ผลของความแข็งตึงในวัสดุสร้างแกนฟันต่อแรงต้านการแตก ในฟันที่ได้รับการรักษาคลองรากฟันที่มีผนังคลองรากผาย

นายชัยวัฒน์ วราอุบล

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EFFECT OF CORE MATERIAL STIFFNESS ON FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH WITH FLARED ROOT CANALS

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Prosthodontics
Department of Prosthodontics
Faculty of Dentistry
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Thesis Title	EFFECT OF CORE MATERIAL STIFFNESS ON FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH WITH FLARED ROOT CANALS
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Field of Study	Prosthodontics

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ชัยวัฒน์ วราอุบล : ผลของความแข็งตึงในวัสดุสร้างแกนฟันต่อแรงต้านการแตกในฟันที่ได้รับการรักษาคลองรากฟันที่มีผนังคลองรากผาย. (EFFECT OF CORE MATERIAL STIFFNESS ON FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH WITH FLARED ROOT CANALS) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.ทพ.ดร.แมนสรวง อักษรนุกิจ, 59 หน้า.

ความสำคัญและที่มา วัสดุสร้างแกนฟันที่ต่างกันมีอิทธิพลต่อแรงต้านการแตกในการบูรณะฟันที่ได้รับการรักษารากฟันที่มีคลองรากฟันผาย

วัตถุประสงค์ เพื่อเปรียบเทียบค่าแรงต้านการแตกในการบูรณะฟันที่ได้รับการรักษารากฟันที่มีคลองรากฟันผายด้วยเดือยคอมโพสิตเสริมเส้นใยร่วมกับวัสดุสร้างแกนฟันที่มีค่ามอดูลัสของสภาพความยืดหยุ่นแตกต่างกัน

วัสดุและวิธีการ ฟันกรามน้อยล่างซี่ที่สองจำนวน 32 ซี่ ตัดส่วนตัวฟันออกให้เหลือความยาวราก 15 มม. ทำการรักษารากฟันและผายคลองรากฟันให้มีความหนาของเนื้อฟันโดยรอบ 1 มม ลึก 7.5 มม.ของความยาวราก ทำการบูรณะด้วยเดือยฟันดีทีไลท์โพสท์เบอร์1 ร่วมกับการใช้ซูเปอร์บอนด์ซีแอนด์บี เรซินซีเมนต์ในการยึด แบ่งกลุ่มทดลองออกเป็น 4 กลุ่ม กลุ่มละ8 ซี่ โดยใช้วัสดุสร้างแกนฟันสี่ชนิด; เคลียร์ฟิลโฟโตคอร์, มัลติคอร์โฟลว์ เรซิน, บิวท์อิท และ คอร์โฟลว์ เรซินคอมโพสิตในการสร้างแกนฟัน นำชิ้นตัวอย่างที่ได้มายึดในบล็อกอะคริลิกโดยสร้างเอ็นยึดปริทันต์จำลอง จากนั้นนำมาทดสอบด้วยเครื่องทดสอบแรงสากลความเร็วหัวกด 1 มม.ต่อนาที กดที่ด้านใกล้แก้มโดยทำมุม 135 องศากับแนวฟันจนเกิดการแตก

ผลการศึกษา ค่าเฉลี่ยความต้านทานการแตกในกลุ่มที่ 1, 2, 3 และ 4 เท่ากับ 864.7 ± 189.8 นิวตัน, 1519.2 ± 278.9 นิวตัน, 1110.8 ± 229.8 นิวตัน และ 901.6 ± 183.6 นิวตันตามลำดับ ผลการทดสอบทางสถิติโดยใช้การวิเคราะห์ความแปรปรวนแบบทางเดียวและการเปรียบเทียบชนิดตูกีเอชเอสดี พบว่าค่าเฉลี่ยความต้านทานการแตกในกลุ่มที่ 2 มากกว่ากลุ่มที่ 1, 3 และ 4 อย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) ในขณะที่กลุ่มที่ 1, 3และ 4 ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ

สรุปผลการศึกษา ภายใต้ข้อจำกัดของการทดลองนี้พบว่าการใช้วัสดุสร้างแกนฟันมัลติคอร์โฟลว์ เรซินคอมโพสิตในคลองรากที่ผายให้ค่าแรงต้านทานการแตกหักที่ดีและมีรูปแบบการแตกหักที่เหมาะสม

ภาควิชา ทันตกรรมประดิษฐ์ ลายมือชื่อนิสิต..
สาขาวิชา ทันตกรรมประดิษฐ์ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก............................
ปีการศึกษา ..2554........................

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KEYWORDS: FRACTURE RESISTANCE / FRACTURE MODE / MODULUS OF ELASTICITY / FLARED ROOT CANALS

CHAIWAT VARAUBOLN: EFFECT OF CORE MATERIAL STIFFNESS ON FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH WITH FLARED ROOT CANALS. ADVISOR: ASSOC. PROF. MANSUANG ARKSORNNUKIT, Ph.D., 59 pp.

Background and rationale: Different core materials may have an influential effect on the fracture resistance of endodontically treated teeth (ETT) with flared root canals

Objective: This study compared the fracture resistance of endodontically treated teeth with flared root canals, restored using core build-up materials with different modulus of elasticity and a quartz fiber post.

Material and methods: Thirty two extracted human mandibular premolars were decoronated to obtain 15 mm of root length, endodontically performed and prepared as flared canal with 1 mm of dentin thickness wall to the depth of 7.5 mm into root. All teeth were restored with D.T. Light post #1 and luted with Super-Bond C&B resin cement and then randomly divided into 4 groups (n=8). Four core build-up resin composites: Clearfil Photocore, Multicore Flow, Built-it and Coreflo were used as core foundation. The specimens were embedded in self-cured acrylic resin blocks with a simulated PDL. All specimens were loaded on a universal testing machine with a crosshead speed of 1 mm/min on the buccal surface at an angle of 135° to the long axis of the tooth until failure occurred.

Results: The fracture resistance of groups 1, 2, 3 and 4 were 864.7 ± 189.8 N, 1519.2 ± 278.9 N, 1110.8 ± 229.8 N, and 901.6 ± 183.6 N, respectively. One-way ANOVA and Tukey HSD post-hoc analysis revealed the fracture resistance of groups 1 was significantly higher than group 2, 3 and 4 ($p<0.05$). No significant differences were found in groups 2, 3 and groups 4.

Conclusion: Within the limitation of this study, Multicore Flow showed better fracture resistance in flared canals with favorable fracture.

Department: Prosthodontics Student's Signature……………………
Field of Study: Prosthodontics Advisor's Signature……………………
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LIST OF ABBREVIATIONS

ABBREVIATIONS	DESCRIPTIONS
N	Newton
%	percent
°C	degree in Celsius
µm	micrometer
mm	millimeter
min	minutes
mW	milliwatt
cm^2	square centimetre
kV	kilovolt
kgf	kilogramforce
s	second
et al	et alii (and others)
e.g.	exempli gratia (for example)
fig	figure
ANOVA	analysis of variance

SD	standard deviation
α	alpha
®	registered
GPa	gigapascal
MPa	megapascal
No	number
Ltd	Limited
Inc	Incorporation
ISO	International Standardization and Organization

CHAPTER I

INTRODUCTION

Endodontically treated teeth (ETT) with flared root canals are at high risk of fracture (1, 2). The fracture resistance of the root is related to the existence of a dentin ferrule (3, 4) and the remaining dentin thickness (4-6). An adequate length of ferrule and thickness of root dentin walls increases the fracture resistance of ETT. Therefore, reinforcement of the remaining tooth structure is needed to withstand masticatory forces.

Reinforcement methods have been recommended and described in previous reports (1, 2, 6-11). Traditionally, cast a dowel and core has been used, demonstrating a comparatively high fracture resistance (7, 10). However, vertical root fracture was often observed (10, 12). This fracture type is caused by differences in the elastic modulus between dentin and post materials resulting in uneven stress concentrations at the end of the post (11, 13). The mechanical properties of post systems should be considered when investigating the cause of failure in ETT (14). Post materials should have an elastic modulus similar to dentin in order to evenly distribute forces throughout the root (15). Fiber-reinforced composite (FRC) posts have an elastic modulus close to dentin and demonstrate the restorable fracture patterns with high fracture load (16-18).

Recently, several composite resins have been used with FRC posts to reinforce intra-canal defects (1, 12, 19). A combination of composite resin core materials and FRC posts was found to improve stress distribution along the root (2, 17) and significantly reduce strain values at the cervical region of the root surface (8). Although many types of fiber posts and composite resin core built-up materials are currently avialable on the market, studies have largely focused on the effect of post materials on fracture resistance of ETT with flared root canals (1, 2, 13, 16). Few studies have investigated the effect of elastic moduli of different core built-up material

(20, 21). However, the methods of these two studies did not simulated the weaken canals condition.

Nowadays, there is no consensus in the literatures about which material and technique is better to restore ETT with weaken root. Thus, the purpose of this study was to compare the fracture resistance of ETT with flared root canals, restored with composite resin core built-up materials with different types and a FRC post. The null hypothesis was the different types of core built-up composite resin had no effect on fracture resistance of ETT with flared root canals.

Objective

1. To compare the fracture resistance and fracture mode of ETT with flared root canals, restored using different types of core build-up material and a quartz fiber post
2. To gain the knowledge for further study in restoration of ETT teeth with flared root canals

Research scope

This in vitro study aim to compare the fracture resistance of ETT with flared root canals restored using different types of core built-up composite resin and fiber-reinforced composite. Specimens were prepared in the same manner and test by universal testing machine until fracture. There were no simulated intra oral conditions such as dynamic or fatigue behavior. The fracture resistance and fracture modes were analyzed, respectively.

Agreements

All of the procedures of this in vitro study were performed by only one examiner with the same instruments and the machines. The laboratory was at dental materials research center, 9 th floor, princess mother 93 building, Faculty of Dentistry, Chulalongkorn University. The room temperature was 25±2 ˚C.

Research limitations

This experimental study could not control some factors as in oral environment, such as dehydration of tooth specimens. The static load did not fully simulate human mastication. Therefore, the result of this study may not truly be applicable to actual clinical condition

Type of research

Experimental research

Proposed benefits

1. To find out the fracture resistance of endodontically treated teeth with flared root canals reinforced with quartz fiber post and resin core build-up materials
2. To understand role of different types of core build-up material in reinforcement effect in minimal dentinal thickness canal wall
3. To establish guideline for selecting materials to restored treated teeth with flared root canals

Hypothesis

Null hypothesis: The different types of core build-up material had no effects on fracture resistance of ETT with flared root canals.

Alternative hypothesis: The different types of core build-up material had effects on fracture resistance of ETT with flared root canals.

CHAPTER II

LITERATURE REVIEW

ETT was known to present a high risk of fracture because of the different in stiffness and strength than normal tooth (22). Due to the loss of tooth structure before and during root canal treatment, preparation post space and internal change of tooth structure; collagen degradation, loss of moisture in dentin (22-24) and decrease in propioception have made this tooth prone to fracture (25).

There are many methods to restore ETT e.g. direct restoration, indirect restoration and restoring with post or without post that depend on quality and quantity of remaining tooth structure, location, amount and direction of force, esthetic concern and condition of root canal treatment.

Direct restoration

Direct restoration technique was used to restore the tooth that have a lot of remaining tooth structures or have only access opening in enamel layer.

Filling access opening with adhesive restoration: Restore access opening with resin composite and bonding agent has been introduced (26). Lovdahl and Nicholls founded that restoring the ETT with resin composite and bonding agent resulted in better fracture resistance compared to amalgam or gold dowel and core systems. The technique was claimed in providing optimum success for restoring ETT and the fracture pattern was repairable (27, 28).

Filling access opening with pin retained amalgam or composite restoration Uyehara Davis and Overton suggested to restore the ETT in mandibular molar with adequate remaining tooth structure, especially mesiobuccal cusp by using pin retained amalgam restoration with bonding agent. They founded that the fracture resistance was the same as normal tooth and the fracture mode was occurred at the cervical area which was restorable (29).

Indirect restoration

Indirect restoration technique was used to restore the teeth which excessive loss of tooth structures.

Onlay restoration: this restoration was designed to cover almost the cusp to protect and strengthen remaining tooth structure. Metal, ceramic, and resin composite were used for this restoration. Onlay restoration was used in the cases that have sufficient remaining tooth structure but the remaining cusps were weaken. Liberman Jude and Cohen founded that the restoration in posterior teeth should have resistance to both vertical and horizontal force (30).

Full coveraged crown: this restoration covers the coronal tooth structure mostly, the finishing line was at cementoenamel junction (CEJ), to prevent fracture, leakage and improve esthetic. In some study founded that only crown placement is the optimum treatment for ETT (31).

Full coveraged crown with post and core system: this method was used in the case that have insufficient tooth structure and could not be restored with only crown placement. Therefore, it must have a post and core complex for retain crown restoration.

Comparison between the restoration with and without post placement

In 1985 Trope et al reported that the preparation for post placement may weaken the root and the post was not significantly improve the strength of root structure (32). Post placement was used to retain core when the tooth structure have excessive loss, and the post was believed to distribute the occlusal force from coronal part to apical part. This was believed to cause non-restorable fracture (28, 33, 34).

Fracture mode of the teeth with post placement was occurred at middle and apical third of root. Otherwise, without the post placement was occurred at cervical and middle third only (35, 36). Forberger and Gohring demonstrated that the post and core placement increased the fracture resistance but not influenced the fracture mode (37). Other studies founded that the failure mode of the tooth that had post placement could be repaired because the post and bonding system can distribute the force along root length (38, 39).

Factors that influence the succeed of ETT

Post types:

- Cast metal post

Cast metal post and core is the standard restoration for ETT for many decades (40). A cast post is a single unit that reproduces the contours of the prepared canal with good adaptation to canal wall. The metal has high strength and its modulus of elasticity was about 7-10 times n t t et ehtg et gerg (41, 42). It can absorb occlusal load without distortion and distribute the stress to the root dentin which is lower in the modulus of elasticity (43). Corrosion products of cast metal post are affected the tooth and gingival discoloration. The mismatch in modulus of elasticity between metal and dentin was believed to cause root fracture which ended up in extraction. Moreover, it was difficult to remove when endodontic retreated was indicated. In a clinical study, it showed 28% in 10 years survival rate of ETT that restored with cast post and core (44). Significantly higher fracture threshold was recorded in cast post with amalgam cores (45).

- Prefabricated posts

These posts were classified according to the type of materials used such as stainless steel, titanium, ceramic, fiber reinforced composite, carbon fiber, glass fiber and quartz fiber. A great variety of prefabricated posts has been developed. The variations in surface designs can be divided into smooth, serrated and threaded. The prefabricated posts may be parallel-sided or tapered post.

In some studies found that using prefabricated post with composite or amalgam core have several advantages. They are time-saving (require only a single visit), economical (no laboratory fee), easy to remove and also with good clinical results (46, 47). The fracture resistance of prefabricated post was higher than cast metal post (41, 48, 49) in combination with the lower the risk of root fracture. Fracture mode was occurred at core interface (core debonding) than root fracture (50, 51). However, root fracture has been found in some cases (27).

Post materials

Metal posts: these posts are made of different alloys or pure metals, like platinum-gold-palladium alloys, nickel-chromium alloys, cobalt chromium alloys, stainless steel, copper and titanium alloys. Elastic modulus and the strength of metal post are higher than normal dentin. The color of metal posts can reflect through the thin root dentin, alveolar bone and gingival that causes the esthetic problem, especially in anterior region. Nickel-chromium alloys and nickel-silver-stainless steel alloys have the corrosion products that can deposite into the tooth structure while gold alloys do not corrode in oral environment (44).

The corrosion products of metal post not only cause the root fracture (52) but also affect the periodontal tissue around the tooth such as the alteration of oral mucosa, sensitivity, pain and other reactions (53). Titanium alloy post has the lower fracture resistance values with non-restorable failure (16). The study found that Titanium alloy post showed the highest fracture resistance values when compared with carbon and glass fiber post. The fracture pattern was also non-restorable fracture (54).

Non-metal posts: these posts are made of non-metal materials, like ceramic, fiber reinforced composite (FRC): carbon fiber, glass fiber, quartz fiber and polyethylene woven fiber. They were widely used in restorative dentistry because these materials have good optical properties and reflect the lights near normal teeth (55) .

Ceramic or Zirconia post: this post consists of zirconium dioxide (ZrO_2). It has higher strength and fracture toughness than other ceramics. The optical properties were radiopaque, white or translucent and did not corrode in oral environment.

Zirconia post has the modulus of elasticity around 822 GPa. This could be attributed to rigidity. It does not absorb the stress within the post but transfer almost stress to the interface between post and root canal dentin, which probably cause stress concentration area that leads to post debonding, post dislodgement and root fracture in (16). Zirconia post offers advantages with respect to esthetics (56, 57) and the rigidity is much higher than fiber posts. One *in vitro* study recorded poor resin-bonding capabilities of zirconia post to radicular dentin and resin composite (58). However, surface treatments of post in combination with resin cement enhanced the bond strength and types of resin cement was also influenced the retention values of zirconia post (59). Restoring ETT with zirconia posts showed higher resistance to fracture when compared to the teeth that restored with cast metal posts or titanium alloy posts (28). Survival rate of zirconia post and cast metal post after apply load in stimulated oral condition were comparable (60). Other study suggested that a zirconia post had significantly more survival rate after stimulated condition and continuous intermittent loading than carbon fiber post (61).

Fiber reinforced composite post (FRC post): FRC posts consist of a high volume percentage of continuous unidirectional reinforcing fibers in a finally polymerized polymer matrix. The fibers used in prefabricated FRC posts are carbon or glass (E-glass, S-glass, quartz/silica) fibers, polyethylene fibers and the matrix is usually an epoxy polymer or a mixture of epoxy and dimethacrylate resins with a high degree of conversion and a highly cross-linked structure. The fibers give strength and stiffness, while the polymer matrix combines the fiber together, forming a continuous phase around the reinforcement. The in vivo studies found that FRC post was less in a stiffness due to the suitable elastic modulus that similar to dentin which should result in a fewer root fractures and a fewer unfavorable failures (16, 41, 62). However, this property leads to more stress concentrate at the core part, causing premature failure of the core restoration (41, 63). This problem may occur when a little or no coronal tooth structure remained (64).

Glass fiber post: Glass fibers (GFs) are the most commonly used as reinforcing fibers in both dental and industrial applications. This is because they offer several advantages such as high tensile strength, excellent compression and impact properties, with low cost. This post consists of the continuous unidirectional reinforcing fibers in a polymer matrix. The GFs are classified into A (alkali)-, C (chemically resistant)-, D (dielectric)-, E (electrical)-, R (resistant)- and S (high strength)- glass types. The composition of GFs in the matrix tends to play an important role in strength of the post. The post is white translucent and transparent, good biomechanical property and favorable esthetic demand (65). The GF post is available in different shapes: cylindrical, conical and cylindroconical. An *in vitro* study indicated that parallel-sided GFs post are more retentive than tapered post (66). This post is more elastic, better to distribute force along the root, less likely to cause root fracture than cast metal post (67). The modulus of elasticity of this post is similar to that of dentin but lower than carbon fiber post (68).

Carbon fiber post: The matrix of this post is an epoxy resin reinforced with unidirectional carbon fibers parallel to the long axis of the post. The post contains 8 μm in diameter with 64% weight content of fiber. This post is biocompatible and easy to be removed (62). The carbon fiber post can be bonded to resin material and has modulus of elasticity similar to that of dentin (14-18 GPa). The post is originally radiolucent however, a radiopaque post was now developed by placing traces of barium sulfate and/or silicate inside the post. Finger et al in 2002 evaluated the radiopacity of seven fiber reinforced resin post and found a carbon fiber post had an acceptable radiopacity (69). This post is also available in different shapes: conical shape, conical with cylindrical shapes. The surface texture of post may be smooth or serrated. Study has indicated that the serration of post increase mechanical retention although the smooth-sided post also bonds well with adhesive dental resin (70). Physical strength of carbon fiber post tested varied in values (71, 72). The strength of carbon fiber post increased, while the diameter of post increased (73). The fracture resistance of teeth restored with this post was higher than teeth that restored with titanium post or cast metal post (48), while the other studies found a significantly higher fracture threshold for cast metal posts (63, 74). Consideration in fracture patterns, one study indicated the carbon fiber post was less likely to cause root fracture than metal posts (71). However, other studies found no significant differences in fracture patterns (48, 75).

Quartz fiber post: the mechanical behavior of quartz fiber post is similar to that of dentin. This post is available in both transparent and translucent. The translucent property offers transmission of light along post length that enhanced the polymerization of resin cement in root canal. Similar to GF post, quartz fiber post has been shown to be less likely to cause root fracture. The fracture pattern may occur in coronal region that can be retreated (16).

Polyethylene woven fiber or Woven polyester bondable ribbon: Ribbon : Polyethylene woven fiber-reinforced post is made of ultra-high molecular weight polyethylene-woven fiber ribbon undergone cold gas plasma treated. This post must be used with bonding systems and resin composite. Polyethylene woven fiber was used in un-polymerized form in order to bond with resin monomer of resin cement. One study showed that the bonding property of Polyethylene woven fiber did not depend on the type of bonding system (76). The addition of a small-size of prefabricated post to the Polyethylene woven fiber post can reduce the incidence of vertical root fracture (41). In the study of Lassila et al in 2004 found that Polyethylene woven fiber (EverStick® post) had the highest flexural strength when compared to other FRC post (73).

FRC post is a composition of composite materials. The degradation of this material mostly occurred on delamination between fiber and resin matrix. Flexural strength and modulus of elasticity of this post were affected when water was absorbed in their structure (77). Lassila et al in 2004 found that thermocycling method reduced the flexural modulus approximate 10%, moreover the strength and the fracture resistance decreased about 18% (73).

In the study of Akkayan et al in 2002 (78) compared the modulus of elasticity between metal post, ceramic post and fiber reinforced composite post . The results found that fiber reinforced composite post had the modulus of elasticity similar to that of dentin than cast post and ceramic post. This post can create monoblock dentin-post-core system when using with dentin bonding agent, that was believed to better stress distribution along the root (79). Other studies found that the rigid post and core, as metal post was better to absorb and distribute the stress at cervical part than fiber reinforced composite post. The non rigid post can absorb stress more than normal limit because of the bending resistance of this post. Some studies demonstrated that stress was transferred to the post (16, 74, 80), that lead to core debonding, post bending and core fracture (16, 81) but root fracture was not observed (55, 62). In addition to the post movement, the restoration is allowed to displace and the marginal leakage of crown margin was occurred. This leads to secondary decay and/or recurrent endodontic infection (82-84).

Post diameter

The diameter of post should be "as small as possible" to increase the fracture resistance by minimizing the loss of tooth structure. The optimal diameter is one third the diameter of the root and the diameter at apical part of post should not be over than 1 mm (35). Increasing post diameter may affect on internal stress within the root canal that cause root fracture. According to Sorensen and Martinoff, an increase in post diameter does not influence retentive capacities significantly but it reduces remaining dentin around the post that decreases the fracture resistance of the tooth (35).

Post design

The parallel post show higher retention capacity than taper post (66). A parallel-sided post disperses the stresses uniformly along its length (35) that reduces the risk of root fracture. While the tapered post shows greater stress concentration at the coronal shoulder (85). The higher concentration of the stress on external surface at the apex of parallel posts was considered due to the thin remaining tooth structure after post space preparation (32). A research has demonstrated that tapered or tapered-end posts causes a wedging effect (86). The surface designs of post are another important factor that should be considered. They can be divided into serrated, threaded and smooth surface designs. A serrated post significantly increases the retention of the post compared to a smooth post (32, 35, 70) but the threaded post exhibits unfavorable stress distribution patterns on placement and during function.

The concentration of stresses is observed at the dentinal thread interface(87). It was found that post design did not affect the fracture resistance value when the tooth had full coverage restoration (32).

Post length

There were many guidelines in the literatures concerning the effect of post length. Several studies suggested the length of post should be long but not interfere the gutta percha at the apical third of the root or should be equal to or greater than the length of the crown, that provide 97 % of success rate (35) or equal the half of root length (88) or equal half of root length in bone. Breg et al (89) found that using the post that have the length equal to half of the root length same as using the post that have two thirds of the root length. It has been suggested that leaving at least 3-5 mm of root-filling material is necessary to maintain the apical seal (44). The length of the post influences retention capacity, survival rate and stress distribution in the root, and also affects its resistance to fracture. Posts with the greater in length showed reduction and better stress distribution compared to a shorter post (90, 91). Moreover, when the length of post increased the retentive capacity increased (81). Giovani et al (93) showed the effect of post lengths in fiber reinforced composite post. This result demonstrated that the fracture resistance of fiber reinforced composite post in 10 mm post length was significantly more than 6 mm post length.

Core material

There are many types of core material available such as amalgam, glass-ionomer and resin composite.

Amalgam**:** this material has high compressive stress. It is easy to use and the modulus of elasticity and dimensional stability are higher than resin composite and glass-ionomer. Disadvantages of amalgam are high thermal expansion coefficient (COE) (94), no bonding to dentin, unacceptable in color, slow setting time (95), corrode with high-noble metal that lead to tooth and gingival discoloration. Moreover, this material are not safe in some patients who allergy to amalgam restoration.

Glass-ionomer: this material has been first recommended in 1972 (96). The advantage of this material is fluoride release (97). Coefficient of thermal expansion (CTE) is similar to that of dentin and can bond to tooth structure (98). Disadvantages are sensitive to moisture, low wear resistance, brittle and low tensile strength (99). However, this material is not popular in clinical use because of its low fatigue resistance that cannot absorb stress during functional load.

Resin composite: the most common type of resin composite using for core build-up is hybrid, microhybrid and high viscosity (packable/condensable) (100). Mode of curing is light cured, chemical cured (self cured) or dual cured. Advantages of this material are esthetic, bond to tooth structures (11-28MPa) (100) when use with dentin bonding agent and do not corrode in oral environment. Although the resin composite is in high strength but this material demonstrated leakage due to the polymerization shrinkage, low dimensional stability and 3 times greater in thermal expansion coefficient than tooth structure (101). The thermal change can create the space between core material and crown restoration that prone to cause marginal leakage. Martin and Jedynakiewicz (102) found that the water absorption of resin composite could compensate for the polymerization shrinkage in this material (3.0-9.3% by volume after 6 months later). This has influenced the fitting of crown (103) caused fracture of ceramic crown (104). The stiffness of core material did not significantly affect the fracture resistance of ETT, if crown was placed over core material (21). The failure mode occurred at core part that can be restored. Yaman and Thorsteinsson (20) demonstrated that the increase in core material stiffness, the stresses shifted from apical to cervical area of the root. Therefore, fracture pattern was commonly occurred at the favorable level of the root that can be repaired. Salameh (106) compared the bond strength of 5 different resin composite to FRC post. The result demonstrated that the flowable composite showed the highest bond strength this due to the flowable properties of this material which reduced the void and porosity between post and core material. Moreover, the silane application did not significantly affect bond strength of core materials (107).

Luting cements

Dental cements play important role to absorb and distribute the stress within the bonding unit. It should be low solubility, resistance to water and acid reaction, low leakage, good handling characteristics, low film thickness, good adhesion to tooth structure and restorative material, low viscosity, long working time with rapid set at oral temperatures. It also should have high compressive and tensile strengths, high proportional limit, biocompatibility, translucency and radiopacity. There are several luting cements currently available. There are as follows:

Zinc phosphate cement: This cement has a long history of use in dentistry and continues to be used despite physical properties that are less than ideal. It consists of zinc oxide powder particles and phosphoric acid in liquid part. The advantages of this cement are easy to manipulate, rapid set, good strength after setting, high compressive stress (96-110 MPa), acceptable thin film thickness (lower than 25 microns), the modulus of elasticity near the dentin (13 GPa), easy to remove excess cement. The primary disadvantages of zinc phosphate cement are lack of adhesion to tooth structure and a high degree of solubility. This cement creates mechanical interlock between material and tooth structure, low initial pH (2-3.5) and exothermal reaction after setting which may lead to post-cementation sensitivity.

Zinc Polycarboxylate cement: This cement was developed in the late 1960s as an adhesive dental cement. The powder consists of approximately 90% zinc oxide, 10% magnesium oxide powder. The liquid is an 32% to 43% aqueous solution of polyacrylic acid. The main advantages of this cement are the low pulpal irritation, chemically adhere to the tooth structure, easy manipulation, and low film thickness. The major disadvantages include short working time, tooth conditioning step prior to cementation, low compressive strength (80 MPa) and low modulus of elasticity, dimensional change after setting, critical powder/liquid ratio and difficult to remove excess cement.

Glass-ionomer cement: This cement consists of aluminofluorosilicate glass powder and the aqueous solution of polymers and copolymers of acrylic acid. The advantages are chemical bond to enamel and dentin, good flowable property, biocompatibility, coefficient of thermal expansion similar to that of tooth structure, high compressive strength, low solubility, low film thickness and release fluoride. The fluoride release reduces the potential for recurrent caries around the restoration. The disadvantages include low initial pH which may lead to post-cementation sensitivity, sensitivity to moisture contamination and desiccation, lower compressive strength and modulus of elasticity than zinc phosphate cement. It was not recommended to cementation the post.

Resin-modified glass ionomer cement: This cement contains an acid-soluble glass, polyacid polymers (polyacrylic, itaconic, or maleic), and polymerized dimethacrylates. The polyacid polymers react with the calcium in the glass filler and the dentin, while the dimethacrylates polymerize into a solid resin. This combines the advantages of a conventional glass-ionomer and resin technology. They do exhibit some fluoride release, resistance to marginal leakage, adhesion to enamel and dentin with micromechanical interlock, some moisture resistance, and less solubility than the conventional glass-ionomer cement, low film thickness ,high compressive and tensile strength but lower than resin cement. This cement is less sensitive and easy to manipulate compared to resin cement. However, this class of cement imbibes water and expands with time (109, 110). There was anecdotal evidence that volumetric expansion of this cement cause fracture all-ceramic crowns relatively soon after cementation (111). If this cement can fracture all-ceramic crowns, its expansion will likely cause vertical root fracture if used in cementation of posts.

Resin cement: These cement has the composition the same as the resin composite or monomer. Resin cements are either visible light-activated, chemically-activated, or dual-activated (both visible light- and chemically- activated). It bonds to tooth structure via hybrid layer that created by infiltration of monomer in exposed dentinal tubule after etching process (112, 113). It bonds to restorative materials with chemical and micromechanical interlock. Bond strength of resin cement is higher than zinc phosphate cement and glass-ionomer cement (about 6 and 2 times, respectively). It is also better in fatigue resistance than zinc phosphate cement. This cement increases the retention of the post to root canal wall (114-116). Moreover, the fracture resistance, compressive strength, tensile strength are relatively high. It is low in solubility in oral environment (117)and low in leakage than other cements (118, 119). The phenolic compound inhibits the free radical that initiated resin polymerization. Thus, it should be careful when the root canal sealer and temporary cement that contain eugenol was used.

Wiskott et al (120) founded that the film thickness of resin cement may influence the resistance to fatigue failure of restoration. They stated that higher film thickness decreased the fatigue resistance values. In the study of Bex et al (121) demonstrated that the resin cement can reduce the risk of root fracture. Moreover, resin cement can strengthen the root in case of thin canal wall and improper adaptation of post (122). Saupe et al (2) founded that using high rigidity, low elasticity, created the stress concentration at dentin-cement-dowel interface. This result suggested to use resin cement with the modulus of elasticity similar to that of dentin.

In vitro studies of methods in restoring ETT with weaken canal

In situation that ETT with weakened canal, it was known that showed a higher risk of fracture. Therefore it was recommended to reinforce the remaining tooth structure. The suggested techniques for restoring structurally compromised flared root canals are based on two conventional post–core systems with different design characteristics. The first system involves the cast post and core that closely resembles the morphology of the root canal space. The traditional cast dowel and core reproduces the morphology of the root canal space have been advocated with a comparatively high fracture resistance (7). However, vertical root fractures are often seen (12). This caused by stress concentration at the end of the post due to the difference in modulus of elasticity between dentin and post materials. Sorensen and

Martinoff (35) indicated that intracoronal reinforcement did not significantly increase the clinical success rate of any of the anatomic groups of ETT and coronal coverage significantly improved the clinical success rate of endodontically treated maxillary premolars and maxillary molars, mandibular premolar, and mandibular molar when insufficient tooth structure exists to prepare a tooth for coronal coverage, a technique must be used to restore lost dentin. A post facilitates the retention of core material in both posterior and anterior teeth (6).

In the second systems, adhesive materials and techniques are used for the intra-radicular reinforcement of roots. Several materials have been introduced such as glass ionomer cement, composite resins and hybrids of glass ionomer cement and composite resin. The intention for the use of dentin-bonded resins for root reinforcement is to increase fracture resistance by increase the internal thickness of root with adhesive material that is elastically compatible with dentin and create the stress transferring along the root length (2, 41, 74, 122-124).

Saupe et al in 1996 compared the fracture resistance between conventional custom cast posts and cores and a Luminex resin-reinforced dowel system for structurally compromised roots. Their results indicated that the fracture load of a resin reinforced dowel system was greater than custom cast post and core restoration and they found that no statistically significant difference in strength between group that used an ferrule and without ferrule (2).

Mendoza et al in 1997 evaluated the ability of resin-bonded post to reinforce teeth that are structurally weak in the cervical area, the result showed that when posts were cemented with resin cements, the fracture resistance of the roots was significantly more than using zinc phosphate cement, Panavia provided the greatest resistance to fracture and the fracture line occurred opposite the area where the force was applied. In Zinc phosphate group, the fracture line occurred along the root cause of post dislodgement and root fracture. This because of Zinc phosphate did not create the bonding interface between the dentin in root canal and the post that not a one unit system. They also concluded that the resin materials can internally strengthen ETT (122).

Sirimai Rii and Morgano in 1999 introduced method to reinforced canal wall by use polyethylene woven fiber with dentin bonding agent and light cured composite resin or small diameter prefabricated post. They conclude that the addition of polyethylene woven fibers result in significantly reduce root fracture in post-and-core treated teeth, the use of polyethylene woven fibers with small diameter prefabricated post and composite core showed significantly higher fracture resistance than teeth that restored with polyethylene woven fibers and composite core without prefabricated post (41).

Newman et al in 2003 found that the failure load of the stainless steel posts were significantly stronger than all the composite posts but mode of failure produced no root fracture, whereas the stainless steel posts showed root fracture. Furthermore, each post system showed no statistically significant difference in strength between narrow and flare canal (17).

Marchi et al in 2003 studied effect of different filling material in combination with prefabricated post to reinforce the weakened root. They concluded that the resistance to fracture of a root is directly related to the thickness of remaining dentin around the intra radicular post, and using only resin cement with prefabricated post showed lowest resistance value. The use of adhesive restorative materials such as Vitremer, Dyract AP, Z100 did not reinforce the root to present the same levels of resistance to fractures as the healthy roots (125).

Yoldas et al in 2005 suggested techniques for restoring structurally compromised flared root canals. Their result showed that the mechanical properties of the post and core materials directly influenced the stresses produced at the cervical third of the root when use the resin reinforcement of root canals before post–core applications, stresses at the cervical part of the root surfaces was decrease and stiffness of core material was effect to shift the stress at apical third to cervical third that caused root fracture (8).

Hu et al in 2005 founded that the dentin ferrule preparation was important factor to ensure treatment success and longevity. The use of resin composite post and core with 1-mm ferrule had relatively strong resistance to cyclic fatigue and fracture loading and it also demonstrated favorable root fracture .Using resin composite core in combination with a carbon fiber post showed long fatigue life, and custom cast post-and-core showed the highest fracture resistance. However, all of these demonstrated unfavorable root fracture (1).

Maccari et al in 2007 evaluated the fracture strength of teeth with flared canals and restored with different post systems. In this study the authors suggested to use cast post to restore ETT with flared canal and flare ferrule, the fracture strength of tooth restored with cast posts more than the teeth restored with resin post , but all failure of cast posts were non-repairable (10).

L.V. Zogheib et al in 2008 stated that in case of severely weakened roots, with very thin dentin wall, the use of composite resin associated to a glass fiber post does not recover the full resistance to fracture of roots. In conclusion of this study showed that thicker root dentin walls significantly increase the fracture resistance of ETT (126).

Fukui et al in 2009 used cast metal post and core that reinforced with resin composite to restore structurally compromised tooth with flared root canal, it was exhibited high fracture strength. Moreover the structurally compromised tooth with flared root canal were fracture after restoration, the fracture line extended to the infrabony area tend to increased risk of tooth extraction (12).

Form the various studies that claim above, prefabricated posts associated with resin reinforcement of the root dentin walls have been recommended to increase fracture strength. Nevertheless, there is no consensus in the literatures about which material and technique are better to restored ETT with weakened root. Moreover, the control factors in the studies were differences and there is no study compared the effect of various resin core materials that use to reinforce an ETT with flared canal walls.

CHAPTER III

MATERIAL AND METHODS

Flexural strength and modulus of core built-up composite resins

Four core built-up materials were selected in the present study; their code and polymerization modes are listed in Table 1. Their flexural strength and flexural modulus were measured according to ISO 4049: 2010. Composite resin paste was prepared according to the manufacturer's suggestions; MCF was auto-mixed with the supplied automixing syringe and tip, and CRF were hand-mixed. Composite resin paste was inserted into a splited stainless-steel mold, 2.0 x 2.0 x 20.0 mm, and polymerized according to the manufacturer's suggestions; CPC was light-activated from both sides using a laboratory curing oven (Labolight II, GC Corp, Tokyo, Japan) with light intensity of 300 mW/cm^2); MCF were also light-activated the same as CPC. The bar-shaped specimen was removed from the mold and stored in 37ºC distilled water for 24 hours. The flexural strength and flexural modulus were determined using a universal test machine (1123, Instron, Canton, MA, USA) with a support span of 20 mm and a cross head speed of 1.0 mm/min. Five specimens of each composite were measured. All procedures except for specimen storage condition were performed at (23±2)ºC room temperature.

Canal preparation

The protocol of this study was approved by the ethic committee of Chulalongkorn University (No.12/2010). Thirty-two human mandibular premolars of similar size with a closed apex extracted for orthodontic reasons were selected. All teeth were cleaned with an ultrasonic scaler and stored in 0.9% normal saline solution prior to testing. Teeth were decoronated perpendicular to the root axis at the cementoenamel junction (CEJ) to create a standardized length of 15 mm, using a low-speed diamond saw (Isomet 1000, Buehler Co., Lake Bluff, IL, USA). The root canal of each tooth was instrumented with a conventional step back technique up to an

International Standardization Organization (ISO) #40 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) at the apical constriction. The canal was irrigated with 2.5% sodium hypochlorite solution, and dried with paper points. Each canal was obturated with gutta-percha points (Dentsply-Asia, Wong Chuk Hang, Hong Kong) and modified Grossman's formula root canal cement (C.U. dental product, Bangkok, Thailand) by lateral condensation. Gutta-percha was then removed using a D.T. Light-Post drill #1 (RTD, St. Egréve, France) to a depth of 10.5 mm from the CEJ. The canal space of each root was further shaped using a flat ended taper diamond bur No. 524 (Edenta AG, St. Gallen, Switzerland) to a depth of 7.5 mm, resulting in 1 mm of remaining dentin thickness (Figure 1), and leaving 3 mm apical of the post space for post seating (Figure 2). Radiographic examination was used to confirm the thickness in mesio-distal and bucco-lingual directions (Figure 3). The teeth were randomly divided into 4 groups according to the modulus of elasticity of the core build-up materials tested (Table 1).

Table I Core materials used in this study

Brand name	Code	Manufacturers and batch no.	Curing Mode
Clearfil Photocore	CPC	Kuraray, Okayama, Japan Lot#2325AB	Light-activated
Multicore Flow	MCF	Ivoclar Vivadent, Schaan, Liechtenstein, Lot#22322	Dual-cured
Built-it	BLI	Pentron, Wallingford, CT, USA, Lot#185632	Dual-cured
Coreflo	CRF	Bisco, Schaumburg, IL, USA, Lot#0900010766, 0900010767	Chemical-cured

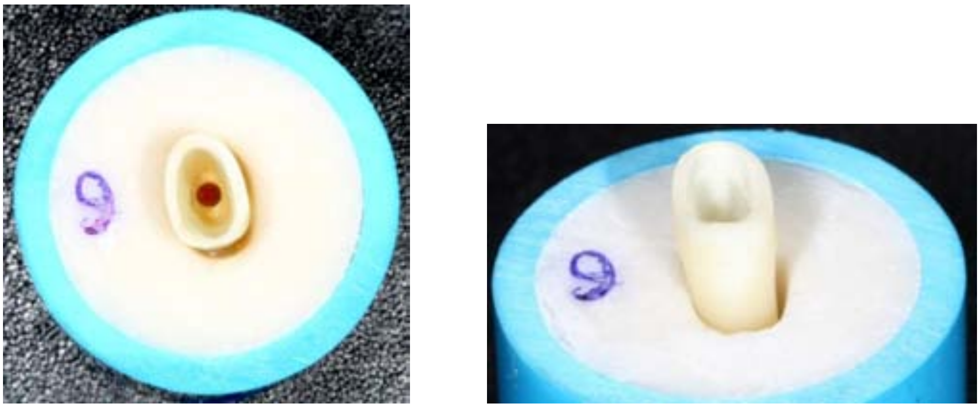


Fig. 1 Specimen preparation

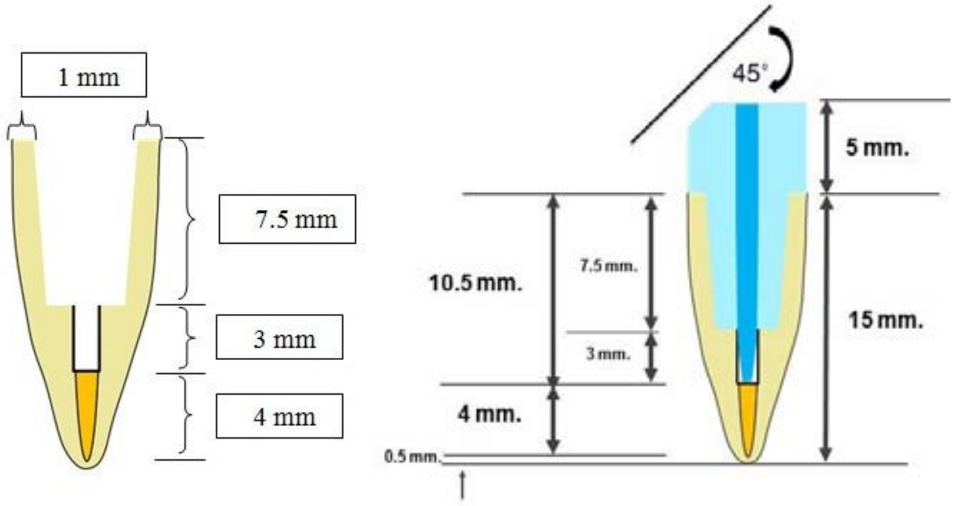
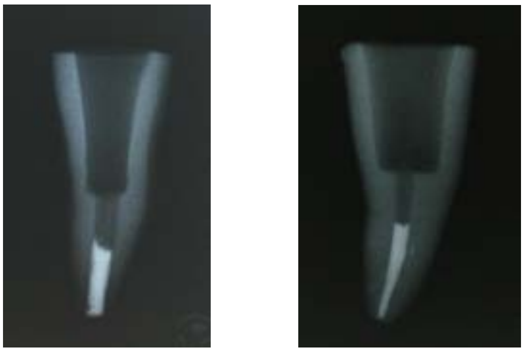


Fig. 2 Schematic illustration of canal preparation and post/core restoration



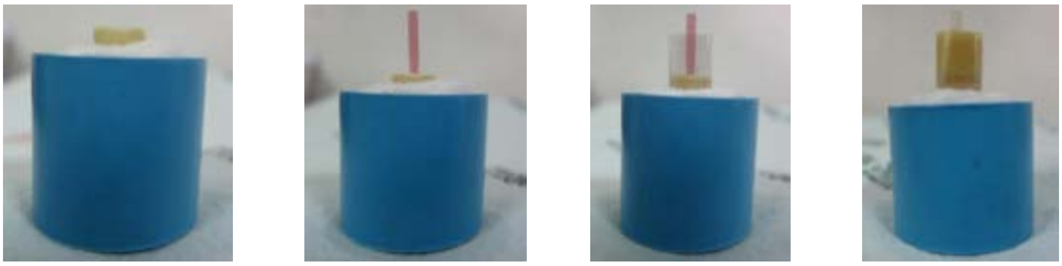
(a) **(b)**

Fig. 3 Radiographic examination of the specimen in mesio-distal (a) and bucco-lingual directions (b)

Post and core restoration

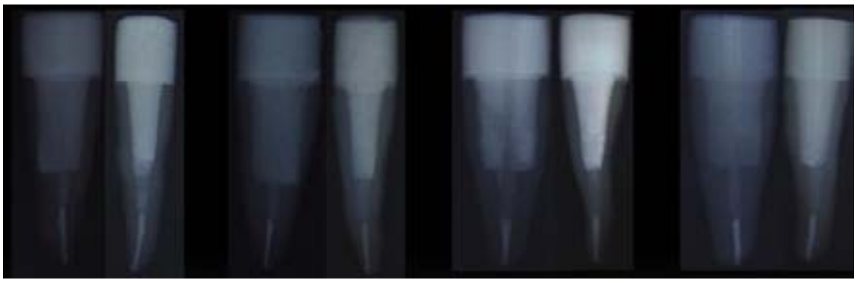
Four core built-up materials selected in the present study, their elastic moduli, and polymerization modes are listed in Table 1. The elastic modulus of core build-up materials ranged from 9.06 to 19.25 GPa. The teeth were randomly divided into 4 groups according to the core built-up materials tested (Table 1). A resin-based cement (Super-Bond C&B, Sun Medical, Shiga, Japan) and a FRC post (D.T. light post #1, RTD, St. Egréve, France) were used. The size of the post was 1.5 mm in diameter at the top, 0.9 mm in diameter at the end of post, and 20 mm in length. The root canal and cervical dentin were conditioned with a conditioner (Green activator, Sun Medical) for 10 seconds followed by rinsing with water for 10 seconds, air blown and blotted dry. The resin-based cement was bulk mixed following manufacturer's instructions using a cooling device (Mixing station, Sun Medical), and applied to both the canal wall and the post, then the post was seated in the post space.

Regarding the light-activated built-up core composite resin (CPC), the composite resin was placed into the canal with incremental filling technique using the celluloid core matrix. CPC was light-activated for 40 seconds using a light curing unit (Elipar Trilight, 3M ESPE, Seefeld, Germany; Maximum intensity: 800 mW/cm^2), and incrementally filled up to approximately 6 mm above the coronal surface of the root. Regarding dual-cured built-up core composite resins (MCF, BLI), the composite resins were auto-mixed with the supplied automixing syringe and tip. They were directly injected into the dowel space up to approximately 6 mm above the coronal surface of the root. Then light-activation was performed for 40 seconds from buccal and lingual sides and on the top of each specimen using the same light curing unit with the same intensity. Regarding the chemical-cured core built-up composite resin (CRF), base and catalyst pastes of CRF were hand-mixed, and injected into the canal space using a syringe delivery system (Unit-dose syringe, Bisco, Schaumburg, IL, USA) up to approximately 6 mm above the coronal surface of the root (Figure 4). All procedures were performed at (25±2)°C room temperature.



(a) (b) (c) (d)

Fig 4. Core build-up procedure (a) acid etching and apply resin cement (b) fixed post (c,d) core build-up with resin composite



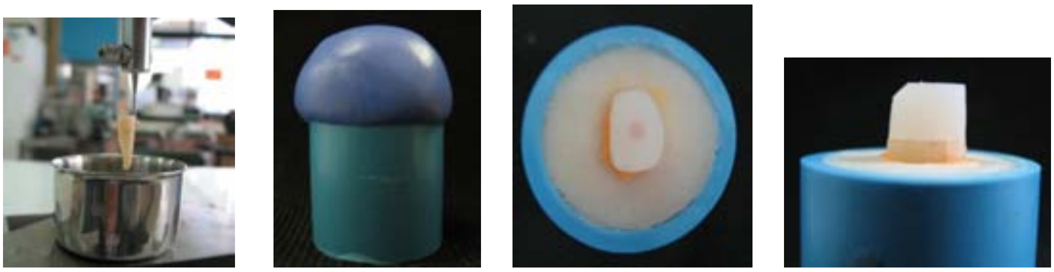
(a) (b) (c) (d)

Fig. 5 Radiographic examination in bucco-lingual and mesio-distal direction after post and core restoration (CPC;(a), MCF;(b), BLI;(c), CRF;(d))

After completion of the polymerization time suggested by the manufacturer's recommendation for each composite resin, the length of the post was adjusted and the axial wall of each specimen was prepared parallel to the root using a diamond bur (FG 837L, Intensive SA, Grancia, Switzerland), to achieve a height of 5 mm (post and core) above the coronal surface of the root. A forty-five degree bevel was established on the buccal cusp to create the plane for loading (Figure 1). All specimens were stored at 37˚C, 100 % humidity for 24 hours prior to test.

Preparation acrylic resin blocks

Each specimen was fixed on a surveyor with vertically moving rods to ensure that the tooth was perpendicular to the horizontal plane. Root surface of specimens was dipped into melt pink baseplate wax (Modelling wax, Dentsply, Trubyte, Surrey, UK.) to a depth 2mm below buccal CEJ to produce a 0.2 mm. layer approximately to serve as the artificial periodontal ligament. PVC blocks (length and diameter: 22 mm,20 mm, respectively) were filled with an self-cured acrylic resin (Formatray, Kerr Manufacturing, Romulus, CA) and the specimens were embeded using the surveyor to the level of pink baseplate wax. The teeth were removed from the resin block when the first sign of polymerization was observed. After polymerization complete, silicone index was prepared using polyvinyl siloxane: putty type)Reprosil, Dentsply, Caulk, Milford) to correct by position when reinserted the teeth into test blocks. To create artificial periodontal ligament, the wax spacer was removed from the root surface and the socket in resin blocks. Thin layer of polyvinyl siloxane: light body type was applied around root surface. The teeth were then reinserted into resin blocks in the same position, by using silicone index, and the impression material was allowed to set (Figure 6). Excess silicone materials were removed with scapel blade. All specimens were stored in plastic boxes at 37˚C, 100% humidity, for 24 hours to prevent dehydration of specimens and allowed for cement setting similar to oral environment prior testing.



(a) (b) (c) (d)

Fig. 6 Preparation acrylic block and artificial PDL (a) specimen was dipped into melt pink baseplate wax (b) silicone index was prepared by polyvinyl siloxane: putty type (c) yhin layer of polyvinyl siloxane: light body type was applied around root surface (d) sxcess silicone materials were removed

Fracture resistance testing

The specimen was loaded at 45˚ to the beveled plane of the buccal cusp using a universal testing machine (8872; Instron Co., Canton, MA, USA) with a crosshead speed of 2 mm/min until fracture (Figure 7). The maximum fracture resistance was recorded in Newton (N) and fracture modes of each specimen was examined by using stereomicroscope (ML9300, MEIJI, Tokyo, Japan) at X30 magnification. The fracture modes were classified as repairable failure; core debonding, core fracture, cervical fracture less than 2 mm below the CEJ of the root or non-repairable failure; fracture more than 2 mm below the CEJ of the root, oblique or vertical root fracture.

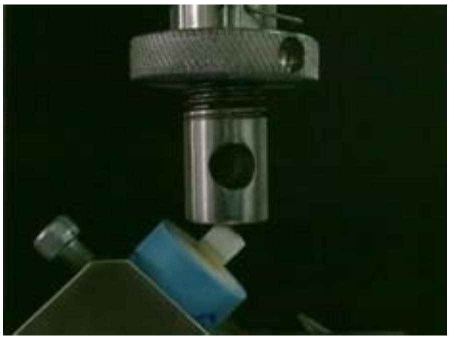


Fig. 7 Fracture resistance testing

SEM observation

Representative fracture surfaces of the specimen were evaluated by scanning electron microscopy (SEM). Each specimen was mounted on an aluminum stub, sputter coated with gold and evaluated at X75 and X350 magnification using a scanning electron microscope (SEM) (JSM-5410LV, JEOL, Tokyo, Japan) at an acceleration voltage of 15 kV.

Statistical analysis

Fracture loads were analyzed by using statistical analysis software (SPSS 16.0, SPSS Inc, Chicago, IL, USA). Descriptive statistic demonstrated means, standard deviation (SD), maximum and minimum of fracture resistance in each specimen group

1. Mean of fracture resistance were analyzed statistically in all groups. Normal distribution of all data was confirmed with Kolmogorov-Siminov test and test of homogeneity of varience was detected with Levene’s test.
    - one-way analysis of varience (1-ways ANOVA) ($\alpha=0.05$) and Tukey tests for post-hoc pairwise multiple comparision with a significance level of ($\alpha=0.05$) were used

CHAPTER IV

RESULTS

Flexural strength and modulus

Flexural strength, flexural modulus of the tested core build-up resin composite are shown in Table 2.

Table 2 Results of flexural strength and modulus

Code	Flexural strength MPa (SD)	Flexural modulus GPa (SD)
CPC	143.9 (7.4)	19.25 (1.62)
MCF	123.8 (9.1)	9.49 (0.53)
BLI	131.2 (10.2)	9.06 (0.88)
CRF	106.9 (15.1)	9.60 (0.77)

Fracture resistance

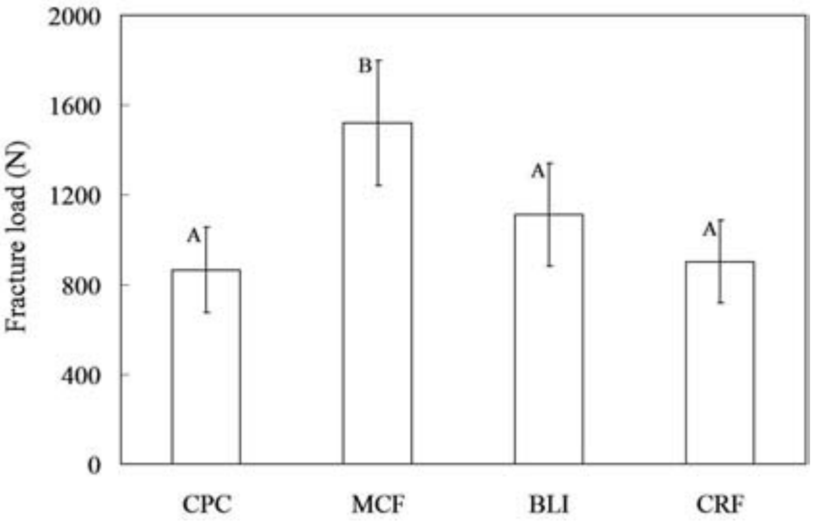
The mean failure load and standard deviation for the 4 groups are demonstrated in Table 3. All data of each group had normal distribution and homogeneous varience with Kolmogorov-Siminov test and Levene's test, respectively. MCF demonstrated the highest fracture resistances at 1519.17 N, followed by BLI, CRF and CPC at 1110.85 N, 901.63 N and 864.69 N, respectively (Figure 8). One-way ANOVA showed significant differences among groups at $p<0.001$. Tukey HSD multiple comparisons revealed MCF was significantly higher in fracture resistance than the others ($p<0.05$).

Table 3 Mean failure load and standard deviation for the 4 groups

Experimental groups	Mean±SD (N)
1. Clearfil Photocore (CPC)	864.69±189.8 ^{a}
2. Multicore Flow (MCF)	1519.17±278.9 ^{b}
3. Built-it (BLI)	1110.85±229.8 ^{a}
4. Coreflo (CRF)	901.63±183.6 ^{a}

Different in superscript letters indicate statistical differences ($p<0.05$).

Figure. 8 Mean failure loads (N) for each group.



*Same letters indicate no significant differences at $p<.05$ using Tukey HSD

Fracture modes

Fracture modes are summarized in Table 4. Regarding CPC and BLI, almost fracture mode of each specimen was the debonding at the buccal interface between resin composite and cervical dentin in combination with vertical lingual root fracture apical to the reference line. Only crack lines were observed without separation of core built-up from the lingual root surface. Therefore the fracture mode of CPC and BLI were classified as 100% and 75% non-restorable failure, respectively. Regarding MCF and CRF, the fracture mode was horizontal fracture within core built-up material at cervical region or cervical root fracture coronal to the reference line. (Figure 9) The specimens of these two groups were split into two parts. The highest number of restorable failure (62.5%) was observed in the MCF and followed by group CRF (50%).

Table 4 Frequency of fracture mode after fracture resistance testing

(N= 8/group).

Mode of failures	Number of teeth			
	CPC	MCF	BLI	CRF
Restorable	0	5	2	4
Non-restorable	8	3	6	4
Total	8	8	8	8

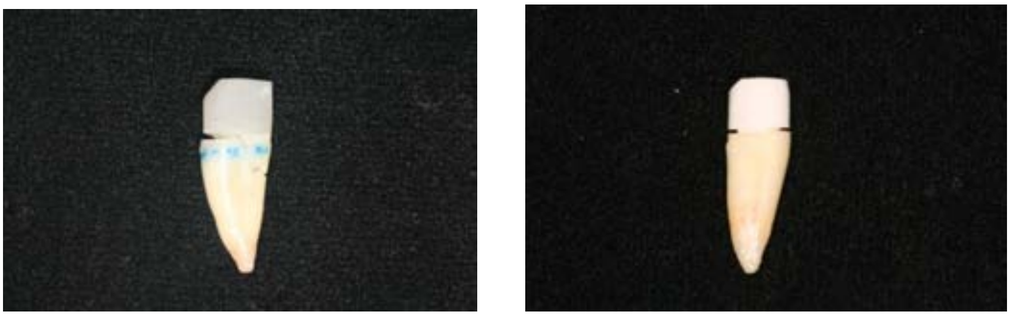


Fig. 9 Fracture mode of specimen which was non-repairable and repairable

SEM observations

Fracture surfaces of only MCF and CRF were observed with SEM, because CPC and BLI did not show separation of fracture parts. Typical fracture patterns are demonstrated in Figure 10. Numerious voids within the composite resin were observed in the SEM image of CRF, whereas a few small voids were observed in that of MCF.

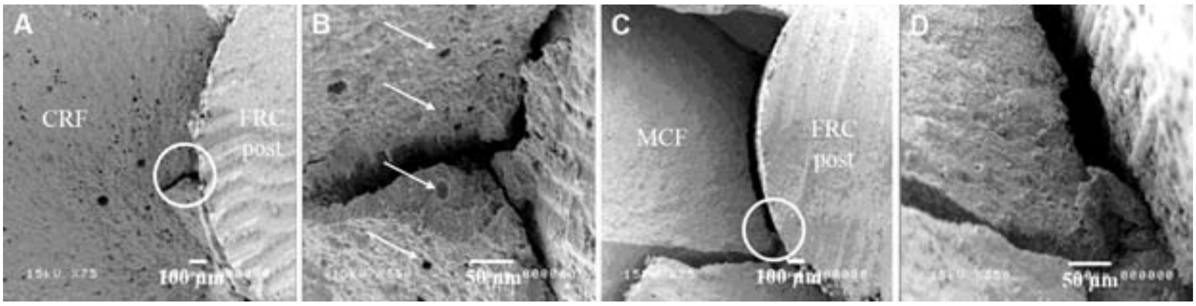


Fig. 10 SEM images of the fracture surface of CRF (A) and MCF (C). (the original magnification was 75). The area with circular labeled at the higher magnification view demonstrated numerous voids (white arrows) in fracture surface of CRF (B), whereas no void presented in MCF (D) .(X350)

CHAPTER V

DISCUSSION

Material and method

This experimental study used the natural teeth that presented some problems due to the anatomic variations and the heterogenous nature of tooth matter. However, the use of natural teeth has been considered acceptable by previous studies (1, 10, 126). In this present study, a lower human mandibular premolar was used because it presented with the single, straight and large root canal. It has a small variation and the major reason for extraction is orthodontic treatment, therefore it did not have any defect, such as caries or filling.

The endodontic procedure used in this study was using lateral condensation technique with zinc oxide eugenol cement (ZOE). The lateral condensation technique has been proposed to produce the stress within the root (127) however, this is a common procedure in endodontic treatment and this technique is not complicate. The effect of zinc oxide eugenol cement is not concern because the previous studies suggested that ZOE showed no statistically significant difference on the retention of fiber posts and root canal walls when using a resin cement (128). Although eugenol-containing sealer was chosen because of its common use, the posts were cemented 24 hours after root canal obturation. After 24 hours, no adverse effect on resin materials was shown by eugenol-containing sealer (129).

In the simulated flared root canal walls procedure, the thickness of root canal walls in all specimens may be vary due to the root morphology variation. However, the radiographic examination was used to evaluate the thickness of root canal walls in order to create the similar thickness in all specimens. This study could not mimic the moisture and the temperature conditions as in oral cavity. However, all procedures were done under moisture condition such as, covering the specimens by gauze with water and stored in plastic boxes at 37˚C, 100% humidity, for 24 hours to prevent dehydration.

In the case of severely damage root canal walls, it is necessary to evaluate the extent of root weakness prior to the treatment, by taking into account of the success in the restorative treatment. If the root lost a large amount of radicular dentin, the extraction might be a good alternative treatment. Some authors concluded that the degree of weakness of root structure had the effect on the treatment success in ETT (126, 130, 131). Recommendations for the adequate amount of the remaining radicular dentin in the root vary among literatures (5, 6, 41, 132). However, the preservation of 1-mm of canal wall thickness was recommended as the appropriate amount for reconstruction the root structures (6, 132). Therefore, 1-mm residual dentin thickness without the ferrule preparation was used in the present study to simulate a structurally weakened root. The placement of full crown with ferrule preparation would change the pattern of stress distribution around the tooth (4), however, the direct apply load on the core built-up composite resin was selected to easily observe the difference.

Result

This study was designed to compare the fracture resistance of endodontically treated mandibular premolars with flared root canals. The results showed that the different types of core built-up composite resin affected fracture load. Therefore, the null hypothesis was rejected.

The elastic modulus of core built-up composite resins affected the result of this study. CPC which has the highest modulus of elasticity in this study, demonstrated the lowest fracture load with high percentage of non-repairable fracture even though its modulus of elasticity was close to that of dentin. The high modulus of elasticity material creates higher stress compare to the low modulus one (133). When a load was applied to a structure composed of dissimilar materials; thin canal wall and CPC, the higher modulus in this material deforms less and produces areas of stress concentration at the tooth and restorative material interface (9, 13). The rigidity of this material also restricted the tooth displacement (11), resulting in stress concentration in the remaining dentin and bonding interface. Therefore, the premature failure was hypothesized to occur at the canal wall which had the lower strength. CPC which is a light cured resin material, the degree of polymerization was depended on the depth of cavity and the light transmitting property (134). At the deep level of the root canal, light intensity may be insufficient to induce proper polymerization in this material. Thus, the strength of core build-up material decreased. Moreover, the incremental filling is advised (135) for optimal polymerization. This procedure may create voids and un-polymerized areas between the incremental layers that interferes the stress distribution in material.

On the contrary, MCF, which its modulus of elasticity is less than half of dentin, demonstrated the highest mean fracture resistance with a relatively high percentage of repairable fracture. A low modulus of elasticity material allows greater bending under load (133). Therefore, synchronize bending of the heterogeneous structure; thin canal wall and MCF can occur. This creates homogeneous stress distribution within the root. Moreover, the damping effect of the low modulus of elasticity material may play a role in this situation. The damping material acts as a shock absorber minimizing the strain from the external impaction (136, 137). In this study, the low modulus of elasticity material; MCF which is more viscoelastic, can better dissipate the strain energy. This results in the reduction of the concentrated stress within the structure. Therefore, it is suggested that the low modulus of elasticity material contributes to the stress-reduction effect.

MCF, BLI and CRF showed a significant difference in the fracture resistance despite their similar in modulus of elasticity. The differences in mode of polymerization may affect the mechanical properties of material (138, 139). In CRF, it was self manipulate material, the manipulation characteristics were considered to influence the bond strength of core build-up materials to tooth structure (19). This may alter the stress transferring in material structure. SEM images demonstrated that numerous voids were presented in CRF, whereas no voids were observed in self mixing material (MCF) (Figure 9). These voids might have occurred as a result of air entrapment during manipulation which caused fractures at a lower load.

The cause of different between MCF and BLI may attribute to the differences in monomer composition and concentration of filler particles that play an important role in the mechanical properties of resin-based materials (140). According to the manufacturers' information, MCF presents 70 % wt of filler particles, while BLI present filler content of approximately 68.2% wt in their composition. Increasing filler particle concentration can improve hardness and depth of cure of light-cured composites(141). The differences in adhesion between core build-up materials and dentin structure also affect the result of this study (142). When compared the composition of these two core build-up material (MCF and BLI), BLI has a matrix of bisphenol A-glycidyl dimethacrylate (Bis-GMA), difunctional monomers (urethane dimethacrylate (UDMA) and 1,6-hexanediol dimethacrylate (HDDMA)). For MCF, it has a different matrix composition comprising Bis-GMA, UDMA, and triethyleneglycoldimethacrylate (TEGDMA). Mixing the low viscisity resins has been shown to increase conversion level (143). This may influence the mechanical properties of light-cured composites (144).

Fracture loads of flared root canal with a FRC post and composite resin in this study were ranges from 864.69 to 1519 N. When compared to the previous reports; 291.3 - 411.9 N (1, 10), 98.3 - 108.8 N (10), 172.5 to 176.5 kgf (2), 745.69 to 920.64 kgf (145), it was found the large variation in fracture resistance range among those studies. However, the different method and materials used, direct comparison of results is not possible.

The fracture resistance of all experimental groups in this study was higher than the previous studies (1, 12). This was because of the bonding property of selected luting cement used in this study. The bonding effectiveness of Super-Bond C&B was superior in adhesion to the root canal dentin (146). The two-step etch and rinse technique in this material may promote greater bonding potential than a self etch cement when luting the FRC post to root canal dentin (147). Especially, the dentin conditioner;10% citric and 3% ferric chloride that is part of the Super Bond system which is the unique characteristics of this material. After the dentin was etched, the circumferentially oriented collagen fibers that line the dentinal tubules walls were completely exposed and the smear layer was removed (146). This then allow monomers to penetrate into the inter tubules dentin, to form the hybridized dentin and into the exposed tubules to form the hybridized tag. Super-Bond C&B provides a high bond strength to dentin is due to the formation of a dense resin infiltration dentin layer (also known as a hybrid layer) at the interface of resin and dentin (148). The long hybridized resin tag with inter tubular dentin in their lateral branches can encounter the stress caused by the polymerization shrinkage and contribute to enhancing the mechanical bonding strength (149).

In the previous study, fracture modes of flared root canal with a FRC post and composite resin were demonstrated in 100% restorable failure (10). As observed in this study, the fracture patterns were presented in restorable and non restorable fracture. This depends on the modulus of elasticity of the core built-up composite resin. In this study, the fracture pattern of the high modulus of elasticity material mostly occurred at the core margin and extended to infra-bony area in vertical or oblique direction along the root. This was caused by uneven stress concentration at the bonding surface between thin root canal dentin and thick layer of core material. This observation supported the study of Fukui et al (12). It was also suggested that a large polymerization contraction stress of the resin composite at the adhesive interface can affect the failure mode (133). Moreover, the damping properties of the higher rigidity core material might be concern. The high modulus core material can stop the oscillation quickly with rapid energy dissipation (137). The almost energy was rapidly dissipated to the thin root canal wall. Accompany with the lower strength of thin root canal wall, the stress distribution at the bonding interface might obscured (4, 126). Therefore, the peak of fracture load was suddenly increased, resulting in the demonstration of fracture lines at the severe position. For the low modulus groups, the fracture pattern was core material fracture or cervical root fracture at supra-bony level. The fracture line was not extended apically. This is due to the low modulus core material created the slow energy transferring rate to thin root canal wall. The concentrated stress was uniformly distributed around tooth structure. Fracture lines were demonstrated in the weakest point in core material structure or the interface between the core material and the root. Interestingly, in BLI group, the fracture mode demonstrated in non restorable more than 50% of almost specimens. This occurring could be explained by the different in bonding property between BLI and MCF with dentin wall. The good bonding property of MCF can create the stress transferring along tooth structure that promotes the restorable fracture in this situation. Therefore, it could be suggested that a low modulus of elasticity core material created the stress concentration in coronal region.

In this weakened structural condition as in this study, using high modulus of elasticity core build-up materials could not shift the stress coronally as stated by Yaman et al (20). In that study, the experimental models were not simulated the loss of root canal dentin, which may have contributed to reduce fracture strength of the specimens. The fracture mode of the specimens in this study may not mimic the clinical condition which usually presented with cuspal coverage indirect restoration. The placement of a crown or onlay on the specimen might affect both fracture resistance and mode of failure (150-152). Providing a crown with adequate ferrule has more influence on the fracture resistance of ETT than factor related to post and core materials and design (21, 28). With optimal strength of core foundation can ensure the high fracture resistance of ETT. Therefore, placing crown over high fracture resistance of ETT might reassure a much higher resistance of ETT.

This in vitro study has limitations as the tests were carried out in single root teeth, with specific dimensions and post preparation, under static compressive loading in one direction. The test conditions of this study differed from intraoral condition, it is therefore difficult to extrapolate the results directly to the clinical condition. Thus, further studies on repeated loading are suggested.

CHAPTER VI

CONCLUSIONS

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

1. The fracture resistances of simulated flared canals mandibular premolars restored with D.T. Light post and reinforced with resin core materials were affected by different types of core material.
2. Multicore Flow, exhibited higher fracture resistance ($p<0.01$) than the core materials with a higher modulus of elasticity.

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APPENDIX

APPENDIX

Contents **Pages**

Statistical analysis

STATISTIC ANALYSIS OF FRACTURE RESISTANCE

One-Sample Kolmogorov-Smirnov Test

		force
N		32
Normal Parameters(a,b)	Mean	1099.0859
	Std. Deviation	339.18906
Most Extreme Differences	Absolute	.080
	Positive	.080
	Negative	-.060
Kolmogorov-Smirnov Z		.452
Asymp. Sig. (2-tailed)		.987

a Test distribution is Normal.

b Calculated from data.

Descriptives

Fracture resistance

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

Test of Homogeneity of Variances

Fracture resistance (N)

Levene Statistic	df1	df2	Sig.
2.752	3	28	.061

ANOVA

Fracture resistance (N)

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

Post Hoc test

Multiple Comparisons

Fracture resistance (N)
Tukey HSD

(I) Tpye of material	(J) Type of material	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
CPC	MCF	-654.48375	111.89115	.000	-959.9815	-348.9860
	BLI	-654.48375	111.89115	.148	-551.6540	59.3415
	CRF	-36.94375	111.89115	.987	-342.4415	268.5540
MCF	CPC	654.48375	111.89115	.000	348.9860	959.9815
	BLI	408.32750	111.89115	.006	102.8298	-959.9815
	CRF	617.54000	111.89115	.000	312.0423	923.0377
BLI	CPC	246.15625	111.89115	.148	-59.3415	551.6540
	MCF	-408.32750	111.89115	.006	-713.8252	-102.8298
	CRF	209.21250	111.89115	.264	-96.2852	514.7102
CRF	CPC	36.94375	111.89115	.987	-268.5540	342.4415
	MCF	-617.54000	111.89115	.000	-923.0377	-312.0423
	BLI	-209.21250	111.89115	.264	-514.7102	96.2852

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

Fracture resistance

Tukey HSD

GROUP	N	Subset for alpha = .05	
		1	2
CRF	8	668.4712	
BLI	8	811.6725	
MCF	8		1339.4238
CPC	8		1474.6663
Sig.		.461	.510

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 8.000.

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