanceday0	Correlation Coefficient	1.000	-.345
		Sig. (2-tailed)	.	.328
		N	10	10
	porosity	Correlation Coefficient	-.345	1.000
		Sig. (2-tailed)	.328	.
		N	10	10

9. Correlation between electrical resistance day0 and solubility

Zinc phosphate

Correlations

			resistanceday0	solubility
Spearman's rho	resistanceday0	Correlation Coefficient	1.000	.153
		Sig. (2-tailed)	.	.520
		N	20	20
	solubility	Correlation Coefficient	.153	1.000
		Sig. (2-tailed)	.520	.
		N	20	20

Glass ionomer

Correlations

			resistanceday0	solubility
Spearman's rho	resistanceday0	Correlation Coefficient	1.000	.289
		Sig. (2-tailed)	.	.418
		N	10	10
	solubility	Correlation Coefficient	.289	1.000
		Sig. (2-tailed)	.418	.
		N	10	10

10. Correlation between electrical resistance day7 and solubility

Zinc phosphate

Correlations

			resistanceday0	solubility
Spearman's rho	resistanceday7	Correlation Coefficient	1.000	-.108
		Sig. (2-tailed)	.	.652
		N	20	20
	solubility	Correlation Coefficient	-.108	1.000
		Sig. (2-tailed)	.652	.
		N	20	20

Glass ionomer

Correlations

			resistanceday0	solubility
Spearman's rho	resistanceday7	Correlation Coefficient	1.000	-.062
		Sig. (2-tailed)	.	.865
		N	10	10
	solubility	Correlation Coefficient	-.062	1.000
		Sig. (2-tailed)	.865	.
		N	10	10

11. Correlation between electrical resistance day30 and solubility

Zinc phosphate

Correlations

			solubility	resistanceday30
Spearman's rho	solubility	Correlation Coefficient	1.000	.194
		Sig. (2-tailed)	.	.412
		N	20	20
	resistanceday30	Correlation Coefficient	.194	1.000
		Sig. (2-tailed)	.412	.
		N	20	20

Glass ionomer

Correlations

			solubility	resistanceday30
Spearman's rho	solubility	Correlation Coefficient	1.000	.765**
		Sig. (2-tailed)	.	.010**
		N	10	10
	resistanceday30	Correlation Coefficient	.765**	1.000
		Sig. (2-tailed)	.010**	.
		N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

12. Correlation between electrical resistance day 30 and porosity

Zinc phosphate

Correlations

			resistanceday30	porosity
Spearman's rho	resistanceday30	Correlation Coefficient	1.000	-.325
		Sig. (2-tailed)	.	.162
		N	20	20
	porosity	Correlation Coefficient	-.325	1.000
		Sig. (2-tailed)	.162	.
		N	20	50

Glass ionomer

Correlations

			resistanceday30	porosity
Spearman's rho	resistanceday30	Correlation Coefficient	1.000	.109
		Sig. (2-tailed)	.	.763
		N	10	10
	porosity	Correlation Coefficient	.109	1.000
		Sig. (2-tailed)	.763	.
		N	10	10

13. Correlation between porosity and solubility

Zinc phosphate

Correlations

			resistanceday30	porosity
Spearman's rho	resistanceday30	Correlation Coefficient	1.000	-.325
		Sig. (2-tailed)	.	.162
		N	20	20
	porosity	Correlation Coefficient	-.325	1.000
		Sig. (2-tailed)	.162	.
		N	20	50

Glass ionomer

Correlations

			solubility	porosity
Spearman's rho	solubility	Correlation Coefficient	1.000	.382
		Sig. (2-tailed)	.	.277
		N	10	10
	porosity	Correlation Coefficient	.382	1.000
		Sig. (2-tailed)	.277	.
		N	10	10

VITA

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