INFLUENCE OF CURVED ROOT CANAL ON RETREATMENT EFFICACY OF BIOCERAMIC SEALER

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อิทธิพลของคลองรากฟันโค้งต่อประสิทธิผลของการรักษาคลองรากฟันซ้ำในฟันที่อุดคลองรากด้วยไบโอเซรามิกซีลเลอร์

นายเกษมสันต์ สุจริตวณิช

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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เกษมสันต์ สุจริตวณิช : อิทธิพลของคลองรากฟันโค้งต่อประสิทธิผลของการรักษาคลองรากฟันซ้ำในฟันที่อุดคลองรากด้วยไบโอเซรามิกซีลเลอร์. (INFLUENCE OF CURVED ROOT CANAL ON RETREATMENT EFFICACY OF BIOCERAMIC SEALER) อ.ที่ปรึกษาหลัก : รศ. ทพญ.ปิยาณี พาณิชย์วิสัย

การศึกษานี้มีวัตถุประสงค์เพื่อประเมินอิทธิพลของความโค้งต่อประสิทธิผลของการรักษาคลองรากฟันซ้ำในคลองรากฟันที่อุดด้วยไบโอเซรามิกซีลเลอร์ ฟันกรามล่างแท้ 60 ซี่ ถูกแบ่งออกเป็น 4 กลุ่มย่อย ได้แก่ ฟันที่มีความโค้งมากอุดคลองรากฟันด้วยซีลเลอร์เอเอช พลัส ฟันที่มีความโค้งน้อยอุดคลองรากฟันด้วยซีลเลอร์เอเอช พลัส ฟันที่มีความโค้งมากอุดคลองรากฟันด้วยซีลเลอร์ไบโอรูท อาร์ซีเอส และฟันที่มีความโค้งน้อยอุดคลองรากฟันด้วยซีลเลอร์ไบโอรูท อาร์ซีเอส หลังจากอุดคลองรากฟันไป 2 สัปดาห์ ทำการรักษาคลองรากฟันซ้ำด้วยไฟล์เวฟวันโกลด์ ไพรมารี่ ชนิดหมุนด้วยเครื่องและไฟล์โปรเทปเปอร์ เนค เอ็กสาม ร่วมกับ แพสซีฟ อัลตราโซนิก อิริเกชัน ประเมินประสิทธิผลของการรักษาคลองรากฟันซ้ำด้วยการกลับมีพาเทนซี เวลา และ ปริมาณวัสดุอุดคลองรากฟันที่เหลือ ประเมินปริมาณวัสดุอุดคลองรากฟันที่เหลือและการแทรกซึมของซีลเลอร์ในท่อเนื้อฟัน ด้วยเครื่องเอ็กซ์เรย์ระดับไมโครและกล้องจุลทรรศน์คอนโฟคอล เปรียบเทียบการกลับมีพาเทนซีด้วยการทดสอบเพียร์สัน ไคสแควร์ เปรียบเทียบเวลาในการรักษาคลองรากฟันซ้ำและปริมาณวัสดุอุดคลองรากฟันที่เหลือด้วยการวิเคราะห์ความแปรปรวนทางเดียวที่ระดับนัยสำคัญ 0.05 ผลการศึกษาพบว่าฟันคลองรากโค้งมากอุดคลองรากฟันด้วยซีลเลอร์ไบโอรูท อาร์ซีเอสให้ประสิทธิผลของการรักษาคลองรากฟันซ้ำเหมือนกับในฟันคลองรากโค้งน้อย ไม่พบความแตกต่างอย่างมีนัยสำคัญของประสิทธิผลของการรักษาคลองรากฟันซ้ำระหว่างกลุ่มที่อุดคลองรากฟันด้วยซีลเลอร์ไบโอรูท อาร์ซีเอส และ กลุ่มที่อุดคลองรากฟันด้วยซีลเลอร์เอเอช พลัส ยกเว้นประเด็นการกลับมีพาเทนซี

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This study evaluated the influence of a curved root canal on the retreatment efficacy of root canals sealed with bioceramic sealer. 60 mandibular molars were divided into 4 subgroups of severely curved canal filled with AH Plus, slightly curved canal filled with AH Plus, severely curved canal filled with BioRoot RCS and slightly curved canal filled with BioRoot. Two weeks after root canal obturation, retreatment was performed with WaveOne Gold Primary and ProTaper Next X3 following with passive ultrasonic irrigation. The retreatment efficacy parameters were regaining canal patency, retreatment time and residual filling material. MicroCT and confocal microscope were used to evaluate the residual filling materials and sealer penetration in dentinal tubules. Regaining canal patency was compared by Pearson Chi-square test. Retreatment time and residual filling materials were compared using one-way ANOVA at 0.05 level of confidence. Retreatment efficacy of BioRoot RCS in severely curved root canal was similar to that of slightly curved root canal. There was no significant difference in retreatment efficacy between BioRoot RCS and AH Plus groups, except for regaining canal patency.

Field of Study: Endodontology Student's Signature .....

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CHAPTER 1
INTRODUCTION

Background and Rationale

Post-treatment endodontic disease results from many etiological factors that result in a persistent periradicular lesion (1). Nonsurgical retreatment demonstrated preferable outcomes with increasing recall time compared with endodontic surgery (2). To obtain healthy periapical tissue during nonsurgical root canal retreatment, regaining access to the apical foramen requires completely removing the root canal sealer (3, 4). A calcium silicate-based sealer, BioRoot RCS (Septodont, Saint Maur des Fosses, France) was introduced in 2015 (5). Obturation with a calcium silicate-based sealer results in dentin bonding and bioactivity (6-8). This BioRoot RCS property might cause difficulty in sealer removal.

Previous studies evaluated the retreatment efficacy of a bioceramic sealer in single and straight root canals (9-15). Canal transportation, perforation, and separated instruments are errors that occur when shaping a curved root canal. Several studies have focused on curved root canal retreatment, especially in severely-curved roots (16, 17). A study (16) compared Reciproc blue and Reciproc for bioceramic sealer retreatment in severely-curved canals. The results indicated no difference after Micro-computed tomography (MicroCT) evaluation. However, the remaining sealer penetration in dentinal tubules was not evaluated. The purpose of this study was to evaluate the influence of a curved root canal on the retreatment efficacy of root canals sealed with a bioceramic sealer. Three retreatment efficacy parameters were evaluated, regaining patency, time, and residual filling material. MicroCT and confocal microscopy were used to obtain the residual filling material data.

Research Question

1. Can severely curved root canals filled with bioceramic sealer be retreated efficiently comparing to slightly curved root canals?

2. Can bioceramic sealer in curved root canals be removed efficiently comparing to AH Plus?

Research Objective

To evaluate influence of a curved root canal on the retreatment efficacy of root canals sealed with a bioceramic sealer

Hypothesis

H0: 1. There is no significant difference in retreatment efficacy of severely curved root canals and slightly curved root canals.

2. There is no significant difference of residual remaining root canal filling on canal wall of the canals sealed with BioRoot RCS and AH Plus after retreatment.

3. There is no significant difference in regaining patency of the canals sealed with BioRoot RCS and AH Plus after retreatment.

4. There is no significant difference in retreatment time of the canals sealed with BioRoot RCS and AH Plus after retreatment.

H1: 1. There is significant difference in retreatment efficacy of severely curved root canals and slightly curved root canals.

2. There is significant difference of residual remaining root canal filling on canal wall of the canals sealed with BioRoot RCS and AH Plus after retreatment.

3. There is significant difference in regaining patency of the canals sealed with BioRoot RCS and AH Plus after retreatment.

4. There is significant difference in retreatment time of the canals sealed with BioRoot RCS and AH Plus after retreatment.

Research Design

Experimental design

Keyword

Retreatment, bioceramic sealer, curved root canal, MicroCT

Expected benefits

The findings could be used as a supporting information for the retreatment of bioceramic sealer. The study could point out the influence of canal curvature on retreatment efficacy. The data would be useful for understanding the retreatability of BioRoot RCS bioceramic sealer in severely and slightly curved root canals. The percentage of residual filling materials would add the information for the outcome prediction.

Limitations of the Research

As this study was an in vitro study, it was unable to create the oral environment. The experiment performed in controlled experimental condition. Mesial root canals of mandibular molars have the complexity of root canal such as isthmus and fin which the initial 2D digital radiography would not reveal. This would impact the evaluation of root canal volumes in 3D micro-computed tomography.

Ethical Considerations

The study protocol was approved by the Ethics committees of Faculty of Dentistry, Chulalongkorn University (No. HREC-DCU 2018-055).

CHAPTER II

REVIEW OF LITERATURE

Bacterial persistence in the root canal which not eradicated by treatment was the major cause of post treatment apical periodontitis. Persistence lesions after long term follow-up indicated that the bacteria were not completely removed. The bacterial colonies could be found between the filling material and root canal wall as well as in the deep part within dentinal tubules (18). That is why the root canal retreatment should begin. In order to acquire favorable outcome of retreatment, all of the obstructions which prevent accessing to root canals have to be removed (19).

1. Calcium silicate-based sealer

Many bioceramic sealers recently been introduced, have calcium and silicate in the sealer component such as BioRoot RCS, Endosequence BC sealer or TotalFill BC sealer, iRoot and MTA Fillapex (20). Bioceramic sealers are biocompatible, nontoxic, non-shrinking, and chemically stable within the biological environment. They are also able to form hydroxyapatite during the setting process and can bond with dentin (21). The study showed that bioceramic sealers do not shrink upon setting and can expand about 0.002%. Moreover, they have an excellent dimensional stability and flowability (22).

1.1 BioRoot RCS (Septodont, Saint-Maur-des-Fossés, France)

It is composed of powder part and liquid part. Powder composition are tricalcium silicate, zirconium oxide and povidone. Liquid part consists of aqueous solution of calcium chloride and polycarboxylate (23, 24). BioRoot RCS had an alkaline pH about 11-12 which was significantly higher than MTA Fillapex at first 14 days (24) and higher than AH Plus at 28 days (6). It also released calcium ion high up to 28 days compared with AH Plus which slightly released (24). The study showed that BioRoot RCS could secrete osteogenic and angiogenic factors because of its bioactive properties (25). The bioactive activity associated with the releasing hydroxyl

and calcium ions. Prüllage *et al.* found the white precipitate on the surface of BioRoot RCS after immersed in PBS buffer at 28 days which was calcium hydroxyapatite (7). Because of the solubility of BioRoot RCS, the notable calcium ion releasing might react with phosphate in body fluid and form the hydroxyapatite crystals (7, 26). Moreover, in the root canal filled with BioRoot RCS showed the fluorescent band adjacent to root dentine which assumed as mineral infiltration zone (8). The final setting time of BioRoot RCS was approximate 5 hours while AH Plus was about 20 hours. As well as the other sealers, BioRoot RCS had radiopacity value greater than 3 mm aluminium defined by ISO 6876 (6, 24). The flow rate was lower than AH Plus and ISO recommendation as well as film thickness of the sealer was greater than AH Plus and ISO recommendation (6).

2. Epoxy resin-based sealer

AH Plus (Dentsply maillefer, USA) has 2 components. First, it composes of Bisphenol-A epoxy resin, Bisphenol-F epoxy resin, iron oxide pigments, calcium tungstate, zirconium oxide and silicon oxide. An additional one consists of Dibenzyldiamine, Aminoadamantane, Tricyclodecane-diamine, Calcium tungstate, zirconium oxide and silicon oxide (27, 28). AH Plus sealer has been used as the gold standard and control material for the studies of sealers (6). AH Plus showed antibacterial activity against *E. faecalis* within infected dentinal tubules (29). The radiopacity value of AH Plus was higher than BC sealer and ISO recommendation(28). The flow of AH Plus was greater than 20 mm as same as BC sealer which was in ISO recommendation. Although in fresh mixing of AH Plus presented the alkaline pH but it considerably decreased to neutral pH from the third hours of the mixing (28, 30). AH Plus could release limited calcium ion (28). The cytotoxicity of AH Plus ceased after the third week period (31).

3. Retreatment of Bioceramic sealer

Hess *et al.* (10) studied the retreatability of BC sealer compared with AH Plus in mesiobuccal roots of mandibular first molars. The samples were divided into 4 subgroups BC sealer using single cone technique at full working length and 2 mm

short of working length and AH Plus using continuous wave technique at full working length and 2 mm short of working length. The study focused on the ability to reach working length and regain patency. Time for root filling material removal and debris remaining were as well concerned. It showed that the patency could regain 100% in AH Plus group, 80% in BC sealer group obturated at full working length and 30% in BC sealer group obturated 2 mm short of working length. However, all groups excepted BC sealer group with obturating 2 mm short of working length (30%) could 100% re-established the working length. The shortest time for removing filling material was in AH Plus group which filled at full working length and the longest was in BC sealer group which filled at full working length. Nevertheless, all groups displayed the debris and remaining material in root canals . For more understanding about retreatment of bioceramic sealer or calcium silicate-based sealer, Neelakantan *et al.* demonstrated the retreatability of calcium silicate-based root canal sealers in single root of maxillary canines by using Cone beam computed tomography (CBCT). This study used MTA fillapex and MTA Plus compared with AH Plus. The study found that the lowest remaining material was MTA Fillapex group and the largest value found in AH Plus group. Moreover, the volume of dentin removal was in the same way as residual filling material and time to reach working length of MTA-based sealer groups were lower than epoxy resin-based sealer. The time to reach working length contradicted to Hess *et al.* as different materials were used. Furthermore, MTA Fillapex had low bond strength so might affect to adhesion capacity and the questionable of forming tag-like structure which might enhance the resistance of MTA Fillapex (13). In 2015, Kim *et al.* evaluated BC sealer compared with AH Plus in removal efficacy and the amount of residual obturating material in the root canal and dentinal tubule using scanning electron microscope (SEM) and confocal microscope. It was performed in single-root teeth. The study showed that all teeth both AH Plus and BC sealer could gain the patency and there was no significant in retreatment time and canal orifice morphology. Although from SEM analysis was no significant difference. AH Plus demonstrated deeper sealer penetration than BC sealer because of the higher fluidity. And at 6 mm from the apex, the remaining sealer in dentinal tubules was 1.14 mm in AH Plus group and 0.58 mm in BC sealer

(9) which was significant difference. Furthermore, there was the study about retreatability between Bioceramic sealer (iRoot SP), MTA-based sealer (MTA Fillapex) and epoxy resin-based sealer (AH Plus) by using stereomicroscope. In this study, mandibular premolars with straight and single canal were chosen. The study investigated that every groups of specimens could not be completely removed root filling material. By the way iRoot SP with single cone technique seem significantly more remnants of filling material than AH Plus with single cone or lateral compaction (15). There was the study about using solvent or no solvent (chloroform) on the retreatment of BC sealer by using SEM. The result showed that removal filling material using solvent left more residual filling material than rotary instrument alone (12). Recently, there was one study on retreatability between BC sealer and AH Plus by using micro-computed tomography. It compared two sealers with or without chloroform using maxillary incisor with straight root. The study contradicted Sherif *et al.*'s study (12) because this study exhibited that using chloroform left less filling material than without chloroform and BC sealer showed more remnants obturated material than AH Plus. Furthermore, this study supported the finding of Hess *et al*. in 2011 that AH Plus could regain 100% patency and BC sealer could gain patency when used solvent and no solvent 93% and 14% respectively (11). One study studied on retreatability of BioRoot RCS compared with MTA Fillapex, MTA C.P.M. which were calcium silicate-based sealer and AH Plus by using light microscope and ImageJ analysis. The study elucidated that AH Plus left more residual filling materials and used longer retreatment time than calcium silicate-based sealers significantly. Moreover, it supported that rotary instrument could be effective in removing root filling materials than hand stainless steel file (23).

4. Retreatment in curved canal

The study on efficacy of reciprocating rotary instrument in curved root canals obturated with calcium hydroxide sealer (Sealer 26) showed 89% removal of filling material (32). One study on removal of filling material obturated with calcium hydroxide sealer (Sealer 26) in moderate curved root canals showed that no significant in removal between 2 rotary instruments. Moreover, additional approach

with passive ultrasonic irrigation could reduce the remaining filling materials significantly (33). Furthermore, the study of retreatment according with passive ultrasonic irrigation supplement in moderate to severe curved root canals obturated with AH Plus showed more reducing filling material at apical and middle third level of root compared with mechanical cleaning alone (34). From that study, there was no significant difference in remaining material between using solvent (xylene) and passive ultrasonic irrigation (34). The comparison of removal 3 root canal sealers (Hybrid Root SEAL, AH Plus and Endosequence BC sealer) in moderate curved root canal with ProTaper universal retreatment instruments showed no significant difference in remaining filling material (35). Another study on efficacy of ProTaper NEXT compared with reciproc in retreatment of severe curved canals filled with AH Plus presented no significant difference in removal efficacy of these rotary instruments (36). One study showed that it was no significant in removing filling material from curved canals between Hedstrom files, ProTaper Universal Retreatment and Reciproc but Hedstrom files removed significantly more dentine than ProTaper Universal Retreatment. Furthermore, retreatment with Hedstrom files required more time than engine-driven instruments (37). However, there was a study on efficacy of reciprocating rotary instruments (Reciproc and WaveOne) along with passive ultrasonic irrigation in retreatment of moderate to severe curved root canals filled with AH Plus demonstrated that 2 reciprocating rotary instruments could remove filling material efficiently in every level of root canals (38). There was another study about efficacy of Reciproc and ProFile in retreatment of severe curved canals and straight root canals filled with epoxy resin sealer (2Seal easymiX) showed that Reciproc removed filling material faster than ProFile in both curve and straight root canals (39).

The using of passive ultrasonic irrigation (PUI) enhances the removal of filling materials in root canals. Passive ultrasonic irrigation could improve the removal of root canal filling materials in the apical third when the ProTaper universal retreatment instruments were used (40). Moreover, Passive ultrasonic irrigation could enhance the elimination of remaining material in moderate to severe curved root canal efficiently (33, 34).

5. Retreatment with reciprocating rotary instrument

The reciprocating motion rotary instrument (Reciproc) left the least remaining filling material after retreatment procedure when compared with conventional technique hand files and continuous motion rotary instruments. Moreover, it required the minutest time in retreatment procedure (41). In curved root canal which obturated with single-cone technique accompanied with AH Plus sealer, Reciproc and WaveOne could remove filling material 93% and 92% of total volume respectively (38). Although they could not completely remove but they were efficiently for retreatment. Moreover, reciprocating motion rotary instruments (Reciproc and WaveOne) seem leaving less debris extrusion than continuous motion rotary instrument (ProTaper Universal Retreatment system) (42). WaveOne Gold reciprocating motion rotary instrument represented the highest torsional resistance compared with reciproc and twisted File Adaptive (43). In stainless steel artificial severe curved canal, WaveOne Gold Primary showed higher cyclic fatique resistance than Reciproc R25 (43, 44). Also, in shaping ability of s-shaped root canal, WaveOne Gold could remove lesser resin from all part of s-shaped artificial resin canal than reciproc (45). There was one study using WaveOne Gold in retreatment of straight and single root mandibular premolar which filled with MTA Fillapex and two resin-based sealers showed (46).

6. Obturation technique

Bioceramic sealers do not shrink and are insoluble in the tissue fluids. For root canal obturation using bioceramic sealer, single-cone technique that gutta-percha performed as the delivery device for bioceramic sealer through the hydraulic condensation is proposed. This technique makes the sealers be the main component and allow them to flow into the irregular canals. Furthermore, gutta-percha can act as the way for retreatment (47). Single-cone technique with matched-taper gutta-percha is able to fill a 3-dimensional homogenous root canal after root canal preparation with rotary instruments. This technique can reduce time consumption. The micro-CT study showed that single-cone technique with bioceramic sealers especially TotalFill BC sealer significantly reduced the voids in apical third (22).

According to the manufacturers, calcium silicate-based sealers should be used with single cone technique. Calcium silicate-bases sealers could slightly expand with agreement of ISO specification, so it provides superiority for single-cone obturation technique (30, 48). Calcium silicate-based sealers were used according with gutta-percha as a single cone technique with the result of good sealing ability (22, 23, 35, 48). One study showed that calcium silicate-based sealer especially BC sealer and MTA plus had higher bond strengths when used as single cone technique compared with continuous wave technique. The heat source could remove sealer during the down-pack resulting in altered the adhesive properties and lowered bond strength of sealer (49). Moreover, increasing in temperature to tricalcium silicate-based sealer could expedite the setting time (27).

7. Micro-computed tomography evaluation

Micro-computed tomography (Micro-CT) is a nondestructive analytical method which gives objective information and can develop a precise 3D model. It provides both quantitative and qualitative data. This method can distinguish gutta-percha cone, sealer, void and tooth structures with high accuracy and resolution (22, 50, 51). Moreover, Micro-CT can be reproducible therefore it can be possible for evaluating the changes of filling material over time (50). There were many studies using micro-CT for evaluation the remnant of sealer after retreatment. One of the following, It was the study using 3D micro-CT to assess the remaining of iRoot SP (bioceramic sealer) in different obturation methods (52). Moreover, one study focused on remaining of root filling material, volume of dentin removal and canal transportation after retreatment of severely curved root canals by using micro-CT which could be construct into 3D image for evaluation (36). Most study used micro-CT for quantitatively evaluating the amount of remaining root filling material after different techniques of retreatment including amount of dentin removal (32, 37, 40, 53-57).

8. Confocal microscopy evalutation

One study using confocal microscopy for evaluation of dentinal tubule penetration of Bioceramic sealer. In this study, Rhodamine B which was mixed into each sealer before filling the root canal according with gutta-percha cone and continuous wave obturation technique. It demonstrated that after retreatment, TotalFill BC sealer could penetrate into dentinal tubule about 0.2 mm. or 40-50% at 1 mm. from apex and about 0.5 mm. or 80% at 5 mm. from the apex (9). Another study used Rhodamine B for labelling the sealer and accessing the penetration of sealers into dentinal tubule using confocal microscopy (58). Moreover, the study compared different sealers penetration into dentinal tubule using single cone and continuous wave obturation techniques used Rhodamine as an indicator (48). The usage of 0.1 % Rhodamine B mixed with EndoFill (zinc oxide eugenol sealer) could be evaluated with confocal microscope for sealer penetration into tubules and the remaining sealer after retreatment (59).

CHAPTER III

METHODOLOGY

Sample preparation

Sixty extracted human permanent mandibular molars were included. Teeth were stored in 0.1% Thymol solution after extraction. Bucco-lingual radiographs of teeth were taken by digital radiographs. Canal curvature was measured. Mesial root with severe curvature (25-70 degrees) and slightly curvature (<15 degrees) as classified by Schneider (60) were used. (Figure 1) Canals larger than size 20 after determining the working length and with previous root fillings, resorptive defects, calcifications, caries, microcracks or fractures were discarded. In order to standardize the root length, all molar roots were cut by the precision saw (ISOMET1000, Buehler, USA) to 10 mm root length from the apex. A size 10 K-file (SybronEndo, CA, USA) was introduced into the canal until it was visible at the apical foramen. The working length (WL) was established 1 mm short to this length. The samples were divided into 2 groups of severely curved root canals (n=30) and slightly curved root canals root canal (n=30).

Figure 1 Root canal curvature measurement by Schneider's classification

Mesio-buccal root canals were prepared with ProTaper Next rotary instrument (Dentsply Maillefer,Ballaigues, Switzerland) to size X2 (25/.06). The canals were irrigated with 2.5% sodium hypochlorite (NaOCl) through 27-gauge needle. 2 ml of 2.5% NaOCl was used to irrigate the canal between each instrument. After

completed instrumentation, the canals were irrigated with 5 ml of 2.5% NaOCl, followed by 5 ml of 17% ethylenediaminetetraacetic acid (EDTA) for 1 minutes and final flush with 5 ml of 2.5% NaOCl (61).

The severely curved root canals (Sev) and slightly curved root canals (Sli) were randomly divided into 2 subgroups of 15 according to sealers, AH Plus (A) and BioRoot RCS (B). The root canals were filled with a matched-taper single-cone technique. The sealers were prepared according to the manufacturers' instructions and introduced into the canals with lentulo spiral. The matched-taper gutta-percha cone (25/.06) was coated with sealer before inserting into the canal. Excessive gutta-percha was removed by System B (SybronEndo, CA, USA).

One tooth in each subgroup was randomly chosen for confocal microscopy evaluation. Sealers were mixed with Rhodamine B before filling into the root canals. All teeth were stored at 37 °C in 100% humidity for 2 weeks to allow the sealers to set completely. All endodontic procedures were performed by a single operator.

Retreatment technique

The root canal filling materials were removed by WaveOne Gold Primary (25/.07) with no solvent used. Gently apical pressure was exerted. If the instruments could not advance, stainless steel size 10 K-files (SybronEndo, CA, USA) was used to overwhelm the resistance and confirm the glide path as well as working length before reintroducing the rotary instruments. The new working length would be determined, if working length could not be reached. Finally, apical preparation was performed with ProTaper Next X3 (30/.07). Each set of instruments were used in four root canals and then discarded. Canals were irrigated with 2 ml of 2.5% NaOCl at each change of instrument. Passive ultrasonic irrigation with 2.5% NaOCl solution for 20 seconds, 3 times (62) was performed in all root canals followed by 1 minute 17% EDTA and final flush with 5 ml of 2.5% NaOCl (61). The canals were dried with paper points. The criteria for the completion of retreatment was no evident of filling material on the flutes of the last instrument or in the irrigant. All retreatment procedures were done by one endodontist. The time was recorded in seconds

starting from using WaveOne Gold primary (25/.07) and stopped when X3 (30/.07) reached the working length. The canal patency was determined by using K-file #10.

Micro-computed tomography

All 60 specimens were mounted in the putty silicone jig in order to be placed stably in the sample holder each time of scanning (Figure 2 and 3). SCANCO MicroCT 35 (SCANCO Medical, Brüttisellen, Switzerland) (Figure 4) was used to scan the specimens at 70 kVp, 114 μA. The scanning time for each specimen was 112.8 minutes. The intersection distance (resolution) was high resolution and cross-section pixel size was 20.5 μm. The cross-section images were segmented, registered, visualized, quantified and three-dimensional reconstruction using SCANCO medical MicroCT software. Based on the difference of radiopacity between dentine and filling material, it was possible to differentiate and determine the filling material by adjusting the grey scale threshold. (Figure 5) Specimens were scanned 3 times; the preoperative empty canals (CT1), the obturated root canals (CT2) and after filling materials removal (CT3). One tooth in each subgroup was selected randomly and observed for remaining filling material at 3, 6 and 9 mm from the apex. The volumes of remaining filling material were measured in mm^3. The percentage of residual filling material was calculated.

Figure 2 The specimen was mounted in silicon putty jig and fixed in the sample holder.

Figure 3 The specimen in sample holder for MicroCT scanning

Figure 4 SCANCO MicroCT 35 (SCANCO Medical, Brüttisellen, Switzerland)

Left: SCANCO MicroCT35

Right: SCANCO medical MicroCT software

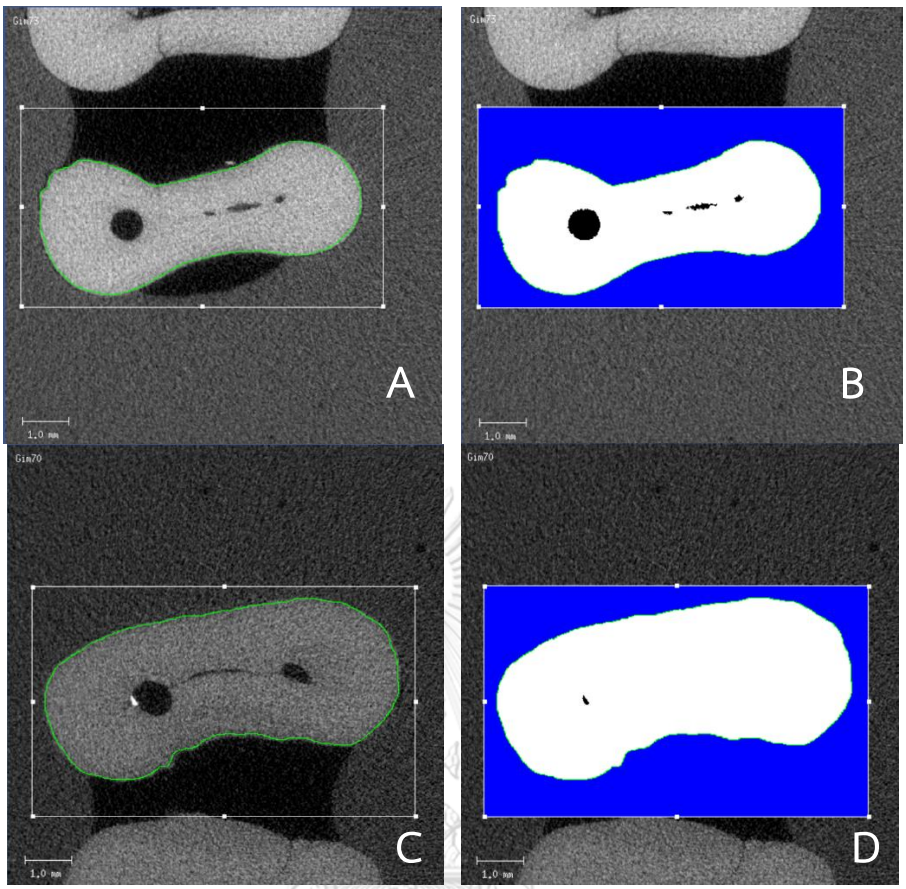


Figure 5 Grey scale threshold adjustment from SCANCO medical MicroCT software

(A) The cross-section of root canal representative the empty mesio-buccal root canal. (B) The cross-section of root canal with grey scale threshold adjustment representative the empty mesio-buccal root canal. (C) The cross-section of root canal representative the residual filling material in mesio-buccal root canal. (D) The cross-section of root canal with grey scale threshold adjustment representative the residual filling material.

Confocal Microscopy

One tooth in each subgroup was randomly selected and embedded in clear resin. The teeth were sectioned horizontally at 3 mm, 6 mm and 9 mm from the apex at 250-micron thickness. The samples were evaluated under a confocal microscope (FV10i; Olympus, MA, USA) (Figure 6) in order to demonstrate the penetration of sealers into the dentinal tubules. The images of confocal microscope were constructed using FV10-ASW version 4.2a. The longest penetration depth of the residual sealer was observed.

Figure 6 Confocal Microscope (FV10i; Olympus, MA, USA)

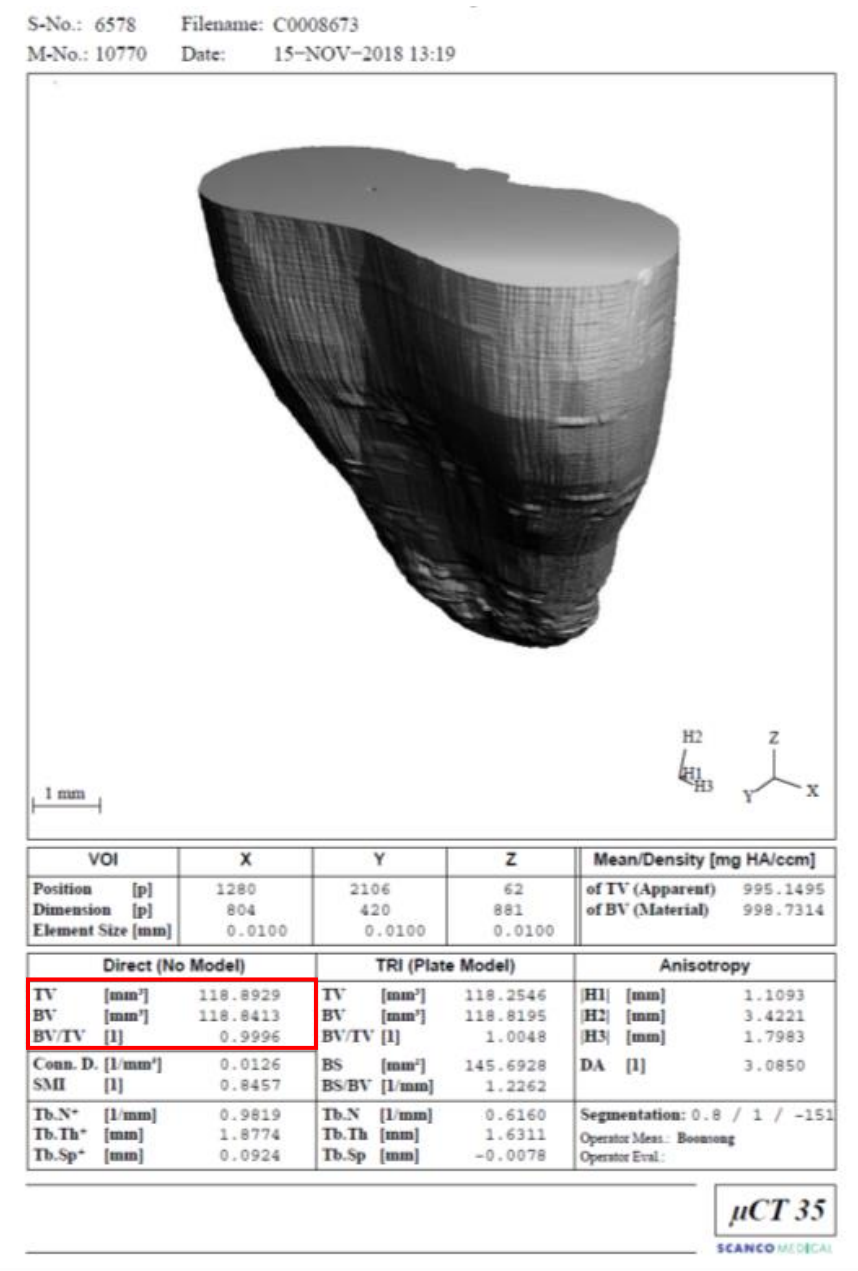
Statistical analysis

Canal curvature in each subgroups was descripted in mean. Retreatment time in each subgroup was compared using one-way ANOVA ($P < .05$). Regaining canal patency was compared using Pearson Chi-square test ($P < .05$). The percentage of residual filling materials was compared among each subgroup using one-way ANOVA. The percentage of residual filling materials in each root canal curvature type was compared between AH-Plus and BioRoot RCS using independent sample t-test ($P < .05$).

CHAPTER IV

RESULTS

Micro-computed tomography (MicroCT) evaluation of residual filling material was presented in mm^3. The residual filling material was calculated by subtraction of total volume (TV) and bone volume (BV) (Figure 7).



VOI		X	Y	Z	Mean/Density [mg HA/ccm]	
Position	[p]	1280	2106	62	of TV (Apparent)	995.1495
Dimension	[p]	804	420	881	of BV (Material)	998.7314
Element Size	[mm]	0.0100	0.0100	0.0100		

Direct (No Model)			TRI (Plate Model)			Anisotropy		
TV	[mm³]	118.8929	TV	[mm³]	118.2546	|H1|	[mm]	1.1093
BV	[mm³]	118.8413	BV	[mm³]	118.8195	|H2|	[mm]	3.4221
BV/TV	[1]	0.9996	BV/TV	[1]	1.0048	|H3|	[mm]	1.7983
Conn. D.	[1/mm³]	0.0126	BS	[mm²]	145.6928	DA	[1]	3.0850
SMI	[1]	0.8457	BS/BV	[1/mm]	1.2262			
Tb.N*	[1/mm]	0.9819	Tb.N	[1/mm]	0.6160	Segmentation: 0.8 / 1 / -151		
Tb.Th*	[mm]	1.8774	Tb.Th	[mm]	1.6311	Operator Meas.: Boonsong		
Tb.Sp*	[mm]	0.0924	Tb.Sp	[mm]	-0.0078	Operator Eval.:		

μCT 35
SCANCO MEDICAL

Figure 7 MiroCT evaluation of residual filling material after retreatment

Figure 11 shows MicroCT images of root sections with remaining AH Plus and BioRoot RCS after retreatment. Mean of canal curvature in all subgroups was 30° (SevA), 12.07° (SliA), 30.13° (SevB) and 10.64° (SliB) respectively (Table 1).

Table 1 Mean of canal curvature, percentage of patency re-establishment, mean of retreatment time and mean percentage of residual filling materials

	subgroup SevA	subgroup SliA	subgroup SevB	subgroup SliB
Canal curvature (degree)	30±4.83	12.07±3.99	30.13±4.87	10.64±5.51
Patency re-establishment (%)	86.67	100	66.67	64.29
Time for retreatment (sec)	216.97±86.33	193.27±80.93	212.60±66.54	232.50±59.13
Residual filling material (%)	7.60±7.34	19.35±18.47	13.31±9.24	11.50±14.03

SevA = severely curved canal with AH Plus, SliA = Slightly curved canal with AH Plus, SevB = severely curved canal with BioRoot RCS, SliB = Slightly curved canal with BioRoot RCS

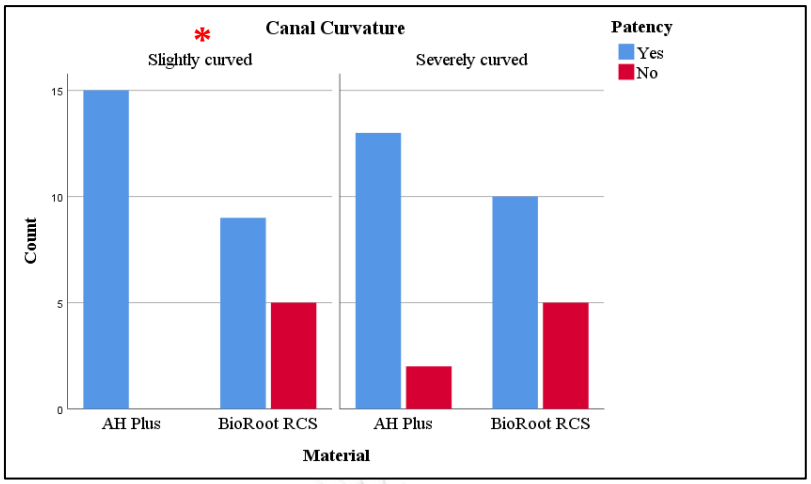


Figure 8 Column graph represented the regaining patency

*A significant between subgroups

Only subgroup SliA regained 100% canal patency. In group SevA, SevB and SliB, canal patency was re-established 86.67%, 66.67% and 64.29% respectively. Chi-square tests indicated that slightly curved root canal was significant (Pearson chi-square value = 6.473, P = .011) (Table 1) (Figure 8).

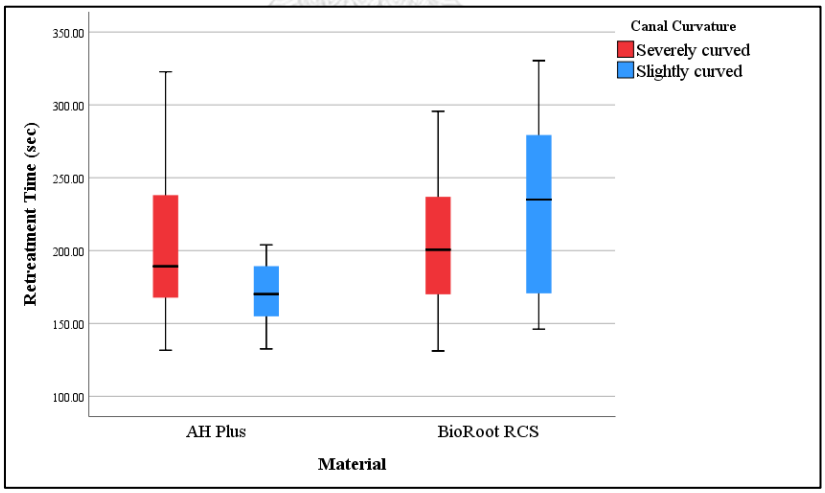


Figure 9 Box plot of retreatment time

The horizontal bar inside the box indicated the median value

The longest retreatment time was group SliB followed by group SevA and SevB. The shortest retreatment time was group SliA. One-way ANOVA showed no significant difference of each subgroups (Table 1) (Figure 9).

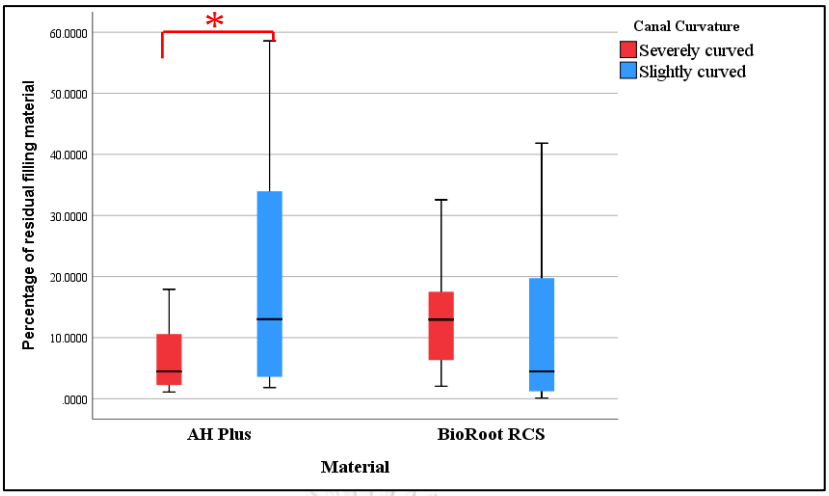


Figure 10 Box plot of residual filling material

The horizontal bar inside the box indicated the median value, *A significant between subgroups.

The least amount of residual filling material after retreatment method was subgroup SevA followed by SliB and SevB respectively. The greatest amount of residual filling material was subgroup SliA. Canals filled with AH-Plus had significant difference in residual filling material between severely curved and slightly curved canal (T-test P= .03). Nevertheless, there was no significant difference among four subgroups (Table 1) (Figure 10).

MicroCT images of root sections with remaining AH Plus and BioRoot RCS after retreatment (Figure 11). Left column illustrated canals at 9 mm from apex. Middle column illustrated canals at 6 mm from apex and right column illustrated canals at 3 mm from apex. A-C showed AH Plus in severely curved canal. D-F showed AH Plus in slighly curved canal. G-I showed BioRoot RCS in severely curved canal and J-L showed BioRoot RCS in slightly curved. MicroCT images showed the residual sealer in the root canals including fin and isthmus which could not be removed (*yellow arrow*).

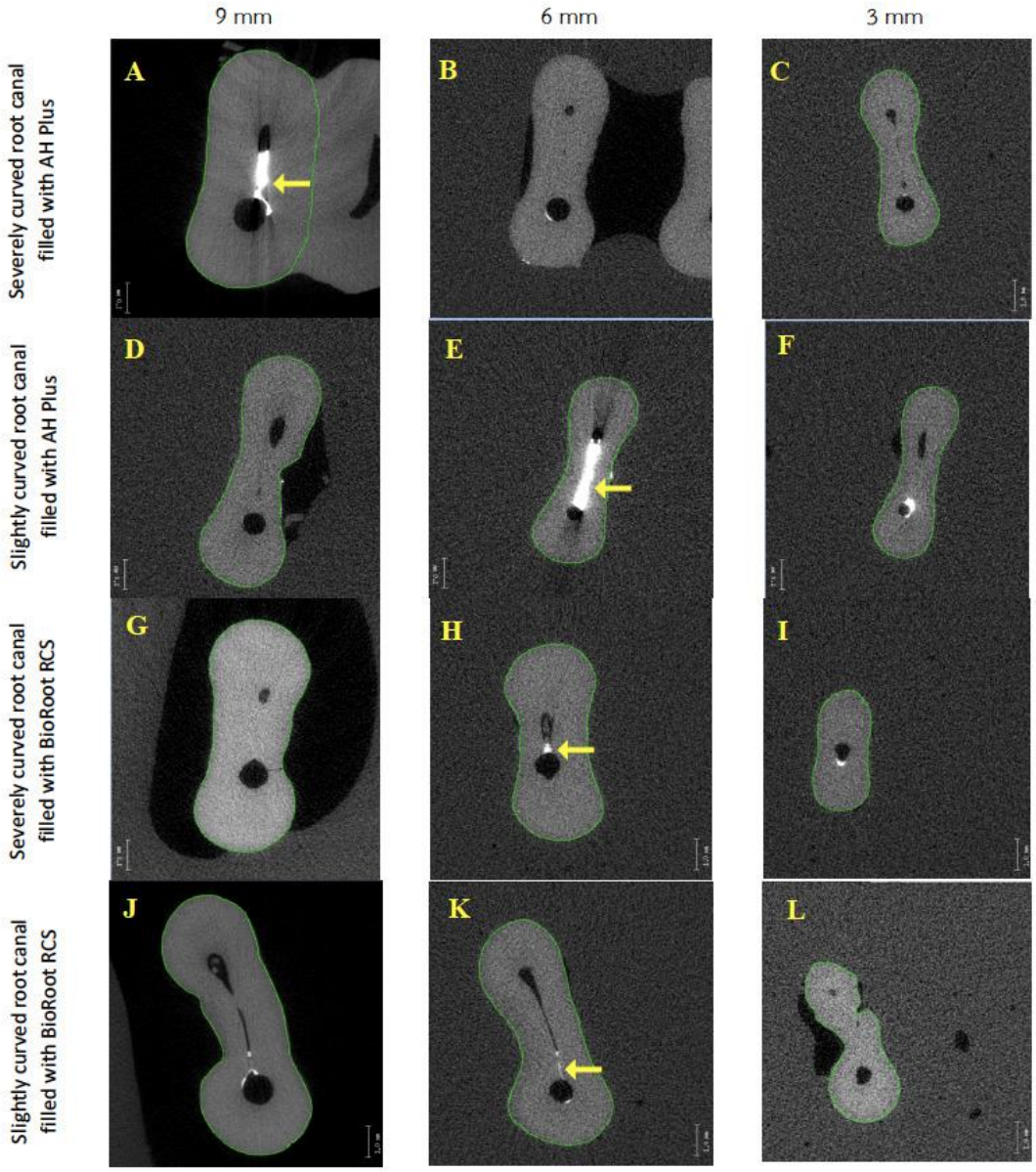


Figure 11 MicroCT images of root sections with remaining AH Plus and BioRoot RCS after retreatment

sealer in the fin and isthmus (yellow arrow)

Confocal microscopy images of root sections with remaining AH Plus and BioRoot RCS, with red indicator of Rhodamine B after retreatment (Figure 12). Left column illustrated canals at 9 mm from apex. Middle column illustrated canals at 6 mm from apex and right column illustrated canals at 3 mm from apex. A-C showed AH Plus in severely curved canal. D-F showed AH Plus in slightly curved canal. G-I showed BioRoot RCS in severely curved canal, the debris at the outer root surface (*yellow star*) and J-L showed BioRoot RCS in slightly curved. Confocal images of all levels of root canals found residual sealer penetration in dentinal tubules with different depth, also found sealer in the fin and isthmus (*yellow arrow*).

At 9 and 6 mm from apex of BioRoot RCS groups, sealer showed more penetration in dentinal tubules than AH plus groups. At 3 mm from apex, both AH plus and BioRoot RCS evenly penetrated in dentinal tubules.

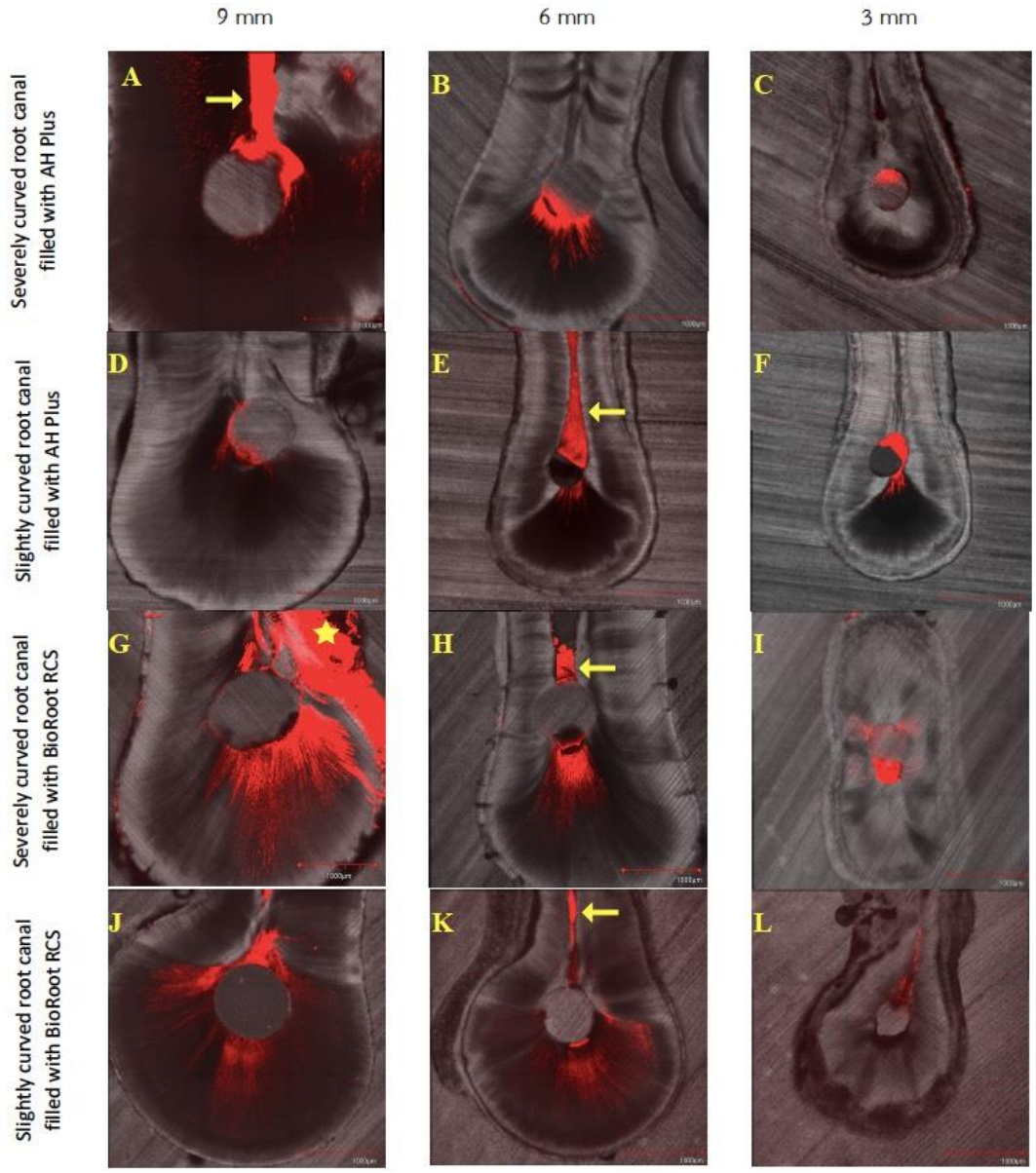


Figure 12 Confocal microscopy images of root sections with remaining AH Plus and BioRoot RCS, with red indicator of Rhodamine B after retreatment

the debris at the outer root surface (*yellow star*), sealer in the fin and isthmus (*yellow arrow*)

CHAPTER V
DISCUSSION

Retreatment efficacy of bioceramic sealer in severely curved root canal has less been investigated. Such a study can play a key role in understanding the influence of root canal curvature on bioceramic sealer retreatment efficacy. Efficacy included the ability to regaining canal patency, time for retreatment and percentage of residual filling material left in curved root canals.

Canal patency

Apical third of persistent infection canal had debris and foreign material along with accumulation of inflammatory cell as well as bacterial colonies (63). Regaining apical patency of curved root canals ensures the correct path to apex and the ability to clean effectively at the apical part of root canal. In curved root canals, maintaining the patency could avoid getting iatrogenic error from losing the working length (64). AH Plus groups could well regain patency with 100% in slightly curved canals and 87% in severely curved canals. The BioRoot RCS groups could regain patency only 64% in slightly curved canals and 67% in severely curved canals. It showed that teeth filled root canals with AH Plus were more possible to reach the apical foramen than roots filled with BioRoot RCS. The previous studies presented the regaining patency among 100% to 14% (9-11) while their methods and type of bioceramic sealers were different. Kim et al (9) used BC sealer and keeping in 100% humidity. When BC sealer confronted with moisture microhardness of the sealer changed (31) which might facilitate file passing the unset sealer to regain 100% patency. Solvent softened the filling material and could lead to regain up to 93% apical patency (10, 11). Oltra et al (11) regained only 14% patency in bioceramic sealer retreatment without solvent. Their root canals were obturated with heat which increased the film thickness and hard setting of bioceramic sealer (27) so that the sealer might be removed harder.

Time for retreatment

The longest retreatment time was 232.5 seconds in slightly curved canals filled with BioRoot RCS and the shortest retreatment time was 193.3 seconds in slightly curved canals filled with AH Plus. In BioRoot RCS group, severely curved root canals used lesser time in retreatment. (Table 1) This might be the effect of lesser sealer loading in severely curved root canals, so it was easier and faster to remove the filling material. The retreatment time was not significant difference between each subgroup (Fig. 3B). This was similar to Donnermeyer et al (14) which showed the retreatment time of BioRoot RCS and AH Plus with Reciprocating rotary file as 206.4 and 230.7 seconds respectively although they used straight and single root canals. Neelakantan et al (13) reported that bioceramic sealers spent shorter retreatment time (350 and 360 seconds) than AH Plus (445 seconds). However, they used MTA Fillapex and MTA plus which are not pure calcium silicate sealers.

Residual filling material with MicroCT and Confocal microscopy

Using solvent in removing sealers left more residual filling material than rotary instrument alone (10-12). PUI enhanced remaining material removal in moderately to severely curved root canal efficiently (34, 65). This study manipulated retreatment without solvent along with using PUI in curved root canals. There was no significant difference in percentage of residual filling materials in all subgroups (Table 1) (Fig. 3C). The severely curved canal of AH Plus group had lesser residual filling materials significantly than slightly curved canal group. When using the rotary instrument and PUI in severely curved canals, the inner curved dentine of canals was removed more than that of the slightly curved canal. This was not true in BioRoot RCS group. BioRoot RCS could release calcium ion which react with phosphate body fluid to form hydroxyapatite crystal that was hard setting and difficult to remove (7, 26).

Different instruments such as scanning electron microscope (9, 10, 12), stereomicroscope (15), microscope (14) and micro-computed tomography (MicroCT) (11, 17, 37, 52, 66) have been used to evaluate the retreatment efficacy. MicroCT along with Confocal microscope analysis were used in this study as an attempt to better reveal the remaining sealers in dentinal tubules. MicroCT is a non-destructive

and reproducible method (67). However, when MicroCT evaluation showed complete cleanliness of root filled with materials, in fact, it did not completely clean when evaluated with confocal microscopy. MicroCT images of BioRoot RCS in severely curved canals at 9 mm from apex (Fig. 1G) showed complete removal of sealer and BioRoot RCS in slightly curved canal (Fig. 1J) showed some remnant of sealers. The confocal microscope images exhibited differently. The severely curved canal at 9 level in Figure 2G revealed more sealer penetration (84.5%) than the slightly curved canal (78.92%) in Figure 2J. Evaluation with Confocal microscope showed more explicit remaining sealer than the MicroCT alone.

Complexity of root canal anatomy was the limitation in retreatment particularly the mesial root of mandibular first molars which have 52% Vertucci Class IV and 35% Vertucci Class II anatomy (68). 30.8% of Vertucci Class II reported the merging isthmus at 7 mm level from apex (69). MicroCT images (Fig. 1E, 1H, 1K) illustrated fin and isthmus at 6 mm from apex which sealers could spread into the isthmus even though the canals were obturated with single-cone technique. MicroCT evaluation showed 13.3% of total residual filling materials in severely curved canal filled with BioRoot RCS. Romeiro et al (16) exhibited 8-15% of residual filling materials in severely curved canal filled with BC sealer without analyzing the residual filling materials in the isthmus region. Their MicroCT evaluation might show more residual filling materials if the residual filling material in the isthmus region were included. During the retreatment procedure, one (6.67%) WaveOne Gold reciprocating rotary instrument had accidentally broken at the apical third of one canal in subgroup SliB. This error might be the torsional failure from the apical blockage of hard setting bioceramic sealer couple with attempt to pass the root filling material to apex.

Most confocal microscope images displayed deeper penetration of BioRoot RCS comparing to AH Plus. At 6 mm from apex, the penetration of into dentinal tubules of BioRoot RCS in severely curved group (1.3 mm) and slightly curved group (1.12 mm) (Fig. 2H, 2K) were deeper than AH Plus groups (0.87, 0.54 mm) (Fig. 2B, 2E). This might be the influence of better fluidity of BioRoot RCS over AH Plus (8). Kim et al (9) showed the penetration of AH Plus (1.14 ± 0.17 mm) in dentinal tubules

deeper than bioceramic sealer (0.573 ± 0.099 mm) at 6 mm from apex. They used continuous wave obturation that heat might reduce flow property of Bioceramic sealer (27, 49).

The root canals at 9 and 6 mm from root apex showed more sealer penetration into dentinal tubules than the 3 mm level corresponding with the size of the dentinal tubules at their levels (70). The tubular sclerosis at the apical third might impair the penetration of sealer in dentinal tubules at 3 mm level (71). Canali et al (72) demonstrated that re-obturation of new sealer into the retreated dentinal tubules could not be accomplished. Therefore, if nonsurgical root canal retreatment failed from the unremovable sealers in the complex area of isthmus and fin or in dentinal tubules, the surgical root canal retreatment should be considered.

There was no significant difference in retreatment efficacy of bioceramic sealer and AH plus in both severely and slightly curved root canals. Slightly curved canals had more counts for re-establishing the apical patency. The retreatment time was no significant difference in all groups. Also, Residual filling materials of canals filled with BioRoot RCS had no significant difference in both type of curved root canals. Bioceramic sealer retreatment in severely curved root canals could be accomplished comparable to that of slightly curved root canals.

Conclusion

The retreatment efficacy of BioRoot RCS in severely curved root canal was similar to that of slightly curved root canal. The retreatment efficacy of BioRoot RCS was comparable to the AH Plus retreatment, except that the AH Plus groups regained significantly more patency than the BioRoot RCS groups in slightly curved canals.

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APPENDIX

Table 2 The depth of sealers penetration into dentinal tubule at 9, 6 and 3 mm from the apex of root

	9 mm	**6mm**	**3mm**
Subgroup IA	0.8 mm	0.87 mm	0.12 mm
Subgroup IIA	0.54 mm	0.54 mm	0.49 mm
Subgroup IB	1.69 mm	1.3 mm	0.34 mm
Subgroup IIB	1.31 mm	1.12 mm	0.25 mm

Table 3 Regaining apical patency, Time for retreatment and Residual filling materials of the severely curved root canals filled with AH Plus group

No	Apical patency (Yes/No)	Time (second)	Residual filling materials (%)
1	Yes	322.72	12.98541
2	Yes	473.59	2.536517
3	Yes	131.65	1.091342
4	Yes	191.62	4.460847
5	Yes	165.98	15.36561
6	Yes	254.31	3.8466
7	No	150.28	1.954994
8	Yes	243.73	1.56515
9	Yes	146.86	3.37289
10	Yes	212.33	1.678859
11	Yes	189.27	5.777607
12	No	187.94	7.25475
13	Yes	182.5	8.181084
14	Yes	169.39	26.06982
15	Yes	232.32	17.91239

Table 4 Regaining apical patency, Time for retreatment and Residual filling materials of the slightly curved root canals filled with AH Plus group

No	Apical patency (Yes/No)	Time (second)	Residual filling materials (%)
1	Yes	185.88	2.359694
2	Yes	162.47	32.86316
3	Yes	171.47	7.634744
4	Yes	156.52	3.845738
5	Yes	167.68	2.478884
6	Yes	153.18	13.0132
7	Yes	453.63	35.06177
8	Yes	144.54	42.61257
9	Yes	170.2	15.3941
10	Yes	132.53	8.845177
11	Yes	133.22	58.57243
12	Yes	285.26	19.00863
13	Yes	203.96	3.300841
14	Yes	187.89	43.50978
15	Yes	190.69	1.818355

Table 5 Regaining apical patency, Time for retreatment and Residual filling materials of the severely curved root canals filled with BioRoot RCS group

No	Apical patency (Yes/No)	Time (second)	Residual filling materials (%)
1	No	392.77	2.04705
2	No	183.34	5.976847
3	Yes	295.59	3.588424
4	Yes	131.13	9.548198
5	No	167.31	32.56446
6	Yes	223.91	15.40242
7	Yes	238.28	12.94654
8	Yes	235.58	19.54342
9	Yes	172.74	16.66031
10	Yes	137.5	13.22747
11	Yes	200.6	18.35473
12	No	158.77	2.74116
13	Yes	210.57	30.32023
14	Yes	246.7	10.03033
15	No	194.26	6.677386

Table 6 Regaining apical patency, Time for retreatment and Residual filling materials of the slightly curved root canals filled with BioRoot RCS group

No	Apical patency (Yes/No)	Time (second)	Residual filling materials (%)
1	Yes	196.77	31.32802
2	Yes	330.38	0.112661
3	Yes	318.84	19.73198
4	No	292.28	0.870144
5	No	232.6	13.43954
6	No	279.33	7.400288
7	Yes	146.08	41.82544
8	Yes	166.21	4.96464
9	Yes	208.36	31.64861
10	No	241.98	1.743403
11	Yes	170.68	0.321973
12	No	264.57	3.974609
13	Yes	237.44	1.212728
14	Yes	169.49	2.417753

Statistical Analysis

Table 7 Normal distribution of retreatment time using Kolmogorov-Smirnov test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Retreatment Time	.150	59	.002	.828	59	.000
a. Lilliefors Significance Correction						

The result showed that the *p*-value is 0.002 based on Kolmogorov-Smirnov test. The null hypothesis was rejected so the retreatment time was not normally distributed at the significance level 0.05.

According to the tests of normality, the normality assumption was violated. Then, the reciprocal square root of the retreatment time (RSRTime) was performed.

Table 8 Normal distribution of RSR retreatment time using Kolmogorov-Smirnov test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RSR_Retreatment Time	.072	59	.200*	.970	59	.158
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Base on the Kolmogorov-Smirnov test, the *p*-value was 0.200. The RSR retreatment time was normally distributed at the significance level 0.05. Thus, One-way ANOVA was used to analyze in retreatment time.

Table 9 One-way ANOVA test of retreatment time

ANOVA					
Reciprocal Square Root of Retreatment Time					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.00042	3	.00014	1.414	.248
Within Groups	.00546	55	.00010		
Total	.00588	58			

p-value was 0.248. The null hypothesis was not rejected. Hence, there was no difference in retreatment time of each subgroups at the significance level 0.05.

Table 10 Number of regaining apical patency count by root canal curvature and type of sealers

Apical patency Crosstabulation					
Count					
Root Canals			Patency		Total
			No	Yes	
severely curved	Material	AH Plus	2	13	15
		BioRoot RCS	5	10	15
	Total		7	23	30
Slightly curved	Material	AH Plus	0	15	15
		BioRoot RCS	5	9	14
	Total		5	24	29
Total	Material	AH Plus	2	28	30
		BioRoot RCS	10	19	29
	Total		12	47	59

Table 11 Chi-Square test of regaining apical patency

Chi-Square Tests						
Root Canals		Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Severely curved	Pearson Chi-Square	1.677[c]	1	.195		
	Continuity Correction[b]	.745	1	.388		
	Likelihood Ratio	1.721	1	.190		
	Fisher's Exact Test				.390	.195
	N of Valid Cases	30				
Slightly curved	Pearson Chi-Square	6.473[d]	1	.011		
	Continuity Correction[b]	4.212	1	.040		
	Likelihood Ratio	8.413	1	.004		
	Fisher's Exact Test				.017	.017
	N of Valid Cases	29				
Total	Pearson Chi-Square	7.042[a]	1	.008		
	Continuity Correction[b]	5.430	1	.020		
	Likelihood Ratio	7.539	1	.006		
	Fisher's Exact Test				.010	.009
	N of Valid Cases	59				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.90.

b. Computed only for a 2x2 table

c. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.50.

d. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.41.

For slightly curved root canals, *p*-value of Pearson Chi-square test was 0.011. The null hypothesis was rejected. Hence, there was association between the regaining apical patency and sealer in slightly curved root canals at the significance level 0.05.

For severely curved root canals, *p*-value of Pearson Chi-square test was p = 0.195. The null hypothesis was not rejected. Hence, there was no association between the regaining apical patency and sealer in severely curved root canals at the significance level 0.05.

Table 12 Normal distribution of percentage of residual filling material using Kolmogorov-Smirnov test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Percentage of Residual filling material	.157	59	.001	.911	59	.000
a. Lilliefors Significance Correction						

The result showed that the *p*-value is 0.001 based on Kolmogorov-Smirnov test. The null hypothesis was rejected so the percentage of residual filling material was not normally distributed at the significance level 0.05.

According to the tests of normality, the normality assumption was violated. Then, the natural log of the percentage of residual filling material (LN_ PercentageResidual) was performed.

Table 13 Normal distribution of LN Percentage of residual filling material using Kolmogorov-Smirnov test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
LN_Percentage of Residual filling material	.070	59	.200*	.981	59	.507
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Base on the Kolmogorov-Smirnov test, the *p*-value was 0.200. The LN residual filling material was normally distributed at the significance level 0.05. Thus, One-way ANOVA was used to analyze the percentage of residual filling material.

Table 14 Homogeneity of variances test of LN Percentage of residual filling material

Test of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
LN_Percentage of residual filling material	Based on Mean	3.872	3	55	.014
	Based on Median	3.633	3	55	.018
	Based on Median and with adjusted df	3.633	3	39.898	.021
	Based on trimmed mean	3.863	3	55	.014

From the homogeneity of variances test, *p*-value of Levene statistic was 0.014. The null hypothesis was rejected because the variances were not equally homogeneous at the significance level 0.05.

According to the tests of equality of error variances, the homogeneity of variances was violated. Welch or Brown and Forsythe test of One-way ANOVA were selected to analyze.

Table 15 Welch or Brown and Forsythe test of One-way ANOVA for percentage residual filling material analysis

Robust Tests of Equality of Means				
LN_Percentage of Residual filling material				
	Statistic[a]	df1	df2	Sig.
Welch	2.518	3	29.472	.077
Brown-Forsythe	2.377	3	37.429	.085
a. Asymptotically F distributed.				

p-value of Welch test is 0.077 and *p*-value of Brown-Forsythe test is 0.085. The null hypothesis was rejected. Hence, there was no difference in percentage of residual filling material of each subgroups at the significance level 0.05.

Table 16 Independent samples t-test of percentage of residual filling material by type of root canal curvature for the root canals filled with AH Plus

Independent Samples Test[a]										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Percentage of Residual Filling Material	Equal variances assumed	13.681	.001	-2.290	28	.030	-11.7510125	5.1309374	-22.2612613	-1.2407637
	Equal variances not assumed			-2.290	18.312	.034	-11.7510125	5.1309374	-22.5175446	-.9844805
a. Material = AH Plus										

p-value of t-test was 0.030. The null hypothesis was rejected. Hence, there was difference in percentage of residual filling material between severely curved root canal and slightly curved root canal for the root canals filled with AH Plus at the significance level 0.05.

Table 17 Independent samples t-test of percentage of residual filling material by type of root canal curvature for the root canals filled with BioRoot RCS

Independent Samples Test[a]										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Percentage of Residual Filling Material	Equal variances assumed	3.326	.079	.413	27	.683	1.8091866	4.3814780	-7.1808637	10.7992368
	Equal variances not assumed			.407	22.274	.688	1.8091866	4.4437658	-7.4000404	11.0184136
a. Material = BioRoot RCS										

p-value of t-test is 0.683. The null hypothesis was not rejected. Hence, there was no difference in percentage of residual filling material of severely curved root canal and slightly curved root canal for the root canals filled with BioRoot RCS at the significance level 0.05.

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