FRACTURE STRENGTH AFTER FATIGUE LOADING OF ROOT CANAL TREATED CENTRAL INCISORS RESTORED WITH POST AND DIRECT COMPOSITE BUILD-UP

Mr. Pawak Tungthangthum

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ความทนต่อการแตกหักของฟันตัดกลางที่ผ่านการรักษาคลองรากฟันซึ่งบูรณะด้วยเดือยร่วมกับการก่อคอมโพสิตโดยตรงภายหลังการให้ภาระความล้า

นายภวัคร์ ตั้งทางธรรม

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Thesis Title	FRACTURE STRENGTH AFTER FATIGUE LOADING OF ROOT CANAL TREATED CENTRAL INCISORS RESTORED WITH POST AND DIRECT COMPOSITE BUILD-UP
By	Mr. Pawak Tungthangthum
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor Chalermpol Leevailoj

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

....Dean of the Faculty of Dentistry

(Assistant Professor Suchit Poolthong, Ph.D.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Sirivimol Srisawasdi, Ph.D.)

....Thesis Advisor

(Associate Professor Chalermpol Leevailoj)

....External Examiner

(Associate Professor Montri Chantaramungkorn)

ภวัคร์ ตั้งทางธรรม : ความทนต่อการแตกหักของฟันตัดกลางที่ผ่านการรักษาคลองรากฟันซึ่งบูรณะด้วยเดือยร่วมกับการก่อคอมโพสิตโดยตรงภายหลังการให้ภาระความล้า. (FRACTURE STRENGTH AFTER FATIGUE LOADING OF ROOT CANAL TREATED CENTRAL INCISORS RESTORED WITH POST AND DIRECT COMPOSITE BUILD-UP) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทพ. เฉลิมพล ลี้ไวโรจน์, 41 หน้า.

วัตถุประสงค์: การศึกษานี้เพื่อประเมินผลความสูงของตัวฟันตัดบนที่เหลืออยู่ภายหลังการรักษาคลองรากฟัน และบูรณะด้วยเรซินคอมโพสิตแบบก่อโดยตรงร่วมกับเดือยฟัน ต่อความต้านทานการแตกหัก และรูปแบบการ แตกหัก

วิธีการศึกษา: นำฟันตัดมนุษย์ซี่กลางบนจำนวน 48 ซี่ แบ่งออกเป็น 4 กลุ่ม ดังนี้ กลุ่มที่ 1 ไม่มีส่วนตัวฟัน ร่วมกับบูรณะใช้เดือยฟัน กลุ่มที่ 2 มีส่วนตัวฟัน 2 มิลลิเมตร ร่วมกับบูรณะใช้เดือยฟัน กลุ่มที่ 3 มีส่วนตัวฟัน 2 มิลลิเมตร ร่วมกับบูรณะไม่ใช้เดือยฟัน และกลุ่มที่ 4 ฟันเต็มซี่ไม่ผ่านการบูรณะเป็นกลุ่มควบคุม นำมาผ่านภาระความล้าจำนวน 250,000 รอบ ด้วยแรง 40 นิวตัน แล้วนำไปทดสอบแรงกดจนเกิดการแตกหัก ผลการทดสอบที่ได้นำมาวิเคราะห์ทางสถิติด้วยการวิเคราะห์ความแปรปรวนแบบทางเดียว การวิเคราะห์แบบตูเกร์สำหรับความแตกต่างของแต่ละกลุ่มทดลอง และวิเคราะห์ความสัมพันธ์ของรูปแบบการแตกหักด้วยไคสแคว์ ที่ระดับนัยสำคัญ .05

ผลการศึกษา: ชิ้นงานทั้งหมดสามารถผ่านภาระความล้า 250,000 รอบได้ การวิเคราะห์ความแปรปรวนแบบทางเดียวพบว่ามีความแตกต่างของความต้านทานการแตกหักระหว่างกลุ่มอย่างมีนัยสำคัญทางสถิติ (p-value < .0001) ผลการทดลองแสดงให้เห็นว่ากลุ่มควบคุมมีความต้านทาน การแตกหักสูงสุด (1326.13 ± 145.25 นิวตัน) ตามด้วย กลุ่มที่ 2 (696.29 ± 191.75 นิวตัน) กลุ่มที่ 1 (592.80 ± 128.10 นิวตัน) และกลุ่มที่ 3 (234.65 ± 80.10 นิวตัน) ซึ่งความต้านทานการแตกหักของกลุ่มที่ 1 และ กลุ่มที่ 2 ไม่มีความต่างอย่างมีนัยสำคัญทางสถิติ (p-value > .05)

รูปแบบการแตกหัก ในกลุ่มที่ 1 ส่วนใหญ่เกิดบริเวณรอยต่อเรซินคอมโพสิต กับฟัน กลุ่มที่ 2 ส่วนใหญ่เกิดบริเวณใต้รอยต่อเคลือบรากฟันกับเคลือบฟัน กลุ่มที่ 3 ส่วนใหญ่เกิดบริเวณรอยต่อเคลือบรากฟันกับเคลือบฟัน และกลุ่มควบคุมส่วนใหญ่เกิดบริเวณรากฟัน เมื่อวิเคราะห์ด้วยสถิติไคสแคว์พบว่ารูปแบบการแตกหักระหว่างกลุ่มที่ 1 กับ กลุ่มที่ 2 และ กลุ่มที่ 2 กับ กลุ่มที่ 3 มีความแตกต่างดันอย่างมีนัยสำคัญทางสถิติ (p-value < .05)

บทสรุป: ความสูงตัวฟันที่เหลืออยู่ ไม่มีผลต่อความต้านทานการแตกหักของฟันตัดบนซี่กลางที่ผ่านการรักษาคลองรากฟันและบูรณะด้วยวิธีก่อเรซินคอมโพสิตโดยตรง อย่างไรก็ตามเมื่อมีการใช้เดือยฟันร่วมในการบูรณะจะช่วยเพิ่มความต้านทานการแตกหักให้แก่ฟันตัดบนซี่กลางที่ผ่านการรักษาคลองรากฟันและบูรณะด้วยวิธีก่อเรซินคอมโพสิตโดยตรง

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
		ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....
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5376145632 : MAJOR ESTHETIC RESTORATIVE AND IMPLANT DENTISTRY
KEYWORDS: DIRECT COMPOSITE RESIN BUILD-UP / FRACTURE STRENGTH / MODE OF FAILURE / FIBER POST / ROOT CANAL TREATED INCISOR / REMAINING TOOTH STRUCTURE / FATIGUE / CYCLIC LOADING

PAWAK TUNGTHANGTHUM: FRACTURE STRENGTH AFTER FATIGUE LOADING OF ROOT CANAL TREATED CENTRAL INCISORS RESTORED WITH POST AND DIRECT COMPOSITE BUILD-UP. ADVISOR: ASSOC. PROF. CHALERMPOL LEEVAILOJ, 41 pp.

Purpose: This in vitro study was to evaluate the effect of remaining tooth height of root-canal-treated incisors restored with fiber posts and direct composite resin build-up on fracture strength and mode of failure.

Methods: Forty-eight extracted human maxillary central incisors were randomly assigned to 1 of 4 groups: group 1 (0mm+post), group 2 (2mm+post), group 3 (2mm+no post), and group 4 (control). All specimens were subjected to a fatigue-loading device at 40 N with a 135° angle. When 250,000 loading cycles were reached, the surviving specimens were subjected to a static load. The presence of differences was analyzed by 1-way ANOVA, Turkey HSD test, and Chi-square analysis (α = .05).

Results: All specimens reached 250,000 cycles. ANOVA showed a significant difference in fracture strength (p-value < .0001). The highest mean fracture strength was recorded for group 4 at 1326.13 ± 145.25 N, followed by group 2 at 696.29 ± 191.75 N, group 1 at 592.80 ± 128.10 N, and group 3 at 234.65 ± 80.10 N. There was no significant differences in fracture strength between group 1 and group 2 (p-value > .05).

Most failures in group 4 occurred due to root fracture. While in group 3, most fracture lines occurred in tooth structure above the CEJ. The coronal failures of composite resin build-up occurred only in group 1. The fractures in group 2 mainly involved tooth structure below the CEJ. When the mode of failure was evaluated, statistically significant differences were noted between groups 1 and group 2, also group 2 and group 3 (p-value < .05).

Conclusions: The remaining coronal tooth structure did not increase the fracture strength of a direct composite resin build-up on root-canal-treated incisors. The presence of a fiber post improved the fracture strength of incisors restored with direct composite resin build-up, regardless of coronal height.

Field of Study: Esthetic Restorative and Implant Dentistry

Student's Signature ....

Advisor's Signature ....

Academic Year: 2013

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CHAPTER I
INTRODUCTION

Rationale and Significance of the Problem

Nowadays when tooth fracture occurs in the incisors area, the patient could replace the fractured tooth with an implant placement. However, many factors—such as time-line, expense, and growth—have to be considered before a fractured incisor is extracted. The preservation of crestal bone level immediately after tooth extraction is necessary for successful implant placement. After tooth extraction, the alveolar ridge will change in morphology and dimensions over time, especially in the buccal bone plate.[1, 2] Even when a socket preservation technique is performed, post-extraction bone resorption cannot be avoided.[3, 4] Long-term follow-up study had shown that the bone augmentation techniques and bone preservation techniques are still in developing.[5] Therefore, root canal treatment with a proper restoration is another choice for preserving the tooth socket.[6]

Traditionally, the root-canal-treated tooth with a full-coverage coronal restoration is the restoration of choice. However, the root-canal-treated tooth has a higher chance of fracture due to the lack of remaining tooth structure. In many cases, after root canal treatment, the remaining tooth structure can be reduced as a result of treatment procedures, such as removal of tooth structure during endodontic access, and cavity preparation.[7]

Furthermore, the cost of coronal restorations must be considered. At present, a direct composite resin restoration is the bonded restoration most often performed in dentistry, and a bonded restoration is necessary for the success of a root-canal-treated tooth by preventing recontamination.

The direct composite build-up might also be a proper restoration for this situation, since it can fulfill the patient's requirements for esthetics, function, and cost.[8, 9]

In addition, to improve the longevity of the restoration on root-canal-treated teeth, a post placement should be considered to reduce the risk of fracture.[10, 11]

Satisfactory outcomes have been reported with the use of a fiber post combined with composite resin, particularly in a root-canal-treated tooth with a conservative tooth structure approach involving adhesive restoration.[12] A direct composite resin build-up for final restoration of root-canal-treated anterior teeth, restored with or without posts, showed an overall survival rate of 98.5% in 5.3 years.[13] Another multi-practice clinical trial has shown a survival rate of 96% after 5 years for a prefabricated post with a composite core without a cast crown covering teeth.[14] A 30-month clinical study has shown favorable results, with 95% of restorations surviving with no marginal leakage or retention failures in root-canal-treated anterior teeth with the presence of at least 50% of residual sound tooth structure.[15] The fiber post has shown a significant increase in modulus of elasticity for composite resin build-up.[16]

From other studies, the presence of a ferrule of at least 1-1.5 millimeter and the location of tooth structure were important factors in the fracture resistance of root-canal-treated teeth.[17-19] Increasing coronal tooth structure significantly increased the fracture resistance of root-canal-treated anterior teeth.[10] Conversely, some studies reported that there was no significant difference in static load between a 2-millimeter-ferrule group and a no-ferrule group on human central incisors.[20-22]

Research Question

Does the remaining coronal height of root-canal-treated incisors affect the fracture strength when restored with direct composite resin build-up, with or without posts?

Objectives of the Study

This in vitro study was to evaluate the effect of remaining coronal height of root-canal-treated incisors restored with direct composite resin build-up in combination with post on fracture strength and mode of failure.

Statement of Hypothesis

Null hypothesis

There are no significant differences on fracture strength in root canal treated incisors restored with fiber post and direct composite resin build-up among non-coronal group and 2-millimeter coronal height group of maxillary central incisors.

Alternative hypothesis

There are significant differences on fracture strength in root canal treated incisors restored with fiber reinforced post and direct composite resin build-up among non-coronal group and 2-millimeter coronal height group of maxillary central incisors.

Conceptual Framework

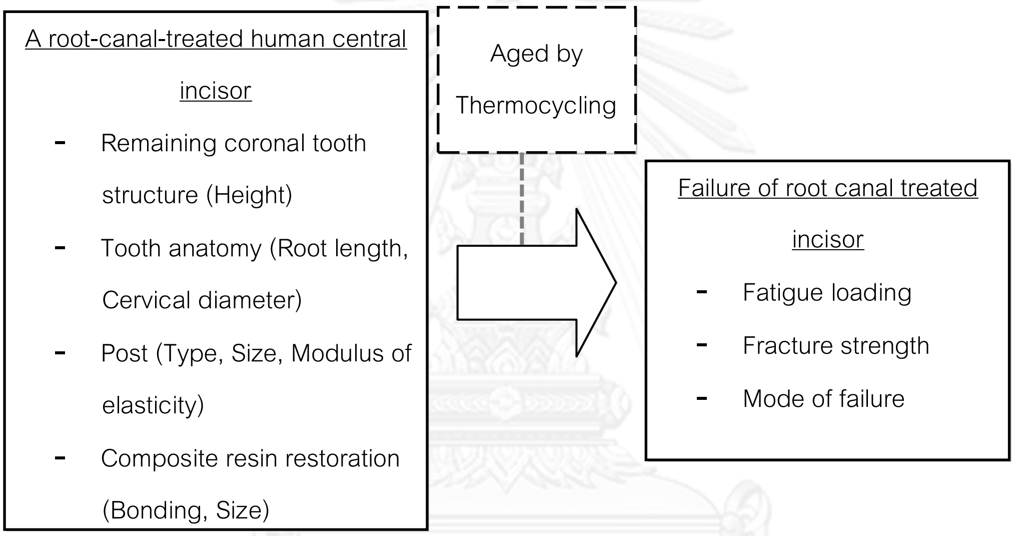


Figure 1 Conceptual framework

Basis Assumptions

1. All procedures were performed under well-controlled conditions and prepared by one operator and evaluated by one examiner.

2. One of the direct composite resin in Thailand was chosen to be used in this study (Premise, Kerr).

3. One of the resin cement in Thailand was chosen to be used in this study (Nexus 3, Kerr).

4. One of the fiber post in Thailand was chosen to be used in this study (Macro-Lock Post Illusion X-RO; R.T.D.).

5. The specimens were restored according to the recommendations of the respective manufacturers by one operator.

Study Limitations

This study was an in vitro study. The teeth in this study were extracted, free hand root-canal treated with vertical condensed of warm gutta-percha technique, restored with the same size and the same length of fiber post with a direct composite resin restoration, and subjected to the fatigue loading method on the acrylic resin mount.

Thus, the result could not be applied throughout to all in vivo root-canal-treated incisors that might have varies root lengths, sizes, and biological structures.

Keywords

DIRECT COMPOSITE RESIN BUILD-UP / FATIGUE LOADING / FRACTURE STRENGTH / MODE OF FAILURE / FIBER POST / ROOT CANAL TREATED INCISOR / REMAINING TOOTH STRUCTURE

The Expected Benefits

The results from this study might draw a clinically limitation of remaining coronal height of root-canal-treated incisor when restore with fiber post and direct composite resin build-up.

And, the results might draw a suggested treatment to postpone an extraction of incisor tooth to preserve the tooth's socket.

In addition, the results of this study will be a benefit for future study especially in the restoring technique on a compromised structure of root-canal-treated incisor.

CHAPTER II
REVIEW OF LITERATURES

Endodontic treatment is a decontamination procedure for root canal system of tooth; the success outcome comes from doing decontaminations and preventing recontaminations by aseptic treatment techniques and immediate coverage restorations after completing the endodontic treatment. Especially for restorations, bonded restorations should be selected to minimize microleakages and recontaminations.[9]

Post Placement in Root-canal-treated Tooth

Post placement in root-canal-treated tooth is necessary for improving core retention in teeth with extensive structural loss.[23] Some studies have supported the ability of posts to distribute stress favorably to prevent the root-canal-treated tooth from future fracture.[24, 25] In addition, fiber posts have demonstrated superior fracture resistance against static oblique loads, in comparison with prefabricated metallic posts, because of their tooth-like modulus of elasticity, which can help 'guide' fractures in a favorable direction.[26-30] The flexural modulus of dentin is equal to 17.5 ± 3.8 GPa, and that of the fiber post equals 24.4 ± 3.8 GPa.[31] Additionally, anterior teeth are usually subject to lateral force.[32] If the remaining tooth structure is limited, the post is needed to provide adequate retention and resistance.[9] Moreover, to improve the longevity of the restoration on root-canal-treated teeth, a post placement should be considered to reduce the risk of fracture.[10, 11] Another advantage of fiber posts in anterior teeth is esthetics, since fiber posts are tooth-colored and allow for light transmission through the post structure. By an in vivo structural analysis study, it was reported that the fiber post system had significantly more favorable failures than the prefabricated post or custom metal post and could improve the fracture strength of a tooth when restored with any crown materials.[25, 33] The tapered post should be selected, and the post length should be minimized or equaled to that of the clinical crown for placement inside the root canal, to minimize post space preparation to avoid extensive root dentin removal in the preparation process and to reduce root fracture after loading, since the effect of fiber post diameter was non-significant on post retention, as reported in an in vitro study.[34-37] With the use of resin cement in a luting process, the post's lack of congruence with the prepared root canal did not influence the outcome of fracture resistance in an in vivo fatigue test.[38]

The post placement in root canal treated tooth is necessary for improving the core retention in extended the loss tooth structure.[23] Some studies supported the ability of post that can distribute the stress in a favorable way to prevent the root canal treated tooth from future fracture.[24, 25] Fiber posts have been recommended to use in many studies because of their tooth-like modulus of elasticity; the flexural modulus of dentin equal to 17.5±3.8 GPa., and fiber post equal to 24.4±3.8 GPa.;[31] with more favorable fracture when failure occurred.[26-29, 31] Anterior teeth usually met the lateral force that was different from posterior teeth, as they were described as in a high-risk area of fracture failure.[32] If the remaining tooth structure was less, it would need the post to provide an adequate retention and resistance for restoration on root canal treated anterior teeth.[9] More advantage of fiber post in anterior teeth is an esthetic result. the fiber post has a tooth colored and allows light transmission through the post structure. Another choice of restorations for traumatized anterior teeth is the combination between polyethylene fibers and composite resins, using the polyethylene fibers for strengthening composite resin materials.[39] By a structural analysis study, it has been reported in an *in vitro* study that the fiber post system had significantly more favorable failures than the prefabricated post or custom metal post.[33] The *in vitro* study demonstrated the lower modulus of elasticity post; double taper light posts (DT Light-Post); had a significant higher fracture resistance compare with the zirconia post.[40] The placement of fiber post in root canal treated incisor could improve fracture strength of the tooth when restored with any crown materials.[25]

For the post-space preparation, it is also important to maintain an apical seal of gutta-percha. Many researchers has recommended to leave 4-5 millimeter of gutta-percha after post-space preparation, and keeping the post-space preparation diameter not more than one-third of the root width, or leaving at least 1 millimeter of dentine around the post. Some studies has suggested that the long post should be avoided because increasing the length of post-space preparation might weaken the root canal wall in the apical third of root. On the other hand, some studies did not show any significant differences in fracture resistance between different post lengths.[41, 42] The finite-element analysis study has shown that there was no difference in the von-Mises-stress between 5 millimeter post length or 10 millimeter post length placed in the root-canal-treated central incisor teeth. However, the shear stress distribution in differences area of the finite-element incisors' roots were shown that in the 5 millimeter post length group the maximal shear stress located in the cervical area of root below cervical margin less than 5 millimeter.[43] However, the length of post should be minimized or equaled to their clinical crown length to avoid an extensive root dentine removal in the preparation process[34] and to reduce the root fracture after loading.[35] The tapered post should be selected for placing in the root canal with a minimize post space preparation to prevent root rigidity reduction.[36] Additionally, the double-tapered post might have a better adaptability of posts to the root canal with a limited amount of root's dentine removal in a post preparation. For the diameter, the fiber post does not affect the retention of post shown by a non-significant outcome of an in vitro tensile study.[37] With the used of resin cement in a luting process, the no form-congruence of post with prepared root canal does not influence the outcome of fracture resistance in in vivo fatigue test.[38]

In a clinical situation, the most often failure of restored root canal treated teeth is loss of restoration retention. Retention failure primarily occurs in a luting cement layer or bonded interface follow by a dislodgement or fracture of post or restoration. Fatigue test is an essential research tool for testing adhesive restoration,[32] because it can constructed the testing situation comparable to physiologic situation.[32, 44]

The fiber post combined with composite resin, in particular with a tooth structure conservative concept with adhesive restoration, on root canal treated tooth showed satisfactory outcome.[12] A direct composite resin build-up for final restoration of root canal treated anterior teeth restored with or without post showed the overall survival rate was 98.5% in 5.3 year.[13] Another multi-practice clinical trials showed the survival rate was 96% after 5-year period in the prefabricated post with composite core without cast crown covering teeth.[14] A 30-month clinical study has shown a favorable results that 95% of restorations survived with no marginal leakages or retention failures in root canal treated anterior teeth with the presence of at least 50% of residual sound tooth.[15] The fiber reinforced post with composite core demonstrated superior fracture strength on root canal treated maxillary incisors in comparison to the all-ceramic and gold alloy post systems.[45] The glass fiber post had a positive effect to composite resin restoration because the post had shown significant increase of the modulus of elasticity of the composite resin build-up.[16]

The Remaining Tooth Structure

From the glossary of prosthodontics, a ferrule has been defined as "a metal band or ring used to fit around the root or crown of a tooth". From previous studies, they have shown that the presence of ferrule was an important factor for fracture resistance of root canal treated teeth. From a 17-year clinical control trial study, direct composite resin reconstruction on root canal treated teeth with more than 75% of remaining tooth height with minimum 1 millimeter of tooth thickness left showed that there were no statistical differences in survival probabilities between teeth in post or no post group.[17] A 1.5 millimeter ferrule has been suggested for a crown restoration with fiber post over a root canal treated tooth. Therefore not only the height of the ferrule was an important factor,[18] but also the location of the remaining ferrule structure affected its fracture resistance.[19] In all ceramic crown restorations (IPS Empress 2) that been cemented with resin cement (Variolink II) which much higher ferrule height displayed significantly more fatigue cycle counts.[11] However, an in vitro study has reported there were no significant differences in a static load between 2 mm ferrule group or no ferrule group on human central incisors.[20, 21] The study between buccal strain and fracture resistance of a 2 millimeter ferrule group and a no-ferrule group in root canal treated bovine anterior teeth showed no significant differences in groups restored by using a ceramic crown with composite resin core or fiber-reinforced core.[22] On the other hand, an increased amount of coronal dentine significantly increased the fracture resistance of root canal treated anterior teeth have been shown in the in vitro study, in addition, the no ferrule group all failures occurred only in core area.[10] Even though the no ferrule group's failure load lesser than ferrule group, the mode of failure in the no ferrule group was predominated in a favorable way.[19]

From the review literatures, the ferrule is the bracing of the complete crown over the tooth structure. The remaining coronal height does not constitute the ferrule. Many clinical reports had shown a direct composite build-up as one choice for final restoration on root canal treated incisors. Surprisingly, there was no study about the effect of remaining coronal height on fracture strength of root canal treated incisors.

CHAPTER III
MATERIALS AND METHODS

Research Design

This study was an in vitro experimental study using extracted human anterior teeth. All specimens were collected from patients that extracted his or her central incisor(s) for treatment reasons in dental clinics or hospitals.

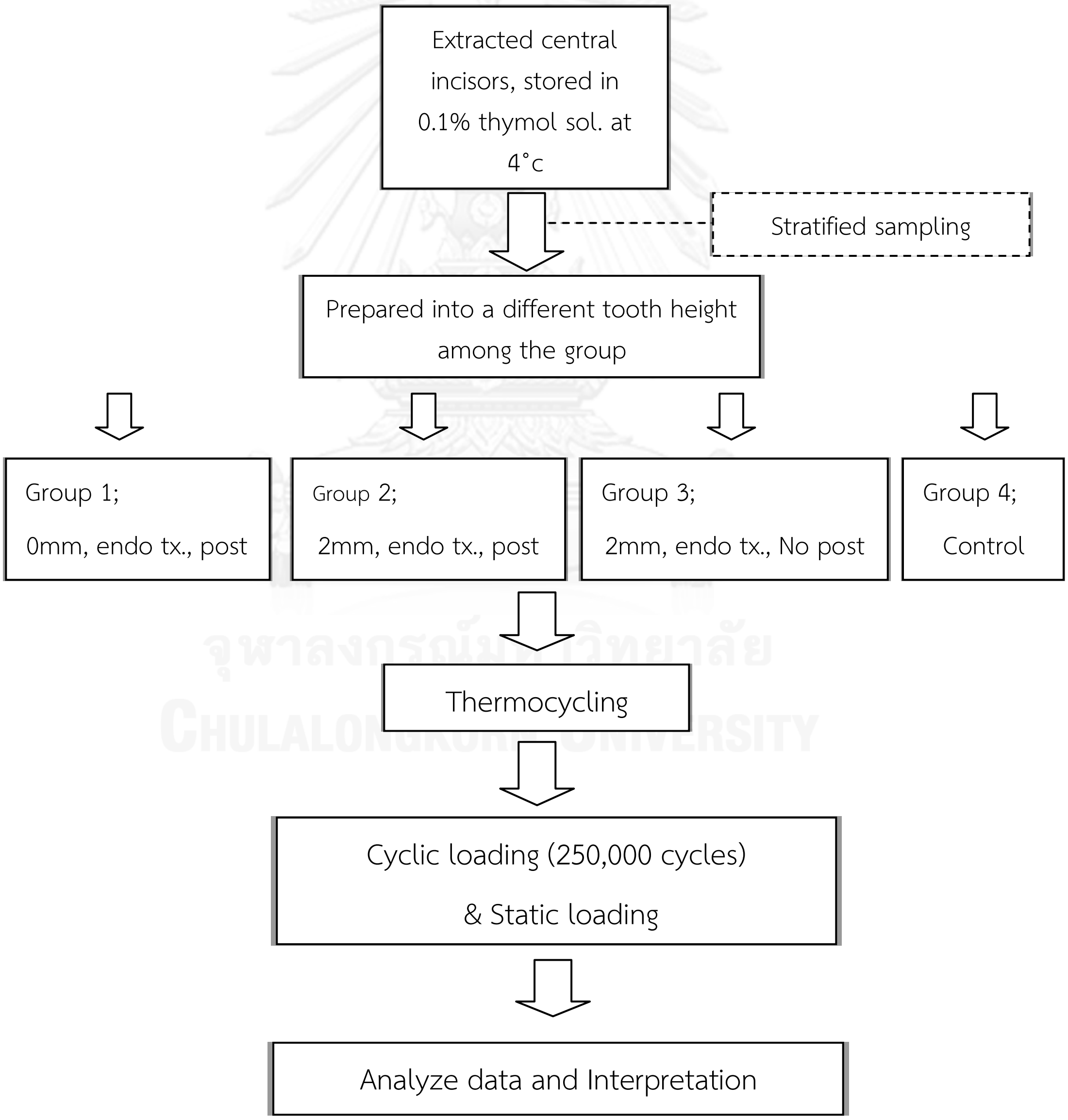


Figure 2 Diagram of the research design

Ethical Considerations

This research protocols had been submitted to the ethical committee of Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand for approval before proceeding throughout the procedures.

This study had been approved by the ethical committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand. The study reference ID was HREC-DCU 2012-040. (Appendix A)

Sample Description

Samples in this study were root canal treated central incisors, which individually mount in an acrylic resin block.

Sample size estimation was calculated from this formula;

$$n_i = \frac{2\,[Z_{\frac{\alpha}{2}} + Z_{\beta}]^2\,\sigma^2}{(\mu_1 - \mu_2)^2}$$

For this study, which the power of test equal to 80% and confident level equal to 5% the $Z_{\frac{\alpha}{2}}$ and Z_{β} are

$$Z_{\frac{\alpha}{2}} = 1.96 \qquad\qquad Z_{\beta} = 1.28$$

From the pilot study (Appendix F), the parameters were replaced as below

$$\mu_1 = 798.35 \qquad \mu_2 = 761.19 \qquad \sigma = 27.68$$

The sample size can be calculated as follow:

$$n_i = \frac{2\times[1.96+1.28]^2\times 27.68^2}{(798.35-761.19)^2} = 11.64 \approx 12$$

Materials

Table 1 List of materials used in this study

Trade name	Composition	Application method
Premise (A1) (Kerr Corporation, Orange, Calif) LOT 3719155 EXP: 2014–05	**Resin:** Ethoxylated bis-phenol-A-dimethacrylate, Triethylene glycol dimethacrylate (TEGDMA) and Light-cure initiators, stabilizers **Filler:** 30 to 50 μm Prepolymerized filler (PPF), 0.4 μm barium glass, and 0.02 μm silica filler	(1) The thickness of the individual increments should not exceed 2.5 mm at a time. (2) Light-cure each increment and each surface for 40 seconds.
Gel Etchant (Kerr Corporation, Orange, Calif) LOT 4539247 EXP: 2015–04	37.5% phosphoric acid	(1) Place gel on enamel and dentin for 15 seconds. (2) Rinse with water until etchant has been completely removed (approximately 15 seconds). (3) Gently air dry (without desiccate dentin).
Optibond FL (Kerr Corporation, Orange, Calif) LOT 4248955 EXP: 2013–04	HEMA, Glycerol phosphate dimethacrylate (GPDM), mono (2-methacrylate monomers), water, acetone, ethanol, and camphoroquinone	(1) Apply Optibond FL Prime over enamel and dentin surfaces for 15 seconds. (2) Gently air dry for approximately 5 seconds. (3) Apply Optibond FL Adhesive over enamel and dentin. (4) Thin using a light application of air. (5) Light-cure for 20 seconds.
NX3 Nexus Third Generation (Kerr Corporation, Orange, Calif) LOT 4349752 EXP: 2013–09	**Catalyst:** Bis-GMA, triethylene glycol dimethacrylate, barium aluminoborosilicate glass **Base:** Bis-GMA, camphoroquinone, barium aluminoborosilicate glass	(1) Apply the dual-cure cement to the post preparation, seat the post, and vibrate the post slightly. (2) Remove all excess cement. (3) Light-cure all surfaces for a minimum of 20 seconds per surface.
Macro-Lock Post Illusion X-RO (R.T.D., Espace	Serrated taper post, length 17.5 mm, Light yellow translucent fiber post embedded in a colored resin matrix	(1) Shape the canal with finishing drill (rotation speed 1,000-2,000 rpm). (2) Clean post with alcohol.

Gavaniere, Saint Egreve, France) LOT 173541109	**Size 4:** diameter at apical tip 1.00, at post head 1.83	(3) Apply a single coat of adhesive to the post. (4) Gently air-dry for 5 seconds. (5) Light-cure for 20 seconds. (6) Seat the post.
Sealapex (Kerr Corporation, Orange, Calif) LOT 1-1301 EXP: 2013–10	**Catalyst:** Isobutyl salicylate resin, fumed silica (silicon dioxide), bismuth trioxide, and titanium dioxide pigment **Base:** N-ethyl toluene sulfanamide resin, fumed silica (silicon dioxide), zinc oxide, and calcium oxide	(1) Mix the sealer on the mixing pad. (2) Place the sealer along the entire length of the canal with a paper-point,or Lentulo spiral. (3) Fill the root canal space with gutta-percha.
Elements Gutta Percha Cartridge (Kerr Corporation, Orange, Calif) LOT 051267103 EXP: 2016–01	trans-Polyisoprene (dry natural rubber), zinc oxide, barium sulfate, and colorants	(1) Heat an element cartridge in the handpiece. (2) Fill the cleaned, shaped, and irrigated root canal space. (3) Remove the tip from the root cana.l (4) Condense the gutta-percha with a condenser.
Gutta Percha (Kerr Corporation, Orange, Calif) LOT 090911 EXP: 2016-09	trans-Polyisoprene (dry natural rubber), zinc oxide, barium sulfate, and colorants	(1) Fill the cleaned, shaped, and irrigated root canal space.
K3 Rotary Files (Kerr Corporation, Orange, Calif) LOT 031215310	Nickel titanium rotary instruments	(1) Locate orifice and obtain patency. (2) Begin crown-down by taking a 0.10 taper and 0.08 taper to resistance. (3) Re-enter crown-down using a size #40 instrument. (4) Complete crown-down preparation with a #35, #25 instrument at 300-350 r.p.m.

Impregum Penta Soft Medium Body (3M ESPE, St. Paul, Minn) LOT 490252 EXP: 2015-02	**Base:** Polyether macromonomer, Fillers, Plasticizer, Pigments, Flavors, Triglycerides **Catalyst:** Initiator (Cation starter), Fillers, Plasticizers, Pigments	(1) Dosing and mixing are done automatically in the Pentamix 2. (2) Load the material. (3) Leave the material to set for 4 minutes.

Methods

Forty-eight freshly extracted human maxillary central incisors with no caries or cracks were selected for this study.

Exclusion criteria

Tooth had dental caries, a cervical lesion, or a visible fracture line.

Every tooth was submerged in 0.1% thymol solution at 4°C for anti-bacterial and anti-fungal purposes, thereby keeping extracted teeth fresh.[46] Teeth were removed from the solution only before the specimen preparation processes began.

Root length and tooth size were measured and analyzed according to descriptive statistics before being processed. The root length mean (mean=14.96, SD=1.24) was used to divide teeth into two strata:

- Above the mean
- Under the mean

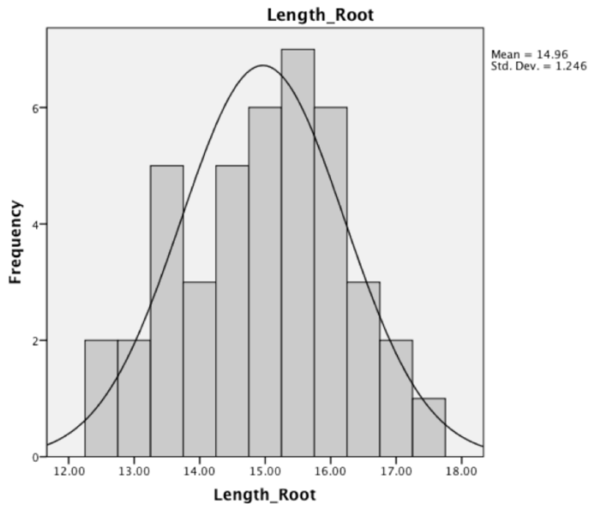


Figure 3 The root length mean

Next, teeth in each stratum were divided into 4 test groups by a simple random-sampling technique.

Next, the analysis of variance was used for testing each group for root length, buccolingual diameter, and mesiodistal diameter. All groups showed no significant difference in root length (p-value = .986), buccolingual diameter (p-value = .559), and mesiodistal diameter (p-value = .562).

Table 2 The Analysis of Variance of specimens' dimension

	Mean (SD)				p-value	F
	Group 1 (0mm+P)	Group 2 (2mm+P)	Group 3 (2mm+NP)	Control		
N	12	12	12	12		
Dimension						
BL width	6.2 (0.54)	6.4 (0.37)	6.3 (0.53)	6.1 (0.64)	0.559	F(3,44) =.698
MD width	5.7 (0.48)	5.8 (0.55)	5.7 (0.51)	5.5 (0.31)	0.562	F(3,44) =.693
Root length	14.8 (1.1)	15.0 (1.38)	15.1 (1.54)	14.8 (1.24)	0.986	F(3,44) =.047

BL = Buccolingual, MD = Mesiodistal.

Tooth Preparation Process

All roots were cleaned with a piezo-scaler (P5 Newtron™ XS; Acteon, Bordeaux, France). Each specimen was decoronated into different heights for different groups by means of a low-speed cutting machine (Isomet 1000; Buehler Ltd., Lake Bluff, Ill) as follows:

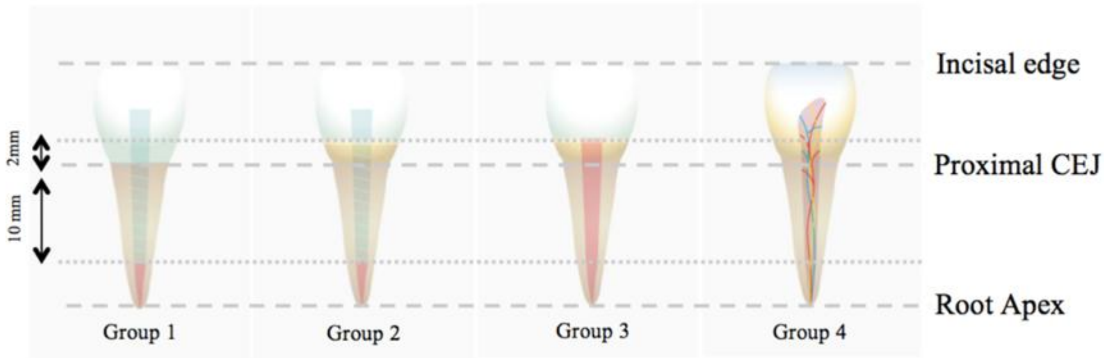


Figure 4 Dimension of test groups

Group 1 : 0.0 millimeter remaining coronal height from proximal cementoenamel junction (CEJ) with post placement

Group 2 : 2.0 millimete remaining coronal height from proximal CEJ with post placement

Group 3 : 2.0 millimete remaining coronal height from proximal CEJ with no post placement

Group 4 : Full coronal intact for control

Endodontic Treatment Procedure

Endodontic treatment was completed on all teeth by means of nickel-titanium rotary instruments, size 0.25 (K3 Nickel-Titanium Files; Kerr Corporation, Orange, Calif) under intermittent irrigation with 1% sodium hypochlorite solution to an apical size 35. Teeth were rinsed with 17% EDTA for removal of the smear layer after instrumentation for increasing bond strength of the root canal sealer,[47-50] and finished by obturation with a vertical condensation technique on warm gutta-percha (Element Gutta Percha Cartridge; Kerr Corporation) with a non-eugenol root canal sealer (Sealapex; Kerr Corporation). After the obturation process, all specimens were stored in 100% humidity at 37°C for one day before the next processes were initiated.

Post Placement Procedure

Root canals were enlarged for the placement of fiber posts by means of peso-drills size #1, #2, #3, and #4, with a finishing drill for fiber post size 4 (Finishing Drill for Macro-Lock Post Illusion X-RO; R.T.D., Espace Gavaniére, Saint Egrève, France). The drill set was changed after treatment of every 5 teeth. The depth of the post space was 10 millimeter below the CEJ, leaving 3-5 millimeter of gutta-percha apically.

The root canals were etched with 37.5% phosphoric acid for 15 seconds, rinsed with air-water spray and a syringe, and then gently dried with air and adsorbent paper-points. Subsequently, a three-step total etch adhesive system (Optibond FL; Kerr Corporation) was used for minimizing microleakage in the root canal system.[51] The three-step total etch adhesive system was applied to the root canal by means of microbrushes, and an adhesive layer was gently thin with air and adsorbent paper-points. A clear dual-cured resin cement (Nexus 3; Kerr Corporation) was used as a luting agent for fiber posts. The cement was applied to the post space by means of an intra-canal tip. Then, a size 4 fiber post (Macro-Lock Post Illusion X-RO; R.T.D.) coated with a layer of adhesive was inserted into the root canal. Excess resin cement was removed by means of a micro-sponge and cured with a visible-light-polymerization unit (Demi Plus; Kerr Corporation) with 1,100 mW/cm^2 intensity for 40 seconds. The light guide was held perpendicularly within 1 millimeter of the post-dentin interface. The light output from the light-polymerizing unit was monitored by means of a light intensity meter (100 Optilux; Kerr Corporation) throughout the study.

After fiber posts were fixed in root canals, they were left 7.5 millimeter superior to remaining tooth level in group 1 and 5.5 millimeter superior to remaining tooth level in group 2. Next, specimens in group 2 and group 3 were prepared for direct composite restoration by the beveling of an enamel margin 1 millimeter around the tooth with a diamond bur (852.FG.010; Jota AG, Ruthi, Switzerland), but no bevel preparation was performed in group 1.

Laboratory Preparation Procedure

Reproduction of the periodontal ligament (PDL) in the specimen is one of the important factors in a fracture resistance test.[52] The polyether material was selected because of its higher ultimate tensile strength.[53]

The specimens' roots were wrapped with a 0.2-mm-thickness aluminum foil comparable with a PDL thickness equal to 0.12 - 0.33 millimeter, to create a space between the root and acrylic resin to simulate the periodontal membrane.[54] Then, specimens were immersed in a PVC mold (diameter, 1 inch; height, 1 inch), filled with an auto-polymerized acrylic resin at level 2 millimeter below the labial-palatal CEJ. A surveyor was used during the immersion procedure to ensure that the long axis of the tooth was vertically aligned. After the acrylic set and the thin aluminum foil was removed, the specimens' roots were coated with polyether material (Impregum™ Penta™ Soft Medium Body; 3M ESPE, St. Paul, Minn), and replanted into an acrylic resin mount for simulation of the periodontal ligament.[52]

Direct Composite Build-up Procedure

All specimens in groups 1, 2, and 3 were etched with 37.5% phosphoric acid for 15 seconds, rinsed with air-water spray, and bonded with three-step total etch adhesive system (Optibond FL; Kerr Corporation).

Then, in group 1, nanofilled composite resin (Premise; Kerr Corporation) was packed into a 10- millimeter-height crown-shaped clear silicone mold and placed on the remaining tooth, and then cured with a visible-light-polymerization unit.

In groups 2 and 3, nanofilled composite resin (Premise; Kerr Corporation) was packed into an 8- millimeter-height crown-shaped clear silicone mold with the same diameter as in group 1 and placed on the remaining tooth, and then cured with a visible-light-polymerization unit.

A cleared silicone mold in groups 1, 2, and 3 were fabricated from the pre-contoured typodont tooth with a 1.5- millimeter-diameter concavity in the center of the lingual fossa area, to serve as a marker for the load cell. After the silicone mold was removed, the direct composite build-ups were cured additionally with a visible-light-polymerization unit for 40 seconds on each side.

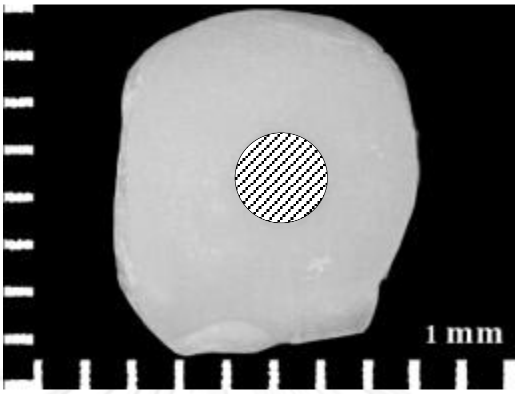


Figure 5 Cross-section of a direct composite resin build-up at 1 millimeter above the CEJ

The thickness of composite resin measured from each external surface to the post-composite interface did not exceed 2.0 millimeter, to provide for adequate light penetration and subsequent polymerization.[55]

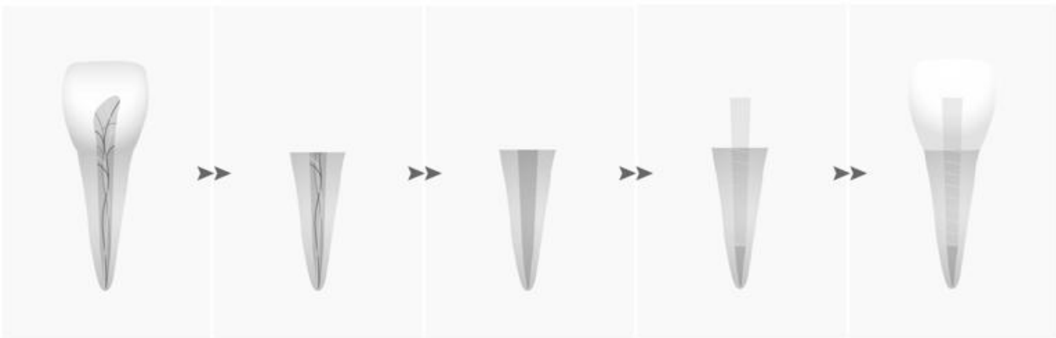


Figure 6 Specimen’s preparation process of group 1 (0 mm+Post)

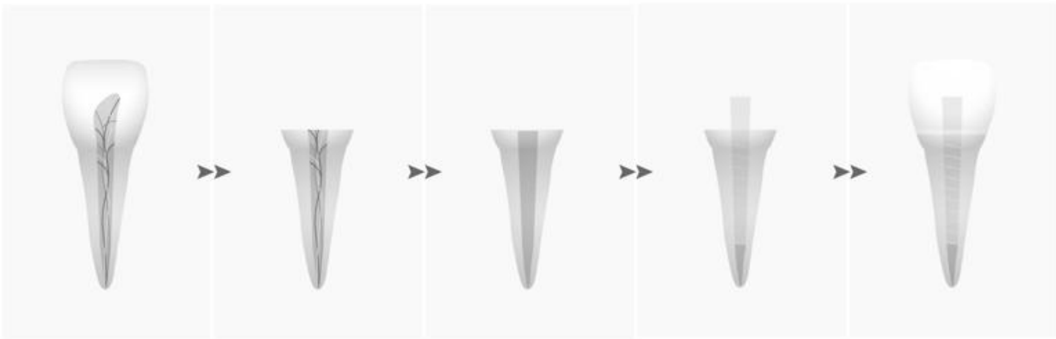


Figure 7 Specimen’s preparation process of group 2 (2 mm+Post)

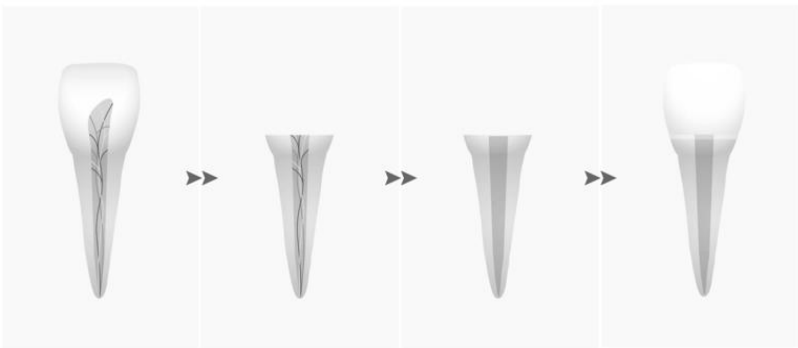


Figure 8 Specimen’s preparation process of group 3 (2 mm+NoPost)

Thermocycling Procedure

After all restorative processes were completed, all specimens were subjected to an artificial aging procedure and thermocycled for 10,000 cycles at 15°C and 45°C with a dwell time of 20 seconds to simulate 1 year of intraoral service time.[56] All prepared specimens were stored at 37°C in 100% humidity until the intervention process began.

Intervention

A cyclic-loading device (Universal testing machine 8872; Instron, High Wycombe, Bucks, UK) was used to apply a load 4.0 kilograms (40 newton) using round-ended stainless steel heads (diameter, 1.5 millimeters) at 8 millimeter from the PVC mold at a 135° angle to the long axis of the tooth to simulate normal chewing force.[57, 58]

The cyclic-loading rate was 120 cycles per minute or 2 Hz,[59] while the upper limit of the cyclic-loading was set at 250,000 cycles.

After that, the surviving specimen was subjected to a static load at a crosshead speed of 1 mm per minute until fracture occurred.

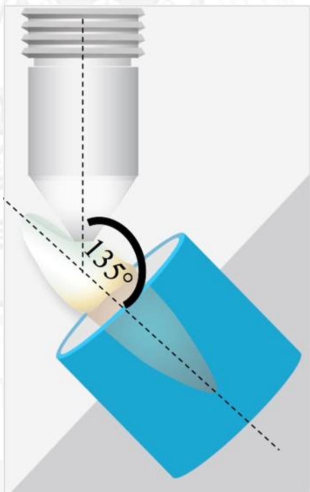


Figure 9 Specimen in a cyclic-loading device

Data Collection

For the cyclic load, if specimens failed before 250,000 cycles, the cycle count was recorded. Conversely, if a specimen reached this limit, the loading stopped, and 250,000 cycles were recorded.[11]

For the static load, fracture was defined as the point at which the loading force reached a maximum value. When fracture occurred in the specimen, the fracture load and mode of failure were recorded.

Fractured specimens were visually evaluated to determine the fracture modes using a classification system modified from Valdivia et al[60] and Heydecke et al[61]. The mode of failure was defined as 'favorable fracture' or 'repairable' (composite-tooth interface, above the CEJ) or as 'unfavorable fracture' or 'catastrophic fracture' (below the CEJ).

Statistical Analysis

PASW statistical analysis software, version 17 (Chicago, Ill), was used in this study.

The analysis of variance was used to detect the presence of differences among groups. A Turkey HSD test was used to compare the mean static loads between groups. Modes of failure were compared between and among groups by the Chi-square test. The level of significance in this study was determined at 5%.

CHAPTER IV
RESULTS

All specimens reached the 250,000 fatigue cycle count.

The Fracture Strength

The highest mean fracture strength was recorded for group 4 (control) at 1326.13 ± 145.25 N, followed by group 2 (2mm+Post) at 696.29 ± 191.75 N, group 1 (0mm+Post) at 592.80 ± 128.10 N, and group 3 (2mm+NoPost) at 234.65 ± 80.10 N.

As the normality of data indicated, the test was analyzed by the analysis of variance, which showed the significant difference in fracture strength of one or more groups (p-value < .0001).

Table 3 The Analysis of Variance of fracture strength

	N	Mean fatigue loading cycles	Mean fracture strength (SD)
Group 1 (0mm+Post)	12	250,000	592.80^{a} (128.10) 95%CI [511.41, 674.19]
Group 2 (2mm+Post)	12	250,000	696.29^{a} (191.75) 95%CI [574.46, 818.13]
Group 3 (2mm+NoPost)	12	250,000	234.65^{b} (80.10) 95%CI [183.76, 285.54]
Control	12	250,000	1,326.13^{c} (145.25) 95%CI [1,233.84, 1,418.42]
			F(3, 44) = 122.83, p-value < 0.0001

BL = Buccolingual, MD = Mesiodistal, CI = Confident interval, SD = Standard deviation

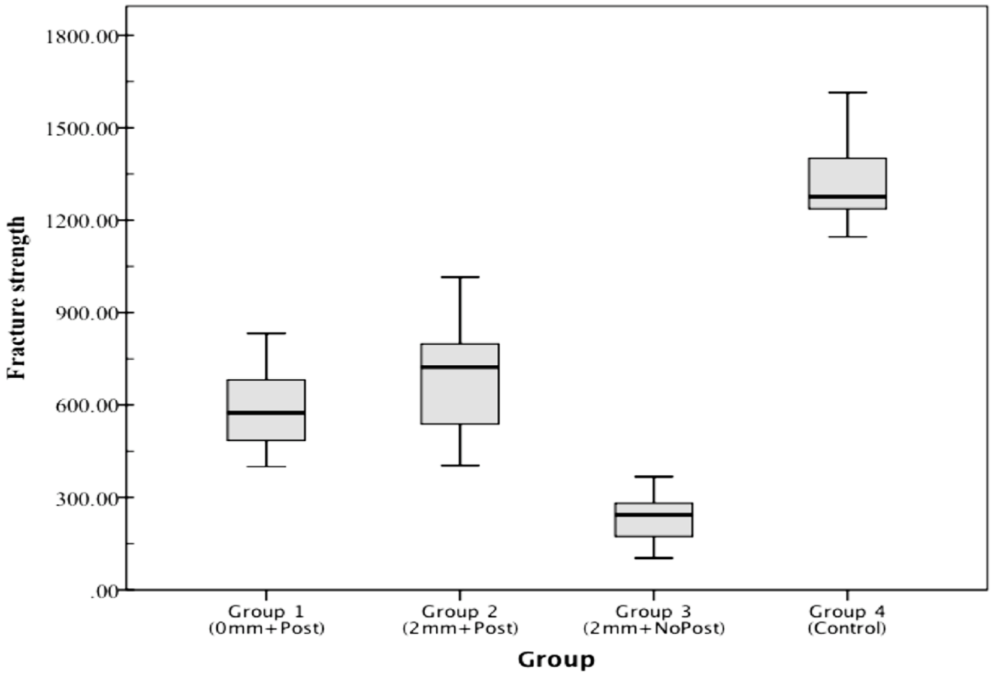
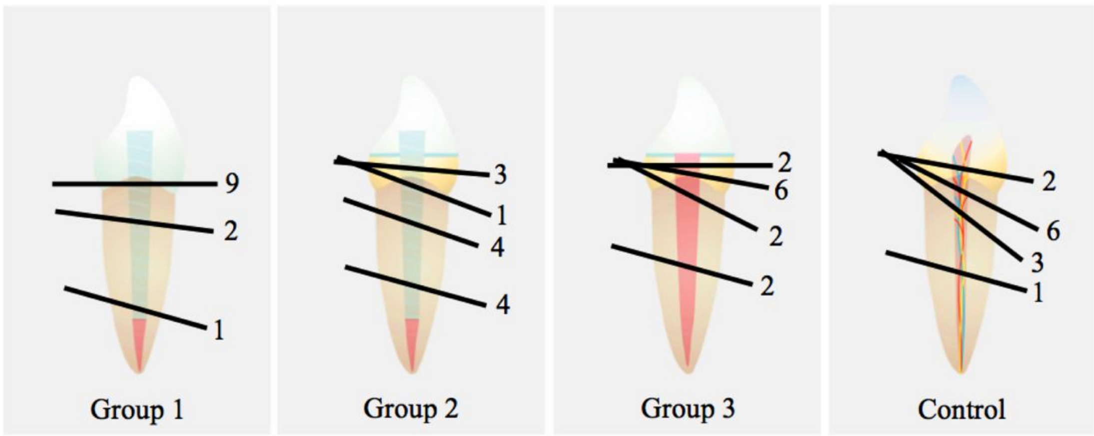


Figure 10 Bar-chart of fracture strength

The Turkey HSD test confirmed that the mean fracture strength for group 3 (2mm+NP) was significantly lower than that of group 1 (0mm+P) and group 2 (2mm+P) (p-value < .0001). Between group 1 (0mm+P) and group 2 (2mm+P), the Turkey HSD test revealed that there was no statistically significant difference found (p-value > .05). For group 4 (control), the Turkey HSD test showed a significantly higher fracture resistance than that of the other groups (p-value < .0001).

The Mode of Failure

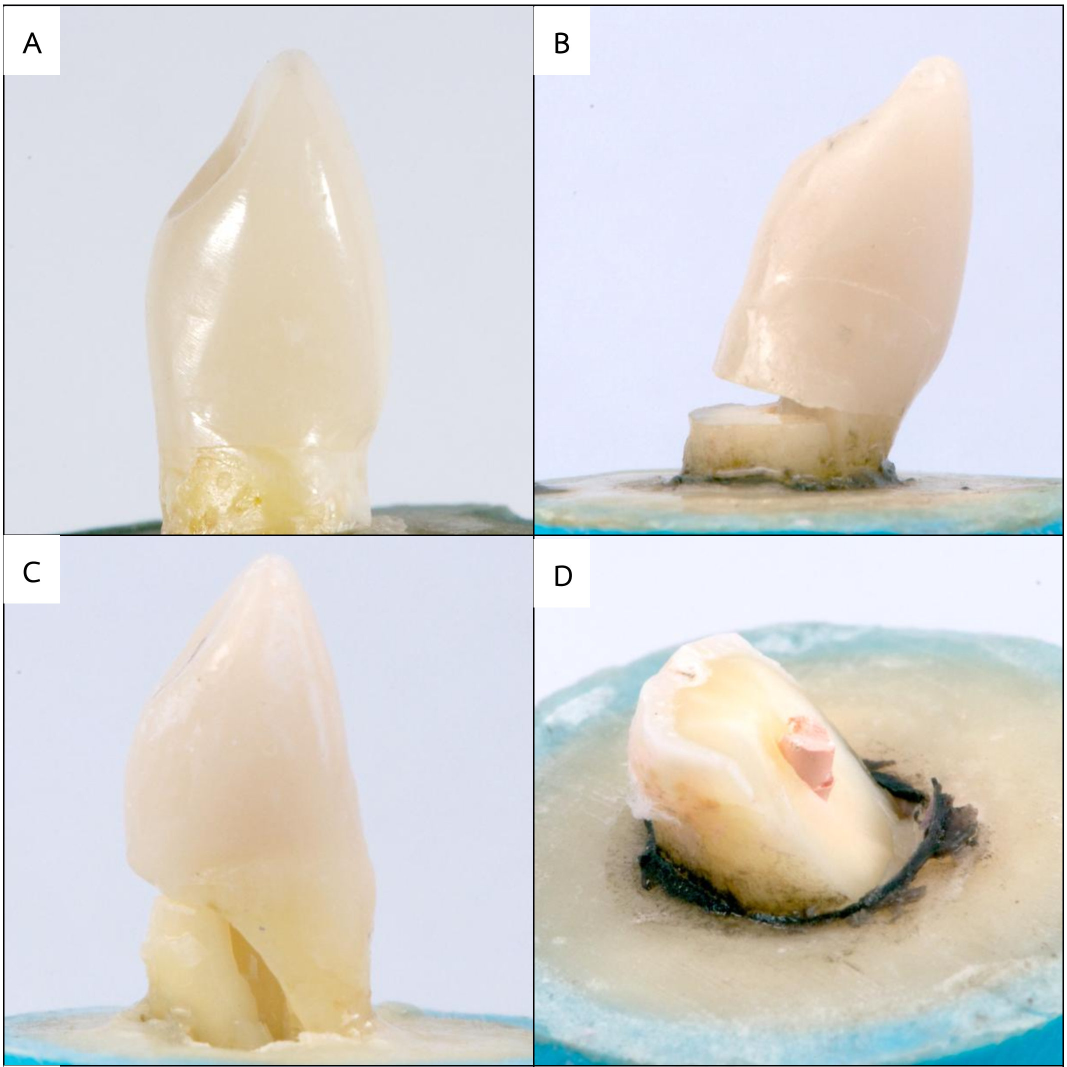


0 mm + Post | 2 mm + Post | 2 mm + No Post | Intact

Figure 11 Numbers indicated the number of fractured specimens

Most failures in group 4 (control) occurred due to root fracture, while in group 3 (2mm+NP), most fracture lines occurred in tooth structure above the CEJ. The coronal failures of composite resin build-up occurred only in group 1 (0mm+P). The fractures in group 2 (2mm+P) mainly involved tooth structure below the CEJ.

In this study, an oblique fracture line or horizontal fracture line involved the root structure of incisors, and ‘unrestorable’ characterized the unfavorable fractures. A Horizontal fracture line or fracture line above the CEJ of incisors, and ‘restorable’ characterized the favorable fractures.



A: The fracture of composite resin interface occurred only in group 1 (0mm+P). / **B:** The fracture of composite resin interface involved tooth structure below the CEJ in group 1 (0mm+P). / **C:** The oblique fracture occurred along the area where the post was located mainly in group 2 (2mm+P). / **D:** In group 3 (2mm+NP), the oblique fractures occurred mainly above the CEJ. / **E:** The fractures occurred mostly in root areas of group 4 (control).

Figure 12 Pictures of fractured specimens

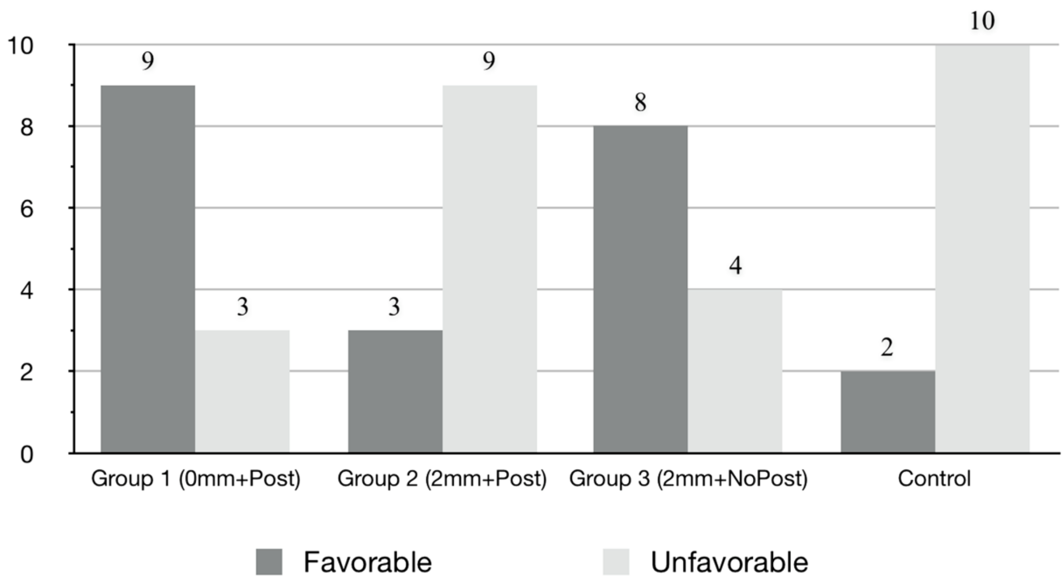


Figure 13 Histogram of the mode of failure

Table 4 The Pearson Chi-Square analysis of the Mode of failure

	N	Mode of failure		
		Favorable		Unfavorable
		Composite interface	Above CEJ	Below CEJ
Group 1 (0 mm+Post)	12	9 (75%)	-	3 (25%)
Group 2 (2 mm+Post)	12	-	3 (25%)	9 (75%)
Group 3 (2 mm+No Post)	12	-	8 (66.7%)	4 (33.3%)
Control	12	-	2 (16.7%)	10 (83.3%)
		Pearson Chi-Square = 12.420, df = 3, p-value = 0.006		

CEJ = Cementoenamel junction, df = Degree of Freedom

*From chi-square, 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.50.

When the mode of failure was evaluated, statistically significant differences were noted among groups (p-value < .05).

Table 5 The Pearson Chi-Square analysis of the Mode of failure between Group 1 and Group 2

	N	Mode of failure		
		Favorable		Unfavorable
		Composite interface	Above CEJ	Below CEJ
Group 1 (0 mm+Post)	12	9 (75%)	-	3 (25%)
Group 2 (2 mm+Post)	12	-	3 (25%)	9 (75%)
		Pearson Chi-Square = 6.000, df = 1, p-value = 0.039		

CEJ = Cementoenamel junction, df = Degree of Freedom

*From chi-square, 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.00.

When the mode of failure between group 1 (0mm+Post) and group 2 (2mm+Post) was evaluated, statistically significant differences were noted between groups (p-value < .05).

Table 6 The Pearson Chi-Square analysis of the Mode of failure between Group 2 and Group 3

	N	Mode of failure		
		Favorable		Unfavorable
		Composite interface	Above CEJ	Below CEJ
Group 2 (2 mm+Post)	12	-	3 (25%)	9 (75%)
Group 3 (2 mm+No Post)	12	-	8 (66.7%)	4 (33.3%)
		Pearson Chi-Square = 4.196, df = 1, p-value = 0.041		

CEJ = Cementoenamel junction, df = Degree of Freedom

*From chi-square, 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.50.

When the mode of failure between group 2 (2mm+Post) and group 3 (2mm+NoPost) was evaluated, statistically significant differences were noted between groups (p-value < .05).

CHAPTER V
DISCUSSIONS AND CONCLUSIONS

Discussions

The maxillary human central incisors in this study were randomly stratified into 4 groups. There was no significant difference between incisor diameters (mesiodistal diameter, buccolingual diameter, and root length) among groups. Thus, the results from all test groups were comparable.

All root canals were prepared according to the most commonly reported criteria: root canal preparation to ¾ of root length with at least 3-5 millimeter of gutta-percha left at the apex to provide an apical seal. In this study, all root canals had been prepped equally to 10 millimeter depth from the cemento-enamel junction with 3-5 millimeter of gutta-percha remaining apically. Moreover, the uncut fiber post (size 4) had been inserted into root canals.

This study was evaluated the effect of remaining coronal height of root-canal-treated incisors restored with direct composite resin build-up in combination with or without fiber post on fracture strength and mode of failure. The null hypothesis—that there would be no significant differences on fracture strength in root-canal-treated incisors restored with fiber post and direct composite resin build-up among non-coronal group and 2-millimeter coronal height group of maxillary central incisors—was accepted.

Furthermore, the results revealed that the fracture strength of composite build-up with a fiber post was greater than that of composite resin build-up without a fiber post. Moreover, none of the restored root-canal-treated incisors had fracture strength equal to that of natural incisors. Maximum force of incisors, in normal function, is 215 newton; in parafunctional use, it is 343-362.6 newton.[62] Thus, the mean fracture strength of specimens restored with posts (Groups 1 and 2) in this study was higher than the reported maximum force. Also, the mean fracture strength of group 3 exceeded the reported normal function force.

In the other studies of coronal tooth structure, the highest remaining coronal tooth structure was shown to have greater fracture strength.[10, 11, 22, 63] However, in those studies, the coronal tooth structure surrounded by the restoration included the ferrule, commonly reported to influence the fracture strength and fracture pattern of teeth. In this study, the composite resin was directly built up on the remaining coronal structure, without a wrap-around restoration.

In the study about composite resin build-up in premolars, it was demonstrated that a fiber post significantly increased fracture strength of restoration with or without coronal tooth structure, and the fracture of restorations with fiber posts dominated in restorable ways. From this study, the outcomes of mode of failure could be affected by many variables such as the loading area, the PDL simulation, and also the methodology. For the results, the majority of fractures in group 1 were restorable at the root-composite interface. However, most fractures of group 2 occurred obliquely, below the CEJ. In contrast, in group 3, the fractures occurred mainly above the CEJ. Only nine samples in group 1 in this study showed adhesive failure at the composite-tooth interface. After debonding failure began at the palatal sides of specimens, the test was stopped and the maximum force was recorded. A possible reason could be drawn from the finite element analysis study showing that highly intensive stress of a composite resin restoration with fiber posts on a destroyed coronal root-canal-treated incisor accumulated at the CEJ and distributed widely along the buccal tooth surface.[64] Moreover, stress was also distributed along the post surface in finite element analysis.[64] According to group 1 specimens, the fracture location occurred possibly because the bonding interface between the composite resin and the tooth was located at the CEJ. In group 2, the fractures occurred along the area where the post was located. The stress that distributed widely along the buccal tooth surface might affect the area of fracture in group 3. Even though the fracture strength of group 3 was less than in groups 1 and 2, the mode of failure in group 1 and 3 predominated favorably, as has been reported in a previous study.[19]

From the previous study, when restored the root canal treated tooth with fiber post, the mode of failure usually occurred in a favorable way because of the modulus of fiber post was closed to the modulus of tooth.[24, 25, 31] However, from the result, the mode of failure in group 2 (2 mm + post) and group 4 (control) shown unfavorable fracture might be related to the specimens' mounting material. The human PDL plays an important role in the fracture pattern and fracture resistance of teeth.[52] The root embedding material for simulated PDL could affect the mode of failure. It has been reported that when the PDL was simulated by means of polyether impression material, the fractures occurred mostly in root areas. Even though the PDL and the polyether impression material are different, they behave similarly when subjected to external stress.[52, 65]

The root canal cement in this study was a calcium hydroxide-based sealer with resin components in its composition that had been previously reported non-influence in bond strength of post and resin luting cement.[66] Another in vitro study shown that the root canal cement had no effect on the push-out bond strength of the fiber post with dual-cured cement and self-etching primer.[67]

According to group 1 (0 mm + post) and group 3 (2 mm + no post), the mode of failure predominately occurred in the area above the CEJ might because the restorations' interface in group 1 (0 mm + post) and cervical area without post in group 3 (2 mm + no post) could not withstood to the loading force. However, the 2-mm of coronal structure could strengthen the CEJ area of teeth in group 2 (2 mm + post). And in combination with the ability of the fiber post that could distribute the stress along itself, the fracture occurred in group 2 (2 mm + post) mostly oblique on the root area along the post. Even though the mode of failure in group 4 (control) mainly unfavorable fractures, the fracture lines mostly start from the coronal structure obliquely to the root structure.

In endodontic literature, the term "monoblock" had been introduced in strengthen the root canal system into mechanically homogenous unit by the application of dentin adhesive system.[68] The specimens in group 1 (0 mm + post) and group 2 (2 mm + post) using silicate coating post that were classified as a tertiary monoblock system depend on the number of interfaces.[68] Even, the root canal sealing material in group 3 (2 mm + no post) did not act as a monoblock because it does not bond strongly to dentin and gutta-percha.[69] The fracture strength of groups restored with post were significantly higher than group restored without post. However, the mode of failure did not seem to be different.

From the study that simulated the coronal destruction of root-canal-treated incisors, the composite resin restored with or without posts on root-canal-treated incisors had a higher fracture resistance than a coronal coverage restoration that required tooth reduction.[60] Consequently, an extensive tooth preparation for a full-coverage coronal restoration significantly increased failure of a minimized tooth structure.[7] Thus, conservative restoration should be considered in teeth with extensive structure loss. From the non-coronal group in this study, the composite restoration with a post was indicated as having acceptable fracture strength that could survive a normal occlusal load.

Thermocycling has been performed to simulate an intraoral environment. Fatigue testing is an essential research tool for adhesive restorations to produce a situation comparable with physiologic conditions.[32, 44]

Most dental implantation into an esthetic zone requires alveolar ridge augmentation due to the original shape and contour of alveolar bone and the resorption or fracture of buccal alveolar bone. Long-term follow-up studies have shown that, even with the guided bone regeneration technique, with the highest implant survival rates, onlay/veneer grafting, ridge splitting, or socket preservation has been required in many situations, and implant survival may depend on residual bone at the placement site.[5] Thus, the techniques for maintaining original alveolar bone architecture are still developing to reduce the need for bone augmentation. Accordingly, Grandini et al. demonstrated that the direct composite build-up with a fiber post on the root-canal-treated tooth is a good option for patient satisfaction.[15] Postponing extraction of the fractured tooth from the socket by performing root canal treatment and restoring the tooth with composite resin could be an option for maintaining alveolar bone structure. However, the remaining tooth and periodontal tissue must be free of infection, to prevent further alveolar bone resorption, and the patient should consider this treatment as a provisional restoration before an implant.

Conclusions

Within the limitations of this study, the following conclusions could be drawn:

- All specimens survived 250,000 cyclic load cycles, equal to 1-year intra-oral service time even the restoration on non-coronal structure tooth.
- Increasing the coronal tooth structure did not increase the fracture strength of a direct composite resin build-up with a fiber post on root-canal-treated incisors.
- The fracture strength of a direct composite resin build-up restored with a fiber post on root-canal-treated incisors was significantly higher than that of a direct composite resin build-up restored without a post.
- When failure occurred, the use of fiber posts on non-coronal incisors promoted favorable outcomes. However, the use of fiber posts on 2-millimeter-coronal incisors caused catastrophic fractures. In contrast, in 2-millimeter-coronal incisors, the use of direct composite resin build-up without fiber posts led to restorable fractures.

Clinically, a direct composite resin build-up with a fiber post might be considered as the cost-effective and successful restoration of choice for prolong a retained dental root as long-term provisional restoration , especially to preserve alveolar bone for future implant placement.

Future study

For future study, an extended direct composite resin into the root canal for retained a direct composite resin build-up should be consider as another choice for restored a root canal treated incisor.

The in vitro approach was a limitation of this study. Thus, the clinical trials should be performed for further evaluation of the outcomes.

Clinical Implications

Postponing the extraction of an incisor by performing root-canal-treatment and restoring with direct composite resin build-up with a fiber post seems to be the option for preserving the tooth socket, even for incisors without coronal structure.

However, when restoring incisors that have 2 millimeter of coronal structure, the use of direct composite resin build-up without a fiber post seems to provide more favorable resistance to fracture than restoration with a fiber post alone.

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APPENDIX

Appendix A. Study Protocol and Consent Form Approval

No. 040/2012

Study Protocol and Consent Form Approval

The Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand has approved the following study to be carried out according to the protocol and patient/participant information sheet dated and/or amended as follows in compliance with the **ICH/GCP.**

Study Title	: Fracture strength after fatigue loading of root canal treated central incisors restored with post and direct composite build-up
Study Code	: HREC-DCU **2012-040**
Study Center	: Chulalongkorn University
Principle Investigator	: Dr. Pawak Tungthangthum
Protocol Date	: Aug 10, 2012
Date of Approval	: August 28, 2012
Date of Expiration	: August 27, 2014

S. Amatyakul

(Associate Professor Dr. Supathra Amatyakul)
Chairman of Ethics Committee

Suchit Poolthong

(Assistant Professor Dr. Suchit Poolthong)
Associate Dean for Research and International Affairs

*A list of the Ethics Committee members (names and positions) present at the Ethics Committee meeting on the date of approval of this study has been attached (upon requested). This Study Protocol Approval Form will be forwarded to the Principal Investigator.

Approval is granted subject to the following conditions: (see back of the approval)

Appendix B. Fatigue Load of Specimens

No	Tooth size			Fatigue Test at Start		Fatigue Test at Stop		
	BL	MD	Root	Position	Amplitude	Position	Amplitude	Cycles
11	6.2	5.9	14.7	-35.890	0.100	-35.890	0.100	250000
12	6.3	6	14.9	-30.450	0.100	-35.470	0.100	250000
13	6	6	13.5	36.630	0.100	36.590	0.110	250000
14	7	5.5	16.8	40.150	0.130	40.150	0.160	250000
15	5.5	5.1	16.1	37.660	0.120	37.620	0.180	250000
16	7.2	5.5	16.5	39.400	0.130	39.400	0.150	250000
17	5.7	5.6	14	42.200	0.370	42.200	0.430	250000
18	5.7	5.2	14.5	41.310	0.300	41.310	0.290	250000
19	6.3	6.4	13.9	43.610	0.320	43.540	0.360	250000
10	5.5	4.8	13.8	42.220	0.350	42.210	0.350	250000
111	6.1	5.9	14.7	43.100	0.350	42.800	0.350	250000
112	6.4	6.2	14.6	42.550	0.350	42.350	0.350	250000
21	6.2	5.9	14.3	-25.980	0.180	-23.550	0.100	250000
22	6.3	6	14.2	-31.200	0.100	-31.450	0.100	250000
23	6.2	5.5	12.8	36.450	0.100	36.450	0.100	250000
24	6.4	5.5	15.7	38.650	0.120	38.650	0.190	250000
25	6.2	5.4	17.6	37.800	0.120	37.600	0.240	250000
26	6.7	6.4	15	43.300	0.160	43.100	0.200	250000
27	5.9	5.7	16	41.500	0.200	41.500	0.330	250000
28	6.2	5	13.5	41.580	0.380	41.560	0.440	250000
29	7.1	5.9	14	42.630	0.300	42.400	0.300	250000
20	6.8	7	15.9	41.200	0.300	41.150	0.300	250000
211	6.9	5.9	16.5	42.570	0.300	42.570	0.300	250000
212	6.1	5.1	14.3	42.340	0.300	42.000	0.300	250000
31	6.2	5.6	14.7	38.340	0.180	38.300	0.190	250000

No	Tooth size			Fatigue Test at Start		Fatigue Test at Stop		
	BL	MD	Root	Position	Amplitude	Position	Amplitude	Cycles
32	6.1	5.8	14.9	24.440	0.130	24.440	0.160	250000
33	6.2	5.4	16.1	35.650	0.100	35.650	0.150	250000
34	6.4	5.2	15.1	38.600	0.130	38.600	0.200	250000
35	6.7	6.1	14.6	38.430	0.150	38.400	0.220	250000
36	7.3	6.2	18.5	38.300	0.120	38.300	0.260	250000
37	6.5	5.7	14.1	41.500	0.120	42.400	1.060	250000
38	5.8	4.8	15.1	41.490	0.350	41.480	0.410	250000
39	6.6	6.2	16.4	41.160	0.350	41.130	0.450	250000
30	6.3	5.2	15.3	41.290	0.300	41.120	0.350	250000
311	6.4	6.6	14.2	41.350	0.350	41.280	0.400	250000
312	5.1	5.7	12	41.850	0.400	41.750	0.390	250000
41	5.7	5.5	15.3	-26.410	0.080	-26.800	0.100	250000
42	5.8	5.6	13.7	-27.100	0.270	-27.690	0.090	250000
43	5.5	5.5	13	-28.070	0.100	-28.070	0.150	250000
44	7.3	5.8	16.3	-29.350	0.110	-29.400	0.100	250000
45	5.8	5.5	12.7	-28.740	0.110	-28.740	0.100	250000
46	6.5	5.6	14.1	-40.900	0.100	-40.900	0.180	250000
47	5.4	5	15	-40.000	0.100	-40.000	0.200	250000
48	6.8	5.1	16.9	-23.220	0.200	-23.230	0.200	250000
49	6.4	5.7	15.4	41.350	0.300	41.100	0.300	250000
40	5.1	6.1	15.4	42.200	0.300	41.900	0.300	250000
411	6.4	5.9	14.9	43.150	0.300	43.000	0.300	250000
412	6.3	5.5	14.9	40.540	0.300	40.200	0.300	250000

Appendix C. Static Load and Location of Failure of Specimens

No	Failed (N)	Extension (mm)	Failed at
11	832.400	1.32	Root-Composite interface
12	764.300	1.52	Oblique root fracture (Apical 1/3)
13	579.710	1.16	Root-Composite interface
14	699.950	1.28	Root-Composite interface
15	489.570	1.39	Root-Composite interface
16	400.100	1.4	Oblique root fracture (Cervical 1/3)
17	479.770	1.32	Root-Composite interface
18	664.410	1.45	Root-Composite interface
19	477.090	1.56	Root-Composite interface
10	609.820	1.49	Root-Composite interface
111	569.710	1.28	Root-Composite interface
112	546.790	1.42	Oblique root fracture (Cervical 1/3)
21	403.560	1.96	Oblique Cervical fracture
22	443.600	1.03	Oblique Crown-root fracture
23	667.520	1.85	Oblique root fracture (Cervical 1/3)
24	720.100	2.55	Oblique root fracture (Middle 1/3)
25	502.490	1.21	Oblique root fracture (Middle 1/3)
26	573.900	1.70	Oblique root fracture (Middle 1/3) + Post fx.
27	725.480	2.76	Oblique root fracture (Middle 1/3)
28	735.200	3.05	Oblique cervical fracture
29	970.270	3.06	Horizontal cervical fracture (Above CEJ)
20	1015.220	2.44	Oblique root fracture (Cervical 1/3)
211	817.740	1.68	Oblique root fracture (Cervical 1/3)
212	780.450	2.35	Oblique root fracture (Cervical 1/3)
31	103.13	1.13	Oblique Cervical fracture
32	367.19	1.21	Oblique Cervical fracture
33	247.82	0.76	Horizontal root fracture (Middle 1/3)
34	190.36	1.39	Oblique root fracture (Middle 1/3)
35	269.98	0.53	Oblique Cervical fracture
36	197.30	1.11	Oblique Cervical fracture

37	144.87	0.75	Oblique Cervical fracture
38	156.36	0.85	Oblique Cervical fracture
39	238.82	0.92	Oblique Crown-root fracture
30	292.81	1.13	Oblique Crown-root fracture
311	259.77	1.39	Horizontal Cervical fracture
312	347.40	0.94	Horizontal Cervical fracture
41	1456.000	1.94	Oblique crown (not involve cervical)
42	1614.200	4.35	Oblique crown (not involve cervical)
43	1254.360	3.05	Oblique Root (middle 1/3)
44	1321.230	3.31	Oblique crown-root (middle 1/3)
45	1286.210	1.95	Oblique crown-root (cervical 1/3)
46	1266.800	2.61	Oblique crown-root (middle 1/3)
47	1559.060	1.77	Oblique crown-root (middle 1/3)
48	1346.000	2.96	Oblique crown-root (cervical 1/3)
49	1250.000	1.84	Oblique crown-root (cervical 1/3)
40	1223.990	1.20	Oblique crown-root (cervical 1/3)
411	1145.970	2.35	Oblique crown-root (cervical 1/3)
412	1189.760	1.47	Oblique crown-root (cervical 1/3)

Appendix D. The Descriptive Analysis and The Normality Test of Fracture Strength

	Group			Statistic	Std. Error
Fracture strength	Group 1 0mm + Post	Mean		592.8013	36.97819
		95% Confidence Interval for Mean	Lower Bound	511.4128	
			Upper Bound	674.1897	
		5% Trimmed Mean		590.1958	
		Median		574.7075	
		Variance		16408.642	
		Std. Deviation		128.09622	
		Minimum		400.10	
		Maximum		832.40	
		Range		432.30	
		Interquartile Range		208.85	
		Skewness		.469	.637
		Kurtosis		-.429	1.232
	Group 2 2mm + Post	Mean		696.2942	55.35395
		95% Confidence Interval for Mean	Lower Bound	574.4609	
			Upper Bound	818.1274	
		5% Trimmed Mean		694.8391	
		Median		722.7900	
		Variance		36768.719	
		Std. Deviation		191.75171	
		Minimum		403.56	
		Maximum		1015.22	
		Range		611.66	
		Interquartile Range		288.08	
		Skewness		.079	.637

	Kurtosis		-.617	1.232
Group 3	Mean		234.6514	23.12287
2mm + No Post	95% Confidence Interval for Mean	Lower Bound	183.7583	
		Upper Bound	285.5445	
	5% Trimmed Mean		234.5949	
	Median		243.3235	
	Variance		6416.008	
	Std. Deviation		80.09998	
	Minimum		103.13	
	Maximum		367.19	
	Range		264.06	
	Interquartile Range		122.24	
	Skewness		.086	.637
	Kurtosis		-.622	1.232
Control	Mean		1326.1317	41.93006
	95% Confidence Interval for Mean	Lower Bound	1233.8442	
		Upper Bound	1418.4191	
	5% Trimmed Mean		1320.1369	
	Median		1276.5050	
	Variance		21097.555	
	Std. Deviation		145.24997	
	Minimum		1145.97	
	Maximum		1614.20	
	Range		468.23	
	Interquartile Range		198.01	
	Skewness		1.004	.637
	Kurtosis		.108	1.232

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Fracture strength	0mm with Post	.124	12	.200*	.967	12	.874
	2mm with Post	.133	12	.200*	.960	12	.786
	2mm without Post	.104	12	.200*	.977	12	.970
	Control	.196	12	.200*	.894	12	.134

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Appendix E. The Analysis of Variance of Fracture Strength

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0mm Post	12	592.8013	128.09622	36.97819	511.4128	674.1897	400.10	832.40
2mm Post	12	696.2942	191.75171	55.35395	574.4609	818.1274	403.56	1015.22
2mm NoPost	12	234.6514	80.09998	23.12287	183.7583	285.5445	103.13	367.19
Control	12	1326.1317	145.24997	41.93006	1233.8442	1418.4191	1145.97	1614.20
Total	**48**	**712.4696**	**420.77138**	**60.73312**	**590.2904**	**834.6489**	**103.13**	**1614.20**

Test of Homogeneity of Variances

Fracture strength

Levene Statistic	df1	df2	Sig.
2.130	3	44	.110

ANOVA

Fracture strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7433682.084	3	2477894.028	122.834	.000
Within Groups	887600.151	44	20172.731		
Total	8321282.235	47			

Dependent Variable: Fracture strength						
Tukey HSD						
(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0mm with Post	Ferrule without Post	358.14983*	57.98381	.000	203.3327	512.9669
	Ferrule with Post	-103.49292	57.98381	.294	-258.3100	51.3242
	Control	-733.33042*	57.98381	.000	-888.1475	-578.5133
2mm with Post	Ferrule without Post	461.64275*	57.98381	.000	306.8257	616.4598
	No ferrule with Post	103.49292	57.98381	.294	-51.3242	258.3100
	Control	-629.83750*	57.98381	.000	-784.6546	-475.0204
2mm without Post	No ferrule with Post	-358.14983*	57.98381	.000	-512.9669	-203.3327
	Ferrule with Post	-461.64275*	57.98381	.000	-616.4598	-306.8257
	Control	-1091.48025*	57.98381	.000	-1246.2973	-936.6632
Control	Ferrule without Post	1091.48025*	57.98381	.000	936.6632	1246.2973
	No ferrule with Post	733.33042*	57.98381	.000	578.5133	888.1475
	Ferrule with Post	629.83750*	57.98381	.000	475.0204	784.6546

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets					
	Group	N	Subset for alpha = 0.05		
			1	2	3
Turkey HSD[a]					
	No ferrule with Post	12		592.8013	
	Ferrule with Post	12		696.2942	
	Ferrule without Post	12	234.6514		
	Control	12			1326.1317
	Sig.		**1.000**	**.294**	**1.000**

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.000.

Appendix F. Pilot Study

Group	No	Cyclic	Static Load	Mode of Failure
0 mm + Post	11	250000	741.62	Unfavorable
	12	250000	780.76	Favorable
2 mm + Post	21	250000	832.40	Unfavorable
	22	250000	864.30	Favorable
2 mm + No Post	31	250000	303.56	Favorable
	32	250000	343.60	Favorable
Control	41	250000	1456.00	Unfavorable
	42	250000	1614.20	Unfavorable

Descriptive Analysis

Static Load								
Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0mm Post	2	761.19	27.68	19.57	513.53	1009.85	741.62	780.76
2mm Post	2	798.35	48.15	34.05	365.70	1231.00	764.30	832.40
2mm NoPost	2	323.58	28.31	20.02	69.20	577.96	303.56	343.60
Control	2	1535.10	111.86	79.10	530.04	2540.16	1456.00	1614.20
Total	**8**	**854.56**	**467.56**	**165.31**	**463.66**	**1245.45**	**303.56**	**1614.20**

VITA

NAME Pawak Tungthangthum

DATE OF BIRTH February 21, 1985

PLACE OF BIRTH Chiangmai, Thailand

ADDRESS 109/93 Sukhumvit 52 Rd., Bangjak, Phrakanong,
BKK, 10260, TH

INSTITUTIONS ATTENDED

- 2012 – 2012 Preceptorship Program in Advanced Implantology from University of California, Los Angeles School of Dentistry, California, USA
- 2005 - 2009 Bachelor of Business Administration from Sukhothai Thammathirat Open University, Nonthaburi, Thailand
- 2003 - 2009 Doctor of Dental Surgery (Hons.) from Faculty of Dentistry, Chiangmai University, Chiangmai, Thailand

PROFESSIONAL PRACTICE

- 2009 – 2010 Chief of Dental Department, Khieansa Hospital, Surat-Thani, Thailand

RESEARCH GRANT

- The Graduated School of Chulalongkorn University, Bangkok, Thailand