Effect of Sonic Application on Push-out Bond Strength of Fiber Posts to Root Canal Dentin

Pornsawan Sirianothaikul

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Oral Health Sciences

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I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

Pornsawan Sirianothaikul

....Signature

(Miss Pornsawan Sirianothaikul)

Candidate

ชื่อวิทยานิพนธ์	ผลของการสั่นด้วยคลื่นโซนิคต่อกำลังแรงยึดแบบกดออกของเดือยฟันเสริมเส้นใยกับผนังคลองรากฟัน
ผู้เขียน	นางสาวพรสวรรค์ ศิริอโนทัยกุล
สาขาวิชา	วิทยาศาสตร์สุขภาพช่องปาก
ปีการศึกษา	2565

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาผลของการสั่นด้วยคลื่นโซนิคต่อกำลังแรงยึดแบบกดออกของเดือยฟันเสริมเส้นใยกับผนังคลองรากฟันเมื่อยึดด้วยเรซินซีเมนต์ชนิดเซลฟ์แอดฮีซีฟและเรซินคอมโพสิตสำหรับสร้างแกนฟัน เตรียมฟันกรามน้อยล่างที่มีคลองรากเดียว รักษาคลองรากฟันจากนั้นแบ่งกลุ่มโดยการสุ่มออกเป็น 4 กลุ่ม ตามการใช้วัสดุยึดติดและเทคนิคการยึดเดือยฟันเสริมเส้นใยที่ต่างกัน ได้แก่ กลุ่มที่ใช้รีไลเอ็กซ์ยูนิเซ็มยึดด้วยวิธีการธรรมดา กลุ่มที่ใช้รีไลเอ็กซ์ยูนิเซ็มยึดด้วยการสั่นด้วยคลื่นโซนิค กลุ่มที่ใช้มัลติคอร์โฟลว์ยึดด้วยวิธีการธรรมดา และกลุ่มใช้มัลติคอร์โฟลว์ยึดด้วยการสั่นด้วยคลื่นโซนิค หลังจากยึดเดือยฟันเสริมเส้นใยแล้ว เก็บตัวอย่างไว้ 24 ชั่วโมง จากนั้นนำตัวอย่างแต่ละชิ้นมาตัดเป็น 6 แผ่น (ส่วนบน 2 แผ่น ส่วนกลาง 2 แผ่น และส่วนปลาย 2 แผ่น) นำไปทดสอบกำลังแรงยึดแบบกดออกโดยใช้เครื่องทดสอบยูนิเวอร์แซล วิเคราะห์รูปแบบการล้มเหลวด้วยกล้องจุลทรรศน์แบบสเตอริโอ และวิเคราะห์พื้นผิวบริเวณที่ยึดติดจากชิ้นตัวอย่างที่เป็นตัวแทนของแต่ละกลุ่มด้วยกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด ผลการทดลองพบว่าการสั่นด้วยคลื่นโซนิคให้ค่าแรงยึดแบบกดออกของเดือยฟันเสริมเส้นใยกับผนังคลองรากฟันไม่แตกต่างอย่างมีนัยสำคัญกับวิธีธรรมดา แต่อย่างไรก็ตามการสั่นด้วยคลื่นโซนิคมีมีแนวโน้มที่ให้ผลดีกว่าในกลุ่มที่ใช้เรซินคอมโพสิตสำหรับสร้างแกนฟันในการยึดเดือยฟันเสริมเส้นใย เมื่อพิจารณาชนิดวัสดุที่ใช้ยึดติดพบว่ากลุ่มที่ยึดด้วยเรซินซีเมนต์ให้ค่ากำลังแรงยึดสูงกว่าอย่างมีนัยสำคัญ และเมื่อพิจารณาระดับของคลองรากฟันพบว่า ระดับของคลองรากฟันส่งผลต่อกำลังแรงยึดในเฉพาะกลุ่มที่ใช้เรซินซีเมนต์ ในส่วนของความล้มเหลวที่พบในทุกกลุ่มจะพบเป็นความล้มเหลวบริเวณรอยต่อระหว่างชั้นวัสดุมากที่สุด ดังนั้นสามารถสรุปผลการทดลองได้ว่า การสั่นด้วยคลื่นโซนิคไม่ส่งผลต่อการยึดติดของเดือยไฟเสริมเส้นใยอย่างมีนัยสำคัญ และการยึดเดือยฟันเสริมเส้นใยด้วยเรซินซีเมนต์ให้ค่าแรงยึดติดที่สูงกว่าการยึดด้วยเรซินคอมโพสิตสำหรับสร้างแกนฟัน

คำสำคัญ : กำลังแรงยึด, เดือยฟันเสริมเส้นใย, การสั่นด้วยคลื่นโซนิค

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Major Program Oral Health Sciences
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ABSTRACT

The purpose of this study was to evaluate the effect of a sonic application on the push-out bond strength of fiber posts to root canal dentin when luting with self-adhesive resin cement and resin composite core material. Twenty single root canal mandibular premolars were endodontically treated and randomly divided into four groups according to the cementation materials and post insertion techniques; RelyX Unicem/conventional technique, RelyX Unicem/sonic application, Multicore flow/conventional technique, Multicore flow/sonic application. After post cementation and 24 hour-storage, the roots were sectioned into six slides (two-coronal, two-middle, two-apical region) and the push-out test was performed by a universal testing machine. The failure mode was evaluated by stereoscopic microscope and the bonded interface of representative specimens were observed using scanning electron microscope. The results revealed that sonic application did not affect the push-out bond strength of the fiber post but tended to yield better results in the resin composite core material group. The resin cement showed a significant higher bond strength, irrespective of the mode of application. Regional factor affected the bond strength only in resin cement group. There was a predominance of adhesive failure in all groups. Conclusion, the sonic application did not significantly improve the adhesion to the fiber post. Luting fiber post with resin cement provided the better result compared to resin composite core material.

Keywords **:** bond strength, fiber post, sonic application

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Pornsawan Sirianothaikul

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LIST OF ABBREVIATIONS AND SYMBOLS

CEJ	= Cemento-enamel junction
mm	= Millimeter
mm^2	= Square Millimeter
N	= Newton
MPa	= Megapascal
Hz	= Hertz
SD	= Standard deviation
LED	= Light emitting diode
HF	= Hydrofluoric acid
R	= cervical failure area radius
r	= apical failure area radius
h	= slice thickness
PBS	= Push-out bond strength
SEM	= Scanning electron microscope
RCC	= RelyX Unicem/conventional technique/coronal region
RSC	= RelyX Unicem/sonic application/coronal region
RCM	= RelyX Unicem/conventional technique/middle region
RSM	= RelyX Unicem/sonic application/middle region
RCA	= RelyX Unicem/conventional technique/apical region
RSA	= RelyX Unicem/sonic application/apical region
MCC	= Multicore flow/conventional technique/coronal region
MSC	= Multicore flow/sonic application/coronal region
MCM	= Multicore flow/conventional technique/middle region
MSM	= Multicore flow/sonic application/middle
MCA	= Multicore flow/conventional technique/apical region
MSA	= Multicore flow/sonic application/apical region

CHAPTER 1

INTRODUCTION

BACKGROUND AND RATIONALE

Endodontically treated teeth with excessive loss of tooth structure are traditionally restored with post and core systems. Currently, fiber posts have become popular in the restorative treatment of endodontically treated teeth as they offer many advantageous properties, such as favorable esthetic outcomes, easy operation, and a modulus of elasticity that is similar to dentin, providing favorable and repairable fractures.[1-3]

Although fiber posts are becoming widely used in clinical practice, failure can occur. The most common modes of failure associated with fiber posts are post debonding, which occurs between post-cement, cement-dentin interface, or cohesive failure of cement.[4]

Several procedures for improving the bond strength have been recommended and described in various literature. Treating the surface of fiber posts with mechanical or chemical processes and techniques of cement application seemed to significantly affect the retention of fiber posts to root canal dentin.[5-10] For cement application methods, it was reported that significantly higher bond strength was obtained when cement was applied only into the root canal compared with the application of cement both into the root canal and around the fiber posts.[5] In order to enhance the fiber posts retention, the lentulo spiral instrument has been reported as a tool for cement application that improves bond strength values of post-cement-dentin complex.[11-12] However, using the lentulo spiral instrument should be aware of premature polymerization of dual-cure resin cement prior to fiber post insertion due to the increased energy input.[13-14] Therefore, some manufacturers do not recommend this method.

Sonic and ultrasonic applications have been applied for use in dentistry, for example, removing smear layers, activating the root canal sealer, and increasing the effectiveness of root canal cleaning for the root canal treatment.(15-17) In restorative dentistry, the use of sonic and ultrasonic application has been introduced for seating inlays or veneer restoration to alter the viscosity of resin-based luting cement, which is a thixotropic material changing from a solid to a liquid state, enhance the surface wettability or surface energy, and increase the flow capacity of the luting material, consequently decreasing the film thickness.(18-22) The sonic application technique is utilized to apply the adhesives inside the root canal prior to fiber post insertion to decrease viscosity. The low viscosity provides superior wettability and promotes deeper penetration of the adhesives, resulting in improved bond strength between fiber posts and intraradicular dentin.(23-25) In addition, one study revealed that sonic vibration of the post during accommodation showed homogeneous resin cement films.(26) Another study found that using a sonic device in the application of self-adhesive resin cement promoted an increased bond strength value.(27)

The viscosity of material could be changed by energy input like the sonic application, consequently promoting a resin cement flow during luting. The vibration process may increase the bond strength of the post to root canal dentin. Moreover, the air bubbles that occur during cementation may be reduced with this method, and the properties of resin cement may be improved. The study regarding the use of sonic application for the fiber post cementation process is still very limited. This technique would be helpful in clinical post cementation procedures.

REVIEW OF THE LITERATURES

It is known that endodontically treated teeth usually have extensive loss of tooth structure due to caries, trauma, or endodontic access preparation. Thus, fractures are more common in endodontically treated teeth than in vital teeth. Coronal restoration is required in order to restore coronal morphology and function and prevent coronal leakage. When there is insufficient tooth structure remaining to support the definitive coronal restoration, a post is commonly used to restore them.

The main function of the post is to retain the core to support the coronal restoration.[28-30]

Fiber-reinforced posts or fiber posts are routinely adapted to restore the endodontically treated tooth due to their clinical advantages for achieving an esthetic, ease of use, time and cost effectiveness, and favorable modulus of elasticity, which is similar to dentin that root fracture occurs less often than metal posts. Moreover, utilizing fiber posts provides favorable and repairable fractures.[1-3]

Failure of endodontically treated tooth restored with fiber posts

Although good clinical performance of fiber posts has been reported in many studies, failure can still occur. The prospective clinical follow-up studies of fiber posts used in endodontically treated teeth have reported 95-99% success rates. The most common failure was debonding of post, which consist of both cohesive failure and adhesive failure. No occurrences of post, core, or root fractures were found during the study periods.[6,31] Achieving adequate bond strength between fiber posts and root canal dentin remains a clinical challenge. Several factors are associated with the retention of fiber posts, such as residual tooth structure, occlusal scheme, sign of parafunction, presence or absence of ferrule, endodontic treatment, and quality of adhesion.[5,32]

Several procedures for improving the bond strength have been recommended and described in various literature. Post pretreatment with mechanical or chemical processes and techniques of cement application seemed to significantly affect the retention of fiber posts to root canal dentin.[5,33]

For post surface and root canal dentin pretreatment, etching the post surface with hydrofluoric acid followed by a silane coupling agent is often employed to improve the bond strength of fiber posts.[34-36] Prior to luting, etching root canal dentin with 37% phosphoric acid to remove the smearing layer and endodontic remnants could improve bond performance.[37]

Resin cement insertion techniques for improving the retention of fiber posts

The bond strength of fiber posts to root canal dentin is a critical factor for the success rates of restored endodontically treated teeth. The resin-dentin and the resin-post bonding interfaces are influenced by several factors. The study by Silva et al. evaluated the effect of resin cement porosity on the bond strength. The presence of porosity like voids and bubbles within the cement layer caused by air entrapment significantly affected the push-out bond strength in all root depths and it was more evident in the apical region. The porosity may affect the retention of fiber posts because of its decreasing the contact bonded area and creating sites for crack initiation and propagation.(38)

In order to increase the bond strength of fiber posts by reducing the number of imperfections and increasing the homogeneity of the cement, different resin cement insertion techniques into root canal were evaluated.(5,12,39-42) Many researchers found that when cement was applied into the root canal alone, a significantly higher bond strength could be obtained compared with the application of cement both into the root canal and around the fiber posts.(5) Some studies recommended using the instruments as a tool for cement insertion for improving bond strength values of post-cement-dentin complexes, such as centrix syringe, elongation tip, explorer, microbrush, k-file, and lenturo spiral.(38-39,41,43) The lentulo spiral instrument has been reported in several studies as a tool that improves the bond strength value of post-cement-dentin complex owing to permitting a favorable continuous cement layer throughout the post space and reducing voids and bubbles within the luting agent.(11-12,42) However, using the lentulo spiral with dual-curing resin cement should be cautious since the increased input energy may cause premature polymerization of cement prior to adequate fiber post seating. Therefore, the use of the lentulo spiral for cement application is not recommended by the manufacturers.(13-14)

Sonic and ultrasonic application used for improving the retention of restoration

Resin-based luting cement is a thixotropic material. When a constant force is applied to a thixotropic fluid, the viscosity decreases. However, if a thixotropic fluid with decreased viscosity is left alone for a certain amount of time, the fluid will return to its original viscosity. The use of vibration has been reported to transfer vibrational energy to alter the viscosity of thixotropic materials.(18) Sonic and ultrasonic applications have been introduced to seat some restorations, such as inlays and veneers, to alter the viscosity of resin cement.

Walmsley and Philip investigated the use of an ultrasonic scaler for the seating of composite inlays. They found that the vibration of the ultrasonic scaler changed the viscosity of the luting agent and allowed the restorations to seat easily. This technique enables the clinician to use the high viscosity resin cement, enhance the surface wettability, or surface energy, and increase the flow capacity of the luting material, consequently decreasing the film thickness.(19) The results of this study were in accordance with the findings of their previous study, which concluded that the use of both sonic and ultrasonic vibration could generate a thin layer of luting agent.(18) Schmidlin et al. found that ultrasonic-aid inlay insertion significantly reduced the mean load applied to seat inlays and resulted in faster seating.(21) SEM analysis in the study of Cantoro et al. revealed a homogeneous structure and reduced porosities for self-adhesive resin cements when an ultrasonic tip provided with a rubber cap was used as an inlay luting technique.(20)

In addition, the sonic application technique is utilized to apply adhesives inside the root canal prior to fiber post insertion to decrease the viscosity. The low viscosity provides superior wettability and promotes deeper penetration of the adhesives, resulting in improved bond strength between fiber posts and intraradicular dentin. Kirsch et al. evaluated the effect of sonic application of self-etch adhesives on the bond strength of fiber posts in root canals by using a modified sonic toothbrush with a frequency of 190 Hz. A microbrush was connected to the head of a toothbrush to apply adhesives to the root canal wall. They found that sonic application of self-etch adhesives did not improve the bond strength of fiber posts to the root canal.(25) These results are in agreement with the study by Zarpellon et al. using a microbrush (Cavibrush long, FGM) attached to the tip of a sonic device with a frequency of 170 Hz (Smart Sonic Device, FGM) to apply etch-and-rinse adhesives. They found that sonic application did not improve the bond strength of the fiber post to the root canal or influence nanoleakage within the hybrid layer, but the sonic application resulted in significantly improved bond strength only in the coronal third.(24) On the contrary, the results of the study by Cuadros-Sanchez et al. showed that using a sonic device (Smart Sonic Device, FGM) with a microbrush with a frequency of 170 Hz applied to etch-and-rinse adhesives could improve the push-out bond strength of the fiber post to the root canal, possibly because of a better infiltration and higher degree of conversion of adhesives, which were indirectly seen by significantly reduced nanoleakage in the hybrid layer.(23)

Some studies revealed that sonic application of the adhesive systems could improve the bond strength of fiber posts to root canal dentin. A few studies try to use sonic devices during the post accommodation to improve the bond strength. One study revealed that when a sonic device (Smart Sonic Device, FGM) with a special tip with a frequency of 241 Hz was applied for the post accommodation during the luting procedure, the results demonstrated that dual-cured resin cement had more homogeneous films and fewer bubbles, even though the use of a sonic device did not affect the bond strength.(26) However, another study found that using sonic insertion (Smart Sonic Device, FGM) with a frequency of 170 Hz of self-adhesive resin cements promoted an increased push-out bond strength value.(27) The use of sonic vibrations during the post accommodation process may enhance the resin cement flow and wettability of dentin walls by creating pressure waves that promote the penetration of the resin cement into the intraradicular dentin.(26-27)

Vibration technique for fiber post luting procedure.

For fiber post cementation, resin-based luting agents consisting of resin cement and resin composite core material were used. The resin composite core material has a modulus of elasticity close to that of dentin and fiber post. It has become popular since it provides convenience for clinicians in using a single material for both cementation of fiber post and core-build up, thereby reducing the number of interfaces among the materials to establish a monoblock.[44] The study revealed a higher bond strength when using resin composite core material over resin cement.[45] The low viscosity luting material would be easier to inject into the root canal and provide good wettability that could be in intimate contacted with root canal dentin and fiber post. However, the resin composite core material has a higher viscosity than that of resin cement, which may produce porosity and could affect the push-out bond strength.

Using vibration technique for improving bond strength between fiber post and luting materials, vibration characteristic must match with luting materials to facilitate them. Ultrasonic vibration has high frequency, short wavelength, it is not appropriate to use to vibrate high molecular or high consistency materials like resin composite core material. While sonic vibration has a low frequency and a wider wavelength, it could match with luting material, which has high consistency.

In summary, there are many techniques that are probably appropriate to improve the bond strength of the fiber post to the root canal dentin. However, the previous study about the use of sonic application technique for post insertion are inadequate.

OBJECTIVES

1. To evaluate the effect of sonic application on push-out bond strength of different regions of fiber posts to root canal dentin when luting with self-adhesive resin cement and resin composite core material.
2. To evaluate the failure mode of endodontically treated teeth restored with fiber posts under conventional technique and sonic application.

NULL HYPOTHESES

1. There is no difference in the push-out bond strength of fiber posts to root canal dentin between sonic application and conventional technique.
2. There is no difference in the push-out bond strength of fiber posts to root canal dentin between using resin cement and resin composite core material as the luting material.
3. There is no difference in the push-out bond strength of different regions of fiber posts to root canal dentin between luting with self-adhesive resin cement and resin composite core material.

CHAPTER 2

RESEARCH METHODOLOGY

RESEARCH DESIGN

Experimental research (Laboratory)

MATERIALS

The materials and composition used in this study are shown in Fig. 1 and Table 1

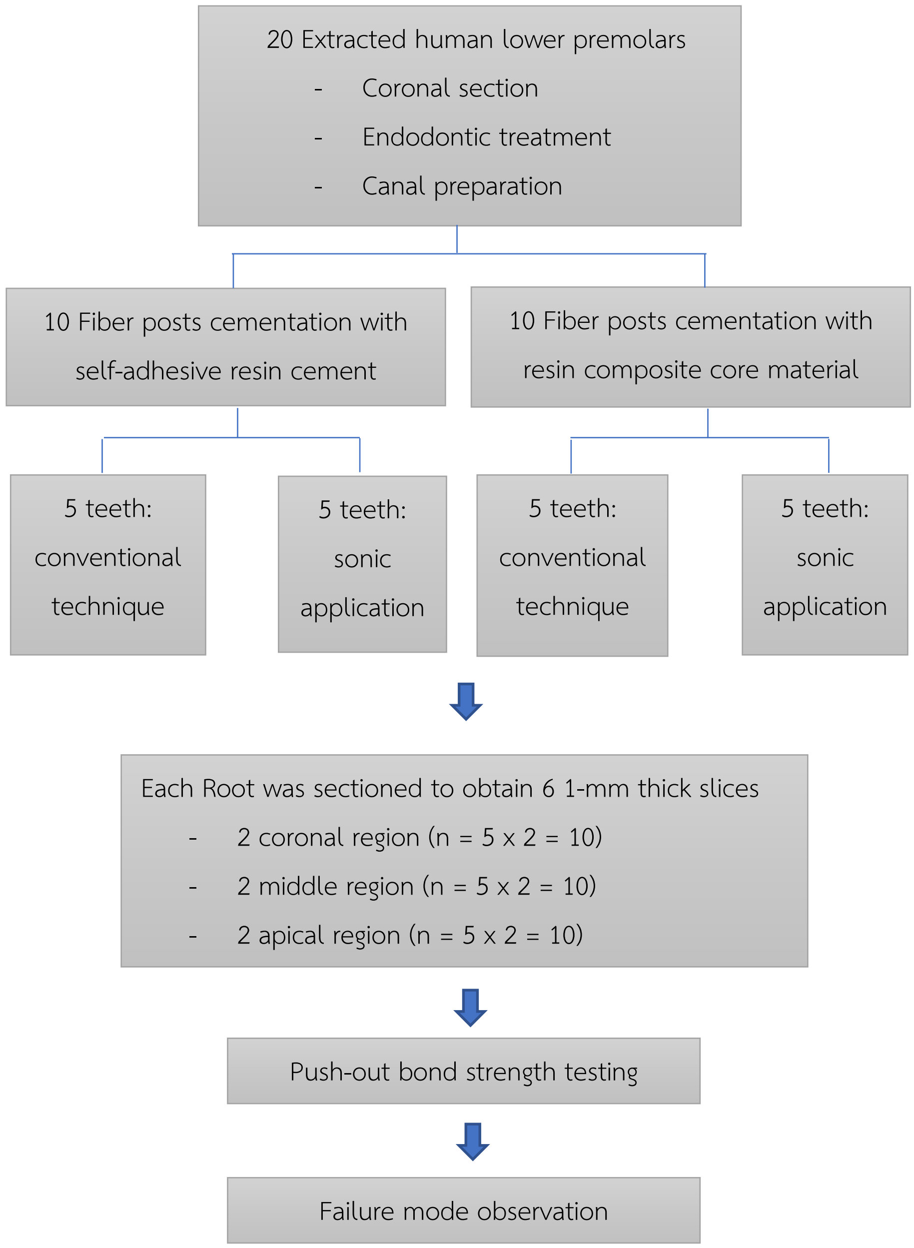
Figure 1 Materials used in the study

Table 1 Materials, composition, and manufacturer of product used in the study.

Product	Composition	Manufacturer
D.T. Light-post illusion	60% quartz fiber 40% epoxy resin	RTD, St-Egreve, France
N-etch	37% phosphoric acid	Ivoclar Vivadent, Schaan, Lichtenstein
IPS Ceramic Etching Gel	4.5% hydrofluoric acid gel	Ivoclar Vivadent, Schaan, Lichtenstein
Monobond S	ethanol, trimethoxysilane [3-(methacryloyloxy)propyl]	Ivoclar Vivadent, Schaan, Liechtenstein
Excite DSC	37% H_3PO_4, HEMA, phosphoric acid acrylate, dimethacrylates, silica, ethanol, catalysts, stabilizers, fluoride	Ivoclar Vivadent, Schaan, Liechtenstein
Multicore flow	dimethacrylates, 71% inorganic fillers (barium glass, Ba-Al-fluorosilicate glass, silicon dioxide, and ytterbium trifluoride)	Ivoclar Vivadent, Schaan, Liechtenstein
RelyX Unicem	55%-65% glass powder 15%-25% methacrylated phosphoric acid esters 10%- 20% TEGDMA 1%-5% Silane-treated silica 1%-5% Sodium persulfate	3M ESPE, St Paul, MN, USA

METHODS

Summary methodology is present in the diagram as follows:



Specimen preparation and root canals obturation

Twenty human mandibular premolars with one straight root canal were used in this study. All teeth did not have crack lines and root caries. All root apexes were fully developed. The root length was in the range of 14.0 – 16.0 mm, measured from root apex to cementoenamel junction. The teeth were collected and kept in a 0.2% thymol solution at room temperature until they were used. Calculus and periodontal tissue remnants were removed with an ultrasonic scaler.

The crowns were sectioned above the cementoenamel junction by 2 mm perpendicular to the long axis of the teeth using tapered diamond bur. Then, the length of the root canal was determined by no. 10 K-file until it was presented at the point of apical foramen. The working length was obtained by subtracting 1 mm from the root canal length. The endodontic treatment started with no. 15 K-file. ProTaper Gold rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) (Fig. 2) were sequentially used, S1, S2, F1, F2, and F3, to the full working length. After each instrument change, the canals were irrigated with 2.5% sodium hypochlorite and finally rinsed with 17% EDTA, followed by 2.5% sodium hypochlorite and dried with absorbent paper points. All preparation canals were obturated using gutta-percha and Grossman's sealer with the warm vertical condensation technique.

Specimens were stored at 100% humidity at room temperature for one week.

Figure 2 ProTaper Gold rotary instruments (S1, S2, F1, F2, and F3)

Post space preparation

All the post spaces were then prepared to a depth of 11 mm using D.T. Finish drills No.3 (Fig. 3) supplied by the manufacturer of the used fiber post system (D.T. Light-post illusion; RTD, St-Egreve, France). The post spaces were irrigated with normal saline solution and dried with absorbent paper points. After canal preparation, all roots were embedded in an autopolymerizing acrylic resin as shown in Fig. 4.

Figure 3 D.T. Finish drills No.3 and D.T. Light-post illusion No.3

Figure 4 Embedding root in an autopolymerizing acrylic resin

Fiber post preparation

Twenty quartz fiber posts size no.3 (D.T. Light-post illusion; RTD, St-Egreve, France) (Fig. 3) were used in this study. To create the optimal bonding between the fiber posts and self-adhesive resin cement or resin composite core material, post surface treatment with hydrofluoric (HF) acid etching and silane application were implemented.[34-36] All fiber post surfaces were treated with 4.5% HF (IPS Ceramic Etching Gel; Ivoclar Vivadent, Schaan, Lichtenstein) for 60 seconds followed by rinsing and air drying. Then the single component silane coupling agent

(Monobond S; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the entire post surface for 60 seconds and dispersed with a strong stream of air.

Post cementation

Twenty specimens were randomly divided in to 4 groups according to the post insertion techniques and cementation materials. Two post insertion techniques were used in this study; a conventional technique without post vibration and a post vibration technique using sonic application.

Four experimental groups

Group 1: Fiber posts luted with self-adhesive resin cement
using a conventional technique (RC)

Group 2: Fiber posts luted with self-adhesive resin cement
using a sonic application technique (RS)

Group 3: Fiber posts luted with resin composite core material
using a conventional technique (MC)

Group 4: Fiber posts luted with resin composite core material,
using a sonic application technique (MS)

The root canal dentin was treated with 37% phosphoric acid (N-etch; Ivoclar Vivadent, Schaan, Lichtenstein) to remove smear layer and endodontic remnant.[37] The etchant gel was applied to the walls of the prepared root canal with a syringe and agitated with a microbrush for 15 seconds, followed by rinsing and dying with cotton pellets and absorbent paper points.

All materials used for bonding were left outside the refrigerator at least 30 minutes prior to bonding procedures.

Group 1: Fiber posts luted with self-adhesive resin cement, using a conventional technique (RC)

Self-adhesive resin cement (RelyX Unicem; 3M ESPE, St Paul, MN, USA) was injected into the root canal until it reached the access opening, and the surface-treated fiber post was then inserted centrally into the root canal. Light-curing was performed by placing the tip of the LED light curing unit (Elipar Trilight; 3M ESPE, St. Paul, MN, USA) directly closed to the post for 40 seconds. The luting procedure was performed within 90 seconds, which was indicated to be the working time of the material in the manufacture instruction.

Group 2: Fiber posts luted with self-adhesive resin, using a sonic application technique (RS)

In this group, after self-adhesive resin cement was injected and the fiber post was placed into the root canal as in group 1, a sonic device (Xiaomi SO WHITE EX3 Sonic Electric Toothbrush; Xiaomi, Beijing, China) (Fig. 5) was applied on top of the post for a period of 10 seconds with a frequency of 31,000 times/min. Then light-curing was performed to the post for 40 seconds. The luting procedure was finished within 90 seconds.

Figure 5 Sonic device (Xiaomi PINJING EX3: Sonic Electric Toothbrush)

Group 3: Fiber posts luted with resin composite core material, using conventional technique (CC)

Dual-cure adhesive (Excite DSC; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the entire etched surface and excessive adhesive was removed with absorbent paper points. Light-curing was performed from the coronal direction for 20 seconds. Then, resin composite core material (Multicore flow; Ivoclar Vivadent, Schaan, Liechtenstein) was injected into the root canal until it reached the access opening, and the surface-treated fiber post was then inserted centrally into the root canal. Light-curing was performed to the post for 40 seconds. The luting procedure was finished within 2 minutes.

<u>Group 4: Fiber posts luted with resin composite core material, using a sonic application technique (CS)</u>

In this group, the root canal dentin was prepared using the same protocol as in group 3. After resin composite core material was injected and the fiber post was placed into the root canal, a sonic device was applied on top of the post for a period of 10 s with a frequency of 31,000 times/min. Then light-curing was performed to the post for 40 seconds. The luting procedure was performed within 2 minutes.

Specimens from all groups were subsequently stored at 100% humidity at room temperature for 24 hours.

Push-out bond strength test

After 24-hour storage, each specimen was sectioned horizontally with a low-speed cutting machine (Isomet 1000; Buehler Ltd., Illinois, USA) (Fig. 6). Two mm of the coronal third of the root was initially cut out. Then the roots were serially sectioned to obtain six 1±0.1 mm thick slices. The thickness of each root section was verified by digital caliper (Mitutoyo, Takatsu-ku, Japan) (Fig. 7). The first 2 slices were termed as coronal region, the next 2 slices were termed as middle region, and the last 2 slices were termed as apical region as shown in Fig. 8. A push-out test was done with a universal testing machine (Lloyd Instruments, LRX-Plus, AMETEK Lloyd Instrument Ltd., Hamphshire, UK) with a 0.4 mm diameter metallic loading plunger at a crosshead speed of 0.5 mm/min. The plunger was positioned to contact only the post. The load was applied from an apical to coronal direction until post dislodgement as shown in Fig. 9, 10. The maximum load was recorded in Newton (N) and the push-out bond strength in megapascals (MPa) was calculated by the load being divided by the bonded surface area (mm^2) which was calculated as follows [46] :

$$A = \pi(R+r)\sqrt{(R-r)^2 + h^2}$$

R is cervical failure area radius (mm)
r is apical failure area radius (mm)
h is slice thickness (mm)

→ Radius was measured with stereoscopic microscope (SMZ1500, Nikon Instech Co.,Ltd., Tokyo, Japan) (Fig. 11)

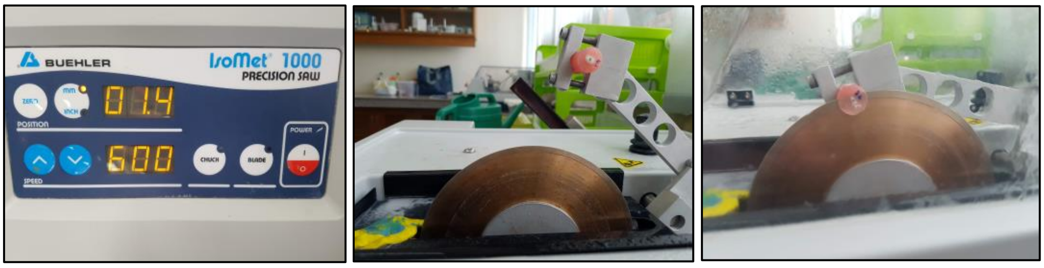


Figure 6 Low speed cutting machine for specimens section

Figure 7 Verification of the root section thickness by digital caliper

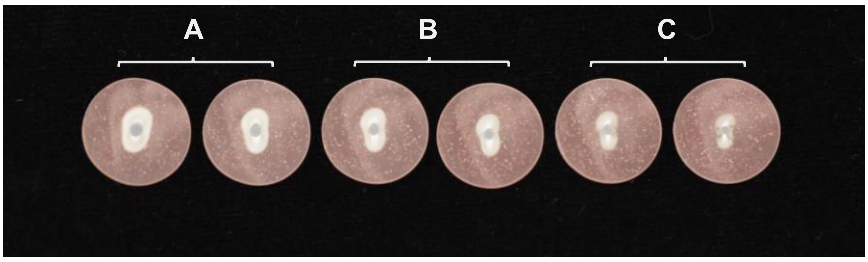


Figure 8 Slices of specimen (A) coronal region (B) middle region (C) apical region

Figure 9 Universal testing machine's setting for push-out testing

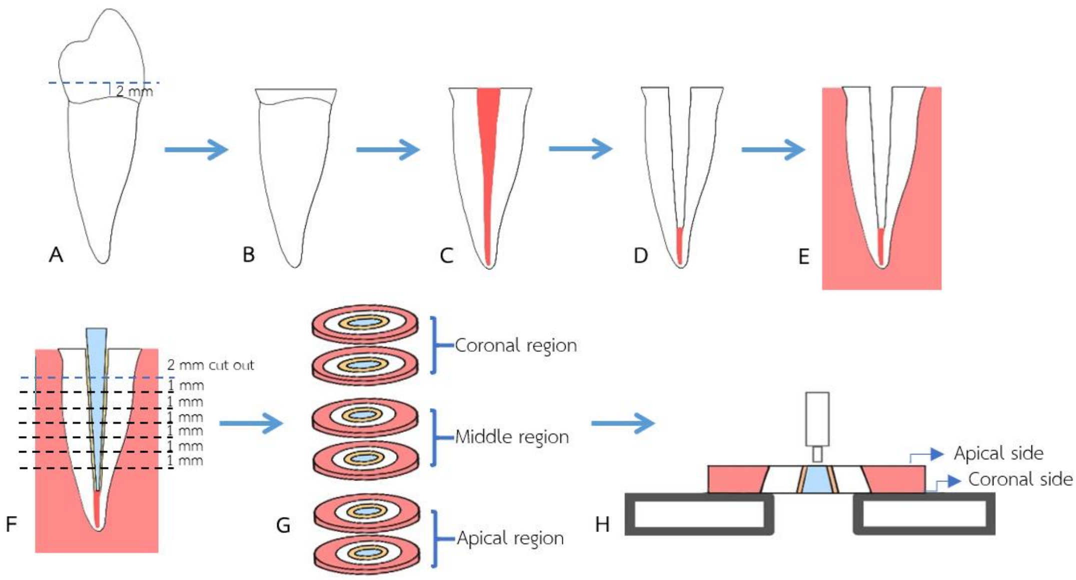


Figure 10 Schematic diagram of specimen preparation and testing apparatus for push-out test. A: Lower premolar. B: Decoronation above CEJ 2 mm. C: Endodontic treatment. D: Post space preparation. E: Specimen embedded in acrylic resin. F: Post cementation. G: Six 1-mm thick slices. H: Push-out test apparatus.

Determination of the failure mode

After push-out testing, all specimens were examined under Stereoscopic microscope (fig.11). The failure mode at apical side of specimens was classified into four groups:

1. Adhesive failure between the post and cement
2. Adhesive failure between the root canal and cement
3. Cohesive failure of cement
4. Mixed failure

The failures were categorized with a decision of more than 70% of that failure fall into that group.

Figure 11 Stereoscopic microscope using in radius measuring and failure determining

SEM observation of the post-resin bonding interface

Four teeth were prepared with the same protocol as each push-out bond strength experimental group to represent specimens for scanning electron microscope observation. Each specimen was sectioned into six slices. One slice from each region of the root, consisting of coronal, middle, and apical regions, were observed using a scanning electron microscope (QUANTA 400, Thermo Fisher Scientific, Czech Republic) (Fig. 12). The bonded interfaces were observed, and SEM micrographs were taken.

Figure 12 Scanning electron microscope (QUANTA 400)

Statistical analyses

The push-out bond strength (PBS) values of two coronal specimens were considered to represent the coronal region of the post space, two middle specimens represented the middle region, and two apical specimens represented the apical region. Therefore, the sample size (n) of each experimental group in each region was ten. Since normal data distribution and homogeneity of variance (Levene's test) were not indicated, non-parametric statistics were used to compare the data. A Mann-Whitney test was used to compare the PBS mean rank between conventional and sonic application techniques and between RelyX Unicem and Multicore flow. Furthermore, the Kruskal-Wallis test was used to test the effect of the regions on the PBS data. Dunn's test for pairwise multiple comparisons of the ranked data was performed as a post hoc test. All statistical testing was performed at a 95% level of confidence.

CHAPTER 3

RESULTS

PUSH-OUT BOND STRENGTH TESTING

The means and standard deviations of push-out bond strength (PBS) for each experimental condition are presented in Table 2. For fiber posts bonded with RelyX Unicem, the conventional technique provided similar bond strengths to the sonic application technique at the middle (P=0.55) and apical regions (P=0.94). However, at the coronal region, the conventional technique provided significantly higher bond strength compared with the sonic application (P=.028). When comparing bond strength between root regions, the results revealed that bond strength at apical regions was statistically higher than that at coronal and middle regions for both post-application techniques (P<0.05), and there were no significant differences in bond strength between coronal and middle regions (P>0.05). For the group bonded with Multicore flow, the average PBS with sonic application technique was higher than that of conventional technique for all three regions, however, no significant difference in bond strength was noted between two post application techniques (coronal-P=0.15, middle-P=0.17, apical-P=0.20). There were no significant differences in PBS among the three regions when the posts bonded with Multicore flow for both techniques. Significant values of this study are presented in table 3-5.

Table 2 Means and standard deviations of push-out bond strength for each experimental condition

Experimental conditions		PBS (MPa)	
Luting material	Region	Conventional	Sonic
RelyX Unicem	Coronal	6.29 ± 4.61 †	2.84 ± 1.77 †
	Middle	5.62 ± 3.06	4.70 ± 2.52
	Apical	9.51 ± 3.74	9.38 ± 2.22
Multicore flow	Coronal	1.77 ± 1.37	2.45 ± 1.55
	Middle	1.12 ± 0.86	1.65 ± 1.21
	Apical	1.67 ± 1.20	2.98 ± 2.67

* Indicates significant difference between regions (*P* < 0.05),

† Indicates significant difference between techniques (*P* < 0.05)

Table 3 Significant value of push-out bond strength between techniques

Luting materials	Regions	P- value
RelyX Unicem	Coronal	0.028 *
	Middle	0.545
	Apical	0.940
Multicore flow	Coronal	0.151
	Middle	0.174
	Apical	0.199

* Indicates significant difference between regions (P < 0.05)

Table 4 Significant value of push-out bond strength between luting materials

Techniques	Regions	P- value
Conventional	Coronal	0.005 *
	Middle	0.000 *
	Apical	0.000 *
Sonic	Coronal	0.705
	Middle	0.010 *
	Apical	0.001 *

* Indicates significant difference between luting materials (P < 0.05)

Table 5 Significant value of push-out bond strength between regions

Luting materials	Techniques	P- value	
RelyX Unicem	Conventional	Coronal - Middle	0.879
		Coronal - Apical	0.040 *
		Middle - Apical	0.027 *
	Sonic	Coronal - Middle	0.195
		Coronal - Apical	0.000 *
		Middle - Apical	0.003 *

* Indicates significant difference between regions (P < 0.05)

Fig. 13 presents bar graph comparing PBS between two materials when the same techniques and regions were considered, RelyX Unicem provided significantly higher PBS compared to Multicore flow (P < 0.05), except for using sonic application in the coronal region, where no significant difference between cementation materials was observed.

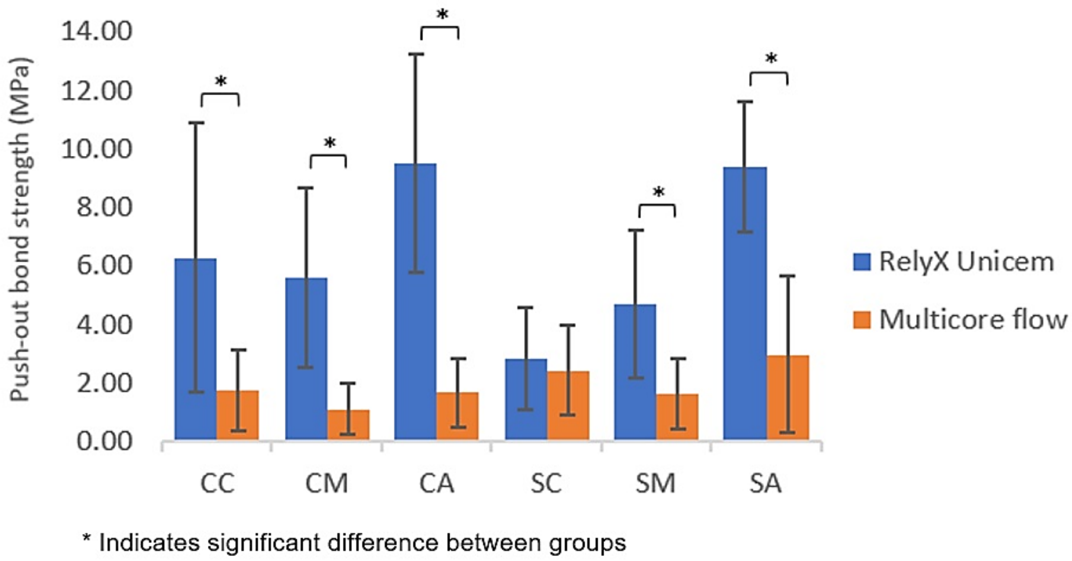


Figure 13 Bar graphs comparing PBS between two luting materials

MODE OF FAILURE

Table 6 shows the number of failure modes of debonded specimens in each experimental group. There were two main modes of failure in the RelyX Unicem group: dentin/cement adhesive failure (Fig. 14B) and mixed failure (Fig. 14C). For the Multicore flow group, the specimens presented predominantly dentin/cement adhesive failure, and approximately one third of the specimens failed as post/cement adhesive failure (Fig. 14A) for both application techniques.

Table 6 Failure mode frequency for each experimental group

Experimental conditions	Failure mode *							
	Conventional				Sonic			
	Ad:P/C	Ad:D/C	Co	Mixed	Ad:P/C	Ad:D/C	Co	Mixed
RelyX Unicem								
Coronal	0	5	0	5	0	7	0	3
Middle	0	7	0	3	0	4	0	6
Apical	0	2	0	8	0	1	0	9
Total	0	14	0	16	0	12	0	18
Multicore flow								
Coronal	5	5	0	0	4	6	0	0
Middle	3	7	0	0	5	5	0	0
Apical	2	8	0	0	4	5	0	1
Total	10	20	0	0	13	16	0	1

* Ad:P/C = Adhesive failure between post and cement, Ad:D/C = Adhesive failure between root canal dentin and cement, Co = Cohesive failure of cement, Mixed = Mixed failure

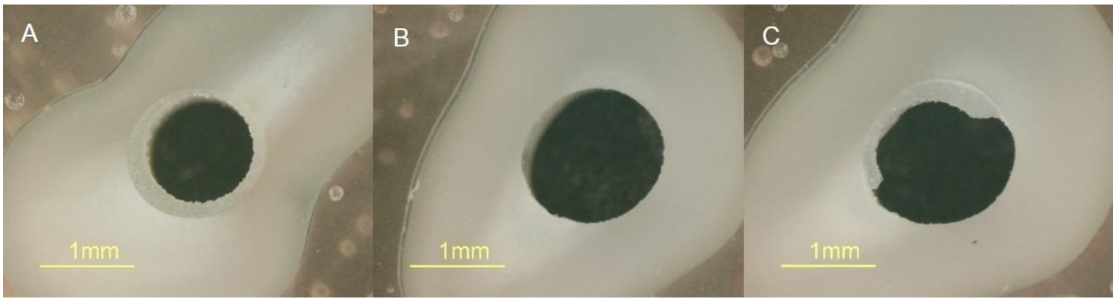


Figure 14 Representative stereo microscopic images of failure modes. A: Adhesive failure between post and cement, B: Adhesive failure between root canal dentin and cement, C: Mixed failure.

Figure 15-20 presents SEM photographs of the fiber post/cement and the cement/dentin interfaces. The fiber post/cement interface demonstrates better intimate adaptation than the cement/dentin interface. With sonic application, smaller gaps seem to be noticed at the dentin and post interface.

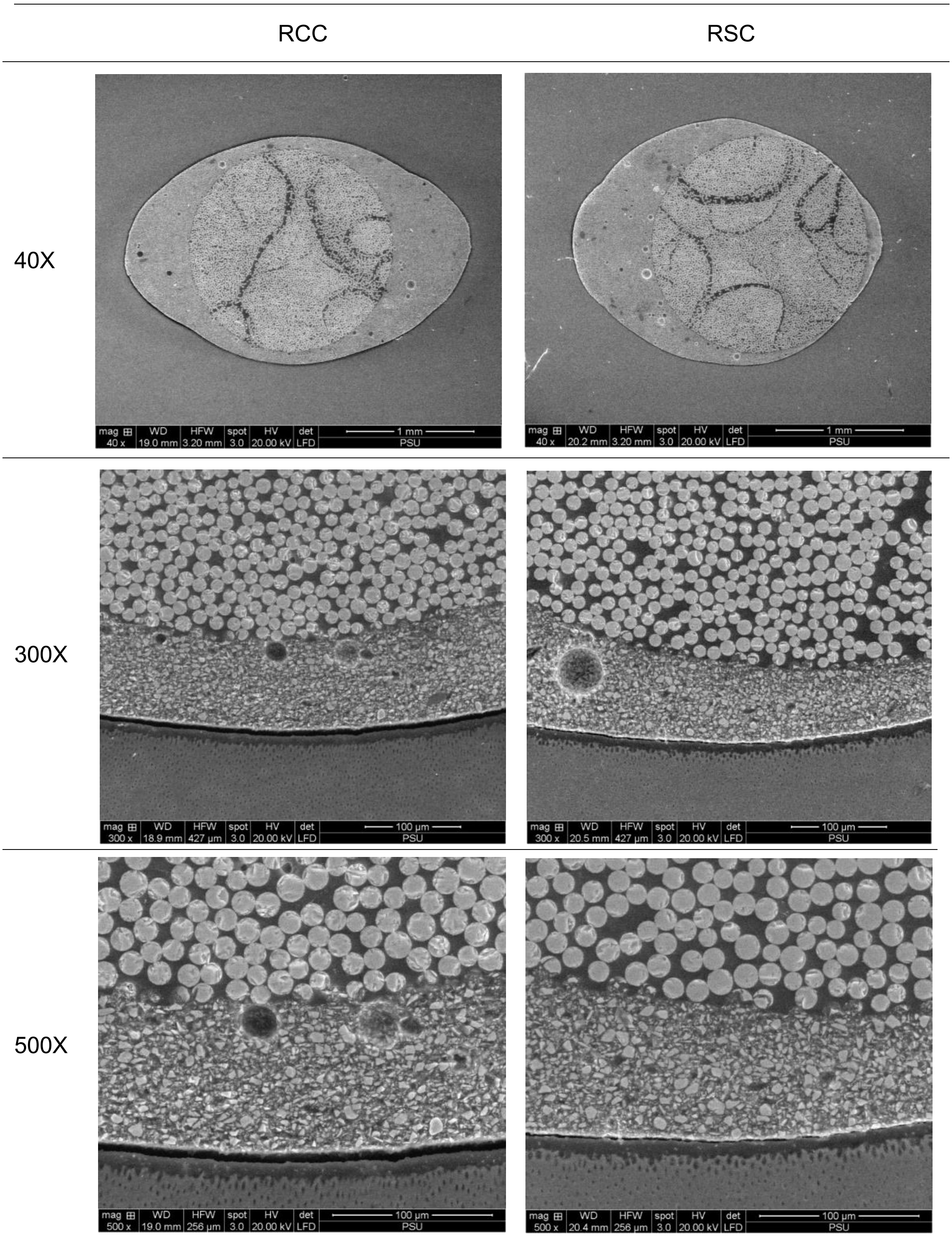


Figure 15 Scanning electron micrographs of representative bonded interfaces of specimens in RelyX Unicem/conventional technique/coronal region (RCC) and RelyX Unicem/sonic application/coronal region (RSC) group

	RCM	RSM
40X		
300X		
500X		

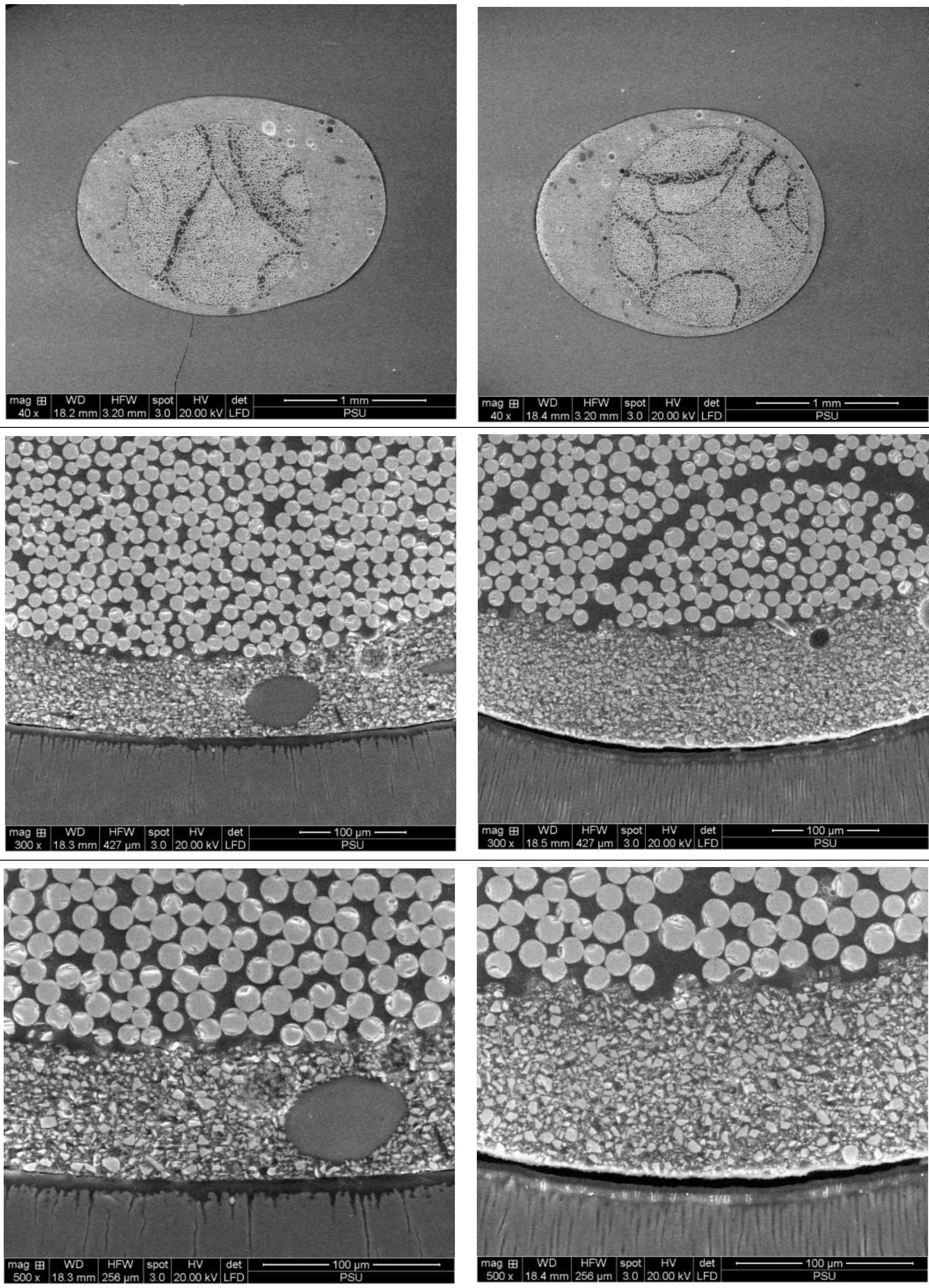


Figure 16 Scanning electron micrographs of representative bonded interfaces of specimens in RelyX Unicem/conventional technique/middle region (RCM) and RelyX Unicem/sonic application/middle region (RSM) group

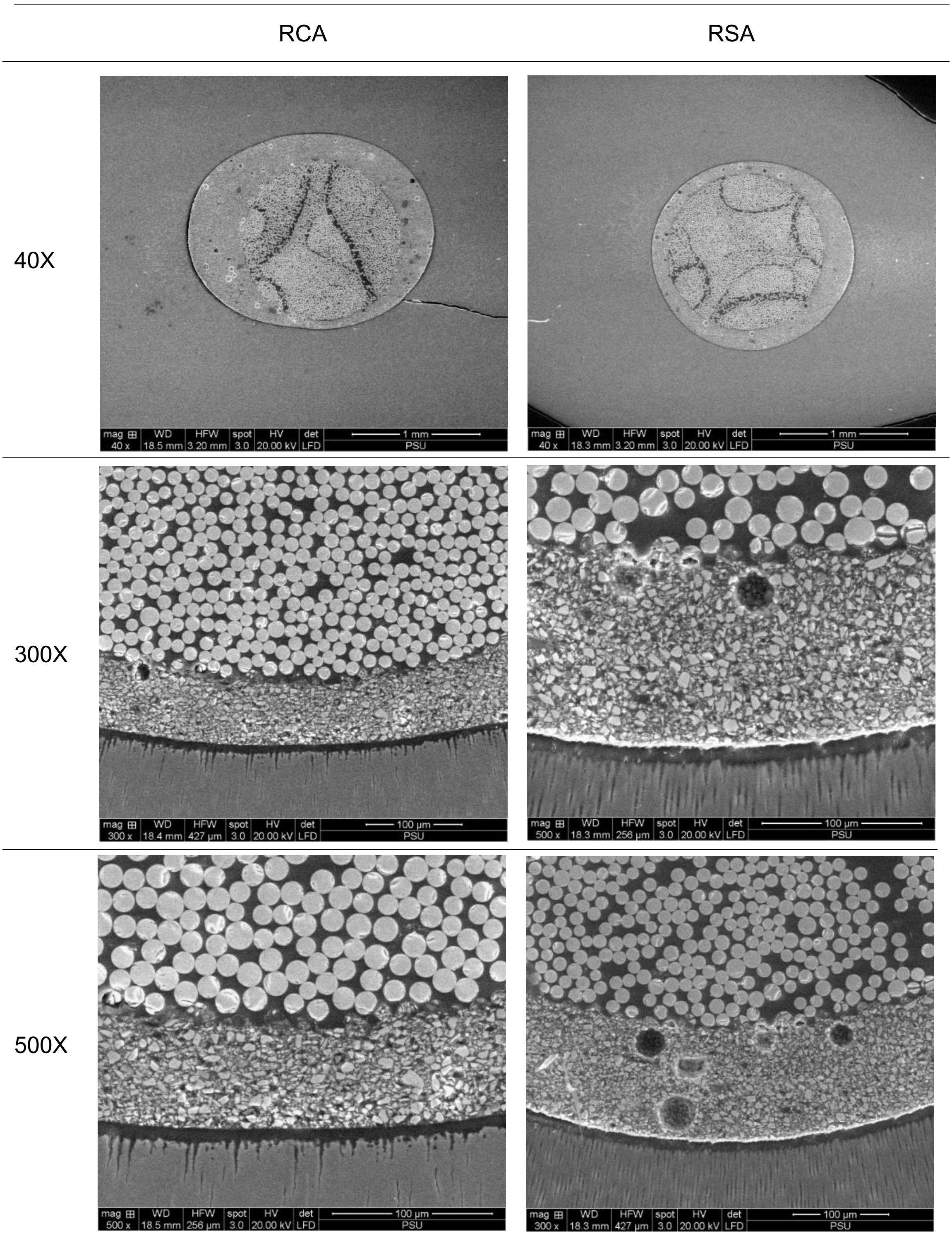


Figure 17 Scanning electron micrographs of representative bonded interfaces of specimens in RelyX Unicem/conventional technique/apical region (RCA) and RelyX Unicem/sonic application/apical region (RSA) group

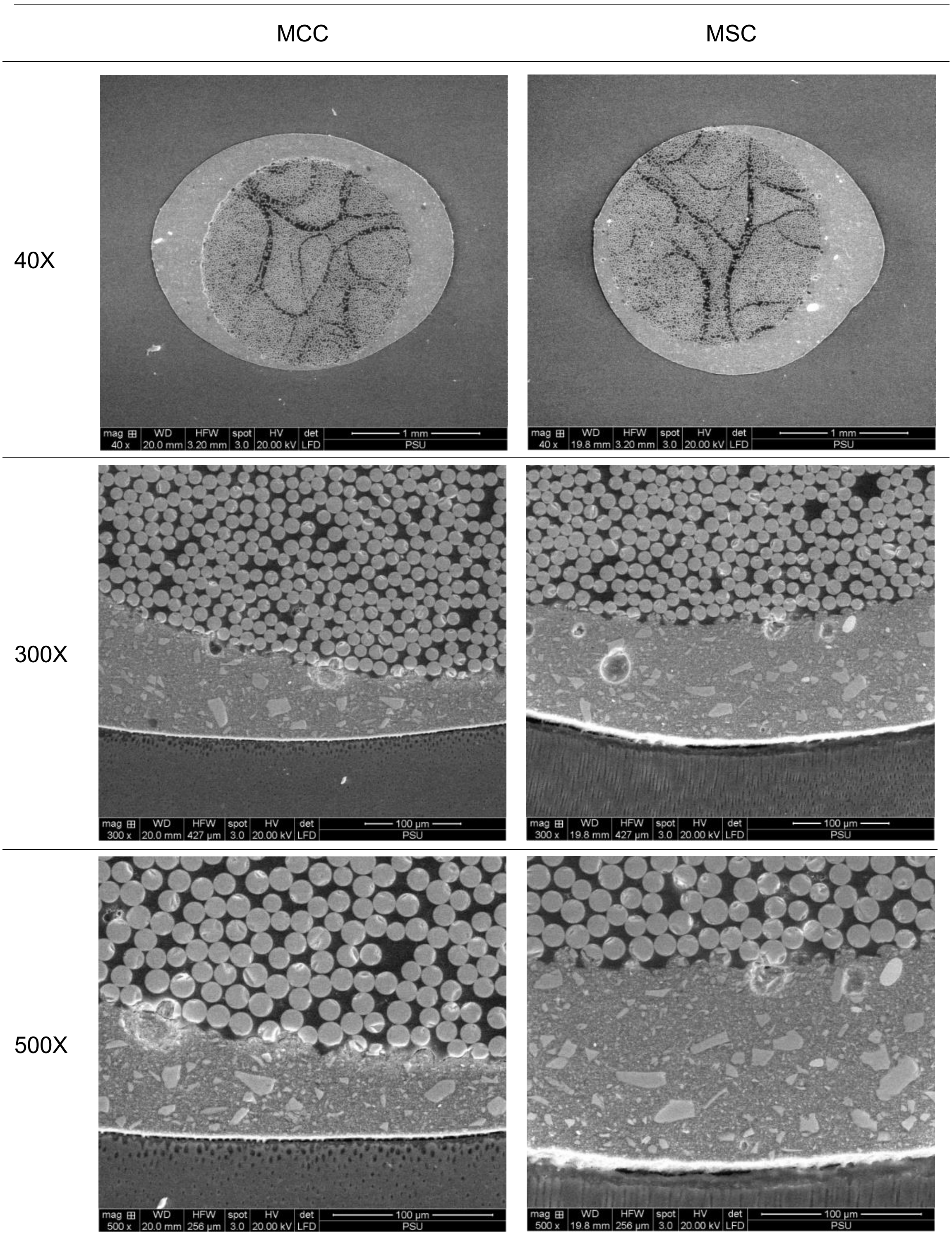


Figure 18 Scanning electron micrographs of representative bonded interfaces of specimens in Multicore flow/conventional technique/coronal region (MCC) and Multicore flow/sonic application/coronal region (MSC) group

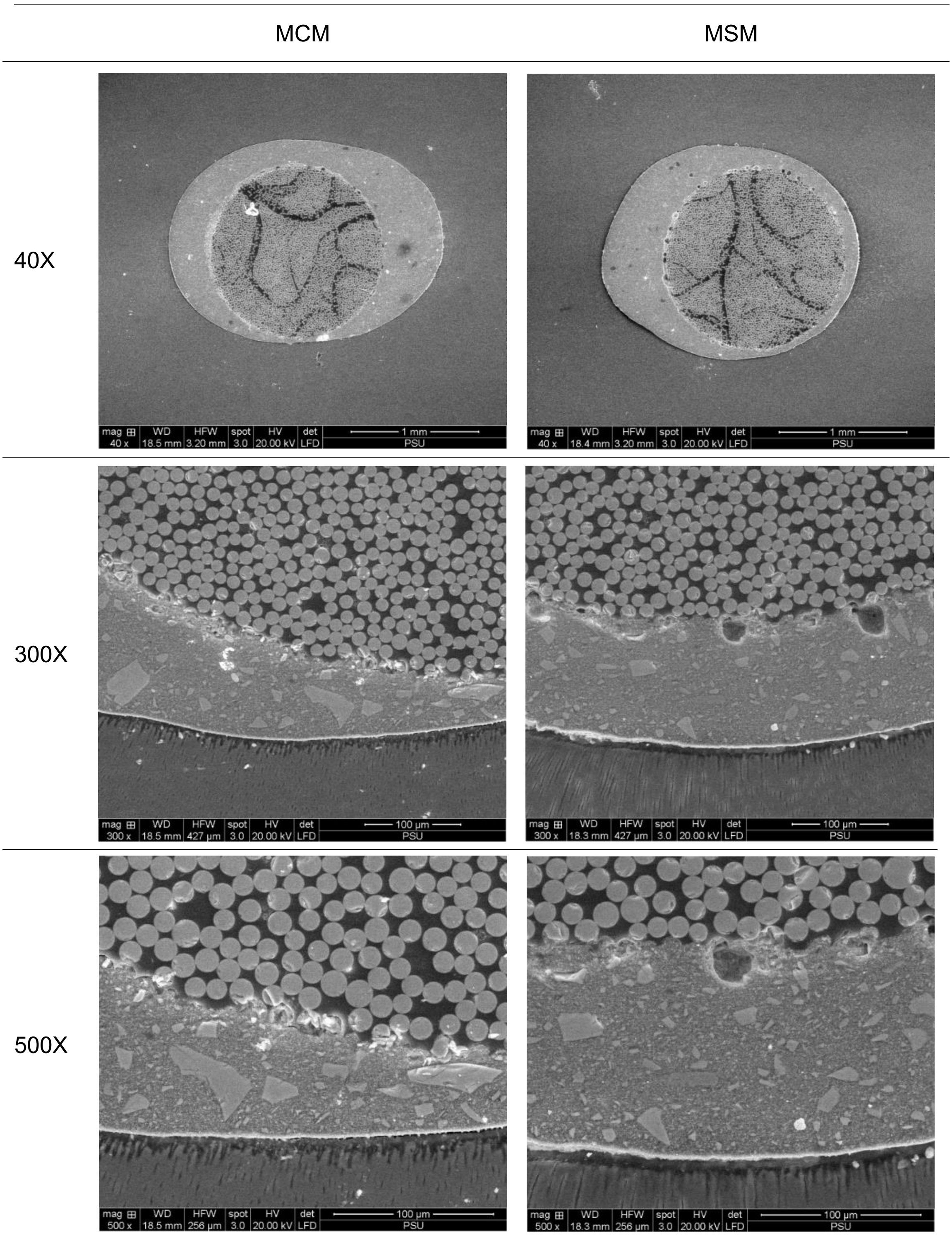


Figure 19 Scanning electron micrographs of representative bonded interfaces of specimens in Multicore flow/conventional technique/middle region (MCM) and Multicore flow/sonic application/middle region (MSM) group

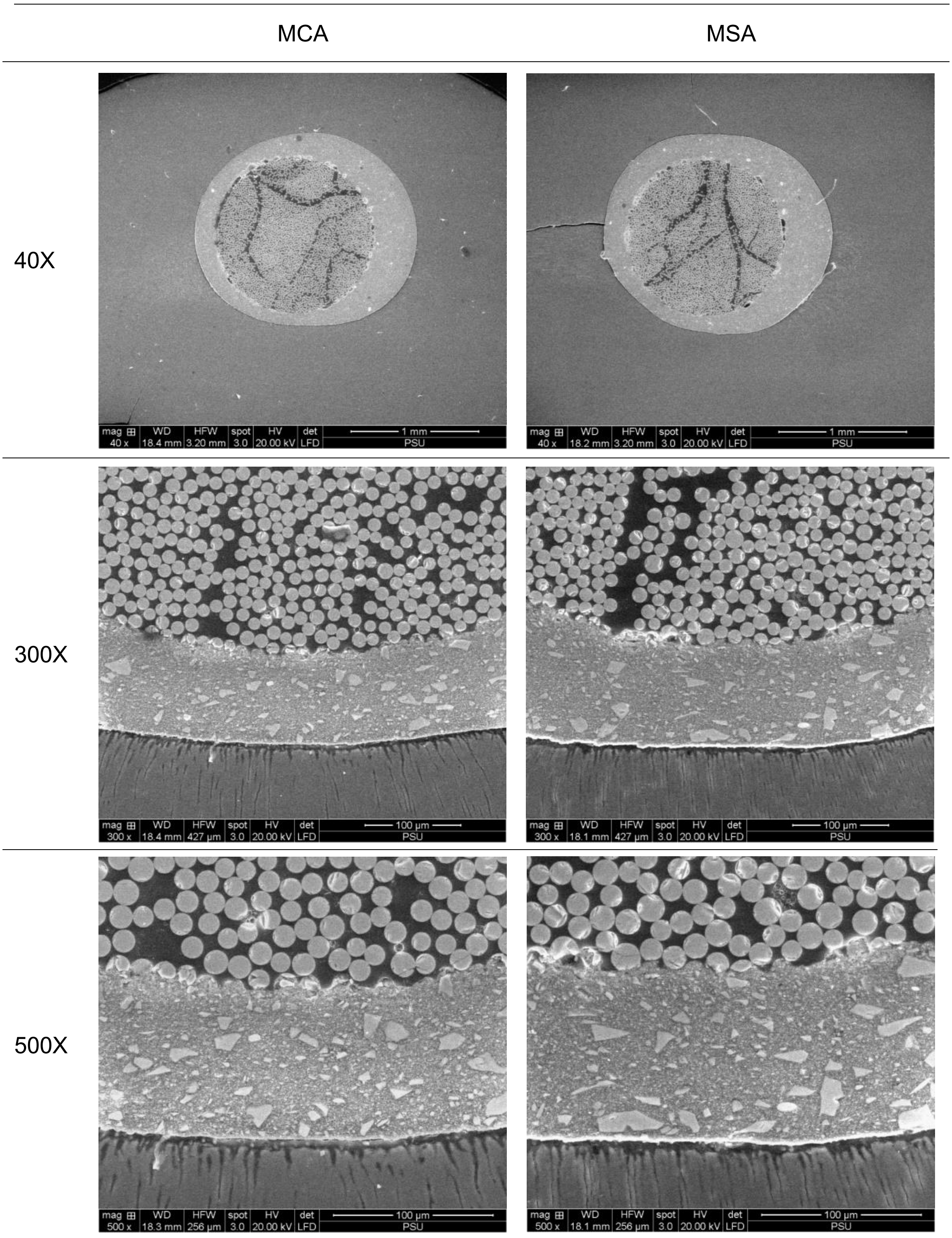


Figure 20 Scanning electron micrographs of representative bonded interfaces of specimens in Multicore flow/conventional technique/apical region (MCA) and Multicore flow/sonic application/apical region (MSA) group

CHAPTER 4

DISCUSSIONS

For improving bond strength between fiber post and root canal dentin, the present study proposed the sonic vibration as an alternative technique to use in fiber post cementation procedure. Regarding the difference in fiber post insertion techniques in this study, the results showed that technique possibly did not affect the bond strength of the fiber post because there was no statistically significant difference between the two techniques in all groups except the coronal region in the RelyX Unicem group, where sonic application statistically significantly decreased the push-out bond strength compared with conventional technique. The type of luting material affected the bond strength. Fiber post bonded with RelyX Unicem provided a higher push-out bond strength value than Multicore flow regardless of techniques. In addition, regional factor affected the bonding to the root canal when RelyX Unicem was used. Therefore, the null hypothesis in this study was rejected.

Based on our preliminary findings, the ultrasonic device has attempted to be used for fiber post cementation. Due to the high consistency of Multicore flow and the high frequency of ultrasonic. It can be noticed that ultrasonic vibration had no effect on cement flow. As a result, the sonic vibration was utilized in this study because it has a low frequency and a wide wavelength, which was supposed to correspond to the luting material with a high consistency. To avoid a premature polymerization of cement prior to adequate fiber post seating, the sonic application was applied on top of the post after the fiber post had already been properly seated.

When the RelyX Unicem, which is a self-adhesive resin cement, was used, the results showed that sonic application did not affect the push-out bond strength, except in the coronal region, where a statistically significant decrease in push-out bond strength was obtained compared with the conventional technique. Since the self-adhesive resin cement has a low molecular weight and consistency, the sonic vibration might not affect this type of luting material in general. In the controversy, the strong vibration of sonic application possibly disturbed the bonding or adaptation to the fiber post in the coronal region. These findings are in accordance with one previous study, which found that the use of sonic to apply resin cement did not promote an increased bond strength value, but it did provide more homogeneous and less bubbled cement films.(26) In contrast, another study demonstrated that using sonic application increased the bond strength values of self-adhesive resin cement.(27)

The resin composite core material has a high molecular weight and consistency. It was apparently less fluid than self-adhesive resin cement. When sonic application was used in the Multicore flow group, it had a tendency to increase the push-out bond strength of fiber posts, especially in the apical region, where a nearly twofold bond strength value was presented, but a statistically significant difference was not found between the two techniques, possibly due to the large standard deviation, which might be caused by technique sensitivity, the different load of the seating post, and the small sample group.

When the push-out bond strength was compared between two luting materials, there was a statistically significant difference in all groups except one that used sonic application in the coronal region. Thus, the properties of the material itself might have more effect on the bond strength than techniques. RelyX Unicem generally showed much higher push-out bond strength values than Multicore flow. The low viscosity of RelyX Unicem might create better adaptation to the post and root canal surface, especially in a properly fitted canal. However, in the flare canal, which has a thick layer of luting resin, the strength of the luting materials may be compromised. Therefore, selection of luting materials needs to be concerned with various factors, such as cement space and remaining tooth structure. Although the low viscosity material is easier to handle and a higher bond strength was presented, its strength may be compromised. According to previous studies, resin composite core materials with a higher filler content tended to promote fracture resistance, flexural strength, and a reduction in water sorption.(47,48)

In the RelyX Unicem group, the push-out bond strength of the apical region was significantly higher compared with the coronal and middle regions. If the bond strength was correlated with resin tag formation, the bond strength value in the coronal region should increase as the density of dentinal tubules and the amount of dentin surface available for bonding increased, but the results of this study showed that when RelyX Unicem was used, the bond strength was significantly higher in the apical region.(49) It might be assumed that the root canals in the coronal region are wider, requiring a greater amount of resin cement, consequently increasing stress at the interface during polymerization shrinkage. That could explain why the bond strength of the coronal region was lower than the apical region. On the other hand, regions of the root canal had no effect on the bond strength when Multicore flow was used. The previous study revealed that the core material demonstrated significantly lower polymerization shrinkage than self-adhesive resin cement.(48) In addition, the high pressure with lower cement space at the apical region might generate the intimate contact between low viscosity resin cement and dentin/post surface. However, the viscosity of Multicore flow was possibly too high to be affected by this pressure.

There was a predominance of adhesive failure in all groups, with debonding between dentin and cement being more common than between post and cement since the fiber posts in this study were treated with hydrofluoric acid followed by a silane coupling agent to improve the bond strength between the fiber post and the luting material.(34,36) These results were in accordance with the SEM evaluation. The fiber post/cement interface appeared to have better intimate contact than the cement/dentin interface (Fig. 21). However, Multicore flow had a higher rate of adhesive failure between fiber post and cement than RelyX Unicem and a lower bond strength was presented. It might be considered that Multicore flow, which has a high viscosity, has poor adaptation to fiber posts, as revealed by SEM analysis.

According to the findings of the present study, sonic application had no effect on the push-out bond strength of fiber post, but it tended to produce better results in resin composite core material due to its high viscosity. While statistically significant differences in bond strength were found between resin cement and resin composite core material. The bond strength of resin cement was higher. However, previous studies have shown that resin composite core material has a higher fracture resistance.(47,48) Further research is needed to make an effort to verify this technique with other frequencies and durations or identify other techniques that are able to increase the bond strength of high viscosity luting resin to obtain both optimal adhesion and fracture resistance of the radicular restored teeth.

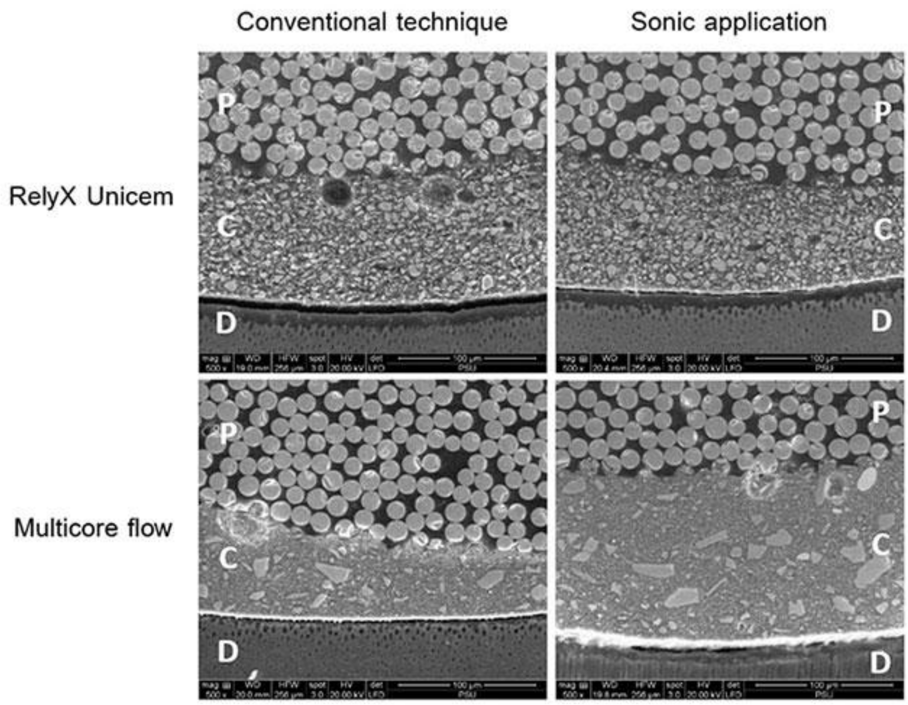


Figure 21 Scanning electron micrographs of representative bonded interfaces of coronal specimens (P is post, C is cement, and D is dentin).

CHAPTER 5

CONCLUSIONS

Within the limitations of this study, it could be concluded that sonic application of fiber post cementation with resin cement or resin composite core material did not improve the bond strength of fiber posts to the root canal dentin but tended to yield higher average bond strength in resin composite core material. Regardless of application technique, resin cement presented a higher bond strength compared with resin composite core material. Regional factor affected the bond strength of self-adhesive resin cement but not for resin composite core material.

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APPENDIX

Maximum load (N)

No.	Maximum load (N)											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	101.90	64.56	35.63	5.22	10.82	11.06	25.16	4.43	9.57	21.55	6.71	5.09
2	28.37	28.67	58.17	15.37	2.84	38.01	11.82	2.64	2.44	23.33	2.10	8.77
3	43.32	26.49	37.35	7.53	14.91	44.03	13.03	6.52	8.21	29.20	13.08	22.12
4	39.14	20.05	24.41	35.46	27.95	35.25	8.92	2.30	3.45	15.90	3.92	3.04
5	26.48	11.44	38.43	26.06	32.86	53.86	6.42	6.12	11.11	10.82	14.25	14.91
6	70.46	28.04	53.70	11.32	34.91	32.40	6.53	12.28	1.80	7.88	6.35	7.22
7	5.84	39.63	59.96	6.12	28.37	32.43	4.60	2.49	4.50	6.69	3.15	4.15
8	37.20	24.15	35.24	17.00	23.87	38.32	7.25	7.42	9.23	9.22	16.97	15.41
9	19.47	17.07	23.98	26.72	26.90	33.80	2.73	2.23	3.81	5.80	3.24	4.90
10	20.61	32.22	46.18	20.26	41.81	55.74	6.37	6.01	19.53	10.72	6.83	32.83

The thickness of specimens (mm)

No.	The thickness of specimens (mm)											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	0.98	1.06	1.02	1.05	0.99	1.05	0.98	0.98	0.97	1.02	1.02	1.00
2	1.06	0.99	1.05	1.02	1.00	0.99	1.02	0.98	0.98	0.99	0.98	1.01
3	0.99	0.98	1.05	1.00	1.05	1.03	0.98	1.00	0.99	1.06	1.01	1.00
4	0.98	0.98	0.98	1.00	1.00	1.00	0.95	1.04	0.99	0.99	0.96	1.00
5	1.00	0.98	1.00	0.96	1.00	1.09	0.94	0.98	0.96	0.98	0.99	0.98
6	1.10	1.08	1.02	0.99	1.05	1.00	1.03	1.00	0.98	1.00	1.00	1.00
7	1.03	1.00	1.05	1.09	1.07	1.05	1.00	0.98	1.00	1.02	0.98	1.00
8	1.07	1.02	1.00	1.07	1.08	1.00	1.00	1.01	0.99	1.01	1.01	0.99
9	0.98	1.00	1.00	1.00	0.99	1.00	0.97	0.96	1.00	0.95	1.01	1.01
10	0.97	0.98	0.99	1.02	1.00	1.02	1.00	0.98	1.00	1.01	1.01	1.01

Cervical failure area radius (mm)

No.	Cervical failure area radius (mm)											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	1.04	0.79	0.75	1.05	0.88	0.78	0.82	0.69	0.75	1.12	0.96	0.86
2	1.11	0.94	0.64	1.15	1.01	0.75	0.79	0.94	0.61	0.83	0.70	0.59
3	1.01	0.90	0.75	0.95	0.86	0.75	0.79	0.66	0.60	0.80	0.68	0.65
4	1.24	1.14	0.92	1.00	1.02	0.79	1.11	0.94	0.77	1.17	1.03	0.80
5	1.02	0.95	0.85	1.05	0.86	0.74	1.09	1.00	0.84	1.08	0.71	0.60
6	0.90	0.78	0.63	0.94	0.82	0.77	0.77	0.62	0.70	1.07	0.90	0.77
7	1.00	0.73	0.62	1.08	0.90	0.74	0.72	0.84	0.73	0.76	0.64	0.59
8	0.92	0.87	0.78	0.95	0.81	0.67	1.02	0.90	0.76	0.75	0.76	0.76
9	1.15	1.00	0.84	0.97	1.00	0.84	1.05	0.82	0.75	1.10	0.91	0.71
10	0.98	0.82	0.74	0.99	0.83	0.73	1.04	0.94	0.73	1.02	0.64	0.58

Apical failure area radius (mm)

No.	Apical failure area radius (mm)											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	0.97	0.84	0.68	0.96	0.82	0.69	0.77	0.64	0.72	1.08	0.91	0.79
2	1.07	0.69	0.62	1.08	0.94	0.67	0.74	0.87	0.59	0.78	0.65	0.60
3	0.82	0.89	0.59	0.89	0.81	0.63	0.74	0.62	0.58	0.76	0.63	0.57
4	0.86	1.02	0.73	0.82	0.71	0.59	1.06	0.84	0.75	1.11	0.95	0.73
5	0.86	0.88	0.67	0.89	0.71	0.57	1.06	0.95	0.77	1.03	0.66	0.58
6	0.84	0.74	0.61	0.89	0.75	0.72	0.70	0.58	0.67	1.01	0.88	0.74
7	0.97	0.62	0.58	1.04	0.67	0.62	0.68	0.80	0.68	0.72	0.60	0.58
8	0.89	0.82	0.63	0.89	0.75	0.56	0.92	0.88	0.71	0.69	0.78	0.74
9	1.06	0.92	0.78	0.83	0.84	0.63	0.98	0.78	0.73	1.05	0.83	0.66
10	0.95	0.67	0.58	0.93	0.58	0.54	1.02	0.87	0.69	0.96	0.66	0.57

Push out bond strength (Mpa)

No.	Push out bond strength (Mpa)											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	16.42	11.92	7.77	0.83	2.05	11.06	5.13	1.08	2.13	3.06	1.12	0.98
2	3.91	5.48	14.00	2.15	0.46	8.56	2.41	0.47	0.66	4.65	0.50	2.32
3	7.33	4.82	8.34	1.31	2.70	9.82	2.76	1.62	2.24	5.62	3.16	5.77
4	5.66	3.00	4.70	6.11	4.89	7.97	1.38	0.39	0.73	2.24	0.65	0.63
5	4.43	2.03	7.95	4.40	6.56	11.91	1.01	1.02	2.28	1.67	3.34	4.12
6	11.75	5.43	13.48	1.98	6.74	6.91	1.38	3.25	0.42	1.21	1.13	1.52
7	0.92	9.30	15.13	0.84	5.24	7.18	1.04	0.49	1.01	1.40	0.83	1.12
8	6.12	4.45	7.87	2.76	4.51	9.85	1.18	1.31	2.00	2.02	3.47	3.30
9	2.85	2.82	4.70	4.68	4.66	7.14	0.44	0.46	0.82	0.90	0.58	1.12
10	3.50	6.90	11.16	3.30	9.18	13.38	0.99	1.07	4.38	1.70	1.73	8.96

Failure mode

No.	Failure mode											
	RCC	RCM	RCA	RSC	RSM	RSA	MCC	MCM	MCA	MSC	MSM	MSA
1	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Mixed	Ad:P/C	Ad:P/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C
2	Ad:D/C	Mixed	Mixed	Ad:D/C	Ad:D/C	Mixed	Ad:P/C	Ad:D/C	Ad:P/C	Ad:P/C	Ad:P/C	Ad:P/C
3	Mixed	Ad:D/C	Mixed	Ad:D/C	Ad:D/C	Mixed	Ad:P/C	Ad:P/C	Ad:P/C	Ad:P/C	Ad:P/C	Mixed
4	Mixed	Ad:D/C	Mixed	Mixed	Mixed	Mixed	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C
5	Mixed	Ad:D/C	Mixed	Mixed	Mixed	Mixed	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:P/C	Ad:P/C
6	Mixed	Ad:D/C	Mixed	Ad:D/C	Mixed	Ad:D/C	Ad:P/C	Ad:P/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C
7	Ad:D/C	Mixed	Mixed	Ad:D/C	Mixed	Mixed	Ad:P/C	Ad:D/C	Ad:D/C	Ad:P/C	Ad:P/C	Ad:P/C
8	Ad:D/C	Mixed	Mixed	Ad:D/C	Ad:D/C	Mixed	Ad:D/C	Ad:D/C	Ad:D/C	Ad:P/C	Ad:D/C	Ad:D/C
9	Mixed	Ad:D/C	Ad:D/C	Mixed	Mixed	Mixed	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C
10	Ad:D/C	Mixed	Mixed	Ad:D/C	Mixed	Mixed	Ad:D/C	Ad:D/C	Ad:D/C	Ad:D/C	Ad:P/C	Ad:P/C

* Ad:P/C = Adhesive failure between post and cement, Ad:D/C = Adhesive failure between root canal dentin and cement, Co = Cohesive failure of cement, Mixed = Mixed failure

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