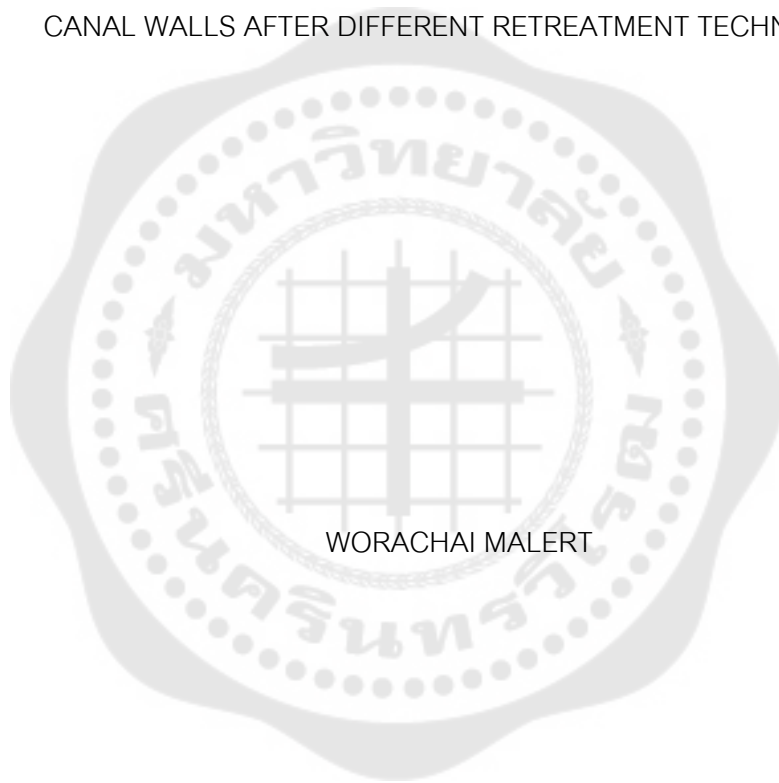




PUSH-OUT BOND STRENGTH OF CALCIUM SILICATE-BASED SEALER TO ROOT
CANAL WALLS AFTER DIFFERENT RETREATMENT TECHNIQUES



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2023

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A Thesis Submitted in Partial Fulfillment of the Requirements
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THE THESIS TITLED

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BY

WORACHAI MALERT

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Degree	MASTER OF SCIENCE
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Aim: To compare the push-out bond strength of calcium silicate-based sealer to root canal walls after various retreatment techniques. Materials and methods: 40 human single-rooted maxillary anterior teeth were decoronated with a standardized root length of 16 mm. The roots were randomly divided into four groups of 10 roots each. The control group was performed without retreatment. The experimental groups were obturated with AH Plus[®], followed by retreated using three retreatment techniques as follows: Mtwo R[®], Mtwo R[®] with GuttaClear, and Mtwo R[®], with xylene after seven days of storage. Retrieval time was recorded in minutes. All samples were re-obturated with a calcium silicate-based sealer and were stored for seven days. The specimens were sectioned 2 mm thickness perpendicularly to the long axis to obtain three slices per root, representing the coronal, middle and apical levels, and then loaded by a Universal Testing Machine until root canal filling dislodgement occurred. The maximum failure load was expressed in MPa. Failure modes were examined under stereomicroscopy at 50x magnification. Results: Mtwo R group exhibited the highest bond strength in all experimental groups. From statistical analysis, at the coronal and middle levels, the bond strength between control group and Mtwo R group showed no significant differences, furthermore, the Mtwo R group was superior to Mtwo R with xylene. At the apical level, no statistically significant difference was noticed. The pattern of filling dislodgement as cohesive failures was predominantly observed. Additionally, the shortest time taken was Mtwo R with GuttaClear group. Conclusion: Retreatment without solvent exhibited the highest bond strength among all groups when retreatment using calcium silicate-based sealer as sealer.

Keyword : Retreatment Gutta-percha solvent Calcium silicate-based sealer Push-out bond strength

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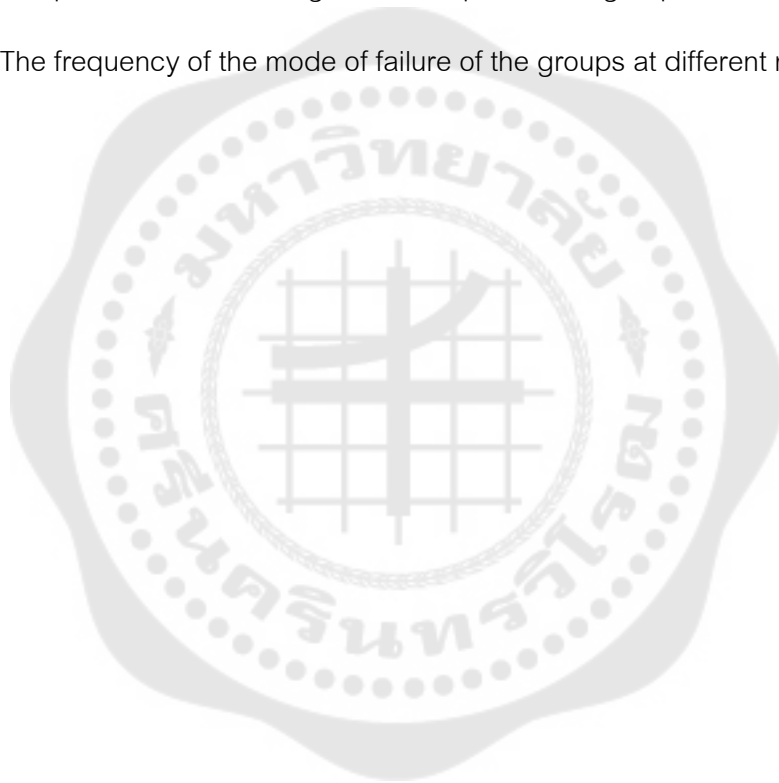
TABLE OF CONTENTS

	Page
ABSTRACT	D
ACKNOWLEDGEMENTS.....	E
TABLE OF CONTENTS.....	F
LIST OF TABLES.....	H
LIST OF FIGURES	I
CHAPTER I INTRODUCTION.....	1
Background of the study.....	1
Research Question.....	5
The objective of the study.....	5
Scope of the study	5
The hypothesis of this study	5
Variables of the study	6
Conceptual framework of the study.....	7
CHAPTER II LITERATURE REVIEW.....	8
Non-surgical root canal retreatment	8
Factors affecting root canal filling materials removal	9
The root canal filling materials removal techniques	10
Gutta-percha solvents.....	12
Efficacy of root canal filling material removal using various retreatment techniques..	14
Effects of gutta-percha solvent on dentin.....	15
The push-out bond strength between sealer and root canal walls	16

Effect of retreatment techniques on the push-out bond strength between sealer and root canal walls	18
Calcium silicate -based sealer.....	19
CHAPTER III MATERIALS AND METHODS	24
Samples calculation and selection	24
Tooth preparation	25
Endodontic procedures	25
Push-out bond strength testing procedures.....	30
Data collection and statistical analysis.....	32
CHAPTER IV RESULTS	33
Time taken to retrieve gutta-percha in experimental groups.	34
The push-out bond strength between root canal filling material and radicular walls. .	35
The mode of failure at different root levels.	37
CHAPTER V DISCUSSION CONCLUSION AND SUGGESTION	39
Discussion.....	39
Conclusion	44
Suggestion	45
REFERENCES.....	46
VITA	57

LIST OF TABLES

	Page
Table 1 Examples and basic information of calcium silicate-based sealers	21
Table 2 The mean and standard deviation for the taken time for gutta-percha retrieval using the different techniques.....	34
Table 3 The push-out bond strength of the experimental groups.....	36
Table 4 The frequency of the mode of failure of the groups at different root levels.	37



LIST OF FIGURES

	Page
Figure 1 Conceptual framework of the study.....	7
Figure 2 Mtwo R retreatment files and its cutting tip design	11
Figure 3 Equation of calcium silicate-based sealer reaction	20
Figure 4 Sample size calculation	24
Figure 5 Decoronated tooth preparation	25
Figure 6 Measuring the shape and diameter size of canal space	26
Figure 7 Specimen preparation from length determination (A) and root canal obturation (B)	27
Figure 8 Radiographic images of specimens to verify quality of root canal filling materials in buccolingual view (A) and mesiodistal view (B)	27
Figure 9 Radiographic images of specimens to verify removal process	29
Figure 10 Radiographic images of specimens to verify quality of root canal filling materials	29
Figure 11 Embedded specimen in acrylic resin	30
Figure 12 Slicing dentin thickness of the sample	30
Figure 13 Schematic drawing of the push-out bond strength test	31
Figure 14 The formula of push-out bond strength.	31
Figure 15 Schematic drawing for analysis of the mode of failures.....	32
. Figure 16 Representative images of root sliced specimens in all groups at the apical level (x50).	33
Figure 17 The bar graph depicts the mean time taken for the removal of gutta-percha.	34

Figure 18 The bar graph depicts the mean push-out bond strength..... 35

Figure 19 Representative images of root sliced specimens in all groups at the apical level (x50). 38



CHAPTER I

INTRODUCTION

Background of the study

The removal of the existing root canal filling, which facilitates disinfection and instrumentation from the failed primary endodontic treatment, is one of the procedures for non-surgical endodontic retreatment ⁽¹⁾. Residual gutta-percha after root canal retreatment creates a mechanical barrier that prevents irrigating solutions, intracanal dressings, and root canal filling material from approaching the canal walls ⁽²⁾, which may affect the disinfection capacity and sealing ability leading to a reduction in the success rate of root canal retreatment ^(3, 4), therefore, removing root canal filling material plays an important role in retreatment procedures ⁽⁵⁾.

Gutta-percha is the most commonly used as core of root canal filling material with different root canal sealers for endodontic obturation ⁽⁶⁾. Several techniques have been proposed for removing gutta-percha from the root canal systems. These methods can be classified into four types, thermal, mechanical, chemical method, and also combined methods mentioned including burs, hand files, rotary files, ultrasonic, heat, and gutta-percha solvents ^(7, 8).

Gutta-percha removal employed by file, both hand file and rotary file, is commonly used. Several studies were reported that rotary instruments were more effective to eliminate root canal filling and safe for cutting the root canal walls than hand file ^(9, 10). Removal mechanisms due to gutta-percha cutting during rotation and softening that material from friction heat between file and root canal filling were suggested. To facilitate this process, combination with chemical agents such as chloroform, xylene, eucalyptol oil, and orange oil is recommended ⁽¹¹⁾, which was advantageous in increase softening and dissolving capacity of gutta-percha ^(12, 13). Moreover, use of this technique has beneficial effect in clinical chair time reduction and operator's fatigue lessening ⁽¹⁴⁾.

Although NiTi rotary instrument in gutta-percha removal was effective, residual material remained inside root canal was still problematic. Schirmeister, et al.⁽¹⁵⁾ reported that the different systems of rotary instrument affected the quantity of remaining root canal obturation material. Instrument with more acute angle can remove more gutta-percha than the other with more obtuse angle, which may due to easily to penetrate into the mass of root canal filling. Moreover, the more taper the rotary instrument is, the more root canal dentin the instruments remove. Newly designed rotary instruments for retreatment with sharp cutting tip and also less taper was offered.

The Mtwo[®] Retreatment (Mtwo[®] R) files (VDW, Munich, Germany) is one of retreatment files for obturation eliminating. It is comprised of cutting blades with two instrument files (size 25.05 and size 15.05) for the efficient retrieval of root canal fillings⁽¹⁶⁾. The techniques and methods of root canal retreatment with rotary instruments are identical to the conventional procedure, and the gutta-percha is removed using a file's brushing motion against the lateral root canal walls⁽¹⁷⁾. According to the study of Madhu, et al⁽¹⁸⁾ revealed that maximum efficacy for removal of filling materials was Mtwo[®] R instruments in comparison with ProTaper[®] retreatment files, WaveOne[®] files, and Hedstrom files. Complete removal of the root canal material from the root canal was proved to be unreachable.

To ensure the success of root canal retreatment, many studies were revealed the cleanliness, remaining filling, and effect to the root canal wall^(15, 19). The study of Horvath, et al⁽²⁰⁾ showed that less surface covered by filling was found in the retreatment without solvent. Rodig, et al.⁽²¹⁾, revealed that different retreatment procedures were affected to the quantity of the remaining material inside the root canal. Another report from Rached-Junior, et al⁽²²⁾ supported the effect of the remaining of obturation material on push-out bond strength of gutta-percha with AH Plus[®].

Push-out bond strength is generally used to evaluate interfacial bond strength between the materials and root canal walls^(23, 24), in the endodontic field, it was proved adhesion strength of the dentin and obturation material^(25, 26). This method has the advantage of permitting the evaluation of low bond strength even like root canal sealer.⁽²⁷⁾

The bond strength between endodontic sealers and root canal walls after the different retreatment techniques might be affected by root canal cleanliness. Palhais, et al.⁽²⁸⁾ showed that the push-out bond strength of Epoxy resin based- sealer was reduced after root canal retreatment especially retreatment with solvent. The same result from Shokouhinejad, et al⁽²⁹⁾ demonstrated the reduction of the push-out bond strength of Resilon/Epiphany SE sealer after retreatment with chloroform. Both studies confirmed that the remaining material on the root canal walls reduced the bond strength.

Although, the uncleanliness of root canal walls was confirmed in many studies, several techniques or new materials were used in order to improve their bond ability. Different types of sealer selected after retreatment may be one of the points which can be enhanced. Epoxy or methacrylate resin was the material of choice in retreatment due to high bond strength. However, a great number of published data were still shown unpromised results, it may be minimal surface bonded by those materials⁽³⁴⁾⁽³⁰⁾.

Nowadays, iRoot SP[®] (Innovative Bioceramik, Vancouver, BC, Canada), the first sealer in the group of calcium silicate-based sealers, was introduced to the market, maybe a novel choice of treatment. This sealer, an injectable premixed-paste, mainly composed of di- and tricalcium silicates mixed in colloidal silica, has good physicochemical properties, which include suitable setting time, high flow rate, low solubility, radiopacity, alkaline pH, and water absorption^(31, 32).

The setting mechanism of single premixed-paste calcium silicate-based sealers is water absorption from dentinal tubules with the concomitant formation of

hydroxyapatite at the surface within the root canal systems^(30, 33, 34). The study of Zhang, et al⁽³⁵⁾ found that iRoot SP[®] had the high bond strength, which explained by its composition. Calcium silicate uses the humidity existing in dentinal tubules to initiate and accomplish the setting reaction so that no shrinkage occurs during processing. Moreover, iRoot SP[®] could easily flow into the complexes of root canal systems such as dentinal tubules, lateral canals, and webs, caused by its greatly petite particle size⁽³⁶⁾. The study of Ersahan and Aydin⁽³⁷⁾ showed that iRoot SP[®] sealer had higher push-out strength than conventional resin-based sealers. Therefore, iRoot SP[®] displays improved dislocation resistance, as it has a micromechanical bond to dentin, which decreases the gap at the interface.

As mentioned before, lack of information regarding to the bond strength of calcium silicate-based sealer to root canal walls after the use of various retreatment techniques was studied. This study is designed to compare to the push-out bond strength of calcium silicate-based sealer to the root canal walls after the use of retreatment file, Mtwo[®] R, with or without two different gutta-percha solvents in simulated retreatment procedures.

Significance of the study

Success of non-surgical endodontic retreatment is depended on the effective removal of root canal filling material. Removal mechanisms due to gutta-percha cutting during rotation and softening the material from friction heat between file and root canal filling were suggested. Furthermore, the solvent was discovered to soften gutta-percha⁽³⁸⁾. On the other hand, the limited penetration depth of the sealers in the prior endodontic treatment during the retreatment process. By the way, the use of Mtwo[®] R files, GuttaClear and xylene during the retreatment process may showed an advantage⁽¹⁸⁾.

Many studies have been evaluated the effects of various root canal treatment procedures on the bond strength of root canal sealer⁽³⁹⁾. However, there is no information about the effects of various retreatment techniques used over different solvents on the bond strength of sealers to root canal walls. Therefore, assess the push out strength of the sealers during root canal retreatment for a more reliable retreatment technique is still necessary.

Research Question

Is there a difference in the push-out bond strength between calcium silicate-based sealer and the root canal walls after the use of various retreatment techniques?

The objective of the study

This study aims to compare the push-out bond strength of calcium silicate-based sealer to the root canal walls after the use of retreatment file, Mtwo R, with or without two different gutta-percha solvents in simulated retreatment procedures retreatment techniques.

Scope of the study

This study is an experimental laboratory research comparing the push-out bond strength after using various removal root canal filling techniques in simulated retreatment procedures.

The hypothesis of this study

Null hypothesis: There is no difference in the push-out bond strength between calcium silicate-based sealer and the root canal walls by using various retreatment techniques.

Alternative hypothesis: There are differences in the push-out bond strength between calcium silicate-based sealer and the root canal walls by using various retreatment techniques.

Variables of the study

1. Independent variables

Retreatment techniques

- No retreatment (Control)
- Retreatment with Mtwo R and Mtwo rotary instrument files alone
- Retreatment with Mtwo R and Mtwo rotary instrument files with GuttaClear
- Retreatment with Mtwo R and Mtwo rotary instrument files with xylene

2. Dependent variable

Push-out bond strength between calcium silicate-based sealer and the root canal walls

3. Controlled variables

- 3.1 Length and diameter of the tooth
- 3.2 Thickness and diameter of dentin slices
- 3.3 Duration and volume of orange oil and xylene using
- 3.4 Techniques of endodontic procedures
- 3.5 Techniques of push-out bond strength test procedures
- 3.6 Environment conditions (temperature and humidity)

Conceptual framework of the study

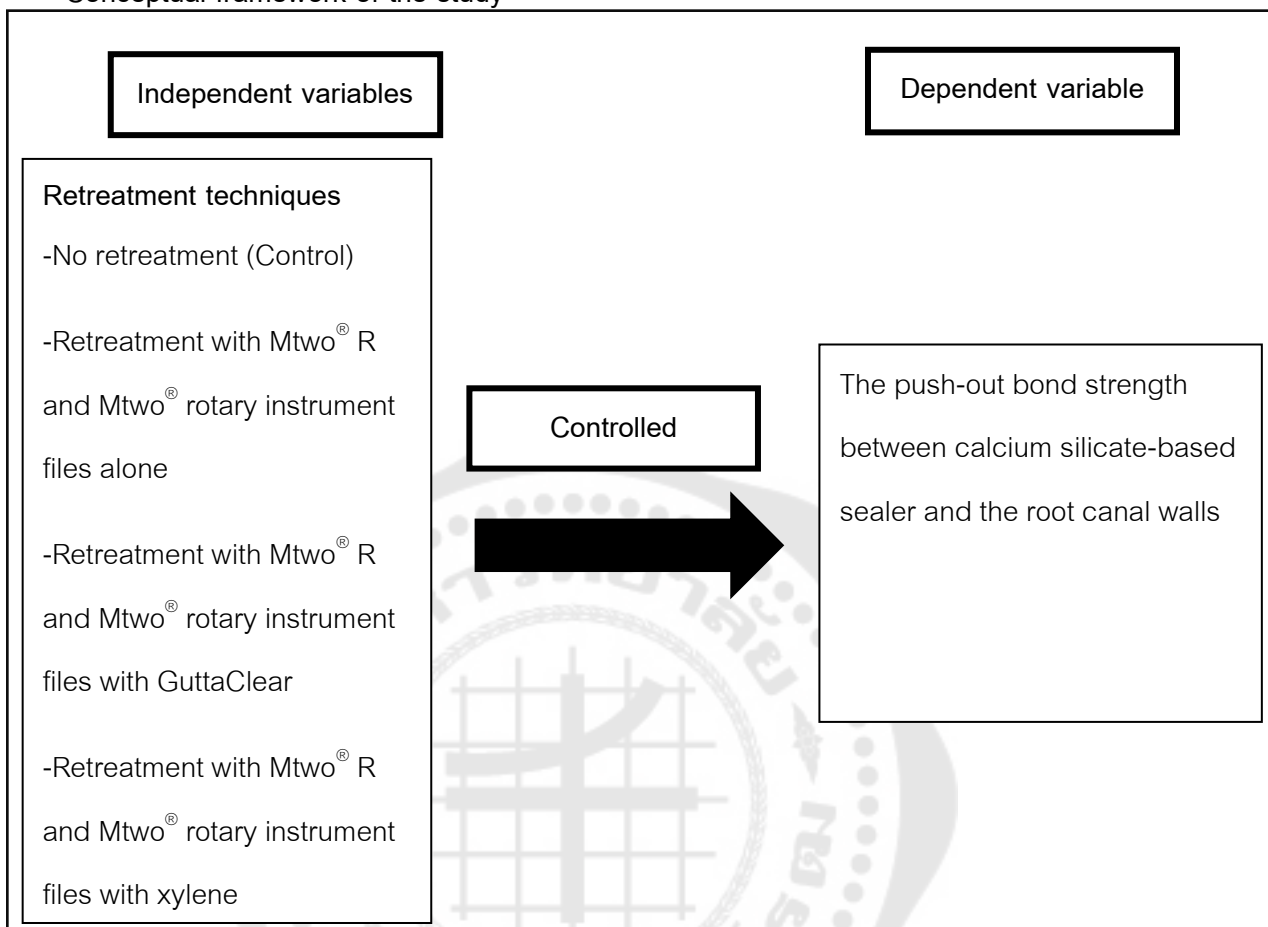


Figure 1 Conceptual framework of the study

CHAPTER II

LITERATURE REVIEW

Non-surgical root canal retreatment

Endodontic treatment aims to prevent pulp inflammation and eliminated intracanal microorganisms in order to heal the apical lesions⁽⁴⁰⁾. A great number of studies have shown that even particularly perfect endodontic treatment ends in treatment failures. The residual infection can cause the failure of primary root canal treatment from both the persistence of the infection from the initial endodontic treatment or the newcomers from the leakage of the root canal filling or restoration material^(4, 40).

Successful endodontic treatment can be found more than 80% of treated cases, but in case of failed cases, non-surgical or surgical endodontic retreatment was recommended to improve the success rate⁽⁴¹⁾. Although modern endodontic retreatment has been improved, it still results in some failure in both of non-surgical or surgical endodontic retreated cases, with 17-29.1% and 22.2-28.2%, respectively⁽¹⁾. Previous reports showed high success rate of non-surgical endodontic retreatment over surgical retreatment. Because intracanal infection which is common cause of that failure, can be reduced the quantity of intracanal microbes and promote the healing of periapical inflammation^(1, 41). In addition, non-surgical endodontic retreatment is less traumatic for the patient and requires fewer resources than surgical endodontic retreatment⁽⁴²⁾.

The removal of the original root canal filling material, which was determined to be inhabited by bacteria, is a crucial step in this root canal retreatment procedure⁽⁴³⁾. After a root canal retreatment, the remaining root canal filling material may impede the capability of reaching the apex, affecting both instrumentation and obturation, which can lead to the failure of the root canal retreatment^(3, 4). Moreover, it may hinder bacteria from intracanal chemical disinfection.

Several strategies, including mechanical, chemical, and combination techniques, were advocated to eliminate the root canal filling materials. Use of burs,

Gates Glidden drill or rotary files was proved to rid the root canal filling off the root canal especially gutta-percha. Ultrasonic, another mechanical method, can remove root canal filling in the group of metal core or hard setting cement such as silver cone or phosphate cement. The other technique is use of chemical agent that can soften and dissolve root canal filling, specifically gutta-percha and sealers, in the root canal systems. In several cases, gutta-percha removal by solvent was proved to be effective in gutta percha removal. ^(12, 13)

Factors affecting root canal filling materials removal

Gutta-percha with sealer is the most common root canal filling material. Three considerations are made prior to the root canal retreatment: ⁽⁷⁾.

1. The density of root canal filling material

The root canal filling is quite loose; file removal is recommended. However, if the root canal filling is utilized to seal the root canal tightly, it is advisable to soften the gutta-percha using gutta-percha solvent before removing it with a file.

2. The configuration of the treated root canal

The configuration of the root canal's curvature, gutta-percha should be eradicated using instruments such as Files and Gates Glidden if the root canal is straight. For curved root canal configurations, however, it is advised to employ gutta-percha solvent to soften the gutta-percha in order to prevent ledges or perforation.

3. The distance between the root canal filling material and the apex of the root

The root canal filling is shorter than the root apex; gutta-percha solvent is indicated for softening the gutta-percha. The gutta-percha solvent is not advised since the root canal filling extends beyond the apex ⁽⁸⁾.

Numerous methods for removing gutta-percha, and in some instances, a combination of tools and techniques is necessary. There are five techniques for removing root canal fillings^(7, 8), it must be considered appropriate on a case-by-case basis.

The root canal filling materials removal techniques

1. Pulling out the gutta-percha

This technique is used when the gutta-percha is loose, and the K-file is inserted into the root canal through the filling material. Then use a Headstrom file to peck into the gutta-percha and pull it out. To remove excess gutta-percha when the filling extends beyond the tip of the tooth root, use the same approach but put the file via the apical foramen.

2. Rotary instruments to remove the gutta-percha

It should only be used when root canal filling is terminated shorter than the apical foramen. This technique uses the K-file inserted into the root canal through the filling material and uses rotary instruments such as a nickel-titanium rotary instrument by operating the machine as specified by the manufacturer will cause gutta-percha to come out.

Recently, the retreatment rotary instrument systems were introduced for instances ProTaper Universal retreatment files, Mtwo R[®] retreatment files, D-Race[®], and R-Endo[®] with specifically designed files with cutting tips for non-surgical endodontic retreatment. Mtwo R retreatment files (Figure2) also include two files with retreatment-specific cutting tips. Mtwo R (15/0.05 and 25/0.05) files were utilized in an electric handpiece at a constant speed of 280 rpm and the manufacturer-recommended torque. Behind the blades, the depth of the space designed for dentine removal is increased, creating space for dentine removal and facilitating efficient GP and sealer removal. Due to its structure, it is able to effectively remove material. The Mtwo[®] R instruments with

positive rake angles behave more like Hedstrom files and are more effective at removing large quantities of filling material⁽¹⁶⁾.



Figure 2 Mtwo R retreatment files and its cutting tip design

3. Ultrasonic tools to remove the gutta-percha

In this way, heat is generated at the tool, thus, causing gutta-percha to soften with the instrument's long-slender head design, allowing easy access to the root canal. It also causes the gutta-percha to move up to the cavity in the tooth.

4. Heat-conducting tools

A heat carrier can be used to heat a fire, or use a spreader that is heated from the gutta-percha cutter in the relatively tight upper part and then use a file to pass through the filling material.

5. The combination using of gutta-percha solvents with the instruments

Gutta-percha solvents are used firstly to soften the gutta-percha to make it easier to insert the device through the root canal for removal. Especially the tight root

canal filling or curvature of the root canal, using a gutta-percha solvent to soften the gutta-percha helps reduce mishap procedures from the instruments.

From the above, it is essential to take into consideration the procedure for removing the root canal filling material in order to take into mind the variables that were discussed above. Additionally, the preferences of the user need to be taken into consideration here. In circumstances when the root canal filling material packed with gutta-percha is tight or in the root canal with a curve, it is important to be able to remove gutta-percha as quickly as possible without causing any hazard or mistake. This is the case in order to maximize patient safety. In order to successfully clear out the root canal filling material, it is important to make use of gutta-percha solvent.

Gutta-percha solvents

Gutta-percha is currently the most used filler material for root canals. If the initial root canal treatment is unsuccessful, a retreatment is required. Root canal removal is a crucial step in non-surgical root canal retreatment. It was discovered that removing root-filling material is problematic and necessitates additional processes and supplies. It aids cleaning and filling during root canal therapy. Gutta-percha solvent was discovered to dissolve gutta-percha in order to eliminate root canal filling materials. Therefore, gutta-percha solvents are needed for endodontic retreatment without surgery.

The study of Tamse et al.⁽¹²⁾ investigated the gutta-percha solvent efficiency of four gutta-percha solvents, such as chloroform, xylene, Endosolv-E[®], and orange oil. It was revealed that chloroform had the most outstanding efficiency followed by xylene in gutta-percha dissolution. It was also found that the orange oil could dissolve gutta-percha, similar to Endosolv-E[®]. In addition, Martos et al.⁽⁴⁴⁾ showed that xylene/xylol was the most efficient in softening gutta-percha, followed by chloroform and natural extracts

(eucalyptol oil and orange oil), respectively. It still needs to be more effective in softening gutta-percha than inorganic substances.

The study of Jantarat et al.⁽³⁸⁾ evaluated the softening effectiveness of gutta-percha solvent derived from natural extracts to chloroform. It was demonstrated that grapefruit oil and tangerine oil efficiently soften gutta-percha. Natural extracts can be used to soften gutta-percha, even though chloroform is still the most effective solvent.

In brief, solvents made specifically for gutta-percha are able to effectively dissolve or soften gutta-percha. After chloroform, the most efficient solvent for gutta-percha is eucalyptol oil, and then orange oil comes in third place. It has been proposed that the gradual softening of gutta-percha may be attributable to a shift in the total amount of beeswax elements present in gutta-percha.^(12, 38)

Orange oil is a substance that contains high amounts of d-Limonene. Therefore, it is speculated that orange oil can be a natural gutta-percha solvent. Wourms et al.⁽¹³⁾ investigated different solvents capable of dissolving gutta-percha. It was discovered that orange oil is one of nine natural gutta-percha solvents that can be dissolved. The average duration was 9.57 minutes, compared to 2.54 minutes for chloroform. Orange oil was able to dissolve gutta-percha, as was evident. The study of Jantarat et al.⁽³⁸⁾ consistently showed that natural extracts, for instance, grapefruit oil and tangerine oil, can soften the gutta-percha.

Orange oil has been shown to be more biocompatible than eucalyptol oil, xylol, chloroform, and halothane.⁽⁴⁵⁾ It was discovered that orange oil dissolves zinc oxide–eugenol-based sealers similarly to eucalyptus oil, chloroform, and xylene/xylol⁽⁴⁶⁾. Orange oil and eucalyptol are, however, poorly dissolving resin-based substances. According to certain studies, orange oil has a lesser dissolving capacity than chloroform and xylene. In contrast, several investigations demonstrated that orange oil, eucalyptol

oil, chloroform, and xylol all dissolve similarly. ^(47, 48) Orange oil may be suitable for dissolving or softening gutta-percha root canal filling materials.

Efficacy of root canal filling material removal using various retreatment techniques

None of the various endodontic retreatment techniques could entirely elucidate the root canal filling materials ^(10, 15, 19). The Mtwo retreatment instrument system was the most effective at removing root canal filling material, followed by ProTaper retreatment and WaveOne. Hedstrom files revealed the greatest amount of remaining filling material ⁽¹⁸⁾. Due to their design and distinctive characteristics, Mtwo retreatment files were most effective at removing obturation material. These files have two cutting blades with positive rake angle tips, enhancing the length of pitch from the apical to the coronal region, and an S-shaped cross section. The vertical spiral of the cutting blades allows for greater control and more precise cutting throughout the root canal ^(9, 18).

Many mechanical retreatment devices, including Mtwo[®] retreatment, ProTaper[®] retreatment, D-RaCe[®], and R-Endo[®], have been invented and manufactured in order to remove obturation materials from the root canals for subsequent endodontic treatment. Continuously rotating files are favored for the removal of root filling material ⁽⁴⁹⁾. Due to their high resistance and more flexibility to cyclic fatigue, the reciprocating instruments, such as Wave One[®] and Reciproc[®], are also recommended for non-surgical root canal retreatment. According to the findings of current studies ⁽⁵⁰⁾ revealed that the efficacy between retreatment and reciprocating systems was not differed.

The study of Rodig, et al ⁽²¹⁾ revealed that the effectiveness of D-RaCe[®], ProTaper[®] retreatment, and ProTaper[®] Universal in eliminating gutta-percha from curved canals was compared. When compared to ProTaper[®] retreatment, the quantity of remaining root canal materials was reduced when D-RaCe[®] rotary files were utilized, it can be explained by the cutting blade aspects and smooth surface manufactured by a

special electrochemical treatment, which may also attribute to the higher sharpness of D-RaCe[®] files. However, both NiTi retreatment methods exhibited a significant rate of procedural mistakes, including instrument separation and lateral perforation.

A recent study⁽⁵¹⁾ showed that Twisted-Files Adaptive (Kerr Dentistry, Orange, CA) enhanced the quantity of obturation materials removed from single oval canal of mandibular molars in distal roots compared to ProTaper[®] retreatment and Reciproc[®] R50 in the apical and middle levels. This outcome could be related to the reciprocating action of the instrument, which propels it forward continuously and could extrude debris into the apices. Conversely, the adaptive motion is a merging of reciprocating motion and, continuous rotating motion with the prior motion promoting the cutting of the obturation material and the second motion promoting material displacement in the coronal direction. However, no instrument systems and techniques have successfully elucidated all root canal material similar to other related investigations.

Effects of gutta-percha solvent on dentin

The effect of gutta-percha solvents on dentin was reported by the study of Rotstein, et al⁽⁵²⁾, which soaked teeth in chloroform, xylene, or halothane and found 29%, 7%, and 8% microstructural strength reduction in dentin, respectively. This reduction was also reported in dentin exposed to eucalyptol oil, but orange oil had no significant difference before and after exposure⁽⁵³⁾. These consequences may come from the intense lipid of these solvents that may jeopardize the dentin and its composition^(20, 38). Dentin strength was affected by chloroform, eucalyptol, and orange oil, with chloroform causing a statistically significant decrease in dentin strength. In contrast, the other agents had no effect on dentin strength because chloroform altered mineral deposition in root dentin.⁽⁵³⁻⁵⁵⁾

According to Topcuoglu et al⁽⁵⁶⁾ the immersion of chloroform for 5 minutes decreased the bond strength between AH plus[®], Sealapex[®], and MTA Filapex[®] and dentin, whereas eucalyptol oil extract and citrus oil extract had no statistically significant

effect at either 2 or 5 minutes. Chloroform decreased the adhesive strength between different types of sealers and dentin. Therefore, it is possible to understand how chloroform can alter the mineral composition that accumulates in the dentin and weaken the bonding material that is linked to the root canal filling material. In contrast, natural extracts like eucalyptol oil and orange oil did not affect the bonding strength of root canal filling materials because they did not alter the mineral composition of the dentin.

Altering the mineral composition in the dentin can be described by a study of Kaufman et al. ⁽⁵⁷⁾, which examined the effects of three gutta-percha solvents on phosphorus and calcium levels in teeth. After 15 minutes, Endosolv-E increased both phosphorus and calcium levels in the dentin, while chloroform and xylene had the effect of increasing only the phosphorus level in the dentin. Nonetheless, after 30 minutes, Endosolv-E[®], chloroform, and xylene increased both phosphorus and calcium levels in dentin.

Consequently, gutta-percha solvents affect the bond strength between endodontic sealers and root canal walls. Results change the mineral composition in the dentin and affect the bond strength between the sealer and the root canal walls. Especially the chloroform, which can increase the phosphorus and calcium levels in the dentin.

The push-out bond strength between sealer and root canal walls

The push-out bond strength test permits the evaluation of regional differences in bond strength between root levels, with an acceptable degree of variation in data distribution⁽⁵⁸⁾. Numerous root canal filling materials have been evaluated using the thin slice push-out bond strength technique. The push-out bond strength test is regarded to provide a more accurate evaluation of actual bonding effectiveness⁽⁵⁹⁾.

The bond strength of endodontic sealer is proportional to its efficacy to adhere to the root canal walls, and this property is crucial in both static and dynamic

circumstances. In a static situation, the adhesion eliminated the gaps and spaces that prevent fluid infiltration into the interface between the sealer and dentin. To prevent filling material dislodgement during post space preparation in prosthetic procedures under dynamic conditions, hence, adhesion is essential^(25, 26).

The push-out bond test has been revealed to be reliable and effective for evaluating the bond strength of sealer to root canal walls, which evaluated the dislocation resistance of the material. Furthermore, the push-out bond test resulted in failure parallel to the material-dentin interface, which similarly is to what is noticed in clinical settings⁽³⁹⁾.

The advantages of the push-out bond strength test are convenient specimen preparation, controlled the pressure on the sample, and used in low values test. In addition, it is possible to evaluate the different adhesion values for each level of the root canal. The push-out bond strength test is a reliable method because it can imitate the actual clinical situation compared to microshear bond strength test, which is a method that cannot clearly evaluate the used force in the test due to discrepancy in the positioning of the instrument used for testing between the filling material and the root canal dentin wall. Despite, the microtensile bond strength test can be accurately measured, it is difficulty in preparing the sample, which is very small specimen^(27, 39, 59, 60).

The push-out bond test has been regarded as a effective and reproducible technique for measuring the bond strength of root canal filling materials to radicular dentin. Bond strength created a valuable knowledges on the properties of adhesive materials.⁽⁶¹⁾ Despite the fact that the diameter of the root canal decreases toward the apex, numerous researches finding push-out bond strength have used a single size of plunger tip. The use of three different size of plunger tips to intimately fit to the diameter of the area of the materials attained from different root thirds in order to circumvent this issue. Consequently, the failure force was applied specially along the center of core

obturator material's axis, the using three plungers of varying sizes, without stressing the surrounding root canal walls. The larger diameter of the plunger led to higher bond strength, although the findings were not differed statistically significant^(60, 62).

The present failure mode analysis correlates well with the push-out test results. Therefore, dislocation resistance increases, mode of failure is more likely to happen within the sealer. The diameter of the plunger tip, exhibited significant differences in bond strength. which can be attributed by the push-out bond strength formula: pressure = force/contact area⁽⁵⁹⁾.

Effect of retreatment techniques on the push-out bond strength between sealer and root canal walls

In each of these trials^(22, 28, 29), the non-retreatment group exhibited stronger bond strength than the treated canals. Solvents weaken bond strength, according to Rached-Junior et al.⁽²²⁾ also discovered that the no-retreat group had greater bond strength than the retreatment groups. Regardless of the use of solvents, the interaction between sealers of different chemical compositions was cited as the primary cause for the weakening of the bond between the filling material and dentin. In addition, these studies indicated that canal refining until larger files (F4 and F5) could have a significant impact on the removal of sealer tags from the preceding filling, regardless of the solvent⁽²⁹⁾. This argument may contribute bond strength of the replacement filling.

The effect of gutta-percha solvents on the bond strength between sealer and root canal walls revealed that chloroform significantly reduced the bond strength between sealer and radicular dentin walls. Statistically, neither eucalyptol oil nor citrus oil had any effect^(63, 64).

All retreatment techniques, according to research by Palhais et al.⁽²⁸⁾, revealed that the existed gutta-percha remnants on root canal walls. The group with no

gutta-percha solvents had significantly stronger push-out bond strength than the groups with gutta-percha solvents. The groups treated with rotary instrumentation alone or combined with orange oil and xylol exhibited comparable bond strength, in contrast to the group treated with eucalyptol, which promoted the removal of all obturation materials. According to the prior study, Shokouhinejad, et al.⁽²⁹⁾ demonstrated the push-out bond strength of Resilon/Epiphany SE[®] following endodontic retreatment with Mtwo[®] rotary instruments did not statistically differ from that of non-retreated samples. Thus, it appears that the mechanical eliminating of Resilon/Epiphany S[®]E without the use of a solvent is a suitable retreatment procedure in aspects of the binding strength of the filling materials. Nonetheless, retreatment with a rotary devices and a solvent had no significant effect on the push-out bond strengths of MTA filapex[®] and AH Plus[®] sealers. A solvent can facilitate the penetration of rotary files into gutta-percha, reducing the time necessary for retreatment, as demonstrated by a vast number of prior experiments.⁽⁶⁵⁾

Calcium silicate -based sealer

These endodontic sealers are calcium silicate-based sealer, with Dicalcium silicate and Tricalcium silicate as their primary constituents. Different manufacturers use different proportions and combinations of contrast agents. It was discovered that the two-step reaction is as follows: ^(30, 31, 66) .

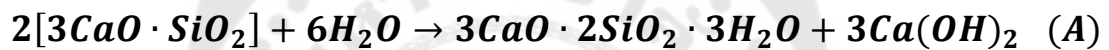
1. Hydration reaction

This reaction involves the addition of water molecules, which its components will dissolve and react with. The reaction begins when the substance comes into contact with water. This reaction produces calcium silicate hydrate gel (CSH) and calcium hydroxide, both of which are hard gels that encase the unreacted interior components.

2. Precipitation reaction

This reaction has a mechanism by which highly saturated ions are released until precipitation. Due to the addition of water molecules, calcium hydroxide is produced. It reacts with the phosphates in the body fluids to form calcium phosphate compounds (Calcium phosphate) and hydroxyapatite crystals upon contact with bodily fluids (Hydroxyapatite)⁽⁶⁷⁾.

Hydration reaction



Precipitation reaction



Figure 3 Equation of calcium silicate-based sealer reaction

The material and surfaces between the material and the dentin of the formed material consist of numerous air-filled cavities and pores. According to the research conducted by Fridland and Rosado⁽⁶⁷⁾, the presence of a large number of voids and pores can influence the occurrence of leakage or the material's strength. According to a study by Bozeman et al⁽⁶⁸⁾ gaps and pores were discovered in the material. However, the material can undergo a chemical reaction that adds water molecules and causes calcium ions to accumulate in the gaps and pores, forming hydroxyapatite crystals that can fill the gaps and pores, resulting in increased intimacy.

There are currently numerous types of calcium silicate-based sealants. Each manufacturer adds or subtracts certain components to create unique properties. The table provides examples of calcium silicate-based sealants and their essential properties.

Table 1 Examples and basic information of calcium silicate-based sealers

Trading name	Manufacturer	Components	Properties
-EndoSequence BC sealer	- Brasseler, USA	Tricalcium silicate,	- Setting time > 24 hrs.
- iRoot SP root canal sealer	- Innovative Bioceramix, Canada	Dicalcium silicate,	- Working time 2.4 hrs.
- Total Fill BC Sealer	- FKG Dentaire, Switzerland	Zirconium oxide, Colloidal silica, Calcium phosphate monobasic, Calcium hydroxide	- Available in Thailand
-Endoseal MTA	-Maruchi, Korea	Calcium silicate, Calcium aluminates, Calcium aluminoferrite, Calcium sulfates, Radiopacifier, Thickening agent	- Setting time 12.31 min. - Available in Thailand
- MTA Filapex	-Angelus, Brazil	Paste A: Salicylate resin, Bismuth trioxide, Fumed silica Paste B: Fumed silica, MTA, Dicalcium silicate, Calcium oxide, Tricalcium	- Setting time 2.5-4.5 hrs. - Working time 30-45 min. - Available in Thailand

Table 1 (continue)

Trading name	Manufacturer	Components	Properties
-ProRoot Endo Sealer	-Dentsply, USA	-Powder: Tricalcium silicate, Dicalcium silicate, Calcium sulfate, Bismuth oxide, Tricalcium aluminate Liquid: Viscous aqueous solution of water-soluble polymer	- Setting time 12 hrs. - Working time 65 min.
-BioRoot RCS	-Septodont, France	-Pure mineral formation and resin-free	- Setting time < 4 hrs.

Despite the availability of a variety of calcium silicate-based root canal sealants on the market, the iRoot SP[®] is one of the most prevalent calcium silicate-based endodontic sealers; the first calcium silicate-based sealer was introduced in 2007. iRoot SP[®], a contemporary endodontic sealer introduced for root canal filling and sealing applications, is a pre-mixed injectable white paste that is easy to handle. It consists of calcium silicate, calcium phosphate, calcium hydroxide, zirconium oxide, and does not contain aluminum. Water is necessary for setting and hardening. With a composition similar to that of white mineral trioxide aggregate (MTA), iRoot SP[®] possesses both superior physical properties and chemical resistance. Biocompatibility. iRoot SP[®] was shown to have an apical sealing capability equivalent to that of AH Plus[®], but with less cytotoxicity because of lack formaldehyde⁽³⁴⁾.

The research by Ersahan and Aydin⁽³⁷⁾ demonstrated that the iRoot SP[®] sealer possessed greater push-out strength than conventional resin-based sealer.

Consequently, iRoot SP[®] exhibits enhanced dislocation resistance due to its micromechanical bond to dentin, which reduces the interface gap. Moreover, iRoot SP[®] was reported to have a superior push-out bond strength than epoxy resin-based sealers when used with the single cone technique, and its push-out bond strength increased over a 3-month period and 100% humidity at 37 Celsius degree (°C)⁽⁶⁹⁾.



CHAPTER III

MATERIALS AND METHODS

Samples calculation and selection

Forty specimens (10 per group) were regarded as the minimum sample size necessary to observe a statistically significant difference between the two groups. The sample size was determined utilizing the F-test family (G*Power 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, North Rhine-Westphalia, Germany) with 80% power and 5% significant level according to Shokouhinejad, et al⁽²⁹⁾ as Figure4.

The research was authorized by the Human and Research Ethics Committee of Srinakharinwirot University (SWUEC-661003).

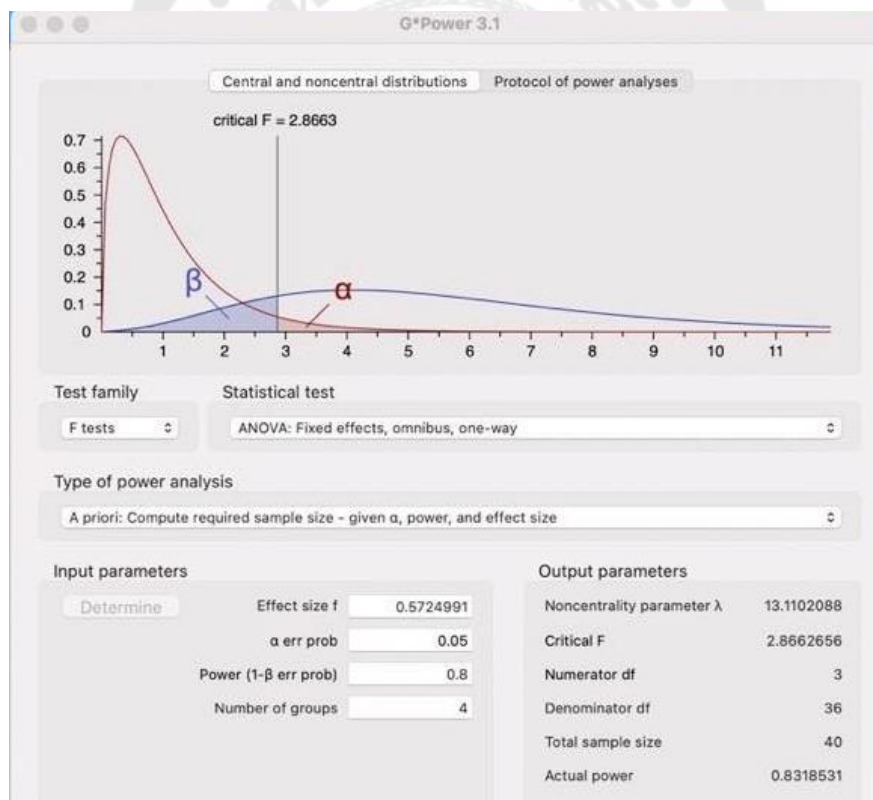


Figure 4 Sample size calculation

Tooth preparation

Forty extracted human single-rooted maxillary anterior teeth, which were more than 22 millimeters in tooth length⁽⁷⁰⁾ with fully formed apices were selected. Specimen storage was performed at room temperature in 0.1% thymol solution (M-Dent, Mahidol University, Thailand). Using an ultrasonic scaler (Satelec, Acteon, France), calculus and tissue debris were eliminated. Teeth with curved canal configuration, root caries, root fractures, cracked roots, calcification, and root resorption will be examined for sample exclusion criteria. The teeth were decoronated under water coolant with a carborundum disc to standardize a root length of 16 millimeters (Figure5). To confirm the presence of a straight single canal, buccolingual and mesiodistal view radiographs were taken.

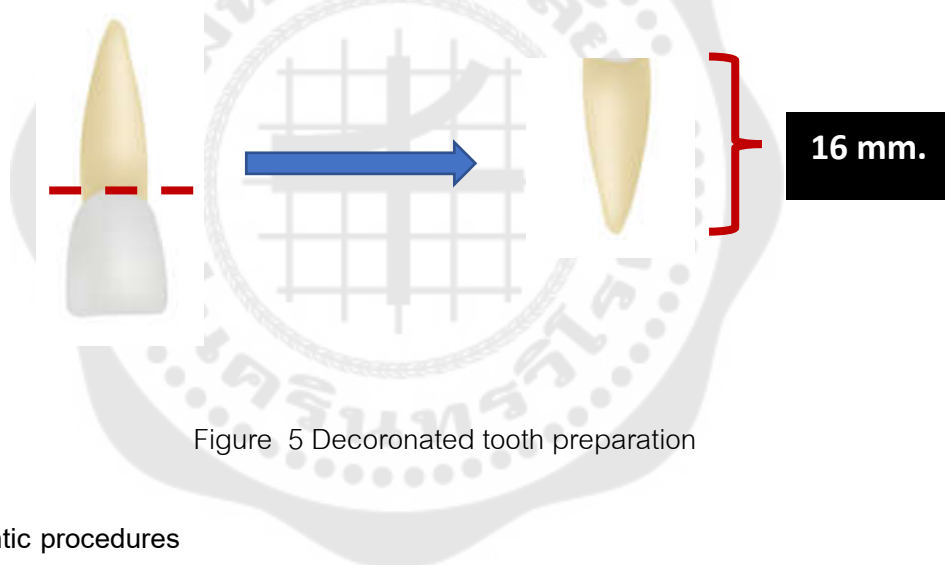


Figure 5 Decoronated tooth preparation

Endodontic procedures

The configuration of the canal space was measured buccolingual and mesiodistal using a digital vernier caliper (Mitutoyo; Absolute DIGIMAX, Japan) (Figure6). For determining the shape of the canal, the ratio of buccolingual and mesiodistal width was calculated to 1.0-1.5⁽⁷¹⁾. The maximum diameter and the initial apical file size (IAF) were measured, any teeth with greater than 1.40 millimeters or IAF larger than size 30 K-file⁽⁷²⁾ (K-file: Dentsply Sirona, USA) were excluded.



Figure 6 Measuring the shape and diameter size of canal space

The working length was established with 30/.02 K-file (Figure7A) and then sequentially instrumented with Nickel-Titanium rotary instrument (VDW, Munich, Germany) to reach the 40/.06 Mtwo[®] file⁽⁷³⁾. The canals were irrigated between each instrument with 5 milliliters of 2.5% sodium hypochlorite (M-Dent, Mahidol University, Thailand).

The teeth were stratified randomly divided into four groups of 10 roots each according to the retreatment techniques.

1. Control group = No retreatment
2. Mtwo R group = Retreatment with Mtwo[®] Retreatment files and Mtwo[®] rotary instrument files.
3. Mtwo R with GuttaClear group = Retreatment with Mtwo[®] Retreatment files and Mtwo[®] rotary instrument files with GuttaClear.
4. Mtwo R with xylene group = Retreatment with Mtwo[®] Retreatment files and Mtwo[®] rotary instrument files with xylene.

In the control group, the prepared root canals were re-instrumented with Nickel-Titanium rotary instruments to the 45/.04 M two[®] file. After that, the canals were rinsed with 10 milliliters of 17% EDTA (M-Dent, Mahidol University, Thailand) for 1 minute followed by 10 milliliters of 2.5% sodium hypochlorite. The root canals were moistly dried with paper point and then obturated with single-matched cone gutta-percha (VDW, Munich, Germany) and premixed calcium-silicate based sealer (iRoot SP[®], Innovative BioCeramix Inc, Canada) under single-matched cone technique.

The remaining thirty root canals were rinsed with 10 milliliters of 17% EDTA for 1 minute followed by 10 milliliters of 2.5% sodium hypochlorite. The root canals were dried with paper points and then obturated with Epoxy resin-based sealer (AH Plus[®], Dentsply DE Trey, Konstanz, Germany) under warm vertical technique (Figure7B). The periapical radiograph was taken in two directions, buccolingually (Figure8A) and mesiodistally (Figure8B), to confirm the quality of root canal filling. Before the retreatment phase started, the specimens were filled by Cavit-G[®] (3M ESPE, St. Paul, Minnesota, USA) and stored in the container at 37°C and 100% humidity for seven days.

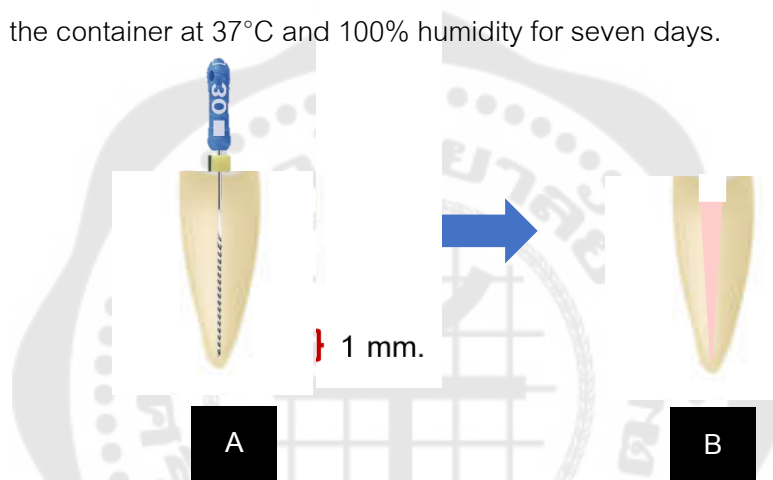


Figure 7 Specimen preparation from length determination (A) and root canal obturation (B)

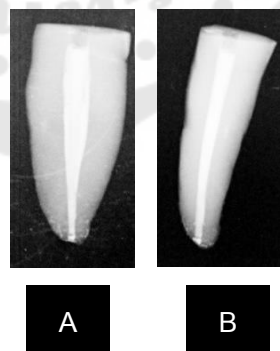


Figure 8 Radiographic images of specimens to verify quality of root canal filling materials in buccolingual view (A) and mesiodistal view (B)

In the next step, the coronal part of the root canal filling was removed using a size #2 Gate-Glidden drill to attain 3.0 millimeters for a gutta-percha solvent reservoir in the Mtwo R with GuttaClear group and Mtwo R with xylene group. Then, 0.5 milliliters of GuttaClear (M-Dent, Mahidol University, Thailand) and 0.5 milliliters of xylene (M-Dent, Mahidol University, Thailand) were dispensed for 2 minutes from a glass syringe into that space, respectively. The remaining gutta-percha was removed using 25/.05 Mtwo[®] R instrument at 8 millimeters in brushing motion. In the Mtwo R with GuttaClear group and Mtwo R with xylene group, 0.5 milliliters of GuttaClear and 0.5 milliliters of xylene were re-dispensed for 2 minutes, respectively, and continued gutta-percha removal using Mtwo[®] R 15/.05 instruments until reached the working length in brushing motion and finally sequential instrumentation to the 45/.04 Mtwo[®] file. In Mtwo R group, the retreatment process was similar to both groups without using solvents.

The root canals were irrigated between each instrument of Mtwo[®] instrument with 5 milliliters of 2.5% sodium hypochlorite. All of the prepared root canals were rinsed with 10 milliliters of 2.5% sodium hypochlorite followed by 10 milliliters of 17% EDTA for 1 minute and finally irrigated with 10 milliliters of distilled water.

Retreatment completion was established when the last file reached the working length, exhibited no visible residual filling material, and the canal walls were smooth and devoid of any observable remnants of the initial filling. These removal processes were examined under a dental operating light microscope at x10 magnification and were radiographed buccolingually (Figure9A) and mesiodistally (Figure9B) to check the residual root canal filling.

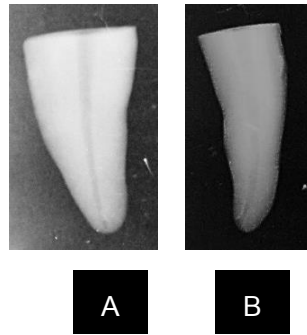


Figure 9 Radiographic images of specimens to verify removal process

buccolingual view (A) and mesiodistal view (B)

The time required for retreatment, from the initial insertion of the file into the root canal until the last file was withdrawn without residual filling material, was measured using a stopwatch and recorded in minutes. In solvent groups, the immersion time of solvent was subtracted.

Before completion of the retreatment phase, the root canals were moistly dried with paper point and then re-obtured with single-matched cone gutta-percha and premixed calcium silicate-based sealer under the same technique in the control group. The periapical radiograph was re-taken in buccolingual (Figure10A) and mesiodistal (Figure10B) views to ensure the quality of root canal filling. The specimens were filled with Cavit-G[®] and stored in the container at 37°C and 100% humidity for seven days and after that specimen preparation for push-out bond strength test was done.

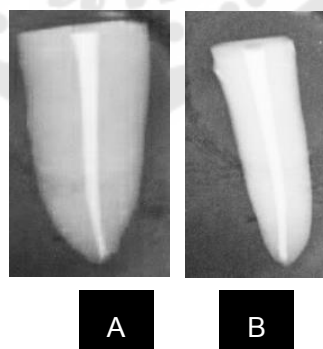


Figure 10 Radiographic images of specimens to verify quality of root canal filling materials

buccolingual view (A) and mesiodistal view (B)

Push-out bond strength testing procedures

Before, 2.0 ± 0.1 millimeter thickness of dentin slices were done, the prepared root was embedded in acrylic resin vertically with surveyor oriented (Ney Dental Inc., USA) (Figure 8) followed by transversely sectioned off 3.0-millimeter of coronal and apical end relation to the axis of the root. Each block was cut into three slices at the coronal, middle, and apical levels using a water-cooled precision saw (Isomet 1000: Precision section saw, Buehler, USA) as Figure 9. The sample's lumen diameter was measured using a digital vernier caliper (Mitutoyo; Absolute DIGIMATIC, Japan). The specimen was excluded when the diameter was larger than 1.40, 1.00, and 0.80 millimeters at the coronal, middle, and apical levels, respectively.

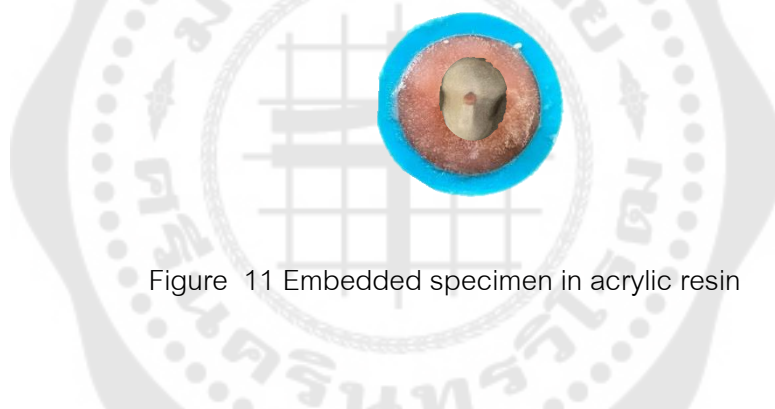


Figure 11 Embedded specimen in acrylic resin

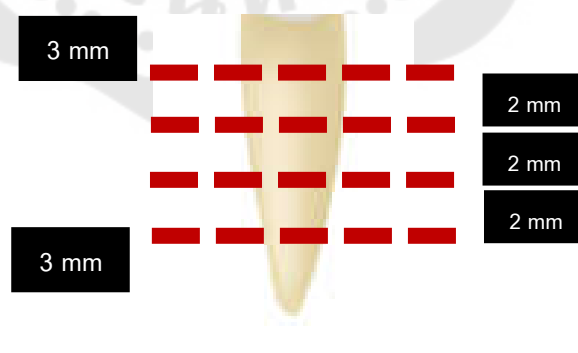


Figure 12 Slicing dentin thickness of the sample

Each level of root section was fixed in the mold and loaded by a Universal Testing Machine at a crosshead speed of 0.5 millimeters per minute using a 1.0, 0.8, or 0.6-millimeter diameter stainless steel cylindrical plunger. The slightly smaller plunger tip

than the diameter of the apical part of the root canal at each level for the coronal, middle, and apical slices, respectively, was positioned intimately to the obturation material. The push-out bond testing force was measured in an apico-coronal direction until the presence of the dislodged root canal filling material (Figure10). The maximum failure load was recorded in Newtons and calculated into megapascal (MPa; N/mm^2), using the equation as Figure 14

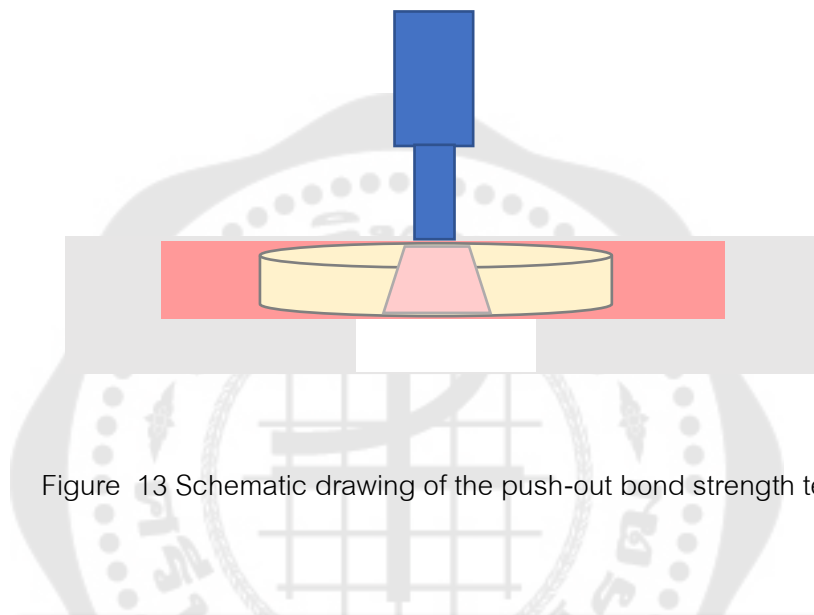


Figure 13 Schematic drawing of the push-out bond strength test

$$\text{Push – out bond strength (MPa)} = \frac{\text{Maximum load(N)}}{\text{Area(mm}^2\text{)}}$$

$$\text{Push – out bond strength (MPa)} = \frac{\text{Maximum load(N)}}{\pi(R + r)h}$$

Figure 14 The formula of push-out bond strength.

R = Mean radius of the coronal part in millimeter

r = Mean radius of the apical part in millimeter

h = Height relative to the tapered inverted cone in millimeter.

Determination of the mode of failure, the sample was examined under stereomicroscopy (Olympus EP50, Olympus optical Co., Tokyo, Japan) at x50 magnification as follows: adhesive failure (cone-sealer or sealer-dentin), cohesive failure within the sealer, and mixed failure (either adhesive or cohesive failure < 70% of the debonded area)⁽⁷⁴⁾ as shown in Figure 15A-C.

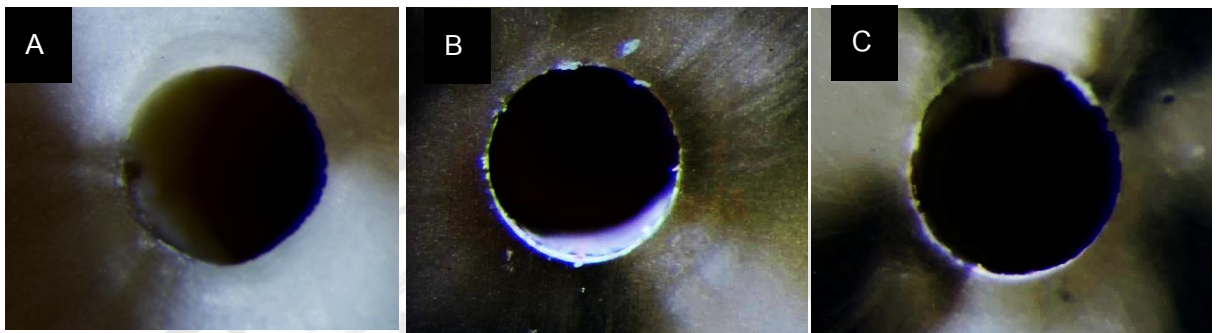


Figure 15 Schematic drawing for analysis of the mode of failures examples for adhesive (A), cohesive (B), and mixed (C) failure types.

Data collection and statistical analysis

The collected push-out bond strength and time taken data were recorded with mean values and standard deviations in megapascals (MPa) and minutes, whilst, the mode of failure was documented in terms of frequency of prevalence and percentile.

Statistical analyses of the push-out bond strength and time taken were performed using IBM SPSS Statistics 20 (SPSS Inc, Chicago, IL). Data distribution using the Shapiro-Wilk test was analyzed, and used one-way ANOVA and Multiple comparison test (Tukey's Test) for comparing the statistically significant difference with a 95% confidence interval.

CHAPTER IV

RESULTS

The sliced root specimens showed that the major content inside the root canals was gutta-percha surrounded by a white line of sealer, no voids presented in all specimens. The thickness of sealer seemed presented in the group of MtwoR with xylene the most (Figure 16A-D). Two specimens were found loss of mass gutta-percha during the tooth sectioning and those were excluded from the study.

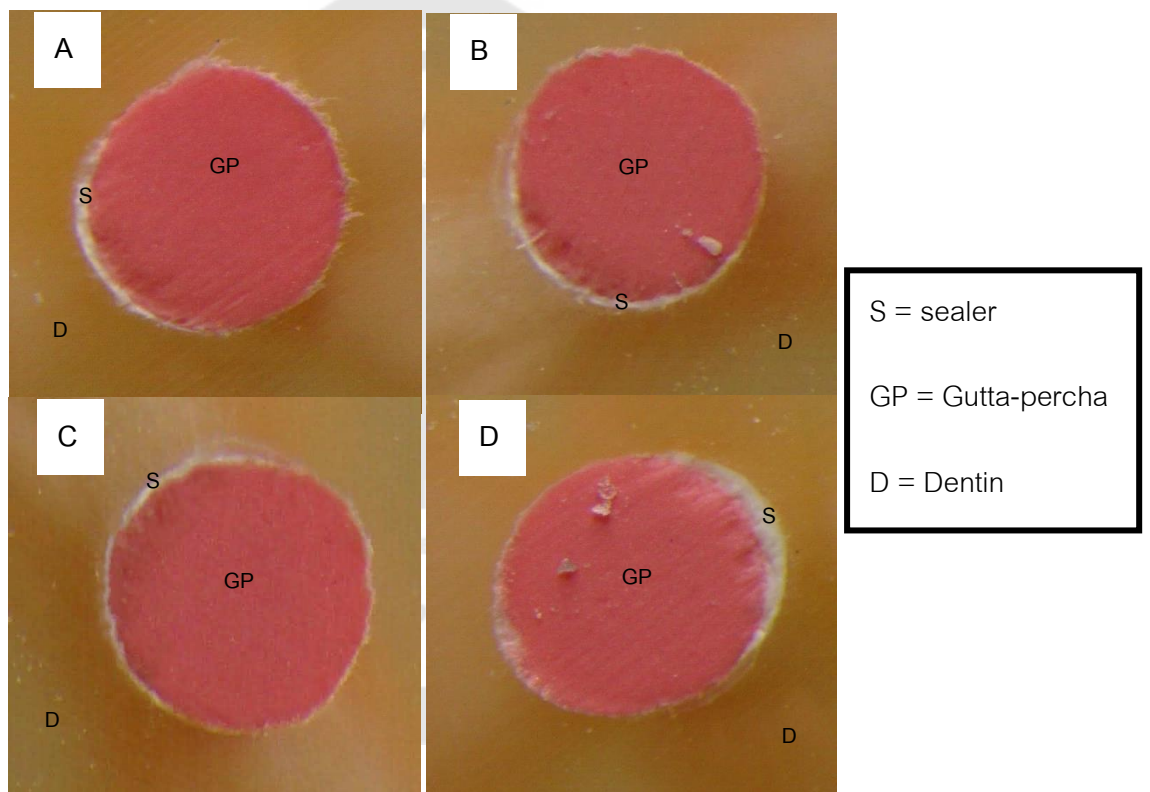


Figure 16 Representative images of root sliced specimens in all groups at the apical level (x50).

A= control group, B= Mtwo R group, C= Mtwo R with GuttaClear group, and D= Mtwo R with xylene group.

Time taken to retrieve gutta-percha in experimental groups.

Among all groups, the least mean time taken for gutta-percha retrieval was Mtwo R with GuttaClear group and the highest time taken was Mtwo R with xylene group as shown in Table 2.

Table 2 The mean and standard deviation for the taken time for gutta-percha retrieval using the different techniques.

Experimental groups	N	The taken time (minute)		Min.	Max.
		Mean	Standard deviation		
Mtwo R	10	5.92	0.57	5.20	6.87
Mtwo R with GuttaClear	10	5.24	0.57	4.32	5.90
Mtwo R with xylene	10	6.76	0.42	5.99	7.23

One-way analysis of variance followed by post hoc Tukey's test indicated that the mean total time taken to eliminate obturation materials for the Mtwo R with GuttaClear group (5.24 ± 0.57 minutes) was significantly shorter than those observed in the other groups ($P < .05$) as shown in Figure 17.

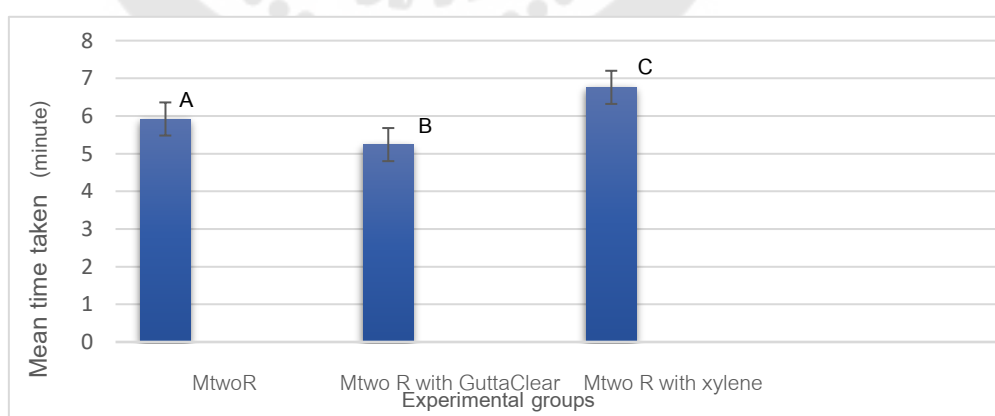


Figure 17 The bar graph depicts the mean time taken for the removal of gutta-percha.

The push-out bond strength between root canal filling material and radicular walls.

The maximum loads after push-out test were recorded and calculated to Megapascal (MPa) for each specimen at every level. The mean and standard deviations of those loads were shown in Figure 18. One-way ANOVA was utilized to prove statistical differences and revealed that at least one experimental group differs from others. The highest mean bond strength was observed in control group followed sequentially by Mtwo R group, Mtwo R with GuttaClear group, and Mtwo R with xylene group at all levels. In terms of the root level, a notable increase in bond strength was observed in the direction from the apical to the coronal level in all experimental groups.

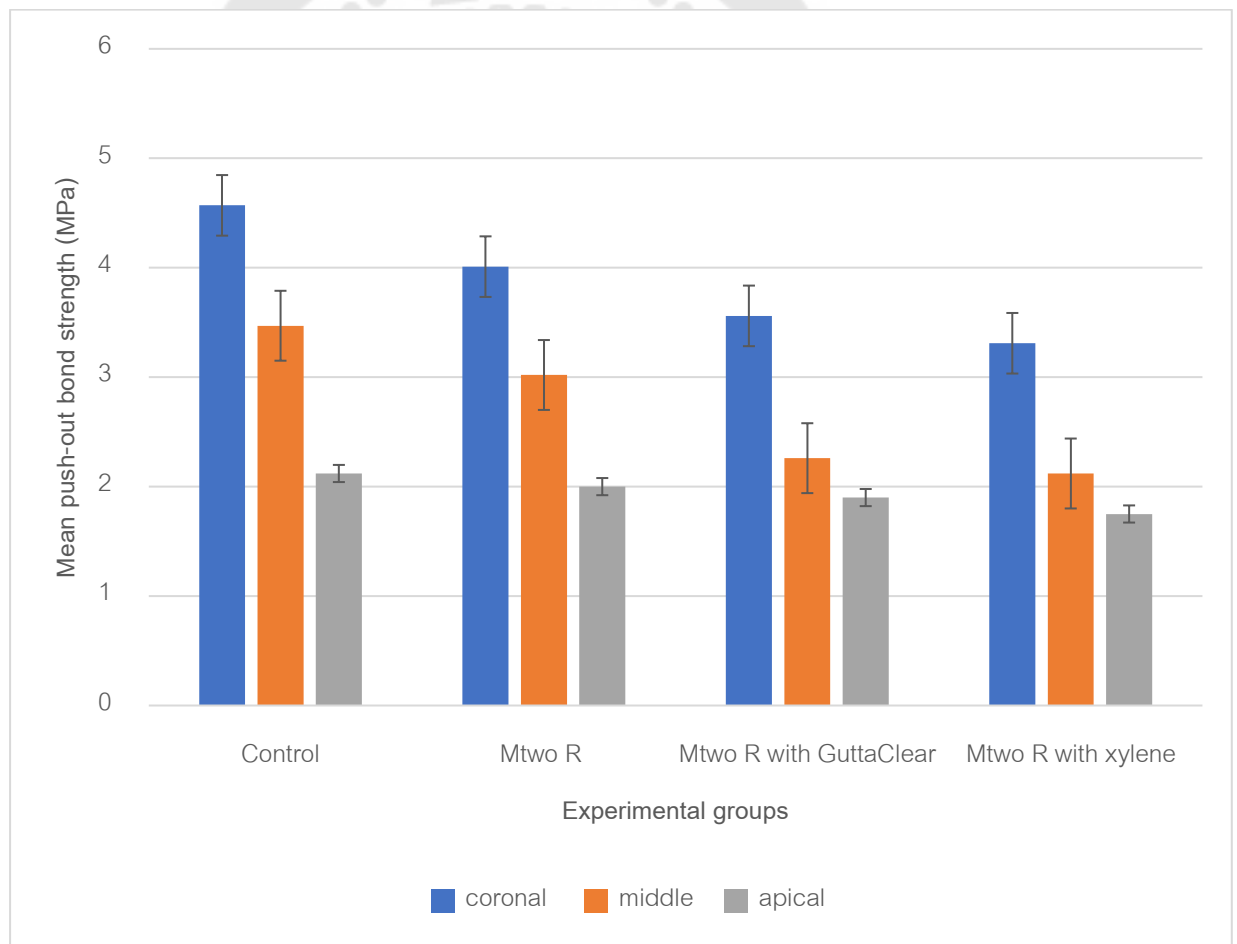


Figure 18 The bar graph depicts the mean push-out bond strength.

For further analysis, the post hoc Tukey's test was tested at each level and presented in Table 3. At the coronal level, no significant difference was found between the control group and Mtwo R group. However, after considering the use of solvents, both groups exhibited higher bond strength compared to the Mtwo R with GuttaClear group and Mtwo R with xylene group. Moreover, there was no statistically significant difference observed in bond strength between the two solvent groups.

At the middle level, the control group and Mtwo R alone group showed no significant difference in push-out bond strength, nevertheless, both groups surpassed observed in the Mtwo R with solvents groups. At the apical level, no significant difference was observed among all experimental groups.

Table 3 The push-out bond strength of the experimental groups

Experimental groups	Push-out bond strength (MPa, mean±SD)		
	Coronal level	Middle level	Apical level
Control	4.57±0.82 ^a	3.47±0.40 [*]	2.12±0.57 ^α
Mtwo R	4.01±0.83 ^{ab}	3.02±0.62 [*]	2.00±0.40 ^α
Mtwo R with GuttaClear	3.56±0.65 ^{bc}	2.26±0.54 ^{**}	1.90±0.66 ^α
Mtwo R with xylene	3.31±0.48 ^c	2.12±0.61 ^{**}	1.75±0.28 ^α

Different superscript letters indicate a significant difference in the columns ($P < .05$).

The mode of failure at different root levels.

The mode of failure analysis is shown in Table 4. All specimen groups predominantly showed cohesive failure modes between root canal filling material and radicular dentin after the push-out bond test (90.83%) followed by mixed failure (9.17%), whereas no adhesive failure in all groups and root levels.

Table 4 The frequency of the mode of failure of the groups at different root levels.

Experiment group	Level	Mode of failure		
		Adhesive failure	Cohesive failure	Mixed failure
Control	Coronal	0	10	0
	Middle	0	10	0
	Apical	0	9	1
Mtwo R	Coronal	0	10	0
	Middle	0	9	1
	Apical	0	8	2
Mtwo R with GuttaClear	Coronal	0	10	0
	Middle	0	8	2
	Apical	0	8	2
Mtwo R with xylene	Coronal	0	10	0
	Middle	0	8	2
	Apical	0	9	1
Total		0 (0%)	109 (90.83%)	11 (9.17%)

The sliced root specimens after the push-out bond test in the apical level of the experimental groups showed that the root canal walls were mostly surrounded by a white line of sealer, which means cohesive failure in the sealer (Figure 19A, B, and D). Some of the specimens showed that the root canal walls were surrounded by both remaining gutta-percha and sealer, which means mixed failure in the specimens (Figure 19C).

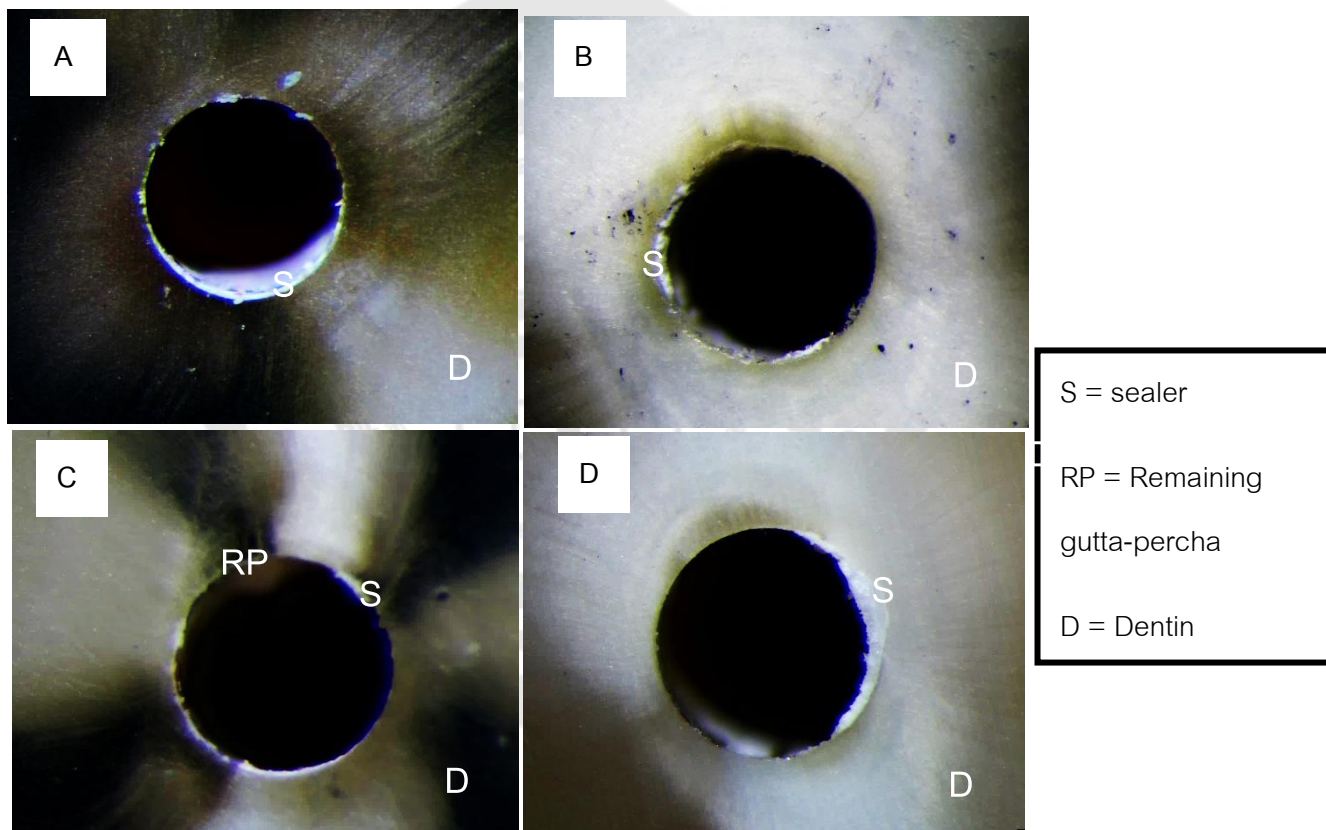


Figure 19 Representative images of root sliced specimens in all groups at the apical level (x50).

A= control group, B= Mtwo R group, C= Mtwo R with GuttaClear group, and D= Mtwo R with xylene group.

CHAPTER V

DISCUSSION CONCLUSION AND SUGGESTION

Discussion

The push-out bond strength in the control group did not differ from Mtwo R group statistically, this finding is consistent with the study by Shokouhinejad et al.⁽²⁹⁾. It is possible that the further enlargement of root canals after removing the gutta-percha allows more effective removal of root canal dentin walls⁽⁷⁵⁻⁷⁷⁾. This procedure results in the exposure dentinal tubules and the more cleaning of dentin⁽⁷⁸⁾, which facilitates the sealer penetration⁽⁷⁹⁾. These results elevate the push-out bond strength by increasing frictional forces between the sealer and the root canal walls⁽⁸⁰⁾. However, these findings are in contrast to the previous study⁽²⁸⁾ that showed a higher push-out bond strength in the control group compared to Mtwo R group. The differences could be attributed to the absence of additional enlargement of the root canal. Additional root canal enlargement after the removal process may reduce the thin layer of remaining root canal filling material, nevertheless it may negatively impact which leading to reduced root strength⁽⁸¹⁾ and increased higher risk of apical transportation⁽⁸²⁾.

A reduction in push-out bond strength of the retreated Mtwo R with solvent group is compared to the Mtwo R group. These results align with the outcomes of several studies^(28, 29), which have highlighted the solvent-induced formation of a thin layer of softened gutta-percha on the root canal walls and dentinal tubules therefore impeding effective sealer penetration⁽²⁰⁾.

The study of Palhias et al.⁽²⁸⁾ showed no significant difference in push-out bond strength between in the groups that underwent retreatment with xylol and orange oil. In consistent to our results, which used GuttaClear, a citrus fruit oil-based solvent containing d-Limonene same as orange oil. This can be explained by using the solvent during the removal of root canal filling material leads to tubular dentin obstruction and prevents sealer penetration^(20, 79).

Interestingly, the push-out bond strength of the retreated with Mtwo R with xylene group had significantly lower than the Mtwo R group. In contrast, the retreated with GuttaClear group showed no difference in push-out bond strength. These results may be attributed to the impact of xylene on altering the mineral contents accumulated in the radicular dentin⁽⁵⁵⁾. Nevertheless, the natural extract solvents, such as eucalyptol oil and orange oil, which do not alter the mineral composition of dentin^(54, 57).

The decreasing bond strength from the coronal to apical direction in all specimens was observed. Aligning with findings from other studies^(28, 29, 56), it could be explained by the higher number and the larger diameter of dentinal tubules presented in the cervical followed by middle and apical thirds, respectively. These characteristics facilitate enhanced penetration of the new filling material into the dentinal tubules^(22, 83). The sealer penetration into dentinal tubules accomplishes mechanical lock, potentially augmenting the retention of the root filling⁽⁸⁴⁾. Additionally, the lowest bond strength in the apical third is not only correlated with the number and size of diameter of the dentinal tubules, but also probably correlated the adherence of the remaining filling material on the root canal walls.⁽⁸⁴⁾

The pattern of filling dislodgement as cohesive failures was predominantly observed in specimens following the push-out bond test to all experimental groups, which similar to the results of various studies^(22, 28, 29). The explanation of the cohesive failures within sealer in the control group was the strong adhesion of the calcium silicate-based sealer to radicular dentin. Similarly, the retreatment specimens, it can be attributed to the weak interaction between the two different sealers (AH Plus and calcium silicate-based sealers)⁽⁸⁵⁾. Moreover, the occluded remnants of initial root canal filling materials did not affect to the refilling materials⁽²⁸⁾.

The shortest mean time for gutta-percha retrieval was observed with Mtwo R with GuttaClear group, while the Mtwo R with xylene group had significantly longer time than

Mtwo R group. This result is in agreement with the study of Oyama, et al.⁽⁸⁶⁾, which revealed that xylene was the least effective. This finding is explained by well condensed of root canal filling in our study, utilizing instruments with solvent can facilitate removing process by softening gutta-percha⁽⁸⁷⁾. However, xylene induced the formation of a more extensive smear layer compared to GuttaClear, presenting challenges in achieving thorough gutta-percha removal. Therefore, utilizing rotary NiTi instruments with various solvents in root canal retreatment may alleviate patient and operator fatigue. They might prove to be more effective and physiologically safer⁽⁸⁸⁾.

The current comparison of the bond strength of endodontic sealers can be tested through the shear test, microtensile bond strength test, and push-out bond strength test^(89, 90). The microtensile bond strength test is conducted on small specimens to allow for the application of force during testing. However, its drawback is the high failure rate during the specimen preparation, resulting in a significant data distribution⁽⁹¹⁾. The push-out test measures the shear stress between the sealer and the root canal walls which is similar to the stress produced under clinical circumstances⁽²⁶⁾. This method is efficient and reproducible, and also measurable even in conditions where the bond strength is low⁽⁹²⁾. Thereby, this study was selected to test the push-out bond strength of sealer due to its reliability and accuracy by applying a force parallel to the bonding surface causing failure from the actual shear test, as well as simulating clinical scenarios closely⁽²⁴⁾.

The orientation of the applied force on the non-perpendicular specimen, as well as the inappropriate size of the cross-sectional area of the applied force, led to an uneven distribution of force within the specimen, affecting the bond strength⁽⁹³⁾. Therefore, this study carefully positioned the plunger tip to align with the desired testing area. Three different sizes of plunger tip with diameters of 1.0, 0.8, and 0.6 millimeters at the coronal, middle, and apical thirds, were used in this study. This was done to correspond to the curvature of the canal at each level.

After sectioning the roots, measurements of the specimen revealed that the diameter of the lumen at the coronal, middle, and apical parts was approximately 1.20-1.40 mm., 0.85-1.00 mm., and 0.65-0.80 mm., respectively. These findings are consistent with Pane's study⁽⁹⁴⁾, which found that the compressive head sizes ranging from 70 to 90 percent of the area of the pressed material have an appropriate size that will not significantly affect the interfacial shear strength. It is recommended to select a smaller head size that is close to the area to be pressed the most in order to prevent the head from contacting the root canal walls during testing, thus reducing interfacial sliding friction. This study took this into consideration, a cylindrical plugger that covered 90% of the canal diameter was chosen. A surveyor was utilized to verify the vertical angulation of the embedded root in the block⁽⁷⁴⁾.

The dentin thickness selected for push-out testing has been also variable in numerous researches. Specimen slices from 0.6 mm to 7.0 mm⁽⁹⁵⁾ have been used. Thin slices, approximately 1.0 mm of thickness, seem to be preferable in order to generate more specimens and also when high push-out bond strength is hypothesized. On the other hand, the risk of sealer detachment while slicing was observed as the study of Gesi, et al.⁽⁹⁶⁾. Additionally, another study also found that the specimen thickness should be greater than 1.1 millimeters in order to obtain a bond strength calculated from a formula that closely approximates the actual value occurring at the interface between the material and the tooth⁽⁹⁷⁾. In the current study, 2 millimeters slice thickness was used in order to prevent premature failure and also in agree with previous studies⁽⁹⁸⁾. It was found that the bonded surface area would be calculated during the push-out bond strength calculations. The model utilized in this current study purposed to simulate clinical conditions by using dentin in radicular region instead of coronal region. The use of coronal dentin could mask some results due to the structural differences between coronal and radicular dentin⁽⁸⁹⁾.

In this study, extracted human teeth were chosen for use, with the advantage being the ability to simulate clinical situations. This is due to the measurement of the push-out bond strength between sealer and root canal walls, as well as the natural tooth structure. However, the limitation is the inability to determine the curvature of the root canal and the shape of the root canal, unlike synthetic root canals, which have a consistent centerline throughout the length of the root. Nevertheless, this study attempted to control the cross-sectional shape of the root canal to be round by using the upper incisors, as they have a relatively straight root canal and a rounded shape. This was done to measure the size of the root canal in both directions; mesiodistal and buccolingual.

This study considered about the variation of root morphology, which varied by the type of tooth, and curvature of the root⁽⁹⁴⁾. Therefore, maxillary anterior teeth were selected as the sample because the maxillary anterior tooth normally has only one canal and straight or slightly curvature root configuration^(72, 99). Moreover, this experiment has focused on studying the radicular part of the tooth, not only the exclusion of the tooth with any root pathology from this experiment but also the decolonization of the tooth for controlling confounding factors from the variation of tooth morphology as much as possible^(94, 100).

Tooth length in the experiment was determined by the minimum working root length in the push-out bond strength test was 16 millimeters. Fibryanto, et al.⁽⁷⁰⁾ reported that the average length of maxillary anterior teeth was 22.00-26.50 millimeters. While the crown length was approximately length 6-10 millimeters, in addition to the shape of the root canal should be the same as the plunger tip for an accurate value of the push-out bond strength⁽⁹⁴⁾, thereby, maxillary anterior teeth with round canal were selected to be the specimen. To verify the shape of the root canal, the ratio of buccolingual and mesiodistal width was calculated to 1.0-1.5 according to Jou, et al.⁽⁷¹⁾. Moreover, the maximum coronal diameter and the initial apical file size (IAF) were determined to

control the size of the root canal, any teeth with greater than 1.40 millimeters or IAF larger than size 30 K-file⁽⁷²⁾ were excluded from the study.

Two fundamental criteria should be determined how the solvents are chosen: their effectiveness and toxicity level⁽⁵⁴⁾. It is crucial to contemplate the potential replacement of solvents with high levels of tissue-related toxicity. Therefore, organic solvent would be a suitable alternative solvent to promote gutta-percha softening compared with potentially toxic solvents such as xylene⁽³⁸⁾. Further, the increasing utilization of organic solvents in endodontics is attributed to their safety, biocompatibility, and non-carcinogenic properties⁽¹⁰¹⁾.

. Therefore, within the limitations of the current study, the null hypothesis was rejected. In this study, only Mtwo R with xylene group had the lowest push-out bond strength at the coronal level. This result is similar to the prior study⁽²⁹⁾ that reported the superiority of instrumentation alone and instrumentation with organic solvent compared with instrumentation with inorganic solvent. The inferior results of inorganic solvent may be due to lower adhesion to root dentin and shallower penetration into dentinal tubules⁽⁸⁴⁾.

Conclusion

The push-out bond strength between calcium silicate-based sealer and the root canal walls using various retreatment techniques was significantly different. The use of a solvent facilitated the removal process and GuttaClear notably reduced the retreatment time however, the highest push-out bond strength was observed in case of retreatment without solvent when using calcium silicate-based sealer.

Suggestion

Further research is still necessary to evaluate the impact of supplemental irrigation on the cleanliness of root canal walls and its potential influence on the push-out bond strength between calcium silicate based-sealer and the root canal walls



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