FRACTURE RESISTANCE OF NON-FERRULED ENDODONTICALLY TREATED TEETH RESTORED WITH DIFFERENT FIBER POST AND CORE METHODS AFTER FIVE YEARS FATIGUE LOADING

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ความต้านทานการแตกในฟันที่ผ่านการรักษาคลองรากฟันที่ไม่มีเฟอร์รูล โดยการบูรณะด้วยเดือยเสริมเส้นใยและแกนด้วยวิธีต่างๆ หลังการทดสอบความล้าระยะเวลาห้าปี

นายภูริวัชร์ มาลากร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	FRACTURE RESISTANCE OF NON-FERRULED ENDODONTICALLY TREATED TEETH RESTORED WITH DIFFERENT FIBER POST AND CORE METHODS AFTER FIVE YEARS FATIGUE LOADING
By	Mr. Puriwat Malakorn
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ภูริวัชร์ มาลากร : ความต้านทานการแตกในฟันที่ผ่านการรักษาคลองรากฟันที่ไม่มีเฟอร์รูล โดยการบูรณะด้วยเดือยเสริมเส้นใยและแกนด้วยวิธีต่างๆ หลังการทดสอบความล้าระยะเวลาห้าปี. (FRACTURE RESISTANCE OF NON-FERRULED ENDODONTICALLY TREATED TEETH RESTORED WITH DIFFERENT FIBER POST AND CORE METHODS AFTER FIVE YEARS FATIGUE LOADING) อ.ที่ปรึกษาหลัก : ผศ. ทพ. ดร.วัชรศักดิ์ ตุมราศวิน

วัตถุประสงค์ของการศึกษานี้เพื่อเปรียบเทียบความต้านทานการแตกและคุณลักษณะความเสียหายในฟันที่ผ่านการรักษาคลองรากฟันที่ไม่มีเฟอร์รูลโดยการบูรณะด้วยเดือยเสริมเส้นใยและแกนด้วยวิธีต่างๆหลังการทดสอบความล้าระยะเวลาห้าปี กลุ่มตัวอย่างคัดเลือกจากฟันกรามน้อยล่างซี่ที่หนึ่งจำนวน 48 ซี่ ทำการกรอตัดฟันที่ตำแหน่งรอยต่อระหว่างเคลือบฟันและเคลือบรากฟัน ทำการรักษาคลองรากฟันและเตรียมพื้นที่สำหรับเดือยเสริมเส้นใย จากนั้นแบ่งกลุ่มตัวอย่างออกเป็น 4 กลุ่มกลุ่มละ 12 ซี่ โดยกลุ่มที่ 1 ทำการบูรณะโดยใช้เดือยฟันเส้นใยและสร้างแกนฟันโดยใช้วัสดุสร้างแกนฟันเรซินคอมโพสิตชนิดไหลแผ่ กลุ่มที่ 2 ทำการบูรณะโดยใช้เดือยฟันเส้นใยร่วมกับเดือยฟันเส้นใยเสริมและสร้างแกนฟันโดยใช้วัสดุสร้างแกนฟันเรซินคอมโพสิตชนิดไหลแผ่ กลุ่มที่ 3 ทำการบูรณะโดยการสร้างเดือยฟันด้วยการใช้เดือยฟันเส้นใยร่วมกับเรซินคอมพอสิต โดยลอกเลียนลักษณะภายในคลองรากฟันและสร้างแกนฟันโดยใช้เรซินคอมพอสิต กลุ่มที่ 4 ทำการบูรณะโดยการสร้างเดือยฟันด้วยการใช้เดือยฟันเส้นใยและเดือยฟันเส้นใยเสริมร่วมกับเรซินคอมพอสิต โดยลอกเลียนลักษณะภายในคลองรากฟันและสร้างแกนฟันโดยใช้เรซินคอมพอสิต จากนั้นชิ้นตัวอย่างทุกกลุ่มจะถูกบูรณะด้วยครอบโลหะผสมประเภทนิเกิล-โครเมียมและยึดกับส่วนแกนฟันด้วยเรซินซีเมนต์ นำฟันมาทดสอบความล้าจำนวน 1.2 ล้านรอบ เพื่อจำลองการใช้งานทางคลินิกระยะเวลาห้าปี จากนั้นทดสอบความต้านทานการแตกด้วยเครื่องทดสอบสากล บันทึกค่าแรงสูงสุดของชิ้นตัวอย่างแต่ละชิ้น ผลการศึกษาพบว่าค่าเฉลี่ยและส่วนเบี่ยงเบนมาตรฐานของความต้านทานการแตกของกลุ่มที่ 1 2 3 และ 4 มีค่า 636 N (133 N), 621 N (152 N), 636 N (114 N) และ 618 N (109 N) ตามลำดับ ผลการวิเคราะห์ความแปรปรวนแบบทางเดียวที่ระดับความเชื่อมั่นร้อยละ 95 ไม่พบความแตกต่างกันอย่างมีนัยสำคัญทางสถิติของความต้านทานการแตกระหว่างกลุ่มตัวอย่างทั้ง 4 กลุ่ม ชิ้นงานตัวอย่างส่วนใหญ่มีคุณลักษณะความเสียหายแบบไม่เอื้ออำนวยต่อการบูรณะ อย่างไรก็ตามค่าความต้านทานการแตกของกลุ่มตัวอย่างทุกกลุ่มภายหลังการทดสอบความล้าระยะเวลาห้าปีมีค่าสูงกว่าแรงบดเคี้ยวปกติ

สาขาวิชา ทันตกรรมประดิษฐ์ ลายมือชื่อนิสิต ....
ปีการศึกษา 2561 ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

5975834732 : MAJOR PROSTHODONTICS
KEYWORD: FRC post cyclic loading compromised endodontically treated teeth accessory fiber post anatomical fiber post

Puriwat Malakorn : FRACTURE RESISTANCE OF NON-FERRULED ENDODONTICALLY TREATED TEETH RESTORED WITH DIFFERENT FIBER POST AND CORE METHODS AFTER FIVE YEARS FATIGUE LOADING . Advisor: Asst. Prof. WACHARASAK TUMRASVIN, Ph.D.

The aim of this study was to compare the fracture resistance and failure mode of non-ferruled ETT restored with different fiber post and core methods after five years in vitro fatigue loading. Forty-eight uniradicular lower first premolar teeth were decoronated, endodontically treated and prepared for the post space. The prepared specimens were divided into four groups (n=12): single fiber-reinforced composite (FRC) post and flowable resin composite core (Group I), FRC post with an accessory fiber post and flowable resin composite core (Group II), resin composite relined FRC post and resin composite core (Direct anatomic post)(Group III), and resin composite relined FRC post with an accessory fiber post and resin composite core (Direct anatomic post)(Group IV). The coronal restoration was fabricated with casted Ni-Cr alloys. All specimens were subjected to the cyclic loading test for 1.2 million cycles to simulate five years of clinical service followed by static loading test. All failure loads were recorded and statistically analyzed using one-way ANOVA at the 95% confidence level. The mode of failure was classified into two groups: favorable failure and unfavorable failure. The results showed that all specimens survived the cyclic loading test. The mean (SD) fracture resistance was 636 N (133 N) for Group I, 621 N (152 N) for Group II, 636 N (114 N) for Group III and 618 N (109 N) for Group IV. There was no statistically significant differences between different experimental groups. Ninety-six percent of specimens showed unfavorable failure. Every fiber post and core method resulted in fracture resistance above the force of mastication after five years of clinical simulation.

Field of Study: Prosthodontics		Student's Signature ....
Academic Year: 2018		Advisor's Signature ....

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Puriwat Malakorn

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LIST OF ABBREVIATIONS

ABBREVIATIONS	DESCRIPTIONS
ETT	endodontically treated teeth
FRC	fiber reinforced composite
CEJ	cementoenamel junction
N	Newtons
P	p value
PVC	poly vinyl chloride
%	percent
mm	millimeter
s	second
min	minute
d	day
ANOVA	analysis of variance
SD	standard deviation
et al	et alii (and others)
°C	degree in Celsius
MC	Multicore flow
TN	Tetric N-Ceram Bulk Fill

CHAPTER I

INTRODUCTION

BACKGROUND AND RATIONALE

Extensive loss of tooth structure of endodontically treated teeth (ETT) is a common clinical problem.(1, 2) These teeth require post and core to provide sufficient retention and support for restorations. Clinically, cast metal posts have been used for decades.(3) Many studies reported unfavorable root fracture after using cast metal post, even though this kind of restoration provided high fracture resistance due to their high modulus of elasticity.(4-7)

Prefabricated fiber posts were first introduced in 1990s.(8) Subsequently, they are more favorable than cast metal posts because their modulus of elasticity are similar to dentin thus, creating uniform stress distribution to root dentin and reducing incidence of root fracture.(7, 9, 10) The fiber posts should be properly fitted in the root canal to provide a thin and uniform layer of cement, so that the amount of stress is properly transmitted from the fiber post to the root dentin resulting in decreasing incidence of dislodged post.(11) Since there are variation in shape of root canal system, the round-shaped fiber posts cannot be fitted to ovoid or triangular root canal anatomy.(12) The existing spaces between fiber post and root canal walls are filled-up with excessive amount of luting cement.(13) The large amount of luting cement in the root canal produces a high stress at the adhesive interfaces due to high polymerization shrinkage, which causes debonding.(14, 15) From these reasons, many techniques of fiber post and core have been introduced to achieve a better fitting quality and reduce the incidence of failure, such as using accessory fiber posts associated with main fiber post or using resin composite relined fiber-reinforced composite (FRC) post to create anatomical post.(5, 13, 16) In some clinical conditions, remaining tooth structure may be presented in the form of non-ferruled teeth which can compromise to the long-term prognosis. Since the restorative methods for these teeth are complicated treatment processes and time-consuming, the laboratory testing should be performed to ensure the long-term treatment success of restorations and find out the proper restorative methods for these compromised teeth. In this study, 1.2 million cycles of fatigue loading simulated five years of clinical service were performed to promote ageing of specimens and estimate the survival possibility of the treatment over a period of time.

The aim of this study was to compare the fracture resistance of non-ferruled ETT restored with different fiber post and core methods after five years in vitro fatigue loading. The mode of failure was classified into favorable and unfavorable failure.

RESEARCH QUESTIONS

1. Which restorative methods of fiber post and core are appropriate to restore non-ferruled endodontically treated teeth?

RESEARCH OBJECTIVES

1. To compare the fracture resistance of non-ferruled endodontically treated teeth restored with different fiber post and core methods after five years fatigue loading.
2. To compare the mode of failure of non-ferruled endodontically treated teeth restored with different post and core methods after five years fatigue loading.

RESEARCH HYPOTHESES

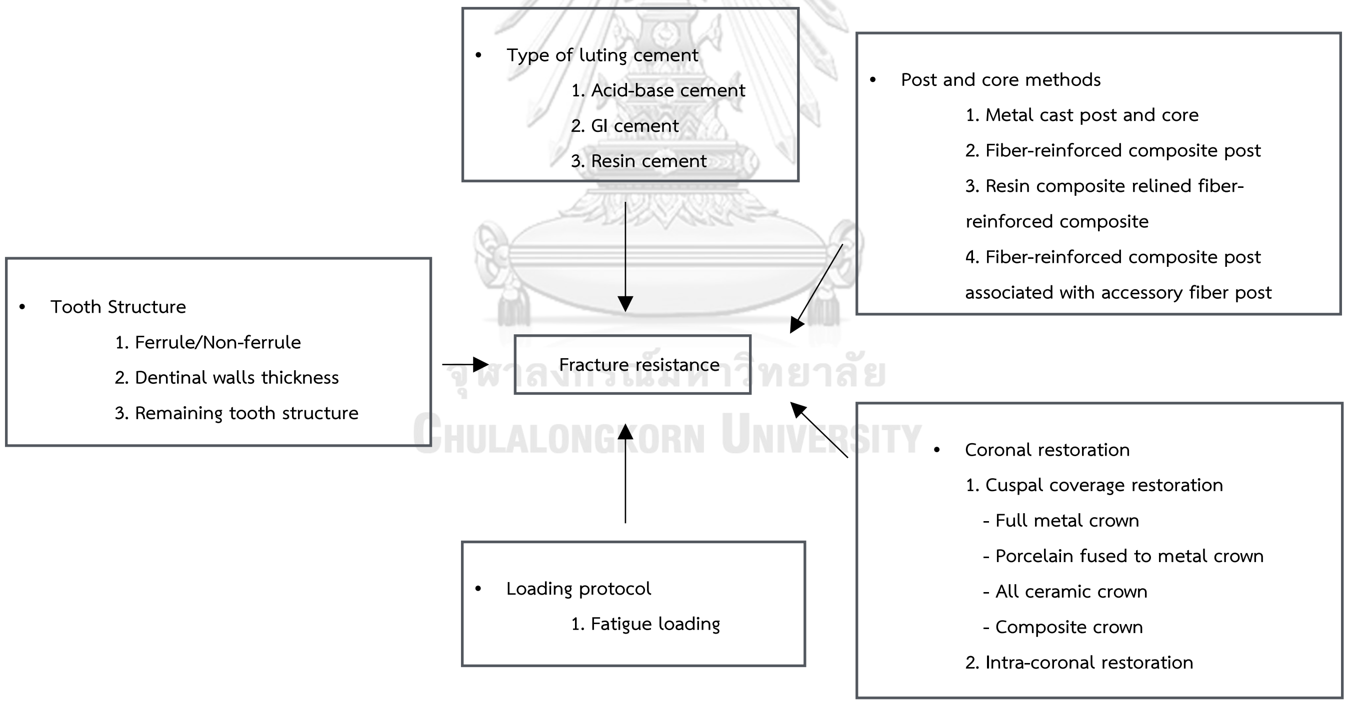
H_0 : Fracture resistance of non-ferruled endodontically treated teeth restored with single fiber post and flowable resin composite core is no statistically significant differences to those teeth restored with alternative methods of fiber post and core after five years fatigue loading.

H_a : Fracture resistance of non-ferruled endodontically treated teeth restored with single fiber post and flowable resin composite core is statistically significant differences to those teeth restored with alternative methods of fiber post and core after five years fatigue loading.

H_0 : Failure mode of non-ferruled endodontically treated teeth restored with single fiber post and flowable resin composite core is no statistically significant differences to those teeth restored with alternative methods of fiber post and core after five years fatigue loading.

H_a : Failure mode of non-ferruled endodontically treated teeth restored with single fiber post and flowable resin composite core is statistically significant differences to those teeth restored with alternative methods of fiber post and core after five years fatigue loading.

CONCEPTUAL FRAMEWORK



KEY WORDS

Fiber-reinforced composite post, Accessory fiber post, Anatomical fiber post, Compromised endodontically treated teeth, cyclic loading

RESEARCH DESIGN

Laboratory experimental study

EXPECTED BENEFITS

1. The results will inform which fiber post and core methods are appropriate to restore non-ferruled endodontically treated teeth.
2. The results obtained from this study will reveal the survival possibility and treatment outcome of restorative methods after fatigue loading test simulated five years of clinical service.

CHAPTER II

REVIEW OF RELATED LITERATURES

Tooth structure after root canal treatment are different from normal tooth. The collagen fibers in endodontically treated teeth (ETT) are immature crosslink that causes a change of mechanical properties (17). However, some studies report that biomechanics between ETT and normal tooth are similar (18). In some clinical conditions, remaining tooth structure after root canal treatment may present in the form of extensive loss of tooth structure or complete loss of tooth structure due to caries, trauma and cavity preparation, leading to non-ferruled tooth condition.

Ferrule is an encircling band of cast metal around the parallel wall of the coronal dental extension from finishing line, which can provides a protective effect by reducing stresses with in a tooth after crown placement called “ferrule effect” (19, 20). Ferrule can also improve structural integrity of ETT by counteracting functional lever forces, and reduced wedging effect of taper post and lateral force exerted during insertion of post(19). Traditionally, crown ferrule should be 2 mm high to provide fracture resistance (21, 22). Some studies report that there are various heights of crown ferrule that can improve the fracture resistance of ETT. Sorensen and Engelman (19) found that only 1 mm of crown ferrule could increase the fracture resistance when exposed to static loading. In contrast, Pereira et. al (23) proposed that fracture resistance between 0, 1 and 2 mm of existing crown ferrule showed no statistically significant difference.

In the evaluation of ferrule design on fracture resistance, Sorensen and Engelman (19) suggested that contra bevel design at finishing line and/or tooth-core junction could not improve the fracture resistance. The results showed similar fracture resistance and mode of failure between non-ferruled ETT with 90 degree shoulder finishing line group and non-ferruled ETT with 90 degree shoulder with a 1 mm wide 60 degree bevel finishing line group. Furthermore, there was no statistically significant differences between 1 mm of crown ferrule with contra bevel at the junction of the core and tooth and 1 mm of crown ferrule without contra bevel. This result was similar to the study of Tjan and Whang (24) who found that the addition of contra bevel design did not increase the fracture resistance of root. In contrast, some studies reported contra bevel design could increase fracture resistance (25).

Remaining tooth structure and restorative methods that use to replace the damaged tooth structure are an important factor to the long-term treatment success of ETT (26, 27). For this reason, post and core are necessary to provide sufficient retention and support for restorations. There are many post and core methods that can be used to restore ETT. Category of post and core can be classified by materials used.

Cast metal posts has been used in clinical application for decades (3). Traditionally, cast metal posts are the restoration of choice (28), including the following: when teeth are extensive loss of tooth structure, teeth that require a core to correct the position of them, and teeth that small size of coronal tooth structure such as the mandibular incisors. The disadvantages of cast metal post are as follows: a weak tooth structure and dentin must be removed, many appointments are needed and the cost is high due to laboratory fee. Since the nature of cast metal posts is stiff and hard, the loads can be transferred directly to the remaining tooth structure which causes root fracture (23, 29).

Prefabricated fiber posts were introduced to overcome the disadvantages of cast metal posts since 1990s (8). The main component of prefabricated fiber posts are parallel fiber in epoxy resin or bis-GMA which can be classified by type of fiber, including the following: carbon fiber post, quartz fiber post and glass fiber post. The compositions of carbon fiber post are continuous and unidirectional carbon fibers in an epoxy resin matrix (7). Even though carbon fiber posts are high corrosion resistance, good mechanical properties and similar elastic modulus to dentin, the post-operative aesthetic problem is occurred due to black color of carbon fiber posts (7). For this reason, glass fiber posts and quartz fiber posts are introduced to solve this problem (7). The glass fiber posts consist of various types of glass such as E-glass (Electrical glass) in which the amorphous phase of SiO_2, CaO_2, B_2O_3, Al_2O_3 and some other of alkali metals and S-glass (high strength glass) which is dissimilar in compositions (10). Epoxy resin and BisGMA (bisphenol A glycidyl methacrylate) are widely used as the resin base for the fiber posts (7).

To evaluate the effect of post and core methods on fracture resistance and failure mode of ETT, many studies report unfavorable root fracture after using cast metal post, even though this type of restoration provides high fracture resistance due to their high modulus of elasticity (4-7). The use of fiber posts can increase the incidence of favorable failure with acceptable fracture resistance (7, 29, 30). Furthermore, they also perform as shock absorbers and strengthened remaining tooth structure (5). These can be explained because of similarity of elastic modulus between fiber posts and dentin (7, 10). The elastic modulus of fiber posts and dentin is 20 GPa and 18 GPa, respectively (9). When post-core-dentin complex have similar elastic modulus, creating uniform stress distribution with lowered interfacial stress, which decreases the incidence of failure. This event has been coined by the bio-mechanical homogeneity unit or Monoblock.

Monoblock is the use of restorative materials with the same elastic modulus to dentin bonded with remaining dentin to achieve homogenous units (31). Therefore, the forces can be distributed over dentin simultaneously, resulting in decreased stress concentration with low incidence of root fracture. There are many factors that affect to the bio-mechanical homogeneity in EET restored with post and core such as type of post, adhesive system, luting cement, core materials and remaining tooth structure (32). In general, the posts should have similar elastic modulus to dentin for increasing resistance to fracture. The size and length of posts should conform to root canal anatomy, which requires at least 3 to 5 mm of gutta-percha for apical seal. The adhesive and luting cement should be total etch technique with dual-cured resin cement because total etch has the phosphoric acid, which can remove the smear layers. Dual-cured resin cements provide a complete polymerization throughout the root canal, resulting in high bond strength value. Resin composite is a favorable core build-up material because it can bond to dentin and reinforce tooth structure (32).

Although the fiber posts should be properly fitted in the root canal to provide a thin and uniform layer of cement (11). In some clinical conditions, the round-shaped fiber posts cannot be fitted to the root canal due to the variation in shape of root canal system such as ovoid or triangular root canal anatomy (12). The existing spaces between fiber post and root canal walls are filled-up with a bulk luting cement (13).The large amounts of luting cement in the root canal produce high stress at the adhesive interfaces because of high polymerization shrinkage, leading to debonding (14, 15). To achieve the better fitting quality between fiber post and surrounding root canal walls, many techniques of fiber post and core are introduced for decreasing the incidence of failure such as using accessory fiber posts associated with main fiber post or using resin composite relined fiber-reinforced composite (FRC) post to create anatomical post (5, 13, 16)(Figure 1).

In anatomical post technique, resin composite is used for relining FRC post to increase adaptation to root canals resulting in, decreasing a cement thickness and polymerization shrinkage stress in the adhesive interfaces (5, 14, 16). According to the study of Silva GR et al. (5), flared ETT restored with resin composite relined FRC post associated with accessory fiber posts and without accessory fiber posts, and FRC post associated with accessory fiber posts were higher fracture resistance than those of single FRC post. In contrast, Aggarwal et al. (6) found that single FRC post, FRC post associated with accessory fiber posts, and resin composite relined FRC post showed similar fracture resistance. This result was in accordance with the study of Zoghib et al. (15) who found that there was no statistically significant differences between compromised ETT restored with resin composite relined FRC post and the FRC post associated with accessory fiber posts.

For the accessory fiber post technique, Clavijo et al. (33) proposed that insertion of the small diameter accessory fiber posts into root canal created a lot of empty spaces, which were filled-up with large amount of luting cement, increasing incidence of bubbles and voids in the luting cement layer. Moreover, the large amount of luting cement could increase polymerization shrinkage stresses leading to adhesive failure (33). This finding was confirmed by the study of Sharafeddin et al. (34) who found that structurally compromised ETT restored with glass fiber post or quartz fiber post associated with and without accessory fiber posts showed similar fracture resistance. However, some study reported that the use of accessory fiber posts could improve the total post diameter, creating a better stress distribution and increasing resistance to fracture (35). The study of Alkumru et al. (36) showed that non-ferruled ETT with oval-shaped root canal restored with FRC post associated with accessory fiber posts were higher fracture resistance than those of single FRC post. Therefore, they concluded that accessory fiber posts could be reinforced compromised ETT.

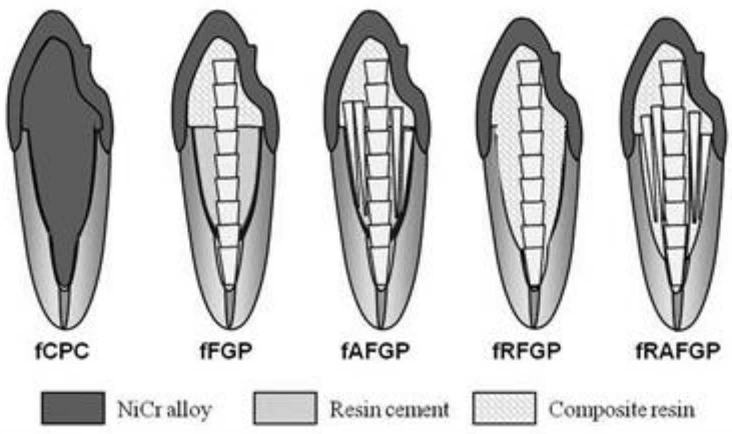


Figure 1 Schematic illustration of the restorative technique for flared ETT (Silva GR et al. 2011)

In the evaluation of relation between post-core complex in combination with adhesive system and remaining tooth structure. Many studies proposed that when fiber post and resin composite core in combination with resin bonding technique are used for restoring compromised ETT, the remaining tooth structure are not the main purpose to fracture resistance (1, 37, 38). Oliveira et al. (38) found that non-ferruled ETT restored with carbon fiber post and ETT with 1 mm, 2 mm and 3 mm of ferrule restored with carbon fiber post showed similar fracture resistance.

This finding was in agreement with Hazaimeh et al. (37) who found that there was no statistically significant differences on fracture resistance between non-ferruled ETT restored with fiber post and resin composite core associated with resin cement and those teeth with 2 mm of crown ferrule. Finally, they concluded that existing crown ferrule did not affect to fracture resistance when using prefabricated fiber post and resin composite core associated with resin cement. According to the study of Saupe WA et al. (1), the resin bonding technique could eliminate the need of crown ferrule and enhanced fracture resistance for compromised ETT at the same time. This can be explained by the elastic modulus of resin similar to that of dentin. The ferrule preparation in compromised ETT does not increase retention and fracture resistance. It is more prone to loss of remaining tooth structure (1, 24).

Due to the restorative methods for compromised ETT are complicated treatment and time-consuming, the laboratory testing should be performed to ensure the long-term treatment success of restorations and find out the proper restorative methods for these teeth. Cyclic loading is used to determine the failure of restorative materials or specimens which are subjected to stress and strain over a period of time. Moreover, it can be used to promote ageing of specimens and estimate the survival possibility of the treatment for a period of time (39). Many studies propose that 1.2 million cycles of cyclic loading simulate five years of clinical service (40, 41). Static loading is used to test the maximum load capability. The importance parameter of static loading is the cross head speed because it can affects to the fracture resistance (42).

To determine the effect of fatigue loading on fracture resistance in ETT, Sterzenbach et al.(39) reported that ETT restored with glass fiber post and core with all ceramic crown were subjected to thermocycling and cyclic loading prior static loading compared to those teeth which were subjected to static loading only. The result showed that the group which was subjected to thermocycling and cyclic loading prior static loading presented lower load to fracture than the static loading group. In contrast, the study of Nie et al. (41) showed that there was no statistically significant difference on fracture resistance between ETT restored with quartz fiber post and core with full metal crown subjected to cyclic loading prior static loading and those teeth subjected to static loading.

Even though many techniques of fiber post and resin composite core have been introduced to restore non-ferruled ETT, there is very little information regarding long-term treatment success and survival possibility of these restorative techniques over period of time. Therefore, the aim of this study is to evaluate fracture resistance of non-ferruled ETT restored with different fiber post and core methods after five years in vitro fatigue loading.

CHAPTER III

RESEARCH AND METHODOLOGY

POPULATION AND SAMPLE

Population

Lower first premolar

Study population

Lower first premolars which are extracted for orthodontic treatment from faculty of dentistry, Chulalongkorn university and private dental clinic.

Study sample

Lower first premolars which are extracted for orthodontic treatment from faculty of dentistry, Chulalongkorn university and private dental clinic which pass all inclusion criteria.

CRITERIA

Inclusion criteria

1. Lower first premolars which have straight and single root canal.
2. Length of root is 14.0 - 15.0 mm from cementoenamel junction (CEJ) to apex.
3. Buccolingual and mesiodistal width of root at CEJ level are 7.0 - 8.0 and 4.5 - 5.5 mm, after post space preparation.
4. Buccolingual and mesiodistal diameter of oval-shaped root canal entrance are 2.8 - 3.0 mm and 1.4 - 1.6 mm, after post space preparation.
5. Buccal/lingual and mesial/distal dentinal thickness of root canal is 1.5 - 2.0 and 2.5 - 3.0 mm, after post space preparation.

Exclusion criteria

1. Teeth with caries, cracked line, fracture and restoration
2. Root dilaceration

SAMPLE SIZE

From the pilot study, the mean (SD) fracture resistance of Group I and Group II were 717 N (95 N) and 583 N (118 N) respectively. The alpha was set at 0.05 and beta was set at 0.20. Estimated sample size was eleven in each group. Then the sample size was adjusted to twelve to prevent errors that might be occurred during experimental process. Finally, estimated total sample size was forty-eight.

The protocol for this study was approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand (011/2018).

DATA COLLECTION

1. Failure load of specimens
2. Failure mode of specimens

STUDY PROTOCOL

Forty-eight lower first premolar teeth were extracted for orthodontic treatment. Teeth with caries, restorations, crack lines and dilaceration roots were excluded from the study. All teeth were radiographed to determine root canal morphology. At cementoenamel junction (CEJ) level, the buccolingual and mesiodistal width of teeth were 7.0-8.0 mm and 4.5-5.5 mm, respectively. The length of root was 14.0-15.0 mm from CEJ to apex. All teeth dimensions were measured by a digital vernier caliper (Mutitoyo, Tokyo, Japan). The coronal portion of each tooth was sectioned at buccal aspect of CEJ level perpendicular to the long axis of tooth with high speed cylindrical diamond bur no.837L (Jota AG, Switzerland). Finally, all roots were stored in distilled water at 37°C.

Root canal preparation

All root canals were prepared with rotary file size 017-050 (Protaper Next, Dentsply/Maillefer Insruments SA, Switzerland), consequently. During instrumentations, the root canals were irrigated with 2.5% sodium hypochlorite, rinsed with 17% ETDA and dried with paper points before root canal obturation. The root canals were obturated using a main cone and lateral cone gutta-percha filling

(Sure-endo, Sure Dent Coporation, Korea) with root canal sealer (CU Product, Bangkok, Thailand). The canal orifices were sealed with 2 mm of temporary filling (Cavit, 3M ESPE, USA) and all roots were stored in 100% humidity at 37°C for 7 days before post space preparation. Peeso reamer size #1 and #2 (Jota AG, Switzerland) were used to remove gutta-percha until it was left only 4 mm from apex of root. The reamer size #0 (Ivoclar Vivadent AG, Liechtenstein) was used to shape the root canal. After this stage, remaining dentinal wall thickness at the flattened root surface was 1.5-2.0 mm for mesial and distal surface and 2.5-3.0 mm for buccal and lingual surface. Buccolingual and mesiodistal diameter of oval-shaped root canal orifices were 2.8-3.0 mm and 1.4-1.6 mm, respectively. All roots were randomly divided into four groups (n=12) and restored with different fiber post and core methods (Figure 2).

Post and core preparation

Group I (Single FRC post and flowable resin composite core): One glass fiber post (FRC Postec Plus, Ivoclar Vivadent AG, Liechtenstein) was tried into root canal. It was cut by high speed cylindrical diamond bur no.837L at 15 mm from the tip of post, leaving 5 mm high of fiber post to retain core and 10 mm inside root canal. Fiber post was applied with Monobond N (Ivoclar Vivadent AG, Liechtenstein) for 60 seconds and any remaining excess Monobond N was dispersed by a strong stream of air. Before the post cementation, the root canal and flattened root surface were etched with 37% phosphoric acid (N-Etch, Ivoclar Vivadent AG, Liechtenstein) for 15 seconds, rinsed with normal saline for 15 seconds and dried with air and paper points. All root canal walls and flatten surface of root were applied with adhesive (ExciTE F DSC, Ivoclar Vivadent AG, Liechtenstein) for 10 seconds and excess adhesive in root canal was removed by paper points. Flowable resin composite core material (MultiCore Flow, Ivoclar Vivadent AG, Liechtenstein) was introduced directly into the root canal followed by gentle insertion of fiber post size#0 into root canal. All cores build-up were standardized in size and shape using the transparent mold fabricated from vacuum sheet with 6 mm high. Polymerization of flowable resin composite core was performed for 40 seconds by holding the light curing machine (Elipar DeepCure-L LED curing light, 3M ESPE, USA) close to the post. The core build-up was trimmed to remove any excess core materials and create a 0.5 mm chamfer finishing line by high speed taper diamond bur no.847R (Jota AG, Switzerland)

Group II (FRC post with an accessory fiber post and flowable resin composite core): Main glass fiber post size #0 was introduced into the center of root canal and an accessory glass fiber post (Reforpin, Ace Dental Group Inc., USA) was tried along with main fiber post. Main fiber post and accessory fiber post were cut by high speed cylindrical diamond bur no.837L and left only 5 mm high to retain core. The prepared fiber post and accessory fiber post were cemented and core build-up were performed as in Group I.

Group III (FRC post relined with resin composite): One glass fiber post was tried-in and reduced as in Group I. Before fiber post relining, root canal walls were applied with separating solution (Separating Medium, Ainsworth Dental Company, Australia). Fiber post was applied with Monobond N for 60 seconds followed by the adhesive for 10 seconds. The resin composite relined (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent AG, Liechtenstein) fiber post was inserted into root canal. It was polymerized by the light-cured machine for 10 seconds after that it was gently removed from root canal followed by light-activated polymerization for 40 seconds. Core was built-up using resin composite (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent AG, Liechtenstein) and it was standardized and polymerized by using the same protocol as in group I. Any excess resin composites were trimmed and 0.5 mm chamfer finishing line was created using high speed taper diamond bur no.847R. The fit of relined post and core to the surrounding root canal walls were determined using polyvinyl siloxane material (FIT TESTER, Tokuyama Dental Corporation, Japan). Before the relined post cementation, all root canal walls were rinsed with normal saline to remove the separating solution and dried with air and paper points. Root canal and relined fiber post were prepared in the same way as in group I. Base and catalyst in a 1:1 ratio of luting cement (Variolink N, Ivoclar Vivadent AG, Liechtenstein) were mixed for 10 seconds. The relined fiber post was applied with mixed luting cement and introduced into root canal immediately after that light-activated polymerization of luting cement was performed for 40 seconds and allowed of complete polymerization by self-curing.

Group IV (FRC post with an accessory fiber post relined with resin composite): Main glass fiber post and an accessory glass fiber post were tried-in and reduced as in Group II. At the step of fiber posts relining, core build-up and cementation were performed as in Group III. The materials and their instruction for use are summarized in Table 1.

Coronal preparation and periodontal ligament simulation

Lower first premolar plastic tooth (Dental study model, Nissin Dental Products Inc., Japan) was prepared by high speed round diamond bur no.801 (Jota AG, Switzerland) to create 3 mm diameter of reserved positioning notch on the buccal surface of crown. The prepared plastic tooth was taken an impression by additional silicone material (elite HD+Putty Soft, Zhermack, Italy). The impression was used as mold for making acrylic crown pattern. Before acrylic crown fabrication, all specimens were coated with the separating solution and dried with air blow. Acrylic resin (DuraLay, Reliance Dental Manufacturing Company, Chicago, USA) was mixed until dough stage and loaded into the prepared mold followed by insertion of the specimen and waiting for complete polymerization of acrylic resin. Acrylic crown patterns were fabricated with Ni-Cr alloys (Argeloy N.P., Argen, USA). At stage of crown cementation, polyvinyl siloxane impression material was used to check the adaptation of crown. Full metal crowns were applied with Monobond N for 60 seconds and any remaining excess Monobond N was dispersed by a strong stream of air. All specimens were etched with N-Etch for 15 seconds and rinsed with water for 15 seconds followed by applying the adhesive for 10 seconds. Prepared full metal crowns were cemented by Variolink N. To simulate periodontal ligament, all specimens were dipped into melted wax below CEJ for 2 mm to preserve space for artificial periodontal ligament. All specimens were embedded in self curing acrylic resin (Formatray, Kerr, Romulus, MI, USA), 2 mm below CEJ, in 30 mm high and 17 mm diameter of polyvinyl chloride ring (PVC). After acrylic resin polymerization, the specimens were removed from the acrylic resin and preserved wax was removed by scalpel blade. Silicone light body (Amcoflex, Amcorp, USA) was used for simulating periodontal ligament and loaded into preserved acrylic resin space followed by immediate insertion of the specimen. Any excess light-body silicones were removed by scalpel blade.

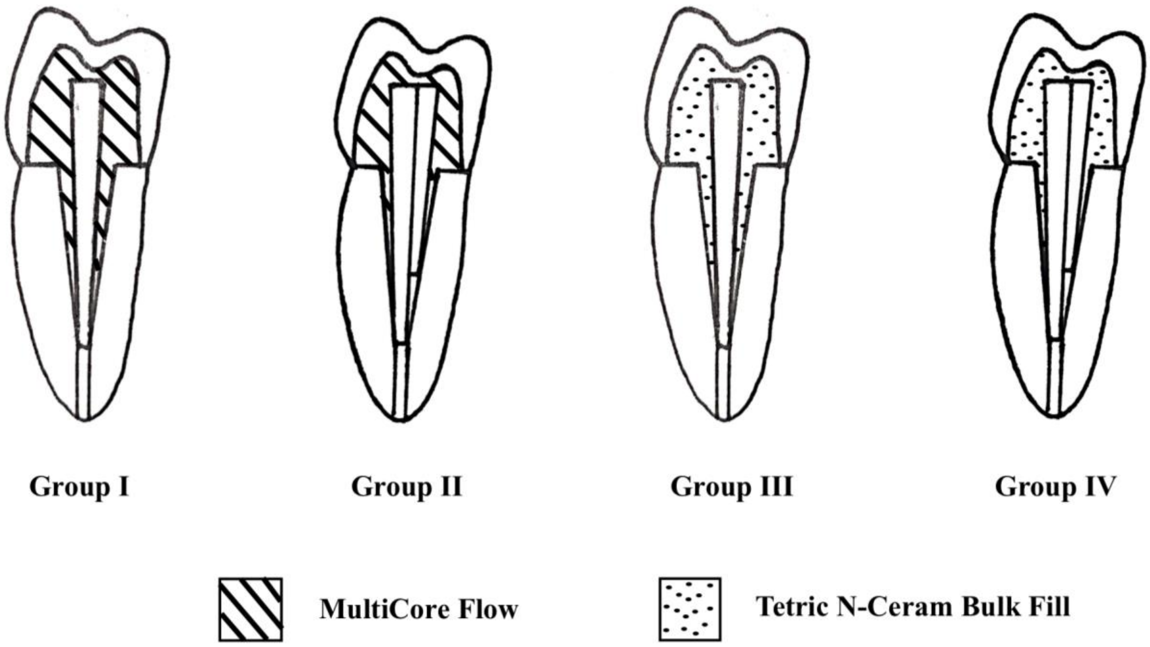


Figure 2 Schematic illustration of the experimental groups

Fatigue loading and fracture resistance test

All specimens were mounted with custom stand at 45 degrees to the long axis of the tooth assembled with the universal testing machine, fatigue tester (E1000 ElectroPuls, Norwood, US). The custom made stylus head diameter 2.5 mm of universal testing machine applied the load of 140 N at 6 Hz frequency to the prepared notch on buccal surface of crown for 1.2 million cycles. Finally, the compressive load was applied to the specimens with the same angulation and position as in cyclic loading test using the universal testing machine (Instron 8872, Norwood, US) at a crosshead speed of 1.0 mm/min until the failure of specimens was presented (Figure 3).

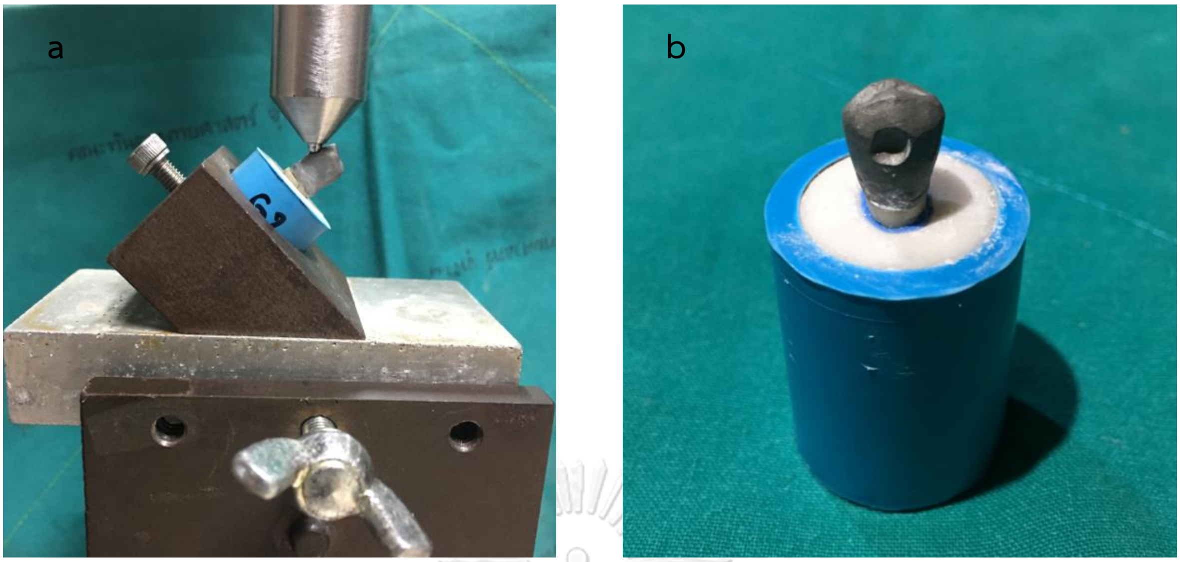


Figure 3 **Test set-up (a) and specimen for fatigue loading and fracture resistance test (b)**

STATISTICAL ANALYSIS

The data was analyzed using the static package for the social science version 22 (SPSS, Chicago, US). From the test of normality, the data presented normal distribution therefore, the parametric test was used to statistically analyze. The P-value below 0.05 was considered as statistically significant difference. The failure loads of specimens were statistically analyzed using one-way ANOVA. The mode of failure was recorded and classified into two groups: favorable failure (cervical third of root fracture, fracture above CEJ, crown-core fracture and core-tooth fracture) and unfavorable failure (middle or apical root fracture, fracture below CEJ and vertical root fracture). The modes of failure were statistically analyzed using Fisher's exact test.

Table 1 **Materials and Instruction**

Material	Components	Company	Instructions
Etchant (N-Etch)	37% phosphoric acid	Ivoclar Vivadent AG, Liechtenstein	- Apply etchant to root canal for 15s and rinse with normal
Primer (Monobond N)	Alcohol solution of saline methacrylate Phosphoric acid methacrylate Sulphide methacrylate	Ivoclar Vivadent AG, Liechtenstein	- Apply Monobond N to restoration for 60 s subsequently, disperse any remaining excess
Adhesive (ExciTE F DSC)	HEMA Dimethacrylate Phosphonic acid acrylate Highly dispersed silicone dioxide Initiators Stabilizers	Ivoclar Vivadent AG, Liechtenstein	- Apply ExciTE DSC to the enamel and dentin and agitate the adhesive on the prepared surfaces for at least 10 seconds.
Resin cement (Variolink N)	bis-GMA Urethane dimethacrylate Triethylene glycol dimethacrylate Barium glass Ytterbium trifluoride Ba-Al-fluorosilicate glass Spheroid mixed oxide	Ivoclar Vivadent AG, Liechtenstein	- Mix Variolink N Base and Catalyst in a 1:1 ratio for 10 s before application. - The working time of mixed Variolink N is about 3.5 min at a temperature of 37 °C
Main fiber post (FRC Postec Plus)	Glass fibers Aromatic and aliphatic dimethacrylates Ytterbium trifluoride	Ivoclar Vivadent AG, Liechtenstein	-
Accessory fiber post (Reforpin)	Glass fiber post 80% Epoxy resin 20%	Ace Dental Group Inc., USA	-
Flowable resin composite core (MultiCore Flow)	Dimethacrylate Barium glass Ytterbium trifluoride Ba-Al-fluorosilicate glass Highly dispersed silicone dioxide	Ivoclar Vivadent AG, Liechtenstein	- The base and catalyst pastes of MultiCore Flow are mixed at a ratio of 1:1 by pressing pastes through the static mixing tip.
Resin composite core (Tetric N-Ceram Bulk Fill)	Dimethacrylate Barium glass Ytterbium trifluoride Mixed oxide and copolymers	Ivoclar Vivadent AG, Liechtenstein	- Anatomical post and core build-up were made with composite resin. - Light-cured for 40 s

CHAPTER IV

RESULTS

The total number of specimens was forty-eight. All specimens survived the 1.2 million cycles of cyclic loading test. The fracture resistance of each specimen is presented in Table 2. The mean (SD) fracture resistance was 636 N (133 N) for Group I, 621 N (152 N) for Group II, 636 N (114 N) for Group III, and 618 N (109 N) for Group IV (Figure 4). The one-way ANOVA indicated that there was no statistically significant differences between different experimental groups (P=0.97). All specimens showed unfavorable failure except two out of twelve specimens in Group I showed favorable failure with in the form of core detachment (Table 3). Fisher's exact test indicated that failure load was no significantly different between single FRC post technique and alternative FRC post techniques (P=0.23). Most unfavorable failure presented in the form of oblique cervical root fracture over CEJ (Figure 5). There were only two specimens which presented middle to apical root fracture.

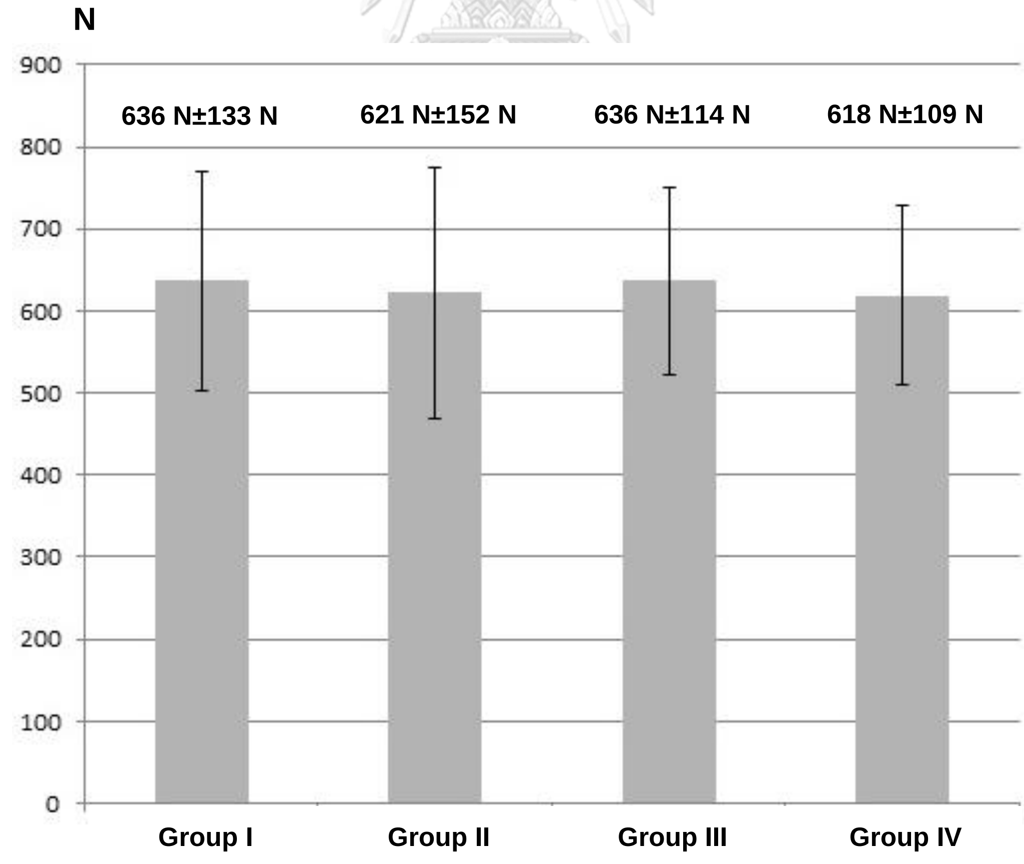


Figure 4 Mean and standard deviation values of fracture resistance (N)

Table 2 Fracture resistance (N) of specimens

	Group I	Group II	Group III	Group IV
1	815.89	715.28	724.59	699.21
2	629.94	551.11	577.02	697.21
3	704.95	484.76	435.40	625.50
4	749.36	602.99	614.66	629.08
5	625.14	523.86	530.04	500.82
6	573.56	465.31	578.30	550.29
7	850.29	879.34	560.21	639.56
8	425.34	524.52	631.18	535.55
9	449.74	474.05	623.73	532.87
10	602.99	579.74	748.50	445.29
11	525.62	809.54	813.98	767.17
12	688.10	852.72	736.88	802.43
Mean(SD)	**636.75 (133.05)**	**621.98 (152.23)**	**636.50 (114.46)**	**618.67 (109.49)**

Table 3 **Failure mode of specimens**

No. of specimens	Group I		Group II		Group III		Group IV	
	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable
1		/		/		/		/
2	/			/		/		/
3		/		/		/		/
4		/		/		/		/
5		/		/		/		/
6		/		/		/		/
7		/		/		/		/
8		/		/		/		/
9		/		/		/		/
10		/		/		/		/
11		/		/		/		/
12	/			/		/		/
Total	2	10	0	12	0	12	0	12

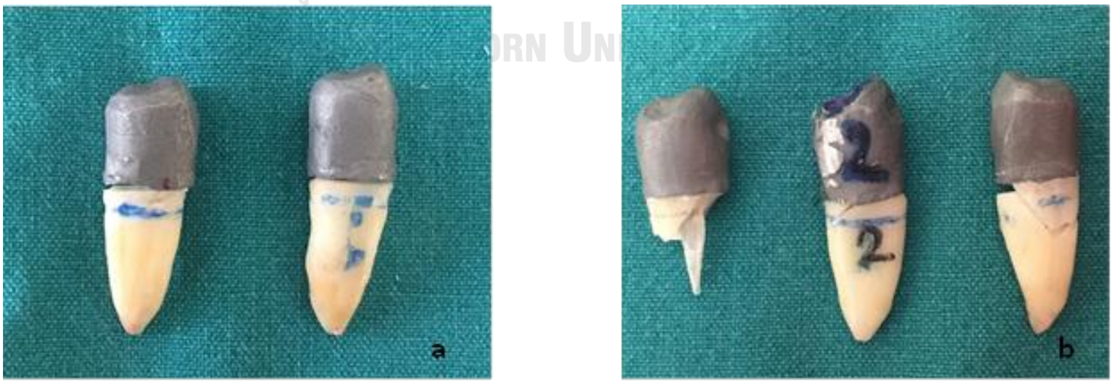


Figure 5 Failure of the specimens

(a) Favorable failure; (b) Unfavorable failure

CHAPTER V
DISCUSSION AND CONCLUSION

DISCUSSION

From the previous studies, various fiber post and core methods have been introduced to provide a positive effect on stress distribution, increase fracture resistance, reduce gap formation and cement thickness (13, 16, 35). However, in the present study, fracture resistance of single FRC post (Group I) and those alternative post and core methods was no statistically significant difference. This result could be explained because the specimens were restored by FRC post associated with and without accessory fiber post in combination with resin composite core materials which were MultiCore Flow (MC) and Tetric N-Ceram Bulk Fill (TN). The MC was used for luting fiber posts and core build-up at the same time without the need for resin cement. The TN was used for relining the fiber posts to enhance the adaptation between fiber post and root canal resulting in, decreasing a luting cement thickness and polymerization shrinkage stress in adhesive interfaces (5, 14, 16). Since the polymerization shrinkage is a natural characteristic of all dental polymers, the volume of its may produce shrinkage stress which may causes of restorative failure (14). Regarding to polymerization shrinkage of luting cement, Burey et al. (43) found that there was no significant difference on polymerize shrinkage values between flowable resin composite core material and resin cement which were used for post cementation. Hence, both restorative methods in this study not only reduced the luting cement thickness but also similar feature of core materials. From these reasons, no statistically significant difference on fracture resistance was found in comparison among experimental groups. This result was similar to the study of Aggarwal et al. (6) who found that there was no significant difference on fracture resistance between compromised ETT restored with single FRC post, FRC post associated with an accessory fiber post and resin composite relined FRC post. However, the mean fracture resistance values in their study were lower compared to the present study. This can be explained because of using resin cement to lute FRC posts in all restorative techniques. In contrast, the study of Silva GR et al. (5) found that fracture resistance of non-ferruled and flared ETT restored with single FRC post was significant lower than those of FRC post associated with accessory fiber posts and resin composite relined FRC post associated with and without accessory fiber posts. Since the spaces between root canal walls and the single FRC post are filled by luting cement which act as the weakest point between teeth and post-core complex, the large amount of luting cement serve to compromise the long-term success of restoration (5, 15).

Due to all root canals were not flared, the restorative methods in Group II and Group IV were restored using only one accessory fiber post associated with FRC post and core build-up with different methods. Therefore, the influence of accessory fiber post in this study may not be obvious compared to the other studies which use accessory fiber posts associated with main FRC post restored flared ETT. This can be explained by the use of accessory fiber posts can improve the total post diameter, creating better stress distribution and higher resistance to fracture than using single FRC post (35).

In compromised ETT, the strengths of core material play the importance role that affects to long-term success of restoration (44). According to the information of manufacturer, the MC is a dual curing, fluoride containing composites with low consistency and the TN is a nano-hybrid resin composite. The amount of filler in MC and TN is 70 wt% and 75-77 wt%, respectively. It is important to note that both materials have similarly high filler contents. The amount of filler has an effect to the flexural modulus and fracture resistance of resin composite core materials with the same trend (5, 45). From these reasons, both methods provided similar fracture resistance without evidence of core fracture for all specimens.

The use of highly filled flowable resin composite core materials can strengthen remaining root structure(45, 46). They reach more integration with the FRC post by reducing incidence of bubbles and voids within post-core interface and/or with in the core structure (47). Moreover, they also penetrate into the undercut area of root canals. The bubbles and voids in post-core complex endanger to the integrity of the post and core restoration (30). Since it was the in vitro study, all restorative methods were properly performed to restore the specimens followed by the radiographic examination to ensure the proper adaptation between material and root canal walls in all groups.

With regards to the different materials of coronal restoration, composite crowns have a lower resistance to deformation. When forces are continuously transferred to the composite crowns, it creates an elastic deformation and early crown fracture, which causes the forces to be unevenly distributed to the root dentin (48, 49). Porcelain fused to metal crowns and all ceramic crowns produce the shielding effect on the core structure in consequence the stresses concentration can be transferred to root dentin which adjacent to those of crowns (49). In this study, full metal crowns fabricated with Ni-Cr alloys were used for coronal restoration of the specimens. Since their high modulus of elasticity resulted in high resistance to deformation, the forces could be directly transferred from the full metal crown to the post-core complex leading to exceeding damage (4, 48). For this reason, the effect of different fiber post and core methods on fracture resistance and mode of failure can be focused on the post and core complexes. However, results showed that all restorative methods were similar fracture resistance and mode of failure. These results were in accordance to the results of Salameh et al. (49) showing that the ETT restored with FRC post and different full coverage crowns were found to significantly affect the results of failure modes.

In this study, all specimens were totally decoronated at CEJ level with remaining uniform dentinal wall thickness to eliminate the effect of crown ferrule followed by different FRC post and core restoration so that the post and core complex could be performed as the main purpose for fracture resistance of the specimens. However, similar fracture resistance for all restorative methods may be in consequence of similar remaining dentinal wall thickness of all specimens (15, 38). The thickness of remaining dentin is the predominant factor in maintaining resistance to fracture (15). Moreover, when lacking of crown ferrule, remaining dentinal wall thickness plays an important factor that affect to strengthen remaining tooth structure more than restorative methods (38).

Most specimens in all groups showed unfavorable failure with in the form of oblique cervical root fracture below CEJ except only two specimens which presented middle to apical third root fracture. This could be explained because of lacking crown ferrule, the loads could be transferred from the crown margin to the cervical third of root, creating the high stresses concentration that cause of cervical root fracture (34). This result confirmed the previous study showing that all non-ferruled endodontically treated mandibular premolars restored with FRC post with the same modulus of elasticity to dentin presented unfavorable failure (50).

To determine the restorative degeneration, all specimens were subjected to the cyclic loading of 1.2 million cycles, simulating five years of clinical service (40, 41). There was not any failure of specimens during cyclic loading. Usually, the normal chewing forces in adults is 70.6 N to 146.1 N (51, 52). However, the failure loads of all specimens were definitively higher than normal chewing forces.

Within limitations of this in vitro study, non-ferruled endodontically treated teeth restored with different FRC post and restorative core materials with full coverage crown survived the fatigue loading simulated five years of clinical service and resulted in similar fracture resistance and mode of failure.

CONCLUSIONS

After 1.2 million cycles of cyclic loading simulated five years of clinical service of non-ferruled ETT restored with different FRC post and core methods associated with Ni-Cr crown. It could be summarized as follows:

1. All specimens survived the cyclic loading test that simulated five years of clinical service.
2. All restorative methods were similar in fracture resistance and mode of failure.

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