ผลของเฟอร์รูลและขนาดเส้นผ่านศูนย์กลางของเดือยเสริมเส้นใย

ต่อความต้านทานการแตกในการบูรณะฟันที่ได้รับการรักษาคลองรากฟัน

นางสาวอาภาพร พงษ์ภัทรินทร์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาทันตกรรมประดิษฐ์ ภาควิชาทันตกรรมประดิษฐ์
คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2553

EFFECT OF FERRULE AND FIBER POST DIAMETERS ON FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH

Miss Arpaporn Pongpattarin

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Prosthodontics
Department of Prosthodontics
Faculty of Dentistry
Chulalongkorn University
Academic Year 2010

Thesis Title	EFFECT OF FERRULE AND FIBER POST DIAMETERS ON FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH
By	Miss Arpaporn Pongpattarin
Field of Study	Prosthodontics
Thesis Advisor	Assistant Professor Prarom Salimee, Ph.D.

Accepted by the Faculty of Dentistry, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

W. Tasachan .... Dean of the Faculty of Dentistry
(Associate Professor Wacharaporn Tasachan)

THESIS COMMITTEE

.... Chairman
(Assistant Professor Orapin Kaewplung, Ph.D.)

.... Thesis Advisor
(Assistant Professor Prarom Salimee, Ph.D.)

.... Examiner
(Assistant Professor Niyom Thamronganantskul, Ph.D.)

.... External Examiner
(Associate Professor Rumpai Rochanakit)

อาภาพร พงษ์ภัทรินทร์ : ผลของเฟอร์รูลและขนาดเส้นผ่านศูนย์กลางของเดือยเสริมเส้นใย ต่อความต้านทานการแตกในการบูรณะฟันที่ได้รับการรักษาคลองรากฟัน. (EFFECT OF FERRULE AND FIBER POST DIAMETERS ON FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ทพญ.ดร.ปรารมภ์ ซาลิมี, 55หน้า.

ความสำคัญและที่มา ฟันที่ได้รับการรักษาคลองรากฟันที่มีเนื้อฟันเหลืออยู่น้อยหรือมีคลองรากฟันที่เตรียมไว้ขนาดใหญ่มักมีผลต่อความยืนยาวของวัสดุบูรณะ

วัตถุประสงค์ เพื่อประเมินผลของเฟอร์รูลและขนาดเส้นผ่านศูนย์กลางของเดือยเสริมเส้นใย (พอดีหรือเล็กกว่าคลองรากฟันที่เตรียมไว้) ต่อความต้านทานการแตกและลักษณะความล้มเหลวที่เกิดขึ้นในฟันที่ได้รับการรักษาคลองรากฟัน

วัสดุและวิธีการ ฟันซี่ตัดหน้าบนกลางจำนวน 32 ซี่แบ่งเป็น 4 กลุ่มทดลองอย่างสุ่ม โดยกลุ่มที่ 1ได้แก่ ฟันที่มีเฟอร์รูล บูรณะด้วยเดือยขนาดพอดีกับคลองรากฟัน กลุ่มที่ 2 ได้แก่ ฟันที่มีเฟอร์รูล บูรณะด้วยเดือยขนาดเล็กกว่าคลองรากฟัน กลุ่มที่ 3ได้แก่ ฟันที่ไม่มีเฟอร์รูลบูรณะด้วยเดือยขนาดพอดีกับคลองรากฟัน กลุ่มที่ 4 ได้แก่ ฟันที่ไม่มีเฟอร์รูล บูรณะด้วยเดือยขนาดเล็กกว่าคลองรากฟัน ทำการรักษารากฟันและเตรียมช่องว่างเดือยฟันด้วยหัวกรอดีทีไลท์เบอร์ 2 โดยในกลุ่มที่ 1 และ 3 บูรณะด้วยเดือยดีทีไลท์เบอร์ 2 ส่วนในกลุ่มที่ 2 และ 4 บูรณะด้วยเดือยดีทีไลท์เบอร์ 1 ทำการยึดเดือยด้วยเรซินซีเมนต์ บูรณะด้วยเรซินคอมโพสิตคอร์ และกรอเตรียมทำครอบฟันโดยขอบเป็นแชมเฟอร์โดยรอบ จากนั้นทำการสร้างครอบฟันโลหะผสมประเภทนิเกิลโครเมียม และยึดด้วยเรซินซีเมนต์ นำมาชิ้นตัวอย่างที่ได้มายึดในบล็อกอะคริลิกโดยสร้างเอ็นยึดปริทันต์จำลอง นำมาทดสอบด้วยเครื่องทดสอบแรงสากลความเร็วหัวกด 1 มม.ต่อนาที กดด้านเพดานโดยทำมุม 135 องศากับแนวฟันจนเกิดการแตก

ผลการศึกษา ค่าเฉลี่ยความต้านทานการแตกในกลุ่มที่ 1, 2, 3 และ 4 เท่ากับ 1474.7 ± 285.5 นิวตัน, 1339.4 ± 120.6 นิวตัน, 811.7 ± 155.7 นิวตัน และ 668.5 ± 170.2 นิวตันตามลำดับ ผลการทดสอบทางสถิติโดยใช้การวิเคราะห์ความแปรปรวนแบบสองทางและการเปรียบเทียบชนิดตูกีเอชเอสดี พบว่าค่าเฉลี่ยความต้านทานการแตกในกลุ่มที่ 1 และ 2 มากกว่ากลุ่มที่ 3 และ 4 อย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) ในขณะที่ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มที่ 1 และ 2 และ ระหว่างกลุ่มที่ 3 และ 4 ($p \geq 0.05$)

สรุปผลการศึกษา การบูรณะด้วยเดือยคอมโพสิตเสริมเส้นใยในฟันที่ได้รับการรักษาคลองรากฟันโดยมีเฟอร์รูล 2 มม.สามารถเพิ่มค่าความต้านทานต่อการแตกอย่างมีนัยสำคัญ และการบูรณะด้วยเดือยที่มีขนาดเล็กกว่าคลองรากฟันมีความต้านทานการแตกลดลงอย่างไม่มีนัยสำคัญกับฟันที่ได้รับการบูรณะด้วยเดือยขนาดพอดีกับคลองรากฟัน

ภาควิชา ...ทันตกรรมประดิษฐ์....... ลายมือชื่อนิสิต อาภาพร พงษ์ภัทรินทร์

สาขาวิชา ...ทันตกรรมประดิษฐ์....... ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก..........................

ปีการศึกษา ..2553.........................

50761264 32: MAJOR PROSTHODONTICS

KEYWORDS: ENDODONTICALLY TREATED TEETH / FERRULE / FIBER REINFORCED COMPOSITE POST (FRC POST) / FRACTURE RESISTANCE/ POST DIAMETER

ARPAPORN PONGPATTARIN: EFFECT OF FERRULE AND FIBER POST DIAMETERS ON FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH. THESIS ADVISOR: ASST. PROF. PRAROM SALIMEE, Ph.D., 55 pp.

Background and rationale: Endodontically treated teeth with less remaining tooth structure of ferrule or a large post space may affect the longevity of restoration.

Objective: The objective of this study is to evaluate the effect of ferrule and fiber reinforced composite post diameter (post fit to space or smaller than post space) on fracture resistance and failure mode in restored endodontically treated teeth.

Material and methods: Thirty two extracted human maxillary central incisors were randomly divided into 4 experimental groups; 1: ferrule + post fit, group 2: ferrule + smaller post, group 3: no ferrule + post fit and, group 4: no ferrule + smaller post. Root canal treatment was performed and post space was prepared using DT light drill no.2. In groups 1 and 3, the teeth were restored using DT light post no.2, while in groups 2 and 4, DT light post no.1 was used. The posts were cemented with resin cement (Panavia F 2.0), then core build-up was fabricated with resin composite (Tetric N ceram). Chamfer preparation was performed around the teeth. Ni-Cr crowns were fabricated and cemented onto the core with resin cement (Panavia F 2.0). The restored teeth were embedded in self-cured acrylic resin blocks with a simulated PDL. The specimens were loaded on a universal testing machine with a crosshead speed of 1 mm/min on the palatal surface at an angle of 135° to the long axis of the tooth until failure occurred.

Results: The fracture resistance of groups 1, 2, 3 and 4 were 1474.7 ± 285.5 N, 1339.4 ± 120.6 N, 811.7 ± 155.7 N, and 668.5 ± 170.2 N, respectively. Two-way ANOVA and Tukey HSD post-hoc analysis revealed the fracture resistance of groups 1 and 2 were significantly higher than group 3 and 4 ($p<0.05$). No significant differences were found between groups 1 and 2 and between groups 3 and 4.

Conclusion: Preparation of 2 mm ferrule significantly increased the fracture resistance of endodontically treated teeth restored with FRC post. The use of posts with smaller diameter did not significantly decrease the fracture resistance compared to posts properly fit to the canal.

Department: Prosthodontics .... Student's Signature Arpaporn Pongpattarin

Field of Study: Prosthodontics .... Advisor's Signature ....

Academic Year: 2010

ACKNOWLEDGEMENTS

I would like to express my gratitude to all those who gave me the possibility to complete this thesis, Assistant Professor Dr. Prarom Salimee, for suggest me to do this research project, Assistant Professor Paipan Bidhyanon for her advice and suggestions in the statistical analysis for this experiment. Furthermore, I would like to thank the staff at the Research Center, Chulalongkorn University for their help and kind assistance.

This research was supported by Faculty of Dentistry Chulalongkorn University for the financial support of this research project.

CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Figures **Page**

CHAPTER I

INTRODUCTION

Restoration of endodontically treated tooth often need a post and core restoration with crown due to extensive structural defects resulting from caries, large restorations, or access preparation in order to reinforce tooth structure and prevent tooth fracture (1-3). Direct post and core restorations with fiber reinforced composite (FRC) posts became popular owing to their lower modulus of elasticity compared with metal posts, which increases stress distribution along the root, decreasing the risk of root fracture (4).The morphology of the tooth root canal is generally tapered in the coronal to apical dimension and oval in cross-section (5). Kasahara et al. studied root canal preparations in endodontic treatment in maxillary central incisors and reported the canal should be flared at the root canal orifice, tapering towards the apical foramen. The canal preparation may result in a large flaring, requiring a post with wider coronal taper (6). Additionally, when the post space is prepared for a precisely fitted post, the root canal dentin in apical part may need to be removed, weakening the remaining tooth structure. Prefabricated post systems may not precisely fit the prepared root canal requiring resin composite or resin cement to fill the space between post and root canal wall (7) especially in the coronal part of the root canal.

Ananviriyaporn studied the effect of diameter and length of fiber posts on the failure resistance of endodontically treated teeth restored with post and core. This study concluded using the diameter of FRC post which only properly fit the cervical part of the canal or using resin composite reinforced the canal space was as strong as those restored with the fiber post that properly fit to the canal as a whole. However, restorations using posts smaller than the canal resulted in a significant decrease in failure resistance (8).

The presence of ferrule of remaining tooth structure in restoring endodontically treated teeth with post and core has been reported to be important (9-13). Ferrule is the band or ring that fit the root or crown of the tooth (14).A tooth with a crown ferrule can transfer chewing force apically along the root canal wall preventing root fracture (15).

When the tooth had at least a 2 mm ferrule, long term success of the restoration could be expected (16). The results of a study of the fracture resistance of teeth receiving ferrule, suggested there were no significant differences in teeth restored with stainless steel post and resin composite core which received ferrule of different heights (17). A limitation of this study is that it did not simulate the effect of the periodontal ligament. Saupe et al. demonstrated when a bonded resin system was used in structurally compromised teeth, there was no statistical difference in fracture resistance between post and core restorations with ferrule and those with no ferrule (18).

Dikbas et al. studied the effect of different ferrule restored with quartz fiber posts. The results suggested there were no significant differences among the groups with remaining tooth structure of one-wall, two-wall, or circumferentially compared to the group with no ferrule (19). The authors claimed the effect of a quartz fiber post in transferring the stress was more significant than the effect of ferrule. However, the teeth in this study were restored with a precisely fit fiber post. In some clinical situations where the tooth has a large post space or less remaining tooth structure, it may be difficult to find a properly fitting prefabricated post. Therefore, the tooth has to be restored with a post smaller than the post space and reinforced with resin cement or resin composite. To our knowledge, there is no study investigating the effect of different remaining tooth structure of ferrule restored with quartz fiber posts of different diameters in endodontically treated teeth.

The purpose of this study was to evaluate the effect of ferrule and post diameter in endodontically treated tooth restored with quartz fiber post under compressive force. For this study, the null hypothesis was there would be no difference in the fracture resistance of the tooth with and with no ferrule, post diameter that properly fit and not fit to the post space include their interactions.

CHAPTER II

LITERATURE REVIEW

Fracture resistance of endodontically treated teeth restored with post

In endodontically treated teeth, the remaining tooth structure was minimized from large caries and restorations, resulting in decreasing the strength of the tooth (1). To prevent the fracture and retained core materials, restoration with posts and core is the treatment of choice (2, 3). Over the past decades, restoration with metal cast post and core was popular, but the disadvantage of this type of post was the unrestorable fracture (20-22). From the study of Fuss et al, the results showed that restoring with cast post resulted in vertical root fracture at cervical third more than middle third. The long cast post distribute the force better than the short post (23), so the greater post space had to be prepared and this might affect the strength of the tooth. Moreover, the result of Sorensen and Martinoff suggested that cast posts required less fracture resistance force compared with FRC posts and amalgam or resin composite core build-up (24). In addition, restoration with post and core combined with crown was more advantageous since the stress could be distributed to the cementoenamel junction, and decreased the wedging effect in post and core materials (25).

Fiber reinforced composite post (FRC)

The materials used in FRC post composed of two components: carbon or silica fiber and polymer resin matrix. The mechanical properties of carbon fiber post were much more advantage than metal cast post such as stiffness, lightness, corrosion resistance and fatigue resistance (26). Moreover, carbon fiber posts which had small diameters were rigid comparable to stainless steel posts with larger diameters (27). However, the carbon fiber post was opaque and did not lend to aesthetic with all-ceramic restoration. This disadvantage was introduced to the silica-fiber posts which were translucent and more esthetic than carbon fiber posts. The silica fiber had two types: glass fiber and quartz fiber. The mechanical properties of silica fiber post were quite similar to carbon fiber post. The modulus of elasticity was 18 - 47 GPa which was nearly the same as that of dentin (28). Furthermore, the thermal expansion coefficient of silica fiber post was quite low (29).

The mechanical properties of FRC post depended on many factors such as the properties of materials used for fiber and matrix, fiber surface treatment and impregnation of fibers with resin, adhesion of fibers to the polymer matrix, quantity of fibers, orientation of fibers, position of fibers and water sorption of resin matrix (30). These factors affected the properties of FRC post such as increasing of adhesion of fibers to matrix which led to higher stiffness and modulus elasticity (31). The orientation of fibers was important in fracture resistance force. Any fiber direction diverging from the longitudinal axis of the post resulted in a stress transmission to the matrix (32). In contrast, the parallel fibers were advantageous when removing the post if the root canal retreatment was required (33).

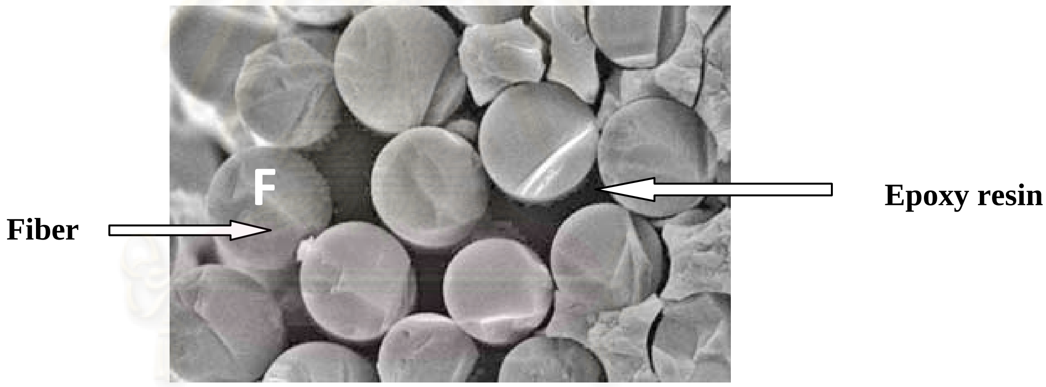


Fig. 1 Fiber impregnanted in epoxy resin matrix

(J Endod 32(1); 44-47) (34)

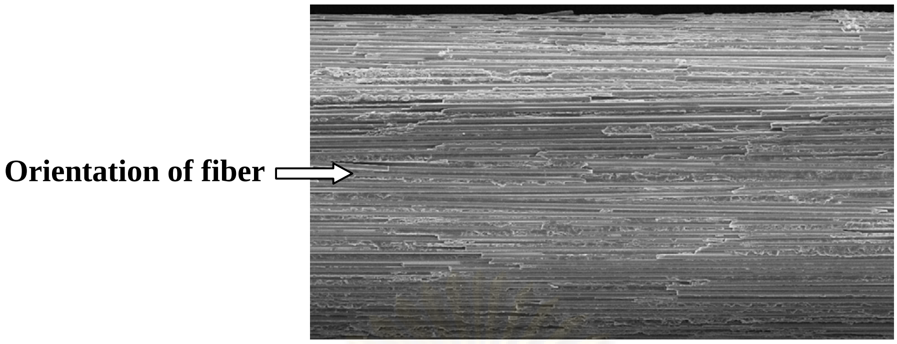


Fig. 2 Fiber orientation in FRC post

(J Endod 33(3); 264-267) (35)

Mechanical properties of FRC posts

1. Fracture resistance

The fracture resistance force of FRC post was less compared with that of cast post (36). When considering the failure modes, debonding or fracture of core materials were observed. These failures were more favorable compared with the failure of vertical root fracture in cast post (36-38). The study of Lassila et al showed that in the same post space, large posts contribute more favorable to the fracture resistance than small posts (29). Hayashi et al suggested that under conditions of vertical and oblique loading, the combination of a FRC post and composite resin core with a full cast crown is the most protective method for maintaining tooth structure (39).

2. Stiffness and flexural strength

The post which had modulus of elasticity or stiffness close to dentin could distribute the force along the post to the root and decreased the risk of root fracture (40). This property was found in FRC post and was important in restoration of anterior teeth because the occlusal force is not directed to their long axis. Furthermore, the FRC post which had high flexural strength could withstand bending force (41). In contrast, too high flexural strength of FRC post was disadvantageous since the force was concentrated at the post, resin cement and root canal dentin interface and this stress caused fracture of restoration (42).

There were many factors affected the flexural strength of FRC posts such as fiber size, fiber density, fiber distribution, adhesion between fiber and matrix, and thermocycling (43). In addition, the strength decreased after soaking posts in wet condition compared to dry condition. This might be because of hydrolysis reaction which caused the swelling and degradation of the matrix layer. In thermocycling processes, the stress concentration was increased within the post materials and debonding between fiber and resin matrix and crack of resin matrix might occur. These processes caused decreasing the flexural strength (44) and make the post more flexible. Furthermore, when the post was loaded by the occlusal force, the stress increased in the post-cement-dentine interface. Then, the resin cement cracked and introduced to debonding of post and core to root canal dentin. This process is precautionary in clinical failure (42).

3. Retention

3.1 Core retention

The retention between post and core materials was the important factor in restoration with FRC post. Purton and Payne compared tensile bond strength of resin composite core bonded with prefabricated stainless steel post (Parapost®) and carbon fiber post. The result suggested that tensile bond strength in Parapost® was much more superior to the other groups. The author claimed that the serrated surface of stainless steel post could increase mechanical retention with resin composite core better than smooth surface of carbon fiber post. From this study, if the smooth surface of FRC post was roughened, it might not be significantly different (27). The recent study of Artopoulou et al claimed that the diameter of resin composite core on FRC post was not significantly different in retention to post since it depended on the contact surface between post and core materials. In contrast, the retention between composite core and serrated metal post was mechanical retention, so the diameter of resin composite core significantly affected the retention (45).

3.2 Post retention in the root

There are many surface treatment of FRC post that increase retention to resin cement such as acid etching with hydrofluoric acid, air-borne particle sandblasting with aluminium oxide and silane coupling agent (46). In the study of sandblasting with air-borne particle, Balbosh and Kern claimed that airborne-particle abrasion significantly improved the retention of FRC posts and resin cement (47). However, the study of Soares et al which found that airborne-particle abrasion produced undesirable surface changes and decreased the retention (48). Concerning silane coupling agent, it was found that the application of a silane coupling agent onto the post surface prior to building up the flowable resin composite core significantly increased the post–core bond strength (49). Furthermore, the silane application combined with sandblasting could increase the retention between quartz fiber post and resin composite core (50). However, many investigations did not suggest that silane coupling agent would increase retention between post and resin cement (47, 51, 52). In 2008, Yenisey and Kulunk studied the surface treatment of glass and quartz fiber post using chemical solvents. The result suggested that the surface treatment with 10% hydrogen peroxide for 20 minutes significantly increased the shear bond strength of the FRC post due to its ability to dissolve the epoxy resin matrix and increase surface roughness which produced micromechanical retention with resin composite core (53). However, there was no study investigated the effect of hydrogen peroxide on mechanical properties of the post.

4. Materials used for bonding and reinforced of post

The retention between post and root canal dentin were related with materials used for bonding and reinforcement which were conventional cement, resin composite and resin cement. Mendoza et al suggested that resin cement was significantly increased the resistant to fracture than conventional cement (54). Moreover, the silane application onto the post surface and core build- up with the flowable resin composite significantly increased the post–core bond strength (49).

Resin cement was classified by polymerization process into auto-polymerized, light-polymerized, and dual-polymerized. When restored with FRC post, dual-polymerized resin cement was more reliable than light-polymerized in bonding with root canal at the apical third since limitation of light transmission of the post (55). The self-etch 10-MDP-based cements resulted in a higher push-out bond strength than the etch-and-rinse two-step cement and the self-adhesive cements (56). Furthermore, to achieve maximum bond strength between quartz fiber post and root canal dentin, the film thickness of resin cement should be 0.1-0.3 mm (35).

The study of Moosavi et al suggested that the flared root canal reinforced with resin cement showed a lower fracture resistance than reinforced with resin composite or Reforpin® which is glass fiber intraradicular accessory posts. The reason of this results may come from high polymerization of the luting cement which resulted in overstress within the materials when the space between the post and canal wall was large (57). However, this study did not compare between the ferrule and non ferrule tooth restored with FRC post which not fit to the root canal.

Regarding restoration with resin composite, the bonding agent should be a point of concern, Mannocci et al found that restoring with self-etching primer and resin cement was popular because of the advantage in moisture control (58). In contrast, the study of Goracci et al concluded that the bond strength of FRC post using dual-cure self adhesive without dentin conditioning was weaker than using total-etch adhesive combination with dual-cure resin cement (59).

The space between root canal dentin and FRC post filled with resin composite could increase the strength of fiber post (60). From the result of Saupe et al, it was demonstrated that the FRC post reinforced with resin composite could tolerate more occlusal force than the FRC post alone (18). Furthermore, the result of Turker et al showed that using polyethylene fiber ribbon-reinforced post could achieve appropriate clinical situation (61).

Effect of ferrule on teeth restored with FRC post.

Saupe et al showed that the fracture resistance of structurally compromised endodontically treated teeth restored with FRC post which have ferrule and no ferrule were not significantly different (18). However, the failure modes were quite different. The failure mode of the tooth which had ferrule was root fracture. In contrast, those which had no ferrule was debonding of post since fracture of resin cement (13). The study of Morgano and Brackett suggested that restoring the non ferrule teeth with flexible post caused microleakage since the bending of post and core from occlusal force resulted in fracture of resin cement(62).

The remaining tooth structures are important in restoration of endodontically treated tooth. From study of Akkayan, the tooth which had 2 mm ferrule restoring with different post system had more resistance to fracture than 1.0 to 1.5 mm ferrule(9). This result was consistent with the study of Ng et al which showed that the fracture resistance of tooth 2 mm ferrule restored with quartz fiber post was significantly higher than the tooth which had no ferrule (13). However, in clinical situation, the endodontically treated tooth might have partial ferrule which might affect the fracture resistance of the tooth. The study of Ng et al showed that anterior maxillary incisors which have only palatal wall restored with FRC post was more effective to resist fracture load than the labial wall (63). The reason was that the failure load in anterior maxillary incisors was the tensile stress from the lower anterior rather than the compressive stress (64).

In the study about ferrule, there are many investigations claimed that the effect of complete crown will block out the effect from the other factors (65, 66). But the other studies suggested that using specimens restored with crowns could refer to the clinical situation (17, 19, 22, 67). In addition, the materials used for crown were varied such as full metal crown (13, 38, 68) or all-ceramic crown (12, 68).

Angulation in fracture resistance test on central maxillary central incisor

There were many studies investigated factors influencing fracture resistance in restoring with FRC post in maxillary central incisors (7, 8, 12, 19, 69-72) such as type of post materials, type of crown materials and angle of loading force. Pegoretti et al studied stress distribution in restoring anterior teeth with FRC post by finite element analysis using 0, 45 and 90 degree to simulate force from bruxism, normal occlusal force and external force from accident, respectively. The results showed that in 0 degree model, the stress concentrated at post dentin interface, in 45 degree model, the stress concentrated on labial site at post dentin interface in cervical to middle third of root and in 90 degree, the stress concentrated at crown margin (73). However, in the studies of mechanical properties of endodontically treated teeth, most loading force were 45 degree to long axis (12, 13, 17, 19, 22, 38, 57, 68, 72, 74) to stimulate biting force of normal occlusion (14).

The purposes of this study

1. To investigate and compare fracture resistance of restoring technique of endodontically treated teeth with and without ferrule.
2. To investigate and compare fracture resistance of restoring technique of endodontically treated teeth which have different post diameters.
3. To investigate and compare fracture resistance of restoring technique of endodontically treated teeth with and without ferrule which have different post diameters
4. To select the appropriate FRC post technique restoration for endodontically treated teeth
5. To gain the knowledge for further study in restoration of endodontically treated teeth.

Hypotheses

<u>Hypothesis 1</u>

Null hypothesis: There would be no significant difference between the endodontically treated teeth restored with FRC post which have ferrule and no ferrule.

Alternative hypothesis: There would be significant difference between the endodontically treated teeth restored with FRC post which have ferrule and no ferrule.

<u>Hypothesis 2</u>

Null hypothesis: There would be no significant difference between the endodontically treated teeth restored with FRC post which properly fit and not fit to the post space.

Alternative hypothesis: There would be significant difference between the endodontically treated teeth restored with FRC post which properly fit and not fit to the post space.

Hypothesis 3

Null hypothesis: There would be no significant difference between the endodontically treated teeth which have ferrule and no ferrule restored with FRC post which properly fit and not fit to the post space.

Alternative hypothesis: There would be significant difference between the endodontically treated teeth which have ferrule and no ferrule restored with FRC post which properly fit and not fit to the post space.

Keywords

- Endodontically treated teeth
- Ferrule
- Fiber reinforced composite post (FRC post)
- Fracture resistance
- Post diameter

Type of research

Laboratory experimental research

Materials used in this study

1. Quartz fiber reinforced post (DT light post, Bisco Inc, Lançon De Provence, France)
2. Resin cement (Panavia F2.0, Kuraray medical, Okayama, Japan)
3. Primer bonding agent (ED PRIMER II A&B, Kuraray medical, Okayama,Japan)
4. Resin composite (Tetric N Ceram, Ivoclar Vivadent, Schaan, Liechtenstein)
5. 37% Phosphoric acid (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein)

6. Bonding agent (Excite, Ivoclar Vivadent, Schaan, Liechtenstein)
7. Silane coupling agent (mixture of Clearfil SE bond primer and porcelain bond activator, Kuraray medical, Okayama, Japan)
8. Self cured acrylic resin (Formatray, Kerr, USA)
9. Additional polyvinyl siloxane impression materials putty and light body type (Reprosil, Dentsply/Caulk, Milford, USA)
10. Pink baseplate wax (Modelling wax, Dentsply, USA)
11. PVC mold 22 mm in diameter
12. Stone type IV (Vel-Mix, Kerr Corporation, Califonia, USA)
13. Blue inlay wax (blue inlay casting wax, Kerr, USA)
14. Fit checker (Fit checker, GC Corporation, Tokyo, Japan)
15. Base metal alloy (4all, Ivoclar Vivadent Williams #0123, USA)
16. Root canal sealer (CU Product, Chulalongkorn University, Bangkok, Thailand)
17. Gutta percha point (Hygenic Guttapercha Points, Coltène/Whaledent Inc., Ohio, USA)
18. 2.5% Sodium hypochlorite (CU Product, Chulalongkorn University, Bangkok, Thailand)
19. Provisional restoration (Cavit, 3M ESPE, Seefeld, Germany)

Instruments used in this study

1. High speed airoter 330,000 rpm (high speed airotor, 798 W&H, Australia)
2. Light curing unit (Elipar Trilight 3M ESPE, Minnesota, USA)
3. Diamond burs (ISO 314197, Intensiv, Switzerland)

Table I Materials used in this study

Materials	Type	Composition
DT light post (Bisco Inc, France)	- Fiber density 32 fibers/mm2(32) - Post diameter 2.0 mm(32) - Fiber diameter 12 µm(32) - Surface occupied by fiber per mm^2. of post surface 38.4%(32)	- Quartz fiber 60% - Epoxy resin 40%(57)
Panavia F 2.0 (Kuraray medical, Japan)	Resin cement	Silanized barium glass, silanized silica, sodium fluoride, BPO, photosensitizer, MDP, hydrophobic and hydrophilic dimethacrylate, bisphenol A polyethoxy dimethacrylate(46)
ED Primer (Kuraray medical, Japan)	-	MDP, HEMA, N-methacryl 5-aminosalicylic acid, sodium benzene sulfinate,N,N-diethanol-p-toluidine, water(46)
Tetric Ceram (Ivoclar Vivadent, Liechtenstein)	Nanohybrid composite	Percentage by weight Catalysts, stabilizers and pigments 0.8%, Monomer 20.2% -> Bis-glycidylmethacrylate (Bis-GMA), Urethane dimethacrylate, Triethyleneglycol dimethacrylate, Mineral fillers 79%: Barium glass, Ytterbium trifluoride, highly dispersible silicon dioxide, Ba-Al-silicate glass containing fluoride mixed spheroidal oxide(75)

(a) **(b)** **(c)**

Fig. 3 Resin cement (a) ED primer (b) and silane coupling agent (c)

Fig. 4 Resin composite core build-up by using silicone index

CHAPTER III

MATERIAL AND METHODS

Tooth preparation

Thirty two caries and restoration-free human maxillary central incisors similar in size, with straight roots and a single pulp canal extracted for periodontal reasons were selected for this study. The teeth were decoronated leaving root lengths of 15 ± 1 mm in group 1 & 2 and 13 ± 1 mm in group 3 & 4. Ferrule 2 mm were prepared on the teeth in groups 1 and 2. The teeth were divided into 4 groups based on the presence or absence of ferrule and post diameters used: group 1: ferrule + post fit, group 2: ferrule + smaller post, group 3: no ferrule + post fit and group 4: no ferrule + smaller post. (Table II)

Table II Differences in remaining tooth structure and post diameter in 4 groups

	Remaining tooth structure	**Post diameter**
Group 1 (n=8)	2 mm ferrule	Properly fit
Group 2 (n=8)	2 mm ferrule	Smaller post
Group 3 (n=8)	No ferrule	Properly fit
Group 4 (n=8)	No ferrule	Smaller post

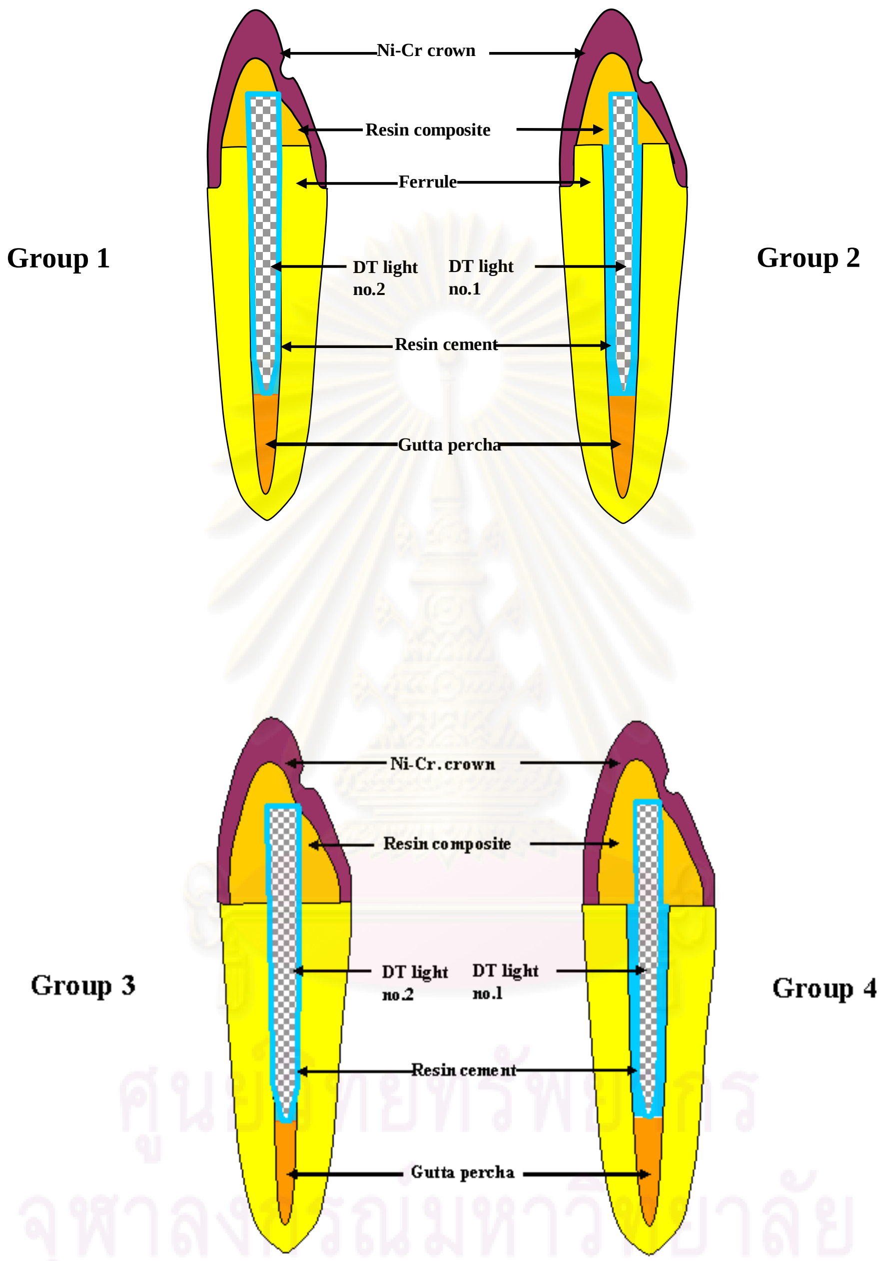


Fig. 5 Schematic drawing of 4 groups of tooth specimens with differences in ferrule and post diameters

Canal preparation

Root canal treatments were performed for all teeth using a step back technique until final instrument with a no.45 master apical file (K-file SybronEndo, SybronEndo Company, California USA). During preparation, the canals were irrigated with 5 ml of 2.5 % sodium hypochlorite and final irrigations were performed with 10 ml of 0.9% normal saline. The canals were dried with compressed air and paper points (CU Product, Chulalongkorn University, Bangkok, Thailand). Root canals were obturated by the lateral condensation technique with main cone and accessory gutta percha points (Hygenic Guttapercha Points, Coltène/Whaledent Inc., Ohio, USA), and root canal sealer (CU Product, Chulalongkorn University, Bangkok, Thailand). The extracoronal excess of gutta percha was removed and vertical condensation was performed with a heated condenser. The pulp chambers were sealed with a provisional restoration (Cavit, 3M ESPE, Seefeld, Germany).

Post space preparation and post cementation

The specimens were randomly divided into 4 groups (Table 1). Post spaces were prepared to a depth of 10 mm in ferrule groups and 8 mm in no ferrule groups with No.2 DT light post drill (Bisco Inc, Lançon De Provence, France) which has a double-taper design providing for proper post adaptation leaving 5 mm of gutta percha for apical seal. In groups 1 and 3, a DT light post no.2 was used. First, the root canal surface was prepared with self-etching primer (ED PRIMER II A&B, Kuraray medical, Okayama, Japan) for 30 seconds, and dried with paper points. The post was applied with silane coupling agent (mixture of Clearfil SE bond primer and porcelain bond activator, Kuraray medical, Okayama, Japan) for 5 sec to treat the post surface. Then, the post was coated with resin cement (Panavia F 2.0, Kuraray medical, Okayama, Japan) and introduced into canal with a pumping and rotating motion. Excess cement was removed and light cured with a light curing unit (Elipar Trilight 3M ESPE, Minnesota, USA) for 20 seconds, and complete polymerization of the cement was accomplished after 6 minutes. An oxygen barrier (Oxyguard II gel, Kuraray dental, Okayama, Japan) was applied to the superficial margins for 3 minutes and then removed with cotton rolls and water spray.

In group 2 and 4, DT light post no.1 was used. Post preparation and cementation were the same as group 1 and 3.

Core build-up and crown cementation

A core build-up with resin composite to 5 mm in height was performed by using a total etch bonding technique. The tooth structure was conditioned with 37% phosphoric acid gel (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 30 seconds on the enamel and then applied for 15 seconds to dentin, rinsed under water spray for 10 seconds, and dried with compressed air. Dentin bonding agent (Excite, Ivoclar Vivadent, Schaan, Liechtenstein) was applied for 10 seconds until glossy, then gently applied with compressed air for 5 seconds. Light polymerization was performed for 20 seconds with a halogen light. A 2 mm thick layer of resin composite (Tetric N Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) was applied around the post, and light cured for 20 seconds. The incremental build-up core was performed until the desired shape was obtained using a silicone index and light cured 40 seconds for complete polymerization. The core was refined with a tapered flat-end diamond bur (ISO 314197, Intensiv, Switzerland) under water spray to creating a 1.5 mm labial reduction with shoulder finishing line and 0.5 mm lingual reduction with chamfer finishing line. An impression was made using polyvinyl siloxane impression material (Reprosil putty and light body consistency, Dentsply/Caulk, Milford, USA), and then poured with type IV dental stone (Vel-Mix, Kerr Corporation, California, USA). Next, the crown pattern was made with casting wax (blue inlay casting wax, Kerr, USA), and casted as a Nickel-Chromium crown (4all, Ivoclar Vivadent Williams #0123, USA). The crowns were finished and polished before evaluating their fit on the die. The crowns were tried on the prepared teeth and checked with explorer and fit checker (Fit checker, GC Corporation, Tokyo, Japan) under visual inspection. All crowns were cemented with resin cement (Panavia F 2.0) following the manufacturer instruction by using constant finger pressure applied for 40 seconds then the excess cement was removed and protected with oxygen guard for 3 minutes. The specimens were stored for 7 days for a complete cement polymerization.

(a) **(b)** **(c)**

(d) **(e)**

Fig. 6 Core build-up procedure **(a)** acid etching with 37% phosphoric acid **(b)** dentin conditioning with primer bonding agent **(c)** core build-up with resin composite **(d,e)** The core was preparation to form 1.5 mm labial reduction with shoulder finishing line and 0.5 mm lingual reduction with chamfer finishing line

(a) **(b)**

Fig. 7 Specimen with crown cementation

Block preparation and periodontal ligament simulation

To simulate the periodontal ligament, the tooth roots were immersed in melted pink wax to produce a 0.2 mm layer of the average thickness of the periodontal ligament (7, 27), to a depth 2 mm below the cervical margin approximating biologic width. The specimens were mounted in PVC cylinders (22 mm in diameter and 20 mm in height) using self-cured acrylic resin (Formatray, Kerr, USA). Each tooth was removed from the resin block after the dough stage of self cured acrylic polymerization to prevent wax melting. After polymerization was complete, the tooth was replaced in the block and a silicone index of the crown to the resin block was prepared to ensure accurate repositioning. The wax spacer was removed from the root surface. Polyvinyl siloxane impression materials (Reprosil putty consistency, Dentsply/Caulk, Milford, USA) was injected into the acrylic resin block, then the tooth was repositioned into the block using prepared silicone index. Excess silicone material was removed with a scalpel blade to provide a flat surface 2 mm below the crown margin. Then, the specimens were stored in 37 ^{0}C for 7 days to ensure a complete polymerization of the resin cement (37)

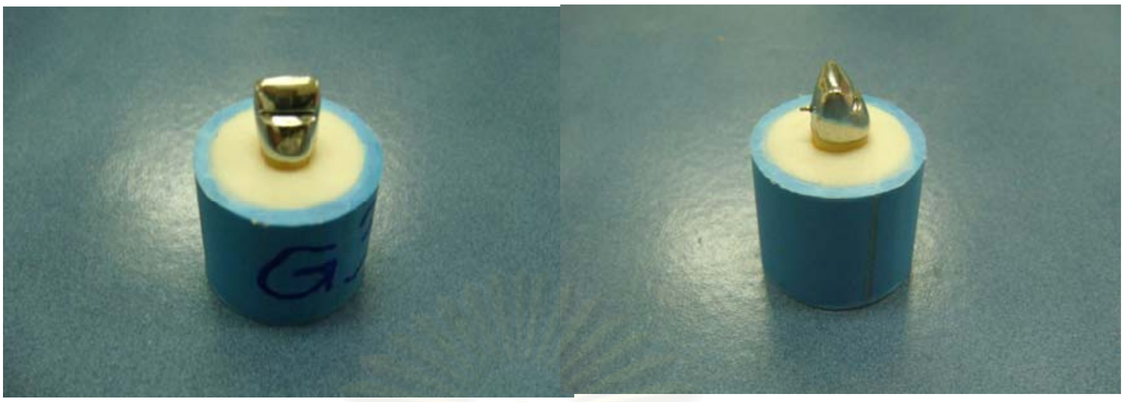


Fig. 8 Specimen for fracture resistance test

Fracture resistance test

The fracture resistance test was performed by using a universal testing machine (Instron universal testing machine model 8872; Instron Co., Canton, Massachusetts, USA). The compressive load was applied onto a prepared notch of the lingual surface (4 mm from the crown margin) at a 135-degree angle from tooth axis with a crosshead speed of 1 mm/min (19) until failure occurred. Fracture force was recorded in Newton (N). Data were analyzed by statistical software (SPSS Statistics version 17.0, SPSS Inc, Illinois, USA) using two-way ANOVA to evaluate the interaction between the effect of ferrule and post diameter. One-way ANOVA and Tukey HSD multiple comparisons post-hoc analyses ($\alpha < 0.05$) were used to analyze significant differences between groups at 95% confidential interval. Subsequently, the mode of failure of each specimen was examined by visual inspection under the stereomicroscope (EOS 100, Canon, Japan).

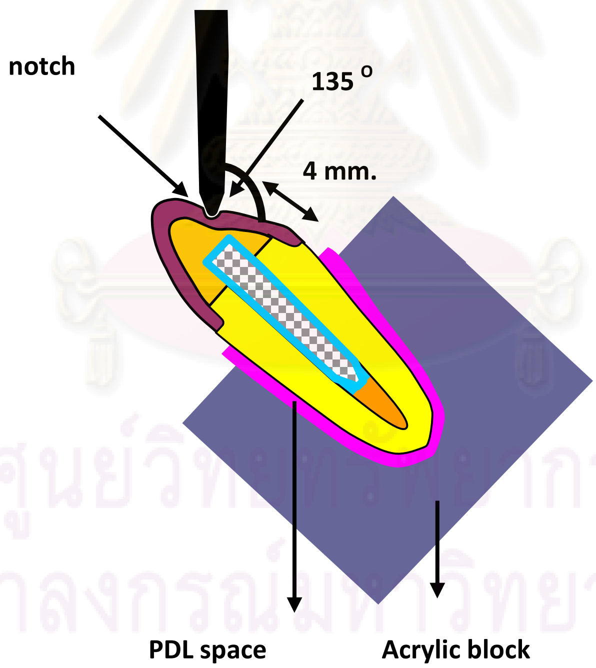


Fig. 9 Schematic drawing of specimen for fracture resistance testing

CHAPTER IV

RESULTS

As seen in table III, the presence of ferrule approximately doubled the fracture resistance compared to teeth without ferrule, irrespective of the fit of the post. These differences were statistically significant. In teeth prepared with ferrule, the presence of a smaller post reduced the fracture resistance by approximately 10%, but this was not statistically significant. In teeth with no ferrule, a smaller post reduced the fracture resistance by about 20%, which was also not statistically significant (table III).

Table III Mean and standard deviation of fracture resistance force of tooth specimens with different remaining tooth structure and post diameters

		Mean ± SD (N)	
		Ferrule	**No ferrule**
Post diameter	**Properly fit**	1474.67± 285.49[a]	811.67±155.71[b]
	Smaller	1339.42±120.59[a]	668.47±170.24[b]

Mean values with the same superscript letters are not statistically significant different ($p>0.05$)

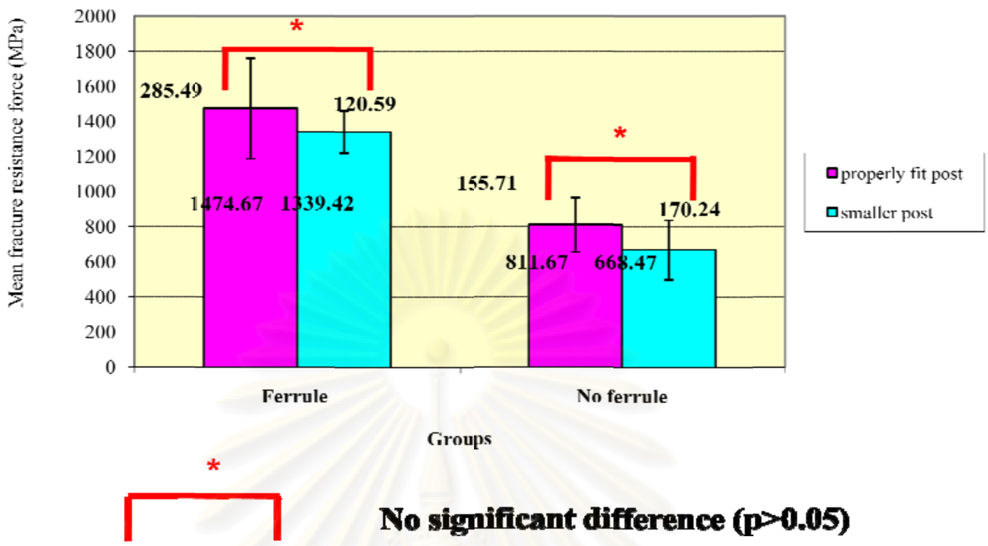


Fig. 10 Mean fracture resistance force of tooth specimen with different tooth structure and post diameters

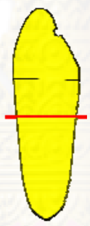
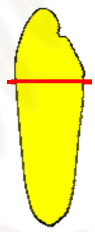
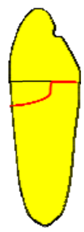
Two-way ANOVA revealed significant effects of the teeth with or with no ferrule in fracture resistance ($p<0.05$) (Table IV), but the diameter of post did not affect fracture resistance. Different post sizes had no effect ($p>0.05$). An interaction effect between these variable was not found ($p>0.05$).

Table IV Two-way ANOVA for effects and interactions of ferrule preparation and diameter of post

	df	**Sum of Squares**	**Mean Square**	**F**	**Sig.**
Ferrule	1	3558825.196	3558825.196	95.363	.000
Post diameter	1	155061.844	155061.844	4.155	.051
Ferrule * Post diameter	1	126.683	126.683	.003	.954

Three modes of failure were observed, horizontal root fracture at cervical root, horizontal fracture at crown margin and debonding of margin combined with cervical root fracture as described in table V. In groups with ferrule (groups 1 and 2), the failure mode was horizontal root fracture at the cervical of root or debonding of margin combined with cervical root fracture. In groups with no ferrule (groups 3 and 4), the failure mode was observed all 3 patterns.

Table V Distribution of different modes of failure of four experiment groups

	Horizontal root fracture at cervical of root	**Horizontal fracture at crown margin**	**Debonding of margin combined with cervical root fracture**
			
Group 1 (ferrule+ properly fit)	3	0	5
Group 2 (ferrule+ smaller post)	7	0	1
Group 3 (no ferrule+ properly fit)	1	4	3
Group 4 (no ferrule+ smaller post)	3	3	2
Total	14	7	11

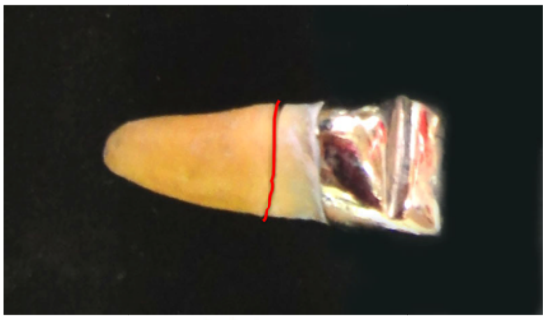


Fig. 11 Fracture mode of specimen which was horizontal root fracture at cervical of root

Fig. 12 Fracture mode of specimen which was horizontal root fracture at crown margin

Fig. 13 Fracture mode of specimen which was debonding of margin combined with cervical root fracture

CHAPTER V

DISCUSSION

The hypothesis that there would be no difference in the fracture resistance of the specimen with and with no ferrule was rejected. Analysis of the results indicated the preparation of ferrule on endodontically treated teeth significantly increased the fracture resistance of the teeth restored with FRC post and cores. The results of the present study may be explained due to the fact that greater remaining tooth structure results in a stronger tooth (9, 12, 76). Ma et al. reported a 1.0 mm ferrule on teeth restored with FRC post and ceramic crown could resist fatigue loading cycle 1.7 times more compared with teeth having a 0.5 mm ferrule. Furthermore, there was significant difference between the no ferrule group and the 0.5 and 1.0 mm ferrule groups. The no ferrule group had mean fatigue loading cycle 1,234 times less than 1.0 mm ferrule and 728 times less than 0.5 mm ferrule groups(11). A 2.0 mm ferrule was found to enhance fracture resistance 3.5 times compared with no ferrule and it was suggested the ferrule could reduce the load transmitted onto the post system (13) and redistribute the stress to the outer surface of the coronal third of the root (77). In addition, when the ferrule was absent, forces were shown to concentrate at the junction of post and core instead (15). In teeth with an incomplete ferrule, the location of the remaining tooth structure may affect fracture resistance. Indeed, anterior maxillary incisor with only a palatal wall was better able to resist fracture load than that with only the labial wall (13). In contrast, another study found the labial ferrule design resulted in the highest fracture resistance (12).These conflicting results suggest further investigations are needed.

The hypothesis that there was no significant difference in the tooth restored with the post which properly fit and not fit to the post space was accepted. Within the parameter of this hypothesis, there are two main factors to consider. The first is the difference in post diameter and the second is the difference in resin cement thickness. Considering differences in post diameter, a correlation was shown between the diameter of FRC post and loading force when testing with flexural properties (29) meaning larger posts should resist the force more than smaller ones. A finite element analysis study indicated the maximum von Mises stress in the FRC post slightly increased with an increase in post diameter. This advantage might help in reducing stress distribution to the remaining radicular tooth structure (78). But in the present study, the results did not show a significant difference in fracture resistance on the basis of post size. One reason might be due to the presence of the metal crown which may overcome the effect of the post diameter. When a crown is present, it could directly distribute the load to the root more effectively than the resin composite core due to its homogeneity and higher elastic modulus than resin composite. Another reason might be from the use of resin cement as a luting material which could increase the retention between the post and root canal dentin. Our results are in agreement with a study showing post fit did not have a significant influence on fracture resistance in specimen using a resin composite core to simulate the crown (79). Other studies suggested the use of composite as a luting material did not decrease the retention when the post did not properly fit the canal (80, 81). This contrasts with another study showing there was a significant difference in failure resistance between teeth where the post was properly fit and a smaller post when cemented with resin cement in specimens without crowns (8). Comparing differences of resin cement thickness, the present study used 2 sizes of DT light post with 0.1-0.3 mm differences in diameter. So the resin cement gap was in the range recommended for luting quartz fiber posts with a dual-cured resin luting agent (35).

The clinical use of a post smaller than the canal space might be found with a flared root canal, where the space between root canal and FRC post is important. When resin cement is used, it acts as a stress breaker under compressive load. If the post does not fit to the root canal, especially at the coronal level, the resin cement layer would be excessively thick and may contain bubbles, which could allow debonding to occur (82). Therefore, with wider cement gaps, the higher yield strength of the resin cement is required (83). In our study, the fracture resistance of a tooth with a smaller post reinforced with resin composite was comparable to a post which properly fit to the canal. While the smaller post reinforced with resin cement had significantly low fracture resistance (8). Similarly, reinforcement with resin composite in flared root canal had higher fracture resistance than reinforcement with resin cement (57). The resin composite could transfer low levels of stress to the cervical region of the root (57, 84). Thus using reinforced materials with a modulus of elasticity close to that of radicular dentin plays an important role in increasing fracture resistance with wider cement gaps (85).

When combining the factors of ferrule and post diameter together, the result of the present study showed the fracture resistances of the teeth with 2 mm ferrule were 1.8 to 2 times more than the teeth with no ferrule, while the effect of post diameter was not significantly different. This indicates the effects of ferrule preparation are more important in restoring endodontically treated teeth than the effect of post diameter. The result agreed with concluded prior study where the strength of the tooth was directly related to the remaining bulk of dentin and was more important than the type of core, post materials (3) and post length (40).

While there have been many reports comparing the effect of ferrule in endodontically treated teeth (11-13, 63, 74), the results have been controversial. Most of those studies were not conducted using crowns on the post and core specimens because they wanted to investigate the direct effect of bonding between materials of post and core and they claimed the placement of a crown may block the influence from other factors (12, 86). However, in clinical situations, the remaining tooth structures of endodontically treated teeth are minimal and prone to crown or root fracture, therefore, the guidelines of such treatment normally require crowns on post and core. The placement of a crown on the specimen might affect both fracture resistance and mode of failure especially in comparing specimens with and with no ferrule. Thus, the results of the studies with crown can be considered more practical to evaluate likely clinical outcomes.

The maximum forces of anterior teeth in healthy young adults are reported to range from 75 to 190 N (87). In the present study, fracture loads in all groups were found to be superior (668.47–1474.67 N) than this. This suggests anterior teeth with or with no ferrule restored with FRC post and full-coverage crown can resist normal occlusal forces (38, 74). The stress distribution in maxillary central incisors is quite different from the posterior teeth because loading occlusal forces are oblique to the long axis of the root. Under a 45° oblique load, teeth behave as a cantilever(38). The horizontal axis of the load has a greater influence on these teeth than the vertical axis (88) thus the flexural strength of the post is important (41).

The failure mode of the specimens in this study was classified into three patterns; pattern 1: horizontal root fracture at cervical root dentin, pattern 2: horizontal root fracture at cervical crown margin and pattern 3: debonding of margin combined with cervical root fracture. Group 1 (ferrule with properly fit post) failures mainly fell in pattern 3. This may be because the stress distributed from the coronal crown dentin through the cement interface directly to the post since the modulus of elasticity of resin cement (Panavia F 2.0) was nearly similar to dentin (18.3 and18.6 GPa) (89). This combination of restorative materials was able to distribute the stress more naturally. The failure mode started at the palatal crown margin through the cement core /crown interface along to the post, then the post bent as the diameter decreased apically leading to the oblique root fracture on the labial side. In group 2 (ferrule with small post), failure mainly occurred as a horizontal root fracture at cervical third of root. This may occur as when loading force is at 45^0 to the long axis of the root, the ferrule effect could help resist cement/crown failure. Therefore, the crown remain attached to the core but the small post bent easier allowing root flexion at the fulcrum point at the level of upper border of acrylic block simulating the alveolar crest. So the fracture started in the root dentin at the alveolar crest level and a horizontal root fracture occurred. In the non-ferrule groups (groups 3 and 4), the failure occurred in patterns 2 and 3. One reason for pattern 2 may be due to the failure at the cement crown/core interface which did not distribute stress along the post. So the fracture propagated along the crown margin at the labial side. The reason for pattern 3 may be stress concentrated at the cement core /crown interface which had differences in elastic modulus which was distributed to the cement post/root interface. So failure started from the lingual margin through the post and distributed apically through the post cement interface since the post detached from the cement. .

These results were similar to a prior study using composite cores with and without FRC post, failure occurred at the margin line of full crowns or between the margin and the embedded root in the resin block (90). When oblique force was applied to teeth restored with FRC post and core crown, the stress concentrated at the labial cervical margin of the crown and strain occurred at the lingual margin. The cervical region of the restored tooth was subjected to the highest strain and stress concentrations, and the higher the rigidity of the crown and core materials the more apically the stress and strain concentrated along the adhesive interfaces (91). In a study of finite element analysis of

FRC post the maximum von Mises stress in the FRC post slightly increased with an increase in post diameter. This should help to reduce stress distribution to the remaining radicular tooth structure (78).

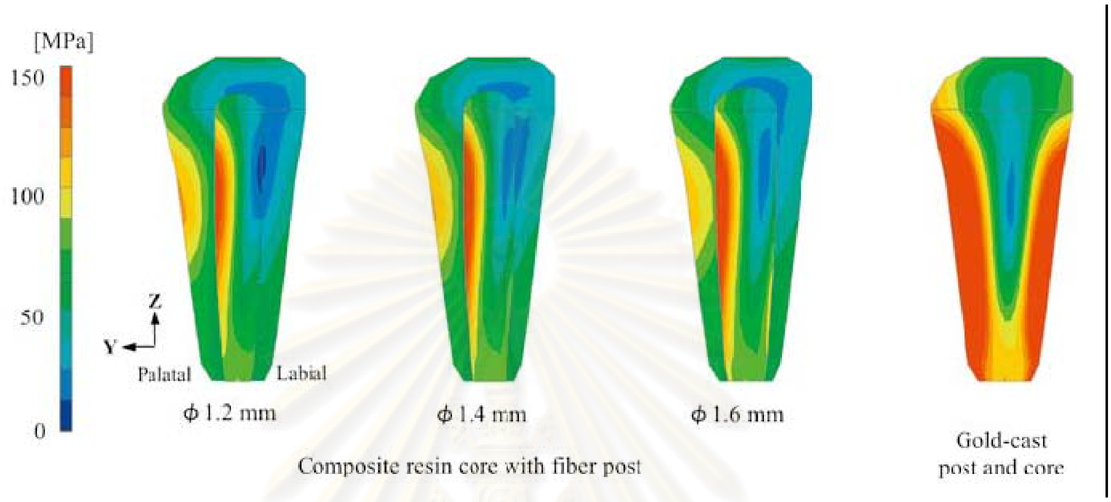


Fig. 14 Distribution of von Mises stresses in the internal area of the post (Dent Mater J 27(1): 49-55.)(78)

However, The failure mode in the present study were quite different from the study of Ng et al which found the initial mode of failure in non-ferrule group was debonding at the crown margin, then vertical root fracture occurred when the load continued beyond the initial failure(13).The reason might be from in this study, the mode of failure was observed when initial failure just occurred which considered to the failure of specimens.

In several studies of FRC post and core without crown, the restorable failure was observed (8, 90). But in the present study with simulated crown, the non-restorable failure was observed. This might be because of the use of resin cement in cementing crown, which provided a strong bond to the composite core and root. If the cement was changed to a conventional one such as zinc phosphate cement, the restorable failure might be observed with lower fracture resistance (54). However, fatigue study might show the different mode of failure in the same protocol.

The failure mode in the present study were quite different from a study which found the initial mode of failure in the non-ferrule group was debonding at the crown margin, followed by vertical root fracture when the load continued beyond the initial failure (13).In this study, however, the mode of failure was determined when initial failure occurred, and not beyond that point.

In this study, the DT light posts were used. These posts are made of pure silica with a modulus of elasticity similar to other glass fibers (32, 92). In addition, the quartz fibers used in this post type are pre-stressed and soaked with resin and released after curing. This procedure causes compression in the glass fibers which are then able to absorb tensile stresses when the post is exposed to flexural stress (31). Panavia F 2.0 resin cement was used because it contains phosphate-based monomer (10-MDP). Its low solubility of the MDP-calcium salt in water can make a stable bond to the tooth structure (93).

The bond between FRC post and root canal dentin is affected by the fiber post surface. Non treated FRC posts have a relatively smooth surface which limits mechanical retention with resin cements and purely adhesive failure modes commonly occurred at the post/cement interfaces (94). The conditioning of the post should be advise in order to roughen the post surface and enhance the bond strength of the FRC posts (95). Surface treatment with silane coupling agent is the most common surface conditioning method. The function of silane is to increase surface wettability of FRC post which is a key role for improved adhesion resulting in chemical bridges formation with OH-covered substrates such as glass or quartz fibers. The surface wettability of silane coupling agent was important since its low viscosity would assist substrate wetting provided physical adhesion. However, interfacial strength is still relatively low (96, 97). Using silane coupling is considered a sensitive technique. The primary factors influenced its efficiency included the type of silane (pH, solvent content, silane molecule, molecule size) and the application mode used (98). Unfortunately, the chemical bond of silane coupling agent may be achieved only between the resin composite and the exposed glass fibers of the post (94). From the result of Cheleux et al, the mechanical action of sandblasting combined with chemical coupling with silane and bonding agent resulted in improving interfacial strength between epoxy resin and resin composite (50).

Eugenol root canal sealer was used in this study. Some previous investigations concluded that eugenol had negative effects on resin compound since its phenolic components influence the polymerization and adversely affects their adhesive properties (81, 99, 100). In contrast, the study of Schwartz et showed that the root canal sealer with or without eugenol did not affect the retention of resin cement used in post bonding (101). From the study of Vassiliadis et al, the result showed that sealer was found deepest in the middle third of the root up to 200-900 microns from the root canal walls (102). In addition, the study of Peutzfeldt and Asmussen attempts decontaminate eugenol in the dentin and they showed that the use of alcohol, EDTA, chloroform and 37% phosphoric acid could eliminate the effects of eugenol on resin-dentin bonding (103, 104). In the present study, the drilling bur which was 1.00-1.77 mm in diameter was used in post space preparation. At the coronal dentin, dentin conditioning with 37% phosphoric acid was used. So the negative effect from eugenol penetration in root canal and coronal dentin on polymerization of resin cement might have been eliminated.

There are several limitations to the present study. Static loading represents a worst case situation and does not directly replicate forces in the oral cavity, regarding to both sizes of the load and nature of the load. In clinical situation, most pulpless teeth probably fail as a result of fatigue due to chewing forces. So resistance to static loads is not the only issue of interest. Further study should be analyzed using a cyclic load or under the thermocycling conditions.

CHAPTER VI

CONCLUSIONS

Within the limitations of this in vitro study, the following can be concluded:

1. The ferrule of endodontically treated tooth significantly increased the fracture resistance of the teeth restored with FRC posts and cores.
2. There was no significant difference in fracture resistance in the teeth restored with properly fitting post or a post smaller than the post space.
3. The effect of the ferrule on fracture resistance was found to be more important than post diameter in the restoration of endodontically treated teeth.

REFERENCES

(1) Albuquerque Rde, C.; Polleto, L. T.; Fontana, R. H., et al. Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil. 30 (2003): 936-943.

(2) Bateman, G.; Ricketts, D. N.; and Saunders, W. P. Fibre-based post systems: a review. Br Dent J. 195 (2003): 43-48; discussion 37.

(3) Milot, P.; and Stein, R. S. Root fracture in endodontically treated teeth related to post selection and crown design. J Prosthet Dent. 68 (1992): 428-435.

(4) Viguie, G.; Chabert, B.; Gerentes, R., et al. [Carbon-epoxy composite cores]. Rev Fr Prothes Dent. (1990): 39-46.

(5) Carrotte, P. Endodontics: part 4. Morphology of the root canal system. Br Dent J. 197 (2004): 379-383.

(6) Kasahara, E.; Yasuda, E.; Yamamoto, A., et al. Root canal system of the maxillary central incisor. J Endod. 16 (1990): 158-161.

(7) Sirimai, S.; Riis, D. N.; and Morgano, S. M. An in vitro study of the fracture resistance and the incidence ofvertical root fracture of pulpless teeth restored with six post-and-coresystems. J Prosthet Dent. 81 (1999): 262-269.

(8) Sirirat Ananviriyaporn. Effect of diameter and length of fiber post on failure resistance of endodontically treated teeth restored with post and core. Master's Thesis, Department of Prosthodontics Faculty of Dentistry Chulalongkorn University, 2008.

(9) Akkayan, B. An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent. 92 (2004): 155-162.

(10) Dorriz, H.; Alikhasi, M.; Mirfazaelian, A., et al. Effect of ferrule and bonding on the compressive fracture resistance of post and core restorations. J Contemp Dent Pract. 10 (2009): 1-8.

(11) Ma, P. S.; Nicholls, J. I.; Junge, T., et al. Load fatigue of teeth with different

ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. J Prosthet Dent. 102 (2009): 229-234.

(12) Naumann, M.; Preuss, A.; and Rosentritt, M. Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: an in vitro evaluation after chewing simulation. Acta Odontol Scand. 64 (2006): 31-36.

(13) Ng, C. C.; al-Bayat, M. I.; Dumbrigue, H. B., et al. Effect of no ferrule on failure of teeth restored with bonded posts and cores. Gen Dent. 52 (2004): 143-146.

(14) Libman, W. J.; and Nicholls, J. I. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont. 8 (1995): 155-161.

(15) Morgano, S. M.; Rodrigues, A. H.; and Sabrosa, C. E. Restoration of endodontically treated teeth. Dent Clin North Am. 48 (2004): vi, 397-416.

(16) Trabert, K. C.; and Cooney, J. P. The endodontically treated tooth. Restorative concepts and techniques. Dent Clin North Am. 28 (1984): 923-951.

(17) al-Hazaimeh, N.; and Gutteridge, D. L. An in vitro study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated post and composite core restorations. Int Endod J. 34 (2001): 40-46.

(18) Saupe, W. A.; Gluskin, A. H.; and Radke, R. A., Jr. A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots. Quintessence Int. 27 (1996): 483-491.

(19) Dikbas, I.; Tanalp, J.; Ozel, E., et al. Evaluation of the effect of different ferrule designs on the fracture resistance of endodontically treated maxillary central incisors incorporating fiber posts, composite cores and crown restorations. J Contemp Dent Pract. 8 (2007): 62-69.

(20) Nakamura, T.; Ohyama, T.; Waki, T., et al. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dent Mater J. 25 (2006): 145-150.

(21) Zhi-Yue, L.; and Yu-Xing, Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. J Prosthet Dent. 89 (2003): 368-373.

(22) Heydecke, G.; Butz, F.; Hussein, A., et al. Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems. J Prosthet Dent. 87 (2002): 438-445.

(23) Fuss, Z.; Lustig, J.; Katz, A., et al. An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod. 27 (2001): 46-48.

(24) Sorensen, J. A.; and Martinoff, J. T. Endodontically treated teeth as abutments. J Prosthet Dent. 53 (1985): 631-636.

(25) Assif, D.; Bitenski, A.; Pilo, R., et al. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent. 69 (1993): 36-40.

(26) Qualtrough, A. J.; and Mannocci, F. Tooth-colored post systems: a review. Oper Dent. 28 (2003): 86-91.

(27) Purton, D. G.; and Payne, J. A. Comparison of carbon fiber and stainless steel root canal posts. Quintessence Int. 27 (1996): 93-97.

(28) Akkayan, B.; and Gulmez, T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent. 87 (2002): 431-437.

(29) Lassila, L. V.; Tanner, J.; Le Bell, A. M., et al. Flexural properties of fiber reinforced root canal posts. Dent Mater. 20 (2004): 29-36.

(30) Dyer, S. R.; Lassila, L. V.; Jokinen, M., et al. Effect of cross-sectional design on the modulus of elasticity and toughness of fiber-reinforced composite materials. J Prosthet Dent. 94 (2005): 219-226.

(31) Seefeld, F.; Wenz, H. J.; Ludwig, K., et al. Resistance to fracture and structural characteristics of different fiber reinforced post systems. Dent Mater. 23 (2007): 265-271.

(32) Grandini, S.; Goracci, C.; Monticelli, F., et al. Fatigue resistance and structural

characteristics of fiber posts: three-point bending test and SEM evaluation. Dent Mater. 21 (2005): 75-82.

(33) de Rijk, W. G. Removal of fiber posts from endodontically treated teeth. Am J Dent. 13 (2000): 19B-21B.

(34) Monticelli, F.; Toledano, M.; Tay, F. R., et al. A simple etching technique for improving the retention of fiber posts to resin composites. J Endod. 32 (2006): 44-47.

(35) D'Arcangelo, C.; D'Amario, M.; Prosperi, G. D., et al. Effect of surface treatments on tensile bond strength and on morphology of quartz-fiber posts. J Endod. 33 (2007): 264-267.

(36) Martinez-Insua, A.; da Silva, L.; Rilo, B., et al. Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. J Prosthet Dent. 80 (1998): 527-532.

(37) Dean, J. P.; Jeansonne, B. G.; and Sarkar, N. In vitro evaluation of a carbon fiber post. J Endod. 24 (1998): 807-810.

(38) Qing, H.; Zhu, Z.; Chao, Y., et al. In vitro evaluation of the fracture resistance of anterior endodontically treated teeth restored with glass fiber and zircon posts. J Prosthet Dent. 97 (2007): 93-98.

(39) Hayashi, M.; Takahashi, Y.; Imazato, S., et al. Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater. 22 (2006): 477-485.

(40) Isidor, F.; Odman, P.; and Brondum, K. Intermittent loading of teeth restored using prefabricated carbon fiber posts. Int J Prosthodont. 9 (1996): 131-136.

(41) Heydecke, G.; Butz, F.; and Strub, J. R. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. J Dent. 29 (2001): 427-433.

(42) Mannocci, F.; Sherriff, M.; and Watson, T. F. Three-point bending test of fiber posts. J Endod. 27 (2001): 758-761.

(43) Drummond, J. L.; and Bapna, M. S. Static and cyclic loading of fiber-reinforced

dental resin. Dent Mater. 19 (2003): 226-231.

(44) Torbjorner, A.; Karlsson, S.; Syverud, M., et al. Carbon fiber reinforced root canal posts. Mechanical and cytotoxic properties. Eur J Oral Sci. 104 (1996): 605-611.

(45) Artopoulou, II; O'Keefe, K. L.; and Powers, J. M. Effect of core diameter and surface treatment on the retention of resin composite cores to prefabricated endodontic posts. J Prosthodont. 15 (2006): 172-179.

(46) Sahafi, A.; Peutzfeldt, A.; Asmussen, E., et al. Retention and failure morphology of prefabricated posts. Int J Prosthodont. 17 (2004): 307-312.

(47) Balbosh, A.; and Kern, M. Effect of surface treatment on retention of glass-fiber endodontic posts. J Prosthet Dent. 95 (2006): 218-223.

(48) Soares, C. J.; Santana, F. R.; Pereira, J. C., et al. Influence of airborne-particle abrasion on mechanical properties and bond strength of carbon/epoxy and glass/bis-GMA fiber-reinforced resin posts. J Prosthet Dent. 99 (2008): 444-454.

(49) Goracci, C.; Raffaelli, O.; Monticelli, F., et al. The adhesion between prefabricated FRC posts and composite resin cores: microtensile bond strength with and without post-silanization. Dent Mater. 21 (2005): 437-444.

(50) Cheleux, N.; Sharrock, P.; and Degrange, M. Surface treatments on quartz fiber post: influence on adhesion and flexural properties. Am J Dent. 20 (2007): 375-379.

(51) Perdigao, J.; Gomes, G.; and Lee, I. K. The effect of silane on the bond strengths of fiber posts. Dent Mater. 22 (2006): 752-758.

(52) Wrbas, K. T.; Schirrmeister, J. F.; Altenburger, M. J., et al. Influence of adhesive systems on bond strength between fiber posts and composite resin cores in a pull-out test design. Dent Mater J. 26 (2007): 401-408.

(53) Yenisey, M.; and Kulunk, S. Effects of chemical surface treatments of quartz and glass fiber posts on the retention of a composite resin. J Prosthet Dent. 99 (2008): 38-45.

(54) Mendoza, D. B.; Eakle, W. S.; Kahl, E. A., et al. Root reinforcement with a resin-

bonded preformed post. J Prosthet Dent. 78 (1997): 10-14.

(55) Akgungor, G.; and Akkayan, B. Influence of dentin bonding agents and polymerization modes on the bond strength between translucent fiber posts and three dentin regions within a post space. J Prosthet Dent. 95 (2006): 368-378.

(56) Zicari, F.; Couthino, E.; De Munck, J., et al. Bonding effectiveness and sealing ability of fiber-post bonding. Dent Mater. 24 (2008): 967-977.

(57) Moosavi, H.; Maleknejad, F.; and Kimyai, S. Fracture resistance of endodontically-treated teeth restored using three root-reinforcement methods. J Contemp Dent Pract. 9 (2008): 30-37.

(58) Mannocci, F.; Sherriff, M.; Ferrari, M., et al. Microtensile bond strength and confocal microscopy of dental adhesives bonded to root canal dentin. Am J Dent. 14 (2001): 200-204.

(59) Goracci, C.; Tavares, A. U.; Fabianelli, A., et al. The adhesion between fiber posts and root canal walls: comparison between microtensile and push-out bond strength measurements. Eur J Oral Sci. 112 (2004): 353-361.

(60) Fernandes, A. S.; and Dessai, G. S. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont. 14 (2001): 355-363.

(61) Turker, S. B.; Alkumru, H. N.; and Evren, B. Prospective clinical trial of polyethylene fiber ribbon-reinforced, resin composite post-core buildup restorations. Int J Prosthodont. 20 (2007): 55-56.

(62) Morgano, S. M.; and Brackett, S. E. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent. 82 (1999): 643-657.

(63) Ng, C. C.; Dumbrigue, H. B.; Al-Bayat, M. I., et al. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. J Prosthet Dent. 95 (2006): 290-296.

(64) Torbjorner, A.; and Fransson, B. Biomechanical aspects of prosthetic treatment of structurally compromised teeth. Int J Prosthodont. 17 (2004): 135-141.

(65) Patel, A.; and Gutteridge, D. L. An in vitro investigation of cast post and partial

core design. J Dent. 24 (1996): 281-287.

(66) Reagan, S. E.; Fruits, T. J.; Van Brunt, C. L., et al. Effects of cyclic loading on selected post-and-core systems. Quintessence Int. 30 (1999): 61-67.

(67) Hu, S.; Osada, T.; Shimizu, T., et al. Resistance to cyclic fatigue and fracture of structurally compromised root restored with different post and core restorations. Dent Mater J. 24 (2005): 225-231.

(68) Naumann, M.; Preuss, A.; and Frankenberger, R. Load capability of excessively flared teeth restored with fiber-reinforced composite posts and all-ceramic crowns. Oper Dent. 31 (2006): 699-704.

(69) D'Arcangelo, C.; De Angelis, F.; Vadini, M., et al. Fracture resistance and deflection of pulpless anterior teeth restored with composite or porcelain veneers. J Endod. 36 (2010): 153-156.

(70) D'Arcangelo, C.; De Angelis, F.; Vadini, M., et al. In vitro fracture resistance and deflection of pulpless teeth restored with fiber posts and prepared for veneers. J Endod. 34 (2008): 838-841.

(71) Naumann, M.; Sterzenbac, G.; Alexandra, F., et al. Randomized controlled clinical pilot trial of titanium vs. glass fiber prefabricated posts: preliminary results after up to 3 years. Int J Prosthodont. 20 (2007): 499-503.

(72) Newman, M. P.; Yaman, P.; Dennison, J., et al. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent. 89 (2003): 360-367.

(73) Pegoretti, A.; Fambri, L.; Zappini, G., et al. Finite element analysis of a glass fibre reinforced composite endodontic post. Biomaterials. 23 (2002): 2667-2682.

(74) Tan, P. L.; Aquilino, S. A.; Gratton, D. G., et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent. 93 (2005): 331-336.

(75) Esclassan Noirrit, E.; Gregoire, G.; and Cournot, M. Morphological study of fiber-reinforced post-bonding system-root dentin interface by evaluation of two bonding systems. J Dent. 36 (2008): 204-213.

(76) Hu, S. H.; Osada, T.; Warita, K., et al. [Resistance to cyclic fatigue of pulpless teeth with flared root canals restored with different post-and-core materials]. Zhonghua Kou Qiang Yi Xue Za Zhi. 40 (2005): 287-290.

(77) Loney, R. W.; Kotowicz, W. E.; and McDowell, G. C. Three-dimensional photoelastic stress analysis of the ferrule effect in cast post and cores. J Prosthet Dent. 63 (1990): 506-512.

(78) Okamoto, K.; Ino, T.; Iwase, N., et al. Three-dimensional finite element analysis of stress distribution in composite resin cores with fiber posts of varying diameters. Dent Mater J. 27 (2008): 49-55.

(79) Buttel, L.; Krastl, G.; Lorch, H., et al. Influence of post fit and post length on fracture resistance. Int Endod J. 42 (2009): 47-53.

(80) Assif, D.; and Bleicher, S. Retention of serrated endodontic posts with a composite luting agent: effect of cement thickness. J Prosthet Dent. 56 (1986): 689-691.

(81) Hagge, M. S.; Wong, R. D.; and Lindemuth, J. S. Effect of dowel space preparation and composite cement thickness on retention of a prefabricated dowel. J Prosthodont. 11 (2002): 19-24.

(82) Grandini, S.; Goracci, C.; Monticelli, F., et al. SEM evaluation of the cement layer thickness after luting two different posts. J Adhes Dent. 7 (2005): 235-240.

(83) Furukawa, K.; Inai, N.; and Tagami, J. The effects of luting resin bond to dentin on the strength of dentin supported by indirect resin composite. Dent Mater. 18 (2002): 136-142.

(84) Yoldas, O.; Akova, T.; and Uysal, H. An experimental analysis of stresses in simulated flared root canals subjected to various post-core applications. J Oral Rehabil. 32 (2005): 427-432.

(85) Mezzomo, E.; Massa, F.; and Libera, S. D. Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: an in vitro study. Part I. Quintessence Int. 34 (2003): 301-306.

(86) Kutesa-Mutebi, A.; and Osman, Y. I. Effect of the ferrule on fracture resistance of

teeth restored with prefabricated posts and composite cores. Afr Health Sci. 4 (2004): 131-135.

(87) Ferrario, V. F.; Sforza, C.; Serrao, G., et al. Single tooth bite forces in healthy young adults. J Oral Rehabil. 31 (2004): 18-22.

(88) Schmitter, M.; Huy, C.; Ohlmann, B., et al. Fracture resistance of upper and lower incisors restored with glass fiber reinforced posts. J Endod. 32 (2006): 328-330.

(89) Li, L. L.; Wang, Z. Y.; Bai, Z. C., et al. Three-dimensional finite element analysis of weakened roots restored with different cements in combination with titanium alloy posts. Chin Med J (Engl). 119 (2006): 305-311.

(90) Nishimura, Y.; Tsubota, Y.; and Fukushima, S. Influence of cyclic loading on fiber post and composite resin core. Dent Mater J. 27 (2008): 356-361.

(91) Sorrentino, R.; Aversa, R.; Ferro, V., et al. Three-dimensional finite element analysis of strain and stress distributions in endodontically treated maxillary central incisors restored with different post, core and crown materials. Dent Mater. 23 (2007): 983-993.

(92) Tezvergil, A.; Lassila, L. V.; and Vallittu, P. K. The effect of fiber orientation on the thermal expansion coefficients of fiber-reinforced composites. Dent Mater. 19 (2003): 471-477.

(93) Yoshida, Y.; Nagakane, K.; Fukuda, R., et al. Comparative study on adhesive performance of functional monomers. J Dent Res. 83 (2004): 454-458.

(94) Monticelli, F.; Ferrari, M.; and Toledano, M. Cement system and surface treatment selection for fiber post luting. Med Oral Patol Oral Cir Bucal. 13 (2008): E214-221.

(95) Schmage, P.; Cakir, F. Y.; Nergiz, I., et al. Effect of surface conditioning on the retentive bond strengths of fiberreinforced composite posts. J Prosthet Dent. 102 (2009): 368-377.

(96) Goracci, C.; Sadek, F. T.; Fabianelli, A., et al. Evaluation of the adhesion of fiber posts to intraradicular dentin. Oper Dent. 30 (2005): 627-635.

(97) Sahafi, A.; Peutzfeldt, A.; Asmussen, E., et al. Bond strength of resin cement to

dentin and to surface-treated posts of titanium alloy, glass fiber, and zirconia. J Adhes Dent. 5 (2003): 153-162.

(98) Matinlinna, J. P.; Lassila, L. V.; Ozcan, M., et al. An introduction to silanes and their clinical applications in dentistry. Int J Prosthodont. 17 (2004): 155-164.

(99) Schmage, P.; Pfeiffer, P.; Pinto, E., et al. Influence of oversized dowel space preparation on the bond strengths of FRC posts. Oper Dent. 34 (2009): 93-101.

(100) Tjan, A. H.; and Nemetz, H. Effect of eugenol-containing endodontic sealer on retention of prefabricated posts luted with adhesive composite resin cement. Quintessence Int. 23 (1992): 839-844.

(101) Schwartz, R. S.; Murchison, D. F.; and Walker, W. A., 3rd. Effects of eugenol and noneugenol endodontic sealer cements on post retention. J Endod. 24 (1998): 564-567.

(102) Vassiliadis, L. P.; Sklavounos, S. A.; and Stavrianos, C. K. Depth of penetration and appearance of Grossman sealer in the dentinal tubules: an in vivo study. J Endod. 20 (1994): 373-376.

(103) Ngoh, E. C.; Pashley, D. H.; Loushine, R. J., et al. Effects of eugenol on resin bond strengths to root canal dentin. J Endod. 27 (2001): 411-414.

(104) Peutzfeldt, A.; and Asmussen, E. Influence of eugenol-containing temporary cement on efficacy of dentin-bonding systems. Eur J Oral Sci. 107 (1999): 65-69.

APPENDIX

APPENDIX

Contents **Pages**

Descriptives

	ferrule			Statistic	Std. Error
FORCE	ไม่มีferrule	Mean		740.0719	43.52276
		95% Confidence Interval for Mean	Lower Bound	647.3053	
			Upper Bound	832.8384	
		5% Trimmed Mean		748.6171	
		Median		694.5300	
		Variance		30307.686	
		Std. Deviation		174.09103	
		Minimum		325.39	
		Maximum		1000.94	
		Range		675.55	
		Interquartile Range		269.4850	
		Skewness		-.549	.564
		Kurtosis		.664	1.091
	มีferrule	Mean		1407.0450	55.73358
		95% Confidence Interval for Mean	Lower Bound	1288.2517	
			Upper Bound	1525.8383	
		5% Trimmed Mean		1406.7833	
		Median		1388.0250	
		Variance		49699.717	
		Std. Deviation		222.93433	
		Minimum		1024.29	
		Maximum		1794.51	
		Range		770.22	
		Interquartile Range		378.4225	
		Skewness		-.043	.564
		Kurtosis		-.784	1.091

Tests of Normality

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	ferrule	Statistic	df	Sig.	Statistic	df	Sig.
FORCE	ไม่มี ferrule	.156	16	.200(*)	.930	16	.241
	มีferrule	.109	16	.200(*)	.976	16	.919

* This is a lower bound of the true significance.
a Lilliefors Significance Correction

Descriptives

	post			Statistic	Std. Error
FORCE	no fit	Mean		1003.9475	93.66114
		95% Confidence Interval for Mean	Lower Bound	804.3135	
			Upper Bound	1203.5815	
		5% Trimmed Mean		1013.6722	
		Median		1061.9250	
		Variance		140358.556	
		Std. Deviation		374.64457	
		Minimum		325.39	
		Maximum		1507.46	
		Range		1182.07	
		Interquartile Range		671.9150	
		Skewness		-.174	.564
		Kurtosis		-1.372	1.091
	fit	Mean		1143.1694	102.03137
		95% Confidence Interval for Mean	Lower Bound	925.6947	
			Upper Bound	1360.6441	
		5% Trimmed Mean		1139.5921	
		Median		1012.6150	
		Variance		166566.404	
		Std. Deviation		408.12548	
		Minimum		556.22	
		Maximum		1794.51	
		Range		1238.29	
		Interquartile Range		781.7300	
		Skewness		.319	.564
		Kurtosis		-1.402	1.091

Tests of Normality

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	post	Statistic	df	Sig.	Statistic	df	Sig.
FORCE	no fit	.199	16	.089	.908	16	.108
	fit	.191	16	.122	.907	16	.103

a Lilliefors Significance Correction

Test of Homogeneity of Variances

FORCE

Levene Statistic	df1	df2	Sig.
1.310	1	30	.261

ANOVA

FORCE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3558825.196	1	3558825.196	88.962	.000
Within Groups	1200111.038	30	40003.701		
Total	4758936.234	31			

Test of Homogeneity of Variances

FORCE

Levene Statistic	df1	df2	Sig.
.114	1	30	.738

ANOVA

FORCE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	155061.844	1	155061.844	1.010	.323
Within Groups	4603874.390	30	153462.480		
Total	4758936.234	31			

Univariate

Tests of Between-Subjects Effects

Dependent Variable: FORCE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3714013.723(a)	3	1238004.574	33.174	.000
Intercept	36880886.999	1	36880886.999	988.269	.000
FERRULE	3558825.196	1	3558825.196	95.363	.000
POSTDIAM	155061.844	1	155061.844	4.155	.051
FERRULE * POSTDIAM	126.683	1	126.683	.003	.954
Error	1044922.511	28	37318.661		
Total	41639823.234	32			
Corrected Total	4758936.234	31			

a R Squared = .780 (Adjusted R Squared = .757)

T-test

Group Statistics

	ferrule	N	Mean	Std. Deviation	Std. Error Mean
FORCE	ไม่มี ferrule	16	740.0719	174.09103	43.52276
	มีferrule	16	1407.0450	222.93433	55.73358

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
FORCE	Equal variances assumed	1.310	.261	-9.432	30	.000	-666.9731	70.71395	-811.39028	-522.55597
	Equal variances not assumed			-9.432	28.335	.000	-666.9731	70.71395	-811.74688	-522.19937

T-test

Group Statistics

	post	N	Mean	Std. Deviation	Std. Error Mean
FORCE	no fit	16	1003.9475	374.64457	93.66114
	fit	16	1143.1694	408.12548	102.03137

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper
FORCE	Equal variances assumed	.114	.738	-1.005	30	.323	-139.2219	138.50202	-422.08074	143.63699
	Equal variances not assumed			-1.005	29.783	.323	-139.2219	138.50202	-422.16725	143.72350

Descriptives

ferrule		post			Statistic	Std. Error
ไม่มีferrule	FORCE	no fit	Mean		668.4713	60.18847
			95% Confidence Interval for Mean	Lower Bound	526.1481	
				Upper Bound	810.7944	
			5% Trimmed Mean		673.3308	
			Median		674.1350	
			Variance		28981.214	
			Std. Deviation		170.23870	
			Minimum		325.39	
			Maximum		924.08	
			Range		598.69	
			Interquartile Range		140.7725	
			Skewness		-.833	.752
			Kurtosis		2.616	1.481
		fit	Mean		811.6725	55.05199
			95% Confidence Interval for Mean	Lower Bound	681.4952	
				Upper Bound	941.8498	
			5% Trimmed Mean		815.3494	
			Median		849.7950	
			Variance		24245.771	
			Std. Deviation		155.71054	
			Minimum		556.22	
			Maximum		1000.94	
			Range		444.72	
			Interquartile Range		248.5025	
			Skewness		-.469	.752

			Kurtosis		-1.107	1.481
มีferrule	FORCE	no fit	Mean		1339.4238	42.63650
			95% Confidence Interval for Mean	Lower Bound	1238.6044	
				Upper Bound	1440.2431	
			5% Trimmed Mean		1337.8469	
			Median		1341.2850	
			Variance		14542.972	
			Std. Deviation		120.59425	
			Minimum		1199.77	
			Maximum		1507.46	
			Range		307.69	
			Interquartile Range		249.2725	
			Skewness		.337	.752
			Kurtosis		-1.322	1.481
		fit	Mean		1474.6663	100.93605
			95% Confidence Interval for Mean	Lower Bound	1235.9904	
				Upper Bound	1713.3421	
			5% Trimmed Mean		1481.9181	
			Median		1596.2550	
			Variance		81504.687	
			Std. Deviation		285.49026	
			Minimum		1024.29	
			Maximum		1794.51	
			Range		770.22	
			Interquartile Range		524.5400	
			Skewness		-.855	.752
			Kurtosis		-.739	1.481

Tests of Normality

			Kolmogorov-Smirnov(a)			Shapiro-Wilk		
ferrule		post	Statistic	df	Sig.	Statistic	df	Sig.
ไม่มี ferrule	FORCE	no fit	.275	8	.076	.889	8	.230
		fit	.249	8	.157	.926	8	.479
มีferrule	FORCE	no fit	.187	8	.200(*)	.898	8	.278
		fit	.284	8	.056	.864	8	.132

* This is a lower bound of the true significance.
a Lilliefors Significance Correction

One-way

Test of Homogeneity of Variances

FORCE

Levene Statistic	df1	df2	Sig.
2.752	3	28	.061

ANOVA

FORCE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3714013.723	3	1238004.574	33.174	.000
Within Groups	1044922.511	28	37318.661		
Total	4758936.234	31			

One-way

Descriptives

FORCE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	8	1474.6663	285.49026	100.93605	1235.9904	1713.3421	1024.29	1794.51
2	8	1339.4238	120.59425	42.63650	1238.6044	1440.2431	1199.77	1507.46
3	8	811.6725	155.71054	55.05199	681.4952	941.8498	556.22	1000.94
4	8	668.4712	170.23870	60.18847	526.1481	810.7944	325.39	924.08
Total	32	1073.5584	391.80872	69.26265	932.2963	1214.8205	325.39	1794.51

Test of Homogeneity of Variances

FORCE

Levene Statistic	df1	df2	Sig.
2.752	3	28	.061

ANOVA

FORCE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3714013.723	3	1238004.574	33.174	.000
Within Groups	1044922.511	28	37318.661		
Total	4758936.234	31			

Post Hoc test

Multiple Comparisons

Dependent Variable: FORCE
Tukey HSD

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	135.2425	96.59019	.510	-128.4788	398.9638
	3	662.9937(*)	96.59019	.000	399.2724	926.7151
	4	806.1950(*)	96.59019	.000	542.4737	1069.9163
2	1	-135.2425	96.59019	.510	-398.9638	128.4788
	3	527.7512(*)	96.59019	.000	264.0299	791.4726
	4	670.9525(*)	96.59019	.000	407.2312	934.6738
3	1	-662.9937(*)	96.59019	.000	-926.7151	-399.2724
	2	-527.7512(*)	96.59019	.000	-791.4726	-264.0299
	4	143.2013	96.59019	.461	-120.5201	406.9226
4	1	-806.1950(*)	96.59019	.000	-1069.9163	-542.4737
	2	-670.9525(*)	96.59019	.000	-934.6738	-407.2312
	3	-143.2013	96.59019	.461	-406.9226	120.5201

* The mean difference is significant at the .05 level.

FORCE

Tukey HSD

GROUP	N	Subset for alpha = .05	
		1	2
4	8	668.4712	
3	8	811.6725	
2	8		1339.4238
1	8		1474.6663
Sig.		.461	.510

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 8.000.

BIOGRAPHY

NAME	Miss Arpaporn Pongpattarin
DATE OF BIRTH	14 June 1981
PLACE OF BIRTH	Bangkok, Thailand
INSTITUTIONS ATTENDED	Chulalongkorn University, 1999 - 2005: Doctor of Dental Surgery
WORK EXPERIENCE	2005 - 2007, Jakarat Hospital, Nakornratchasrima Position: Dentist 2009 -present, Private dental clinics, Bangkok, Thailand
RESEARCH GRANT	Faculty of Dentistry, Chulalongkorn University Fund
CONTACT ADDRESS	77/133 Soi Boromratchachonnanee 68, Boromratchachonnanee Road, Salathammasop, Taweewatana, Bangkok 10170