



# Fracture strength after fatigue loading of root canal treated central incisors restored with post and direct composite build-up

Pawak Tungthangthum<sup>1</sup>, Chalernpol Leeviloj<sup>2</sup>

<sup>1</sup> D.D.S., Student in Master Degree Program in Esthetic Restorative and Implant Dentistry, Faculty of Dentistry, Chulalongkorn University.

<sup>2</sup> M.S.D., Associate Professor, Faculty of Dentistry, Chulalongkorn University.

## Abstract

**Objective:** The aim of 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-ups on fracture strength and mode of failure.

**Materials and 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 fatigue loading. When 250,000 loading cycles were reached, the surviving specimens were subjected to static loading.

**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  $1326.13 \pm 145.25$  N, followed by group 2 at  $696.29 \pm 191.75$  N, group 1 at  $592.80 \pm 128.10$  N, and group 3 at  $234.65 \pm 80.10$  N. Root fractures were observed in group 4; in group 3, there were tooth fractures above the cemento-enamel junction (CEJ); in group 1, there were fractures at the composite resin interface; and in group 2, there were fractures below the CEJ.

**Conclusions:** The remaining coronal tooth structure did not increase the fracture strength of direct composite resin build-ups on root-canal-treated incisors.

**Key words:** direct composite resin build-up, fatigue loading, fracture strength, mode of failure, remaining tooth structure, root-canal-treated incisor

**How to cite:** Tungthangthum P, Leeviloj C. Fracture strength after fatigue loading of root canal treated central incisors restored with post and direct composite build-up. *M Dent J* 2014; 34: 103-13.

### Corresponding author:

Chalernpol Leeviloj  
Faculty of Dentistry, Chulalongkorn University,  
34 Henri-Dunnant Rd., Wangmai, Pathumwan,  
Bangkok, 10330 Thailand.

Tel: 081-5672827

Email: esthetic.implant.chula@gmail.com

**Received:** 4 November 2013

**Accepted:** 16 December 2014

## Introduction

Nowadays, when incisor tooth fracture occurs, the patient can replace the fractured tooth with a dental implant. However, many factors—such as time-line, expense, and growth—have to be considered before a fractured incisor is extracted. After tooth extraction, the alveolar ridge will change in morphology and dimensions over time, especially at the buccal bone plate.<sup>1,2</sup> The preservation of crestal bone level immediately after tooth extraction is necessary for successful placement of a dental implant. Therefore, root canal treatment with a proper restoration is an alternative choice for preserving the tooth socket.<sup>3</sup> However, a full-coverage coronal restoration on a limited tooth structure significantly increases the risk of fracture failures because of extensive tooth preparation.<sup>4</sup> A bonded restoration can prevent recontamination and is considered necessary for long-term success of a root-canal-treated tooth. A direct composite build-up can be a suitable restoration in this situation.<sup>5</sup>

In teeth with extensive structural loss, placement of a post in root-canal-treated tooth is necessary to improve the retention of the core.<sup>6</sup> Some studies have supported the ability of fiber posts to distribute stress favorably to prevent the tooth from future fractures.<sup>7,8</sup> In addition, fiber posts have demonstrated superior fracture resistance against static oblique loads because of their tooth-like modulus of elasticity.<sup>9-11</sup> In an in-vivo structural analysis study, it was reported that the fiber post system had significantly more favorable failures than the custom metal post.<sup>12</sup>

From other previous studies, the presence of a ferrule of at least 1-1.5 mm and the location of tooth structure were also considered as important factors in the fracture resistance of root-canal-treated teeth.<sup>13,14</sup> Conversely, some studies reported that there was no significant difference in static load

between a 2-mm-ferrule group and a no-ferrule group on human central incisors.<sup>15,16</sup>

Satisfactory outcomes have been reported with the use of fiber posts combined with composite resin.<sup>17</sup> A direct composite resin build-up on root-canal-treated anterior teeth, restored with or without posts, showed an overall survival rate of 98.5% in 5.3 years.<sup>18</sup> Another multi-practice clinical trial showed a survival rate of 96% after 5 years for a prefabricated post with a composite core without a cast crown covering the teeth.<sup>19</sup>

However, there is no evidence supporting that the height of remaining coronal tooth structure of root-canal-treated incisors restored with fiber posts and direct composite resin build-ups could affect the fracture strength. The purpose of this in-vitro study was to evaluate the effect of remaining coronal tooth structure on the fracture strength of root-canal-treated incisors restored with fiber posts and direct composite resin build-ups. The null hypothesis was that there was no significant difference on fracture strength in root-canal-treated incisors restored with direct composite resin build-ups with fiber posts on the remaining incisors with various coronal heights.

## Materials and methods

The research methodology employed in this study was approved by the human research ethic committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand. For this study, forty-eight freshly extracted human maxillary central incisors with no caries or cracks were selected. Exclusion criteria were tooth with dental caries, a cervical lesion, or a visible fracture line. Root length and tooth size were measured and analyzed according to descriptive statistics. The mean of the root length was used to divide teeth into two strata: above the mean and under the mean. Teeth in each stratum were divided into 4 test groups by

**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	<b>Resin:</b> Ethoxylated bis-phenol-A-dimethacrylate, Triethylene glycol dimethacrylate (TEGDMA) and Light-cure initiators, stabilizers <b>Filler:</b> 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	<b>Catalyst:</b> Bis-GMA, triethylene glycol dimethacrylate, barium aluminoborosilicate glass <b>Base:</b> 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 Gavaniere, Saint Egreve, France) LOT 173541109	Serrated taper post, length 17.5 mm, Light yellow translucent fiber post embedded in a colored resin matrix  <b>Size 4:</b> diameter at apical tip 1.00, at post head 1.83	(1) Shape the canal with finishing drill (rotation speed 1,000-2,000 rpm). (2) Clean post with alcohol. (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	<b>Catalyst:</b> Isobutyl salicylate resin, fumed silica (silicon dioxide), bismuth trioxide, and titanium dioxide pigment <b>Base:</b> 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 canal. (4) Condense the gutta-percha with a condenser.
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	<b>Base:</b> Polyether macromonomer, Fillers, Plasticizer, Pigments, Flavors, Triglycerides <b>Catalyst:</b> 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.

a simple random-sampling technique. Next, 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). 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 1)

Group 1 : 0.0 mm remaining coronal height from proximal CEJ with post placement

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

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

Group 4 : Full coronal tooth structure intact (control)

Endodontic treatment was completed on specimen by means of nickel-titanium rotary instruments (K3 Nickel-Titanium Files; Kerr Corporation, Orange, Calif) to an apical size 35. Teeth were rinsed with 17% EDTA for removal of the smear layer,<sup>20, 21</sup> and obturated with vertical condensation technique (Element Gutta Percha Cartridge; Kerr Corporation) with a non-eugenol root canal sealer (Sealapex; Kerr Corporation).

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

Gavanière, Saint Egrève, France). The depth of the post space was 10 mm below the CEJ, leaving 3-5 mm of gutta-percha apically. The root canals were etched with 37.5% phosphoric acid, rinsed, and then gently dried. Subsequently, a three-step etch-and-rinse adhesive system (Optibond FL; Kerr Corporation) was used. Then, a size 4 fiber post (Macro-Lock Post Illusion X-RO; R.T.D.) coated with clear dual-cured resin cement (Nexus 3; Kerr Corporation) was inserted into the root canal. Resin cement was cured with a visible-light-polymerization unit (Demi Plus; Kerr Corporation) with 1,100 mW/cm<sup>2</sup> intensity for 40 seconds. 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 intact 7.5 mm superior to remaining tooth level in group 1 and 5.5 mm superior to remaining tooth level in group 2. Next, specimens in group 2 and group 3 were prepared for direct composite restoration by creating a 1 mm bevel at enamel margin around the tooth with a diamond bur (852.FG.010; Jota AG, Ruthi, Switzerland). However, no bevel preparation was performed in group 1.

The specimens' roots were wrapped with a 0.2 mm thickness aluminum foil comparable with PDL thickness equal to 0.12 - 0.33 mm, to create a space between the root and acrylic resin simulating the periodontal membrane.<sup>22</sup> Then, the specimens were immersed in a PVC mold (diameter, 1 inch; height, 1 inch), filled

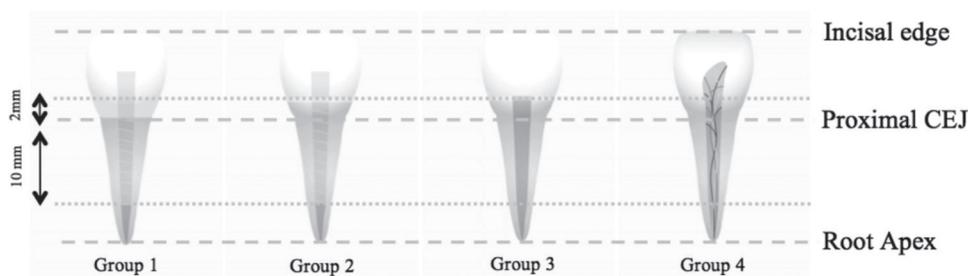


Figure 1 Test groups

with an auto-polymerized acrylic resin at 2 mm depth below the labial-palatal CEJ. A surveyor was used during the immersion procedure. After the acrylic set and the thin aluminum foil was removed, the specimens' roots were coated with polyether impression material (Impregum™ Penta™ Soft Medium Body; 3M ESPE, St. Paul, Minn), and replanted into an acrylic resin mount to simulate the periodontal ligaments.

Remaining tooth surface of all specimens in groups 1, 2, and 3 were etched, rinsed, and bonded with three-step etch-and-rinse adhesive system (Optibond FL; Kerr Corporation). Then, in group 1, nanofilled composite resin (Premise; Kerr Corporation) was packed into a 10-mm-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-mm-height crown-shaped clear silicone mold with the same diameter as in group 1 and placed on the remaining tooth, and then cured. The silicone molds had a 1.5-mm-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 with a visible-light-polymerization unit for 40 seconds on each side.

All specimens were subjected to thermocycling for 10,000 cycles at 15°C and 45°C with a dwell time of 20 seconds.<sup>23</sup> Next, a

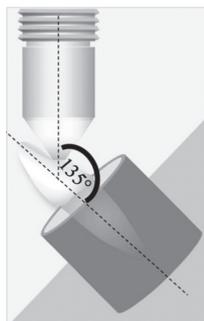


Figure 2 Specimen in Loading Device

fatigue-loading device (Universal testing machine 8872; Instron, High Wycombe, Bucks, UK) was used to apply a load of 4.0 kg (40 N) using round-ended stainless steel heads (diameter, 1.5 mm) at 8 mm from the PVC mold at a 135° angle to the long axis of the tooth to simulate normal chewing force. (Figure 2)<sup>24, 25</sup> The cyclic loading rate was set at 2 Hz.<sup>26</sup> If specimens failed before 250,000 cycles, the cycle count was recorded. Conversely, if a specimen reached 250,000 cycles, the loading was stopped and 250,000 cycles were recorded. The surviving specimen was subjected to a static load at a crosshead speed of 1 mm per minute until the specimen fractured. When fracture occurred in the specimen, the fracture load and mode of failure were recorded. The mode of failure was defined as 'favorable fracture' or 'repairable' (composite-tooth interface, above the CEJ) or as 'unfavorable fracture' or 'catastrophic' (below the CEJ).

PASW statistical analysis software, version 17 (Chicago, Ill), was used in this study. The level of significance in this study was determined at 5%.

## Results

All specimens reached the 250,000 cycle count. The highest mean fracture strength was recorded for group 4 (control) at  $1326.13 \pm 145.25$  N, followed by group 2 (2mm + post) at  $696.29 \pm 191.75$  N, group 1 (0mm + post) at  $592.80 \pm 128.10$  N, and group 3 (2mm + no post) at  $234.65 \pm 80.10$  N. (Table 2)

As the normality of data indicated, the test was analyzed by analysis of variance, which showed significant difference in fracture strength of one or more groups ( $p$ -value < .0001). The Turkey HSD test confirmed that the mean fracture strength for group 3 (2mm + no post) was significantly lower than that of group 1 (0mm + post) and group 2 (2mm + post) ( $p$ -value < .05). The results also revealed that

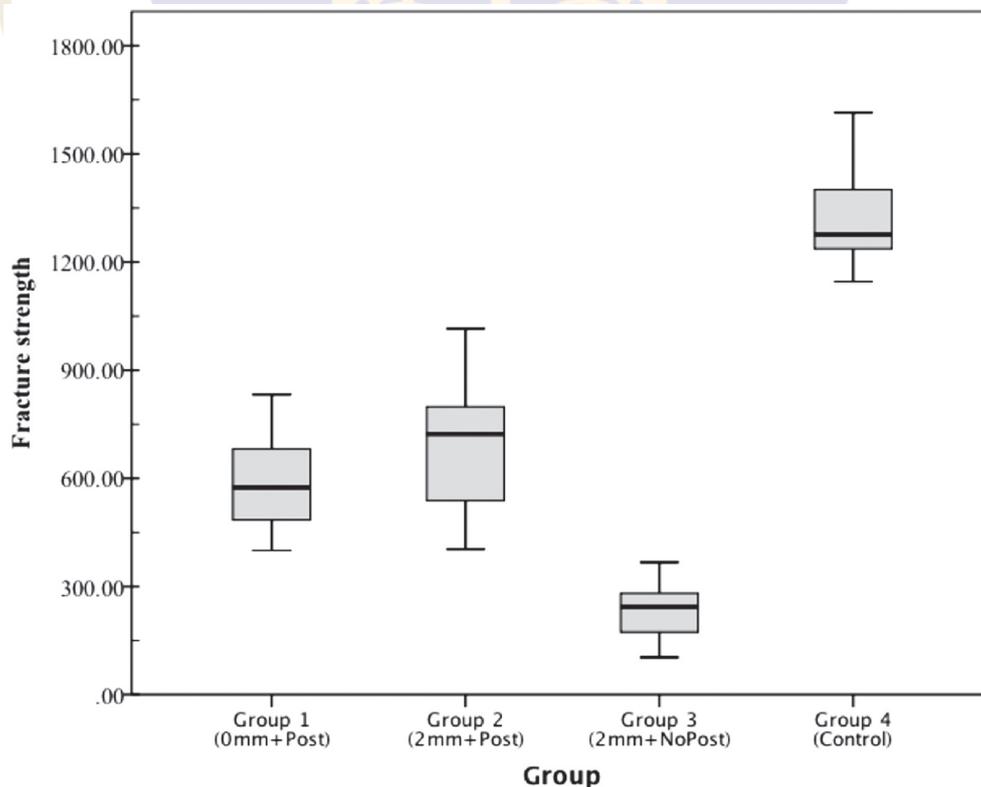
there was no statistically significant difference between group 1 (0mm + post) and group 2 (2mm + post) ( $p$ -value < .05). For group 4 (control), the Turkey HSD test showed a significantly higher fracture resistance compared with that of the other groups ( $p$ -value < .05). (Figure 3)

In this study, an oblique fracture line or horizontal fracture line involving the root structure of incisors were defined as ‘unrestorable’. When the mode of failure was evaluated, statistically significant differences were noted between and among the groups ( $p$ -value < .05). Most failures in group 4 (control) occurred due

**Table 2** The specimens’ dimension analysis, The Analysis of Variance analysis of fracture strength, and The Pearson Chi-Square analysis of Mode of failure

	N	Mean Dimension (SD)			Mean fatigue loading cycles	Mean fracture strength (SD)	Mode of failure		
		BL width	MD width	Root length			Favorable		Unfavorable
							Composite interface	Above CEJ	
Group 1 (0mm+Post)	12	6.2 (0.54)	5.7 (0.48)	14.8 (1.1)	250,000	592.80 <sup>a</sup> (128.10) CI [511.41, 674.19]	9 (75%)	-	3 (25%)
Group 2 (2mm+Post)	12	6.4 (0.37)	5.8 (0.55)	15.0 (1.38)	250,000	696.29 <sup>a</sup> (191.75) CI [574.46, 818.13]	-	3 (25%)	9 (75%)
Group 3 (2mm+NoPost)	12	6.3 (0.53)	5.7 (0.51)	15.1 (1.54)	250,000	234.65 <sup>b</sup> (80.10) CI [183.76, 285.54]	-	8 (66.7%)	4 (33.3%)
Control	12	6.1 (0.64)	5.5 (0.31)	14.8 (1.24)	250,000	1,326.13 <sup>c</sup> (145.25) CI [1233.84, 1418.42]	-	2 (16.7%)	10 (83.3%)
		F(3,44)=.698 p-value = .559	F(3,44)=.693 p-value = 0.562	F(3,44)=.047 p-value = 0.986		F(3, 44) = 122.83, p-value < 0.0001	Pearson Chi-Square = 12.420, df = 3, p-value = 0.006		

BL = Buccolingual, CI = Confident interval, CEJ = Cementoenamel junction, df = Degree of Freedom, MD = Mesiodistal, SD = Standard deviation



**Figure 3** Bar Chart of Fracture strength

to root fracture, whereas in group 3 (2mm + no post), most fracture lines occurred at tooth structure above the CEJ. The coronal failures of composite resin build-ups occurred only in group 1 (0mm + post). The fractures in group 2 (2mm + post) mainly involved tooth structure below the CEJ. (Figure 4, 5)

### Discussion

The maxillary human central incisors in this study were randomly stratified into 4 groups. There was no significant difference between mesiodistal and buccolingual diameters and root length of the incisors in each group (Table 2). All root canals were

prepared according to the most commonly reported criteria: root canal preparation to  $\frac{3}{4}$  of root length with at least 3-5 mm of gutta-percha left at the apex to provide an apical seal.

This study evaluated the influence of remaining coronal structure, in combination with or without fiber posts, on fracture strength and mode of failure of root-canal-treated incisors restored with direct composite resin build-ups. According to the results of the study, the null hypothesis was accepted. It was also observed that the fracture strength of composite build-up with a fiber post was greater than that of composite build-up without

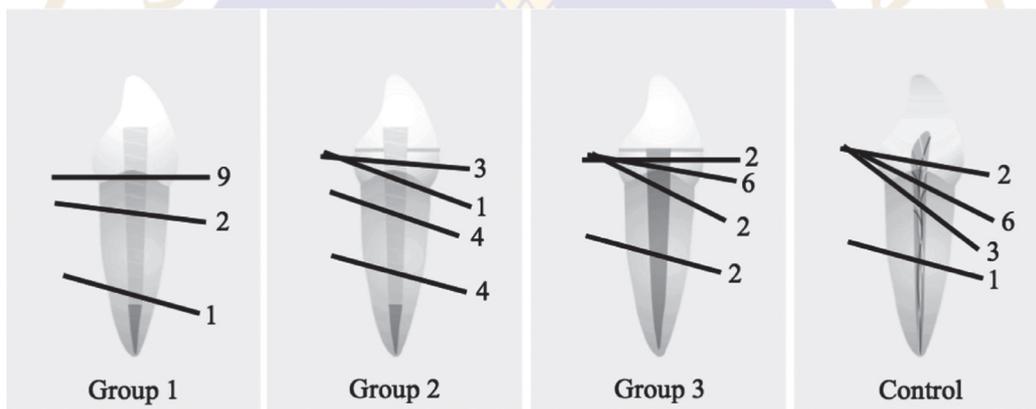


Figure 4 Locations and frequencies of fractures in 4 test groups. Fractures below CEJ were deemed unfavorable.

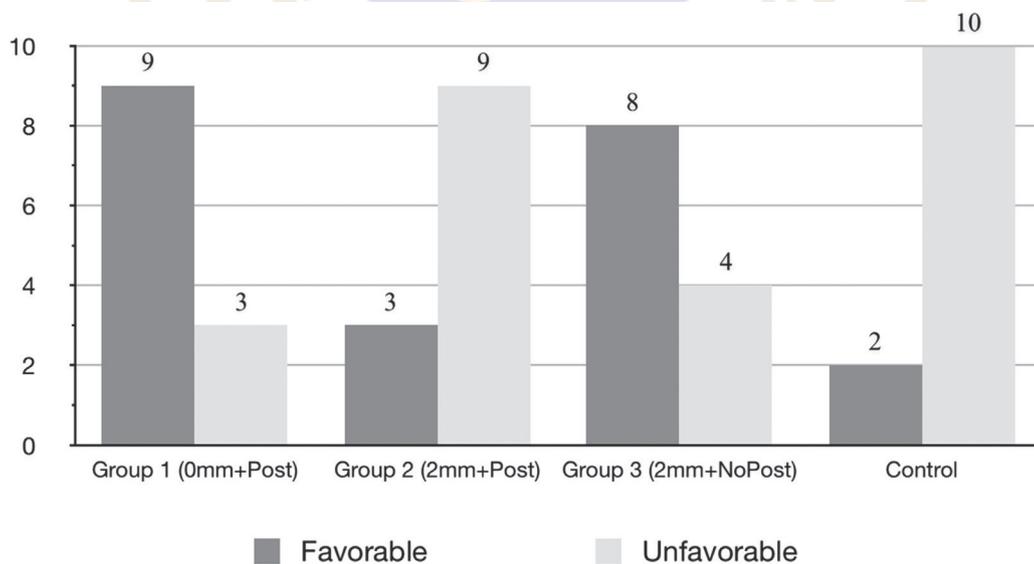


Figure 5 Histogram for Mode of failure

a fiber post. Maximum force of incisors, in normal function, is 215 N; and during parafunction, it is 343-362.6 N.<sup>27</sup> 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 functional force.

Results from other studies have shown the highest remaining coronal tooth structure to have greater fracture strength.<sup>28, 29</sup> However, in those studies, the coronal tooth structure surrounded by the restoration included the ferrule, which is 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 ferrule.

The majority of fractures in group 1 were restorable at the root-composite interface. Then, most fractures of group 2 occurred obliquely, below the cemento-enamel junction. In contrast, in group 3, the fractures occurred mainly above the CEJ. In this study, only nine samples in group 1 showed adhesive failure at the composite-tooth interface. A possible reason could be drawn from a finite element analysis study that showed highly intensive stress of a composite resin restoration with fiber posts on a destroyed coronal root-canal-treated incisor accumulated at the cemento-enamel junction and was distributed widely along the buccal tooth surface. Moreover, stress was also distributed along the post surface in the finite element analysis.<sup>30</sup> 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 have affected 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 3 predominated favorably, as had been reported in a previous study.<sup>31</sup>

The human PDL plays an important role in the fracture pattern and fracture resistance of teeth.<sup>32</sup> Simulation of the periodontal ligament (PDL) is one of the important factors in a fracture resistance test. The root embedding material to simulate PDL could also 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.<sup>33</sup>

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.<sup>34</sup> 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.

Most dental implants placed into esthetic zones require alveolar ridge augmentation due to compromised shape and contour of alveolar bone which occurs due to the resorption or fracture of buccal alveolar bone. Even after bone augmentation, long-term follow-up studies have shown that implant survival may depend on residual bone at the placement site.<sup>35</sup> Post-poning 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 and preparing the alveolar bone

structure for implant placement.

Thermocycling and fatigue testing have been performed to produce a situation comparable with physiologic conditions.<sup>36, 37</sup> However, they do not fully represent the clinical scenario where these restored teeth are rigorously tested under a different environment. Thus, the in-vitro approach was a limitation of this study. Future clinical trials should be performed for further evaluation of the outcomes of this study.

In conclusion, within the limitations of this study, the following conclusions can be drawn: Increasing the coronal tooth structure did not increase the fracture strength of a direct composite resin build-up with a fiber post on endodontically treated incisor. The fracture strength of a direct composite resin build-up restored with a fiber post on endodontically treated incisor 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-mm coronal incisors caused catastrophic fractures. In contrast, in 2-mm coronal incisors, the use of direct composite resin build-ups 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 a retained dental root over the short term, especially to preserve alveolar bone for future implant placement.

**Funding:** This study was supported by grant for supporting student's research from the Graduate school, Chulalongkorn University, Bangkok, Thailand.

**Competing interests:** The authors deny any conflicts of interest. The authors would like to thank SDS Kerr (Thailand) and Acteon (Thailand)

for supporting materials used in this study.

**Ethical Approval:** 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.

## Acknowledgements

This research was supported by the Students' Research Grant from the Graduated School of Chulalongkorn University, Bangkok.

## References

1. Tan WL, Wong TL, Wong MC, Lang NP. A systematic review of post-extraction alveolar hard and soft tissue dimensional changes in humans. *Clin Oral Implants Res* 2012; 23 Suppl 5: 1-21.
2. Fickl S, Zuhr O, Wachtel H, Stappert CF, Stein JM, Hurzeler MB. Dimensional changes of the alveolar ridge contour after different socket preservation techniques. *J Clin Periodontol* 2008; 35: 906-13.
3. Iqbal MK, Kim S. For teeth requiring endodontic treatment, what are the differences in outcomes of restored endodontically treated teeth compared to implant-supported restorations? *Int J Oral Maxillofac Implants* 2007; 22 Suppl: 96-116.
4. Hussain SK, McDonald A, Moles DR. In vitro study investigating the mass of tooth structure removed following endodontic and restorative procedures. *J Prosthet Dent* 2007; 98: 260-9.
5. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. *J Prosthet Dent* 2002; 88: 297-301.
6. Faria ACL, Rodrigues RCS, de Almeida Antunes RP, de Mattos MdGC, Ribeiro RF. Endodontically treated teeth: Characteristics and considerations to restore them. *Journal of Prosthodontic Research* 2011; 55: 69-74.
7. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutoke Y, et al. Stress analysis of endodontically treated anterior teeth restored with different types of post material. *Dent Mater J* 2006; 25: 145-50.
8. Salameh Z, Sorrentino R, Ounsi H, Sadig W, Atiyeh F, Ferrari M. The Effect of Different Full-coverage

- Crown Systems on Fracture Resistance and Failure Pattern of Endodontically Treated Maxillary Incisors Restored with and without Glass Fiber Posts. *Journal of Endodontics* 2008; 34: 842-6.
9. Spazzin AO, Galafassi D, de Meira-Junior AD, Braz R, Garbin CA. Influence of post and resin cement on stress distribution of maxillary central incisors restored with direct resin composite. *Oper Dent* 2009; 34: 223-9.
  10. Le Bell-Ronnlof AM, Lassila LV, Kangasniemi I, Vallittu PK. Load-bearing capacity of human incisor restored with various fiber-reinforced composite posts. *Dent Mater* 2011; 27: e107-15.
  11. Hayashi M, Sugeta A, Takahashi Y, Imazato S, Ebisu S. Static and fatigue fracture resistances of pulpless teeth restored with post-cores. *Dental Materials* 2008; 24: 1178-86.
  12. Fokkinga WA, Kreulen CM, Vallittu PK, Creugers NH. A structured analysis of in vitro failure loads and failure modes of fiber, metal, and ceramic post-and-core systems. *Int J Prosthodont* 2004; 17: 476-82.
  13. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Composite resin core-crown reconstructions: an up to 17-year follow-up of a controlled clinical trial. *Int J Prosthodont* 2008; 21: 109-15.
  14. Tan P, Aquilino S, Gratton D, Stanford C, Tan S, Johnson W, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *The Journal of Prosthetic Dentistry* 2005; 93: 331-6.
  15. al-Hazaimeh N, Gutteridge DL. 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* 2001; 34: 40-6.
  16. Kutesa-Mutebi A, Osman YI. Effect of the ferrule on fracture resistance of teeth restored with prefabricated posts and composite cores. *Afr Health Sci* 2004; 4: 131-5.
  17. Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). *Quintessence Int* 2008; 39: 117-29.
  18. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. *J Dent* 2009; 37: 115-21.
  19. Creugers NH, Kreulen CM, Fokkinga WA, Mentink AG. A 5-year prospective clinical study on core restorations without covering crowns. *Int J Prosthodont* 2005; 18: 40-1.
  20. Vilanova WV, Carvalho-Junior JR, Alfredo E, Sousa-Neto MD, Silva-Sousa YT. Effect of intracanal irrigants on the bond strength of epoxy resin-based and methacrylate resin-based sealers to root canal walls. *Int Endod J* 2012; 45: 42-8.
  21. Coniglio I, Magni E, Goracci C, Radovic I, Carvalho CA, Grandini S, et al. Post space cleaning using a new nickel titanium endodontic drill combined with different cleaning regimens. *J Endod* 2008; 34: 83-6.
  22. Kronfeld R. Histologic study of the influence of function on the human periodontal membrane. *J Am Dent Assoc* 1931; 18: 1242-74.
  23. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent* 1999; 27: 89-99.
  24. Kumagai H, Suzuki T, Hamada T, Sondang P, Fujitani M, Nikawa H. Occlusal force distribution on the dental arch during various levels of clenching. *J Oral Rehabil* 1999; 26: 932-5.
  25. Hattori Y, Satoh C, Kunieda T, Endoh R, Hisamatsu H, Watanabe M. Bite forces and their resultants during forceful intercuspal clenching in humans. *J Biomech* 2009; 42: 1533-8.
  26. Bates JF, Stafford GD, Harrison A. Masticatory function - a review of the literature. III. Masticatory performance and efficiency. *J Oral Rehabil* 1976; 3: 57-67.
  27. Lyons MF, Baxendale RH. A preliminary electromyographic study of bite force and jaw-closing muscle fatigue in human subjects with advanced tooth wear. *J Oral Rehabil* 1990; 17: 311-8.
  28. da Silva NR, Raposo LHA, Versluis A, Fernandes-Neto AJ, Soares CJ. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. *The Journal of Prosthetic Dentistry* 2010; 104: 306-17.
  29. Varvara G, Perinetti G, Di Iorio D, Murmura G, Caputi S. In vitro evaluation of fracture resistance and failure mode of internally restored

- endodontically treated maxillary incisors with differing heights of residual dentin. *J Prosthet Dent* 2007; 98: 365-72.
30. Garbin CA, Spazzin AO, Meira-Junior AD, Loretto SC, Lyra AM, Braz R. Biomechanical behaviour of a fractured maxillary incisor restored with direct composite resin only or with different post systems. *Int Endod J* 2010; 43: 1098-107.
31. Ng C, Dumbrigue H, Albayat M, Griggs J, Wakefield C. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. *The Journal of Prosthetic Dentistry* 2006; 95: 290-6.
32. Soares CJ, Pizi EC, Fonseca RB, Martins LR. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. *Braz Oral Res* 2005; 19: 11-6.
33. Pini M, Wiskott HW, Scherrer SS, Botsis J, Belser UC. Mechanical characterization of bovine periodontal ligament. *Journal of periodontal research* 2002; 37: 237-44.
34. Valdivia AD, Raposo LH, Simamoto-Junior PC, Novais VR, Soares CJ. The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: an in vitro study. *J Prosthet Dent* 2012; 108: 147-57.
35. Aghaloo TL, Moy PK. Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? *Int J Oral Maxillofac Implants* 2007; 22 Suppl: 49-70.
36. Naumann M, Metzdorf G, Fokkinga W, Watzke R, Sterzenbach G, Bayne S, et al. Influence of test parameters on in vitro fracture resistance of post-endodontic restorations: a structured review. *J Oral Rehabil* 2009; 36: 299-312.
37. Nothdurft FP, Schmitt T, Rupf S, Pospiech PR. Influence of fatigue testing and cementation mode on the load-bearing capability of bovine incisors restored with crowns and FRC posts. *Dent Mater J* 2011; 30: 109-14.

