ผลของชนิดของเดือยและซีเมนต์ต่อความต้านทานการแตกของรากฟันตามแนวแกนในฟันที่รักษาคลองรากฟันแล้ว

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THE EFFECT OF POST AND CEMENT TYPES ON VERTICAL ROOT FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH

Miss Chalermkwan Chantarat

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Endodontology

Department of Operative Dentistry

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การทดลองนี้มีวัตถุประสงค์ที่จะมุ่งศึกษาผลของชนิดของเดือย และซีเมนต์ที่มีต่อความต้านทานการแตกของรากฟันตามแนวแกนในฟันแท้ที่ได้รับการรักษาคลองรากฟันและทำการบูรณะด้วยวิธีต่างๆ 6 วิธี ชนิดของซีเมนต์ที่เลือกใช้มี 2 ชนิดได้แก่ ซิงค์ฟอสเฟตซีเมนต์และเรซินซีเมนต์ ชนิดของเดือยที่ใช้มี 3 ชนิดได้แก่ เดือยที่ทำจากโลหะหล่อไม่มีตระกูล เดือยที่ทำจากโลหะไร้สนิม และเดือยเส้นใยคาร์บอน ผลการศึกษาพบว่ารากฟันในทุกกลุ่มเกิดการแตกในแนวแกน ยกเว้นกลุ่มที่รากฟันบูรณะด้วยเดือยโลหะหล่อ ส่วนค่าความต้านทานในการแตกหักในแนวแกนของกลุ่มที่เหลือ พบว่ารากฟันที่บูรณะด้วยเดือยเส้นใยคาร์บอนและยึดด้วย เรซินซีเมนต์ได้ค่าความต้านทานการแตกหักสูงที่สุด (3,517.30 ± 354.34 นิวตัน) รองลงมาได้แก่กลุ่มที่บูรณะด้วยเดือยที่ทำจากโลหะไร้สนิมที่ยึดด้วยเรซินซีเมนต์ (3,368.90 ± 236.91 นิวตัน) และกลุ่มเดือยเส้นใยคาร์บอนที่ยึดด้วยซิงค์ฟอสเฟตซีเมนต์ (2,830.90 ± 236.91 นิวตัน) ตามลำดับ ในขณะที่กลุ่มที่ได้ค่าความต้านทานในการแตกหักตามแนวแกนต่ำที่สุดได้แก่กลุ่มที่บูรณะด้วยเดือยโลหะไร้สนิมยึดด้วยซิงค์ฟอสเฟตซีเมนต์ (2,549.60 ± 356.19 นิวตัน) ผลการวิเคราะห์ทางสถิติโดยการใช้การวิเคราะห์ความแปรปรวนสองทาง ที่ระดับนัยสำคัญ 95% พบว่า ชนิดของซีเมนต์มีผลต่อค่าความต้านทานการแตกหักในแนวแกน ในขณะที่ชนิดของเดือยไม่มีผล นอกจากนี้ยังไม่พบว่ามีอิทธิพลร่วมระหว่างชนิดของเดือยร่วมกับซีเมนต์ที่มีต่อความต้านทานการแตกอีกด้วย ทิศทางของการแตกเกิดขึ้นในแนวด้าน ริมฝีปาก-ด้านลิ้นมากกว่าในแนวใกล้กลาง-ไกลกลาง และยังไม่พบว่ามีรอยแตกใดขยายลงไปเกินกว่าระดับของเดือยที่ใส่ลงในคลองรากฟัน นอกจากนี้ผลการทดลองในส่วนที่สังเกตภายใต้กล้องจุลทรรศน์ อิเลคตรอนชนิดส่องกราด ไม่พบว่ามีซีเมนต์สำหรับอุดคลองรากฟันหรือซีเมนต์ที่ใช้ยึดเดือยซึมเข้าไปในรอยแตกของรากฟัน

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KEYWORDS : VERTICAL ROOT FRACTUYRE / ENDODONTICALLY TREATED TEETH / CEMENT / POST

CHALERMKWAN CHANTARAT : THE EFFECT OF POST AND CEMENT TYPES ON VERTICAL ROOT FRACTURE RESISTANCE IN ENDODONTICALLY TREATED TEETH. (ผลของชนิดของเดือยและซีเมนต์ต่อความต้านทานการแตกของรากฟันตามแนวแกนในฟันที่รักษาคลองรากฟันแล้ว) THESIS ADVISOR : ASSISTANT PROFESSOR DOCTOR VEERA LERTCHIRAKARN, 56 pp., ISBN 974-17-3483-2

This *in vitro* study evaluated the vertical fracture resistance of human extracted maxillary central incisors in six experiment groups. Two different types of luting cement (resin and zinc phosphate cement) and three different post materials (stainless steel, carbon fiber, and casted non-precious metal post) were used. The load was applied vertically at the cross-head speed 0.5 mm/min. All groups showed vertical root fracture except root that restored with cast post and core. Carbon fiber post cemented with resin cement showed the highest mean vertical fracture load at 3,517.30 ± 354.34 N, followed by stainless steel post cemented with resin cement, 3,368.90 ± 236.91 N, and carbon fiber post cemented with zinc phophate cement, 2,830.90 ± 236.91 N, respectively. Stainless steel post cemented with zinc phosphate cement provided the lowest mean vertical fracture load (2,549.60 ± 356.19 N). Statistic analysis by 2-way ANOVA ($P \leq 0.05$) showed that types of cement have an influence on vertical root fracture load. On the other hands, types of post showed no effect on vertical fracture load. There is also no interaction of post types and cement types on vertical fracture load. The majority of vertical root fracture patterns occurred in labio-lingual direction. The fracture line did not extend further than level of the post tip. Furthermore, there was no root canal cement or luting cement extruded into the fracture surface in every group of samples.

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CHAPTER I

INTRODUCTION

Background and rationale

Endodontically treated teeth were claimed that they were weakened and more prone to fracture because of the desiccation or premature loss of fluids supplied by vital pulps (Helfer, Melnick and Schilder, 1972). In contrast, Papa, Cain and Messer (1994) showed that there was no significant difference in moisture content between endodontically treated and vital teeth. Moreover, a study by Fusayama and Maeda (1969) demonstrated that there were no changes in the modulus of elasticity, hardness, or fracture toughness of pulpless teeth. Even though endodontic procedures may not affect the mechanical properties of dentin such as dentin hardness, endodontically treated teeth always present numerous problems because of coronal destruction from dental caries, fractures or previous restorations. In addition, loss of dentin during root canal treatment or during post space preparation increased susceptibility to fracture of these teeth (Sedgley and Messer, 1992; Fuss *et al.*, 2001). Therefore, post and core was recommended for restoration of endodontically treated teeth with extensive loss of tooth structure (Rosensteil, Land and Fujimoto, 1995). For the longevity of the endodontically treated teeth, the restorations should be proper planning.

Vertical root fracture is one of the failures that occur in endodontically treated teeth. Diagnosis is often difficult because signs, symptoms and radiographic features intimate true endodontic failure and periodontal disease. The prevalence of vertical root fracture in endodontically treated teeth ranges from 2-5%. (Testori, Badino and Castagnola, 1993; Torbojorner, Karlsson and Odman, 1995). Testori *et al.* (1993) reported that premolar teeth showed the highest incidence of vertical root fracture in endodontically treated teeth. Moreover, there was a report that the incidence of fracture in endodontically treated incisor increased up to 14% in comparison with 0.9% in nonendodontically treated incisor (Chan *et al*., 1999). The mean age in both male and female patients for vertical root fractures in endodontically treated teeth was lower than that for vertical root fractures in nonendodontically treated teeth in every tooth position (Chan *et al*., 1999).

Recently, the mechanical properties of post , luting agent and core material have been greatly improved in an attempt to prevent root fracture in endodontically treated teeth. The carbon fiber reinforced epoxy resin post, which the manufacturer claims that the elastic modulus of this post type is the same value as dentin. This property is claimed that it can distribute an applied forces along the root dentin with less stress accumulation.

In experimental studies, an oblique angulation of the applied force was frequently used, because it was assumed to be an estimate angle of occlusion. However, in those experiments, samples usually fractured horizontally, while some failures occurred at the core materials before root fracture was occurred. (McDonald, King and Setchell, 1990; Cohen *et al*., 1996; Dean, Jeansonne and Sarkar, 1998; Matinez-Insula *et al*., 1998). The factors that effected the patterns of root fracture are not only the load direction but also the furrule preparation (Sorensen and Engelman, 1990). Al-Hazaimeh and Gutteridge (2001) and Barkordar, Radke and Abbasi (1989) found that the fracture occurred in mid-root at the level of the end of the post with the furrule preparation. In contrast, the fracture line was vertical and extended to involve the root surface in the restored root without furrule preparation. Clinically, some teeth are impossible to prepare for restoration with furrule preparation which these teeth also susceptible to vertical root fracture. Therefore, the aims of this study are to compare load at fracture of vertical root fracture of endodontically treated teeth that restored with different post and core and luting cement types without furrule preparation and to investigate pattern and characteristic of root fractures. The results of this study should provide the preliminary data for the restorative consideration that can decrease failure from vertical root fracture of endodontically treated tooth, especially in non-furrule preparation.

Objective

1. To compare the load at vertical root fracture of endodontically treated teeth, restored with different posts and core materials and luting cements, without furrule when static load is applied.

2. To examine the relationship between root dentin thickness and fracture pattern.

Limitations

1. Root in this study will be carefully selected for standardized size and quality, nevertheless there are still a small variation in size and shape of the teeth. The random sampling could reduce this type of error.

2. A static loaded test is used in this study, because it can provide the comparable fracture resistance among experimental groups. However, a dynamic or cyclic loaded test is suggest to be more closely to the human pattern of mastication.

3. A sample size of this study is small, comparing to sample size that is statically calculated, because of limitation of our budget and a lack of valid samples.

Expected benefits

This study will provide the preliminary data for restorative consideration when the tooth structure has been excessive lost and impossible to prepare with ferrule preparation. The failure and loss of endodontically treated teeth due to vertical root fracture can be prevent with the restoration procedure from the results of this study.

CHAPTER II

LITERATURE REVIEW

Vertical root fracture is one of the serious clinical complications, and has been showed an increase in incidence in endodontically treated teeth (Chan *et al*., 1999). This literature review discusses a consideration of vertical root fracture as a clinical phenomenon and experimental study, restorative options for endodontically treated teeth and effect of furrule preparation. In addition, fracture resistance versus types of restoration is also included in this review.

1. Vertical root fracture

Walton (1999) classified teeth that fractured in longitudinal direction into 5 categories: (1) craze lines, (2) fractured cusps, (3) cracked tooth, (4) split tooth, and (5) vertical root fracture. Vertical root fracture is confined to the root that begins on the internal canal wall and extends outward to the root surface, usually facioligual direction. In contrast, craze lines, fractured cusps, cracked tooth, and split tooth originate at the crown or cervical margin of the root which may extend deeper into the root. Vertical root fracture presents in both endodontically and non-endodontically treated teeth. The incidence of vertical root fracture in endodontically treated teeth versus nonendodontically treated teeth was compared through a long-term survey of 13 years study and a large collection of 315 cases. The data demonstrated that 59% of vertical root fracture occurred in endodontically treated teeth. The mean age in patients with endodontically treated teeth was lower in every tooth position. Among untreated teeth, the molar were most often affected by vertical root fracture, whereas among the endodontically treated teeth, the maxillary premolars were most common (Chan *et al.*, 1999).

1.1 Clinical features of vertical root fracture

Clinical features of vertical root fracture are varies. They may mimic other entities such as periodontal disease or failed root canal treatment with asymptomatic or only mild pain. Tooth mobility is sometime detectable. Pain on pressure or mastication is common but mild. Periodontal-type abscess may either present at the time of examination or in the dental history (Walton, 1999).

Radiographs also show a variety of patterns. In the early stage, there are no significant changes. However, in the advance stage, bone resorptive patterns tend to be marked, extending from the apex along the lateral surface of the root and often include angular resorption at the cervical area. In only small percentage is there a visible separation. Only reliable diagnostic approach is flap reflection (Pitts and Natkin, 1983). Bony defects may present a form of dehiscence or fenestration at various root levels. After removal of granulation tissue, fracture line could be seen. Transillumination or staining with dyes are also helpful (Tamse *et al.*,1999).

Walton, Michelich and Smith (1984) studied and described a histologic feature of vertical root fracture that all fractures extended from the canal to at least one root surface. The fracture often extended only the partial length of the root, usually to the apex but not always to the cervical area. Many irritants were found in the fractured space and the adjacent canal. In addition, periodontal tissue adjacent to the fracture may present in chronic inflamed and occasionally connective tissue grew into the fracture toward the canal. This was often associated with resorption at the root surface.

1.2 Etiology of vertical root fracture

The factors leading to vertical root fracture in endodonticallly treated teeth are difficult to establish. However, many factors contributing to vertical root fracture have been suggested. Prior to endodontic therapy, the tooth may have an existed partial root fracture, which could not be seen. This fracture line might develop from either thermal tensile stress (Brown, Jacobs and Thompson, 1972) or temperature cycling (Lloyd, McGinley and Brown, 1978). Such cracks may be enlarged under many circumstances such as mastication force, excessive root canal preparation and the pressure of condensation of root canal fillings during endodontic therapy (Lommel *et al.*, 1978; Meister, Lommel and Gerstein, 1980), or the placement of metal restorations or posts (Bender and Freeland, 1983).

The recent study by Lertchirakarn, Palamara and Messer in 2003 demonstrated that root canal curvature, external root morphology and dentin thickness were the factors that amplify stress concentration in the root canal wall. Excessive root canal instrumentation may increase weakness and the incidence of vertical root fracture (Bender and Freedland, 1983). That is in agreement with a study by Wilcox, Roskelley and Sutton (1997), who showed that the more root dentin was removed, the more likely the root was tend to fracture. Lateral condensation technique was also blamed as a predisposing factor of vertical root fracture (Onnick, Davis and Wayman, 1994). Lertchirakarn, Pramara and Messer (1999) showed that the mean maximum load exerted during obturation by hand spreader (2.0-2.5 kg) was almost double that encounter with the finger spreader (1.0-1.4 kg). Lindauer *et al*. (1989) also found that the incidence of vertical root fracture during obturation with the D11T spreader was higher than with the finger spreader.

Restorative procedures, especially post and core restoration, suggested to be one of a contributing factors of endodontic failure (Vire, 1991). Interestingly, Tamse (1988) found that as much as 31% of root fractures caused by seating and cementation of intra-radicular post. In addition, cementation of post created significant greater strain measurements on roots than lateral condensation (Obermayr *et al*., 1991). This result indicated that stress from cementation of posts was more likely to cause deformation of roots. However, the accumulation of strain from this study did not significantly increase the incidence of vertical root fracture.

Moreover, some studies suggested that the lack of sufficient periodontal support, the presence of internal root resorption (Telli, Gulkan and Raab, 1999), and flat or thin root of smaller mesiodistal diameter made a tooth more susceptible to vertical root fracture (Chan *et al*., 1999; Lertchirakarn *et al.,* 2003).

2. Restoration of endodontically treated teeth

Restoration of the pulpless tooth is critical for successful endodontic treatment. In the study by Ray and Trope (1995) pointed out the clinical importance of coronal restorations in endodontically treated teeth. This data showed that teeth which categorized as good restoration resulted in significantly more absence of periapical inflammation cases than teeth which categorized as good quality of root filling. In addition, Vire (1991) collected 116 endodontically treated teeth that were extracted, and evaluated for cause of failure. As much as 59% were prosthetic failures. Thus, different clinical techniques must be used to reestablish form and function of these teeth. Restoration of endodontically treated teeth can be varied and was reviewed by Leevairoj (1997) as following:

(1) Access closure

"Access closure" with restorative material can be done in endodontically treated anterior teeth with conservative lingual access. In addition, the access opening can also be closed with directed gold foil in case that endodontic treatment is performed through an existing full coverage restoration.

(2) Cuspal coverage

"Cuspal coverage" is recommended especially for endodontically treated posterior teeth because it significantly improves the rate of clinical success in both premolars and molars. Types of cuspal coverage can be devided into

(2.1) Directed core built-up

In case that the remaining tooth structure is enough, both composite resin and amalgam can be used to restored pulpless teeth efficiently. However the complete occlusal coverage with gold is considerable to be the ideal restoration.

(2.2) Post and core built-up

When there is not enough sound tooth structure, post and core is needed to retain the final restoration in endodontically treated teeth. A post space is best prepared immediately after the gutta percha filling. Post and core system can be classified as

(2.2.1) Corono-radicular stabilizer

Many materials have been used as corono-radicular core such as amalgam, composite and bondable reinforcement fiber. Materials may or may not extended into root canal. If there is a normal 4-6 mm pulp chamber height, there is no need to extend the materials into the canal.

(2.2.2) Cast post and core

A cast dowel and core has long been advocated for the rehabilitation for endodontically treated teeth. A post is customized to fit the canal, and both post and core are cast as a single unit. The length of the post in the root below the level of bony support should be at least equal to the length of the tooth above the bony support. The post diameter should not exceed one third of the root diameter at any level. The custom cast dowel and core, which is followed the prepared canal shape, is usually more conservative of remaining tooth structure. However, complications such as loosening of dowel and core or fracture of the remaining root may sometimes occur.

(2.2.3) Prefabricated post and directed core built-up

Recently, new post systems are invented and available in the market. Prefabricated parallel-sided post and direct core built-up becomes more popular because it is more retentive and easy to use. Prefabricated parallel-sided metal posts can made up of several materials for example, platinum-gold palladium (PGP), nickel-chromium (Ni-Cr), chrobolt-chromium (Co-Cr) or stainless steel. These posts can divide into three groups; active, passive, and semi-active. Active post provides the most retention, however this post also create tremendous strain in the root . Passive post system such as ParaPost® is retained in root canal by using cement. Flexi-Post® is the sample of semi-active prefabricates post. This type of post is split shank threaded post which could eliminate insertion and cementation stresses. The split post also acts as a vent during cementation. Compared to the prefabricated parallel-sided post, tapered cast post exhibited a wedging effect and produced the highest shoulder stress concentration, while parallel-sided post generated stress at both the shoulder and the apical area. Even though mostly parallel-sided posts fitted to the root canal only in apical third and surrounded by large amounts of cement, there was no significant effect on failure loads.

(2.2.4) Modern post and core system

A rigid non-metallic composite "carbon fiber reinforced epoxy resin post" has been introduced in various configurations. Fiber-reinforced composite consisted of fiber material held together by a resinous matrix. The fiber may be arranged in various configurations such as unidirectional, braided and woven fiber (Freilich *et al*., 2000). Carbon fiber post is composed of unidirectional 8 μm carbon fibers that are embedded in a resin matrix (King and Setchell, 1990). The manufacturer claims that the elastic moduli of this post type is very close to those of natural dentin which the applied forces could be evenly distributed along the length of the post to root dentin. In addition, carbon fiber post is highly biocompatible and can be easily used when esthetics is concerned (Freilich *et al*., 2000). Carbon fiber post was also claimed by the manufacturer that it is compatible with 10 methacryloxy decyldihydrogenphosphate that is contained in Panavia21® dental adhesive. This can produce a chemical link between adhesive and post itself. In addition, the carbon fiber post is also easy to remove from the root canal by conventional rotary instrument in case that needs nonsurgical endodontic retreatment (Morgano and Brackett, 1999).

3. Post cementation

Not only post and core are involved in restorative procedure, but also dental cements take an important part in pulpless tooth reconstruction. An ideal luting agent should has a long working time, adheres well to both tooth structure and post-core materials, provides a good seal, has an adequate strength properties and has a low viscosity and solubility etc. (Rosenstiel *et al*., 1995).

Zinc phosphate cement has been used as a luting agent for a long time ,while resin luting agent just has been used since 1950s (Rosenstiel *et al*., 1995). Zinc phosphate cements provided good performance such as adequate strength and working time (Phillips, 1991). The physical properties of properly mixed zinc phosphate cement can resist masticatory stress especially in regions of long spans (Diaz-Arnold, Vargas and Harselton, 1999). This cement, however, does not chemically bond to any substrate and provides a seal by mechanical retention. This makes the taper, length, and surface area of the tooth preparation critical to its success (Phillips, 1991). Zinc phosphate cements show relatively low solubility in water. However, the solubility rate is appreciably greater in diluted organic acid such as lactic, acetic or citric acid (Phillips, 1991). Moreover, under compression, zinc phosphate cement undergoes brittle fracture without any measurable plastic deformation. It is suggest that weak brittle cement may be susceptible to microfracture, especially in marginal area (Li and White, 1999).

The early products of resin cement were not successful because of high polymerization shrinkage. Their properties were greatly improved in the past decade. Typical bonding is achieved with organophosphonates, HEMA (hydroxyyethyl methacrylate) or 4-META (4 methacrylethyl trimellitic anhydride) (Rosenstiel *et al*., 1995). The advantage of using the resin cement was reported in many studies (Mendoza *et al*., 1997; Fredriksson *et al*., 1998; Junge *et al*., 1998; Ferrari, Vichi and Garcia-Godoy, 2000; Glaser, 2001; Al-Hazameh and Gutteridge, 2001). Unlike other cements, resin cement is not soluble in oral fluid (Morgano and Brackett, 1999). In addition, the resin cement could bond to both enamel, dentin and some types of post materials and thereby achieve a stronger, more retentive restoration (Mojon *et al*., 1989). Adhesion to enamel occurs through the micromechanical interlocking of resin to the hydroxyapatide crystals and rods of etched enamel (Buonocore, 1955). Adhesion of resin to dentin is more complex, involving penetration of hydrophilic monomers through a collagen layer overlying partially demineralized apatite of etched dentin (Diaz-Arnold *et al*., 1999). This is greatly useful when preparation for restoration lacks of proper retention. However, proper manipulation requires many steps and they are technically sensitive. O'Keefe, Miller and Powers (2000) showed that Panavia 21® provided the highest bond strengths of all types of post material (stainless steel, titanium, carbon reinforced fiber composite and zirconium oxide post material).

4. The core built-up material

Several materials have been used as a core built-up material such as amalgam, resin composite and glass ionomer cement.

(1) Amalgam

Amalgam can be used as a corono-radicular core alone or as a core material in conjunction with a cemented prefabricated post. The drawback of amalgam is that it requires at least 1 hour after placement to develop a maximum strength (Leinfelder, 1983). Amalgam is not bond to tooth structure, thus it needs retention from undercut, pin or slot. However, it has a good resistance to microleakage and is recommended when the crown preparation will not extend more than 1 mm beyond the foundation-tooth junction (Tjan and Chui, 1989).

(2) Glass ionomer cement

Glass ionomer cement exhibit the advantageous properties of coefficient of thermal expansion similar to natural tooth structure, a physicochemical bond to both enamel and dentin, biocompatibility, and the release of fluoride. However, this material has weak tensile strength and low fracture toughness (Ziebert and Dhuru, 1995). Moreover, glass ionomer core can easily separate from the post (Millstein and Nathanson, 1991) and sensitive to moisture. For these reasons, glass ionomer materials are probably unsuitable as a core material in a tooth with an excessive loss of tooth structure, abutment tooth of fixed or removable partial denture, and area that moisture can not be controlled (Dewald, Arcoria and Ferracane, 1990).

(3) Resin composite

Resin composite can be used with carbon fiber post and prefabricated parallel-sided metal post as a core material (Rosenstiel *et al.*, 1995). Resin composite has undergone significant development and improvement in physical characteristic and bond strength. Increased filler content, decreased filler size, and dual or chemical cure formulations contribute to resin composite's suitability for core fabrication (Wagnild and Mueller, 1998). Unlike other materials, resin composite material is directly bondable to tooth structure (Phillips, 1991). Acid etching of enamel has effectively provided a good mechanism for mechanical bonding between enamel and resin composite, while bonding between dentin and resin composite can be achieved by using dentin bonding agent (Phillips, 1991). Clinical success of using resin composite is dependent on the choice of appropriate resin material and on the proper manipulative technique. One of the problems in the prefabrication of resin composite cores is incorporation of voids. Incorporation of air rapidly reduces desirable features of the materials (Gjerdet and Hegdahl, 1978), since the polymerization is air inhibited. Air inclusions can result in soft spots in the restoration (Phillips, 1991). Thus, the resin composite for core restoration should be inserted with a syringe into the tooth to minimize incorporation of air (Mentink *et al.*, 1995).

5. Furrule effect

"Furrule effect" was described as a 360-degree ring in cast restoration apical to junction of the core (Rosenstiel *et al.*, 1995). "The furrule effect" and the amount of remaining tooth structure were found to be important factors to prevent fracture in endodontically treated teeth (Sornkul and Stannard, 1992; Torbjorner *et al.*, 1995). A retrospective clinical study by Torbjorner *et al.* (1995) pointed out the importance of the furrule effect. The authors evaluated the survival and failure of teeth restored with posts and crowns. The results indicated a higher potential for fracture of the root when the cemented crown did not provide a furrule effect. Sorensen and Engelman (1990), in experimental study, also recommended one millimeter of coronal dentin above shoulder to increase the fracture resistance of endodontically treated teeth.

6. Fracture resistance versus types of restoration

Most of literatures concerning restoration of endodontically treated teeth have been focused on the post-core unit. The traditional objective of post was to strengthen the weakened root. Nowaday, these techniques commonly weaken the root because restoration procedures rarely preserve dentin (Assif and Gorfil, 1994). Trabert, Caput and Abou-Rass (1978) and Trope, Maltz and Tronstad (1985) showed that the preparation of a post space further increased the risk of root fracture. However, some endodontically treated teeth need post and core to retain crown.

In the study of Martinez-Insua *et al.* (1998), endodontically treated teeth that restored with tapered cast post and core were reported a significantly higher of fracture load than both prefabricate parallel-sided post and carbon fiber post. However, the authors also found that mode of fracture in cast post group were found to be fracture of roots (20 from 22 roots). While, the teeth that restored with carbon fiber post and composite core had very little incidence of root fracture (1 from 22 roots). Majority of failure in carbon fiber group was found to be fracture of the post itself (59% of cases). Purton and Payne (1996) reported that tooth fracture were uncommon in teeth restored with carbon fiber post and the most frequent site of failure was at the post and core interface. Isidor, Odman and Brondum (1996) also reported that under cyclic loading test, all teeth restored with cast post presented fracture of the root, while only 4 from 10 roots that restored with carbon fiber post could only be observed microscopically that they had longitudinal root fracture after completion of the test. When force was applied to the root, the carbon fiber post exhibited a greenstick fracture due to progressive of the individual fibers. In contrast, the bending mechanism occurred in the metallic post. That might result in less damage to the tooth structure at failure (Morgano and Brackett, 1999). These advantages of carbon fiber post might probably allow salvage and representation with the minimum of complex treatment (Morgano and Brackett, 1999).

In two clinical studies, carbon fiber post seems to give good results in 2-5 years recall cases (Fredriksson *et al*., 1998; Glazer, 2000). Grazer (2000) evaluated the success rate of 59 Composipost® cemented with Metabond ® and built up with Core Paste ® cores. All the teeth in the study had lost more than 50% of their coronal structure. Each tooth received full coverage restoration and was followed 6.7-45.5 months. There were no fractures. Overall failure rate was 7.7% and the accumulative survival rate was 89.6%. Fredriksson *et al*. (1998) also observed 236 teeth restored with carbon fiber-reinforced epoxy resin posts and found that in 2-3 years no dislodgment or post fracture was observed clinically or on radiograph.

Not only the properties of the post, but the properties of the luting cement also play an important role against root fracture in endodontically treated teeth. It has been suggested that elastic moduli of luting cement should range between those of restoration and tooth structure to prevent root fracture by reducing interfacial stress concentration without causing excessive strain (Li and White, 1999). Junge *et al.* (1998) compared the preliminary failure (micromovement of the prosthesis) of complete cast crowns which cemented with 3 different luting cements under cyclic loading. They found that the resin cement had a significantly higher number of load cycles than both the zinc phosphate and the beneficial for the weakened endodontically treated tooth; especially those are structurally weak in cervical area. Al-Hazaimeh and Gutterridge (2001) also recommended the use of resin cement in weakened endodontically treated teeth to improve the resistance to fracture. This study found that the mean failure load of both furrule and non-furrule groups were high and no statistic different when resin composite cement and core materials were utilized with a Parapost® prefabricated system. The authors suggested that this could be due to cementation with resin cement. However, the mechanism was not discussed.

7. Fracture pattern versus root dentin thickness and root shape

The thickness of remaining root dentin is one of the significant variables in fracture resistance of the root. Experimental impact testing of teeth with cemented posts of different diameters showed that teeth with larger post were more easily root fracture than those with a smaller one. This may be because the large post needs more dentin removal and leaves less root dentin thickness (Trabert *et al.*, 1978). Smith, Schuman and Wasson (1998) recommended post diameter should not more than 1/3 of root dentin thickness in every level. In addition, a root shape was also suggested to be an important factor in root fracture. Developmental grooves, surface irregularities, and non-uniform of root canal walls could lead to a high concentration of stresses in roots (Pitts and Natkin, 1983; Lertchirakarn *et al.*, 2003). Felton *et al*. (1991) suggested that most root fractures originated from root concavities because the remaining dentin thickness is minimal. However, most of the studies found the fracture sites were on the thicker dentin rather than minimal part (Walton *et al.,*1984; Holcomb, Pitt and Nicholls, 1987; Lertchirakarn *et al.,* 1999). The factors and mechanisms of vertical root fracture pattern were demonstrated by finite element analysis work in Lertchirakarn *et al.* study (2003).

Currently, there are still a few researches studying directly about the effect of post and cement types on vertical root fracture especially in non-furrule group which is susceptible to vertical root fracture. The results from this study may reduce the incidence of vertical root fracture in endodontically treated teeth those are impossible to restore with furrule.

CHAPTER III

MATERIALS AND METHODS

PART I : VERTICAL ROOT FRACTURE LOAD

1) Preparation of the restorations

The experiments were performed with a homogeneous sample of 60 similarly sized extracted permanent maxillary central incisors. After extraction, the teeth were stored in normal saline solution with a few crystals of thymal at 4 $^{\circ}$C used within 6 months of extraction. The root surfaces were cleaned and examined at x20 magnification for any root fracture or crack. Any tooth with crack, root caries or open apex was excluded. Radiographs were taken in both labiolingual and mesiodistal direction. The radiographs were examined and any multiple root canal, previous root canal treatment or root resorption were discarded. The labiolingual and mesiodistal dimensions of all samples were measured at the level of cementoenamel junction of labial surface, using a caliper to confirm approximately the same size and shape of the samples. The coronal portion was removed with cylindrical diamond bur and copious water spray in high-speed handpiece 2 mm above cementoenamel junction to make approximately a 15 mm root length.

Root canals were instrumented at the 0.5 mm short of tooth length to a # 50 K file (Kerr, Scafati, Italy) using the stepback technique. The root canals were irrigated with 5 ml of 2.5% sodium hypochlorite before changing the file size and final flush with 10 ml 17% ethylenediaminetetraacetic acid (EDTA) and 10 ml of

2.5% sodium hypochlorite. Canals were then obturated with gutta percha (Products Dentaires, Vevey, Switzerland) and AH Plus® (Densply, Tulsa, OK, USA) with lateral condensation technique. A thin layer of silicone paste (OCI®, OCI USA Inc., Miami, FL, USA) was painted on the root surface to simulate the periodontal membrane, and to provide a space between root surface and dental stone for allowing root breakage. Then the samples were randomly allocated to one of 6 groups for completion of the restoration.

Group I: Carbon fiber post fixed with resin cement and composite core (10 teeth).

Group II: Carbon fiber post fixed with zinc phosphate cement and composite core (10 teeth).

12 mm of post space was prepared by using C-Post Drill no 2 (Bisco Inc., Schaumberg, IL, USA). The cylindrical carbon fiber post with 2 diameters, on apical section with 1.2 mm and the coronal section with 1.8 mm diameter, was used (C-post®, Bisco Inc., Schaumberg, IL, USA). The post was cemented with resin cement (C&B Cement®, Bisco Inc., Schaumberg, IL, USA) in group I and with zinc phosphate cement (Hybond®, Shofu Inc., Kyoto, Japan) in group II. Both cements were mixed according to manufacturer's instruction. The cement was applied on the post surface and immediately seated by finger pressure. The teeth were placed in a static loading device (Durometer®, Pacific Transducer Co., Los Angeles, CA, USA) with 3 kg of pressure for 10 minutes as recommended by Saupe, Gluskin and Radke (1996). The cement was allowed to set and excess cement was removed. Then the teeth were embedded in dental stone (Whip Mix®, Whip Mix Corporation, Louisville, KY, USA) at the center of PVC pipe (2.5 mm in diameter) along their long axis using a surveyor (fig 1).

Figure 1 The tooth embedded in dental stone using surveyor

The sectioned surface is 3 mm above the plaster level, corresponding to the position of alveolar bone clinically as recommended by Turner (1982). After stone setting, the core was built to 5 mm height by using dual-cured composite resin (Biscore®, Bisco Inc., Schaumberg, IL, USA) and All-bond 2 (Bisco Inc., Schaumberg, IL, USA) according to manufacturer's instruction. Tofflemire matrix was placed around the cervical third of the tooth for placing the material.

After complete polymerization of resin composite, similar cylindrical shape of composite cores (4 mm in diameter) were made. All composite cores were prepared approximately by hand as closely to the final shape as possible. The permanent dark circle was marked on the occlusal surface. The axial wall of composite core was cut with cylindrical diamond bur. Shank of diamond bur was placed perpendicular to the base of ring as possible, and the cutting was made follow permanent dark line (fig 2).

Figure 2 Occlusal surface with permanent pen

to make a similar diameter of the core

After that a level was used to check whether occlusal surface of the core is parallel to the base of its ring (fig 3). All procedures were made by the same operator. The sample that was ready to test was shown in fig 4.

Figure 3 A level for checking occlusal paralleling of the core

Figure 4 Cylindrical composite core with 4 mm in diameter, perpendicular axial wall, and parallel occlusal surface

Group III: Prefabricated parallel-sided stainless steel post fixed with resin cement and composite core (10 teeth).

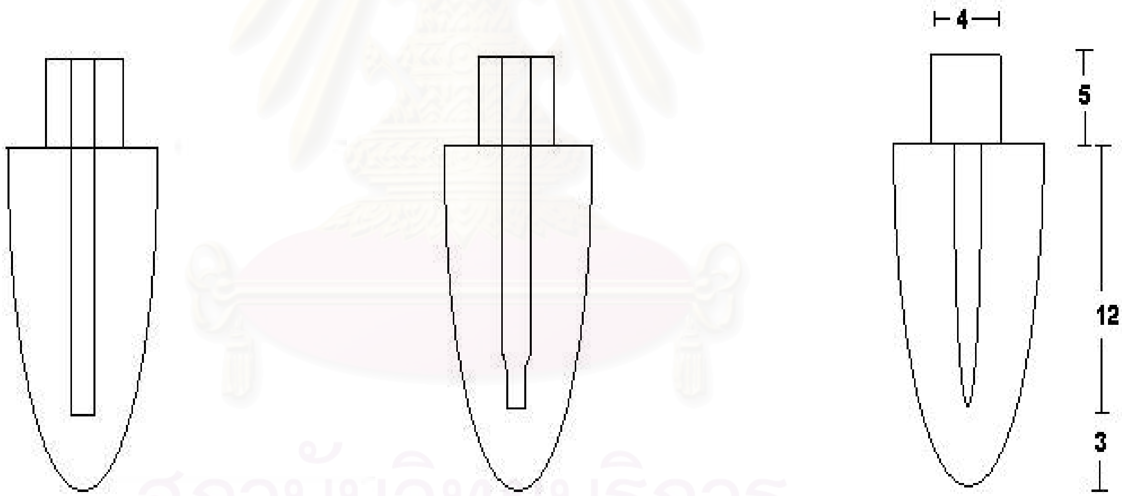
Group IV: Prefabricated parallel-sided stainless steel post fixed with zinc phosphate cement and composite core (10 teeth).

The post space was prepared by using ParaPost Drill® no 3 (Whaledent International, New York City, NY, USA) for a 12 mm post length with 1.25 mm in diameter. The post (ParaPost® no 3, Whaledent International, New York City, NY, USA) was cemented with resin cement (as used in group I) in group III and with zinc phosphate cement (as used in group II) in group IV. The root was embedded in dental stone at the center of PVC pipe along their long axis using a surveyor. The core was built by the same technique as in group I and II after stone set.

Group V: Cast post and core (non-precious alloy) fixed with resin cement (10 teeth).

Group VI: Cast post and core fixed with zinc phosphate cement (10 teeth).

The post space was prepared using ParaPost Drill® no 3 for a 12-mm post length. The root was embedded in dental stone at the center of PVC pipe along their long axis by using a surveyor. The cast pattern was obtained by using Duralay® (Reliance Dental Mfg.Co., Worth, IL, USA), then casted, polished and cemented with resin cement (as used in group I and IIII) in group V and zinc phosphate cement (as used in group II and IV) in group VI. The diagram of carbon fiber, stainless steel and cast post groups were showed in fig 5.



(a) (b) (c)

Figure 5 Schematic drawing of the samples of (a) carbon fiber, (b) stainless steel and (c) cast post group

After the sample preparation, all samples were stored in 100% humidity at room temperature for 24 hours before testing.

2) Testing method of fracture resistance

The sample was mounted perpendicularly to the base of the ring in Lloyd universal testing machine (Lloyd Instrument Ltd., Fareham, Hants, United kingdom). The load was applied vertically to produce vertical root fracture at a crosshead speed of 0.5 mm/min. The flat surface of the crosshead was pressed over the occlusal surface of core material. The load at fracture was then recorded.

PART II : PATTERN OF FRACTURE AND ROOT DENTIN THICKNESS

After vertical root fracture resistance was tested, all samples were removed from dental stone. Patterns of fracture and direction of fracture site were examined. The odd number samples in every group were evaluated for direction of fracture and root thickness. Composite core was removed. The root part of selected samples was embedded in clear acrylic resin (Takilon®, Rodent S.R.1, Milan, Italy). Resin was allowed for setting, then the samples were marked on resin block to identify the root surface and sectioned horizontally with an low speed cutting machine (Isomet 1000®, Buehler, Lake Bluff, IL, USA) (fig 6). The first cut will be made 3 mm below the cut surface, and three more sections were made at 3 mm intervals apical to the first one. The root thickness was measured between root surface and root canal wall. The measurement was performed at labial, palatal, mesial and distal site in every section in order to investigate the relation between root thickness and direction of fracture.

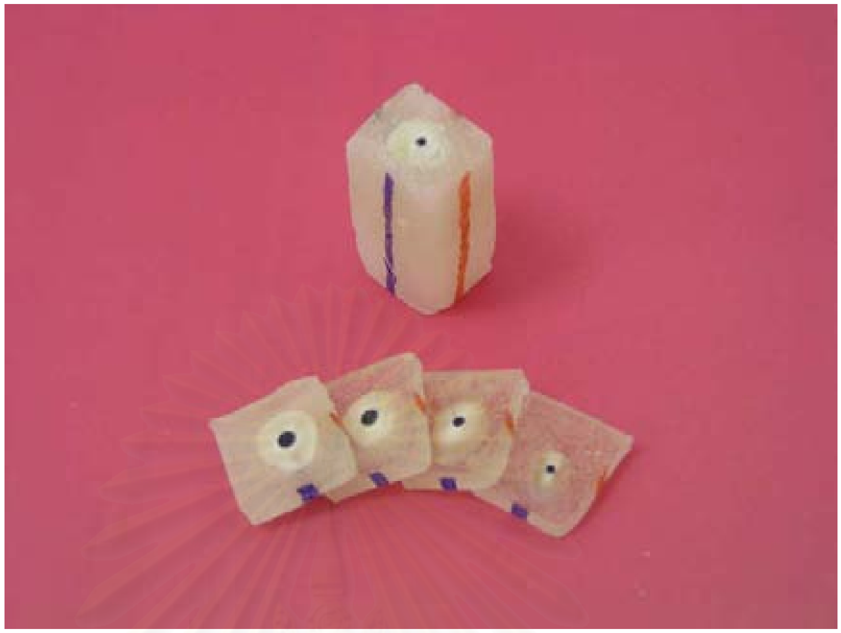


Figure 6 Samples after embedded in clear acrylic resin and cut with Isomet saw

PART III : OBSERVATION OF THE FRACTURE SITE UNDER SEM

The fracture surface of the paired number samples or complete vertical root fracture in every group were grooved at the fracture line approximately 0.5-1 mm depth using separating disc, and then separated into 2 pieces (fig 7). All samples were proceeded with standard technique for Scanning Electron Microscope (SEM) sample preparation and observed under SEM (5410LV, JEOL LTD., Tokyo, Japan).

Figure 7 2 pieces of root after separation

PART IV : ANALYZE OF DATA

I) Analysis of vertical root fracture resistance

Statistic analysis was performed by using SPSS/PC software (Chicago, IL, USA). A two-way ANOVA at the 95% level of confidence was used to compare the force at fracture of roots with different types of posts and luting agents.

II) Analysis of root dentin thickness and SEM observation

Mean and standard deviation of root dentin thickness was analyzed in relationship to site of fracture line and pattern of fracture. Microstructure of dent observed in relationship to fracture surface by SEM.

CHAPTER IV

RESULTS

PART I : VERTICAL ROOT FRACTURE LOAD

In this study, mean root diameter of samples at cervical part of the root is 7.09 mm (standard deviation = 0.2972) in facio-lingual and 5.17 mm (standard deviation = 0.3892) in mesio-distal.

The means load at fracture and standard deviations are presented in table 1, while all data in all experimental groups were shown in appendix table 1.

Table 1 The mean fracture load and standard deviation in four groups

Group	Mean fx load (Newton)	Standard deviation
(I) C post + Composite core + resin cement	3,517.30	354.34
(II) C post + Composite core + zinc phosphate cement	2,830.90	236.91
(III) ParaPost + Composite core + resin cement	3,368.90	382.68
(IV) ParaPost + Composite core + zinc phosphate cement	2,549.60	356.19
(V) Cast post and core + resin cement	-	-
(VI) Cast post and core + zinc phosphate cement	-	-

All samples failed because of vertical root fracture, except samples in group V and VI (teeth restored with cast post and core). Since samples in group V and VI did not fracture but the failure occurred due to stone fracture, these samples were not proceeded in part II (analysis of root thickness) and part III (SEM).

The mean fracture load in teeth restored with carbon fiber post and resin cement (group I) provided the highest value of 3,517.30 newtons, followed closely by teeth restored with stainless steel post and resin cement (group III) at 3,368.90 newtons. While teeth restored with ParaPost and zinc phosphate cement (group IV) showed the lowest mean fracture load which was only 2,549.60 newtons.

Data distribution in group I through group IV were analyzed using Shapiro-Wilk and revealed that data in group I through IV distributed normally as shown in table 2. Therefore, 2-way ANOVA was used as a statistical tool to specifically focus on the effects of post types (carbon fiber post versus stainless steel post) and cement types (resin versus zinc phosphate cement) on value of vertical fracture load. Summaries of theses statistic test procedure were showed in table 3.

Table 2 The statistical analysis of normal distribution in group I through IV

Group		Shapiro-Wilk		
		Statistic	df	Sig.
Fx load	(I) C post + Composite core + resin cement	.044	10	.053
	(II) C post + Composite core + zinc phosphate cement	.200	10	.440
	(III) ParaPost + Composite core + resin cement	.900	10	.281
	(IV) ParaPost + Composite core + zinc phosphate cement	.927	10	.434

Table 3 The statistic analysis of 2-way analysis of variance

Source	Sum of squares	df	Mean square	F	p value
Post	461605.225	1	461605.225	4.059	0.051
Cement	5667831.225	1	5667831.225	49.843	0.000*
Post*Cement	44156.025	1	44156.025	0.338	0.537
Total	386447137.000	40			

df=Degree of freedom

* = Significant difference

The statistic analysis of the data using 2-way ANOVA could be interpreted that vertical fracture load was affected by types of cement (p=0.000). In contrast, types of post had no effect on vertical root fracture load (p=0.051). Moreover, no significant difference was found between post and cement interaction (p=0.537), which indicated that there was no join influence of the post and cement on vertical fracture load. Results of multiple comparison using Scheffe test (P=0.05) were showed in figure 8 and appendix table 2. There were significant differences of vertical fracture load between group I and II, group II and III, group III and IV, and group I and IV.

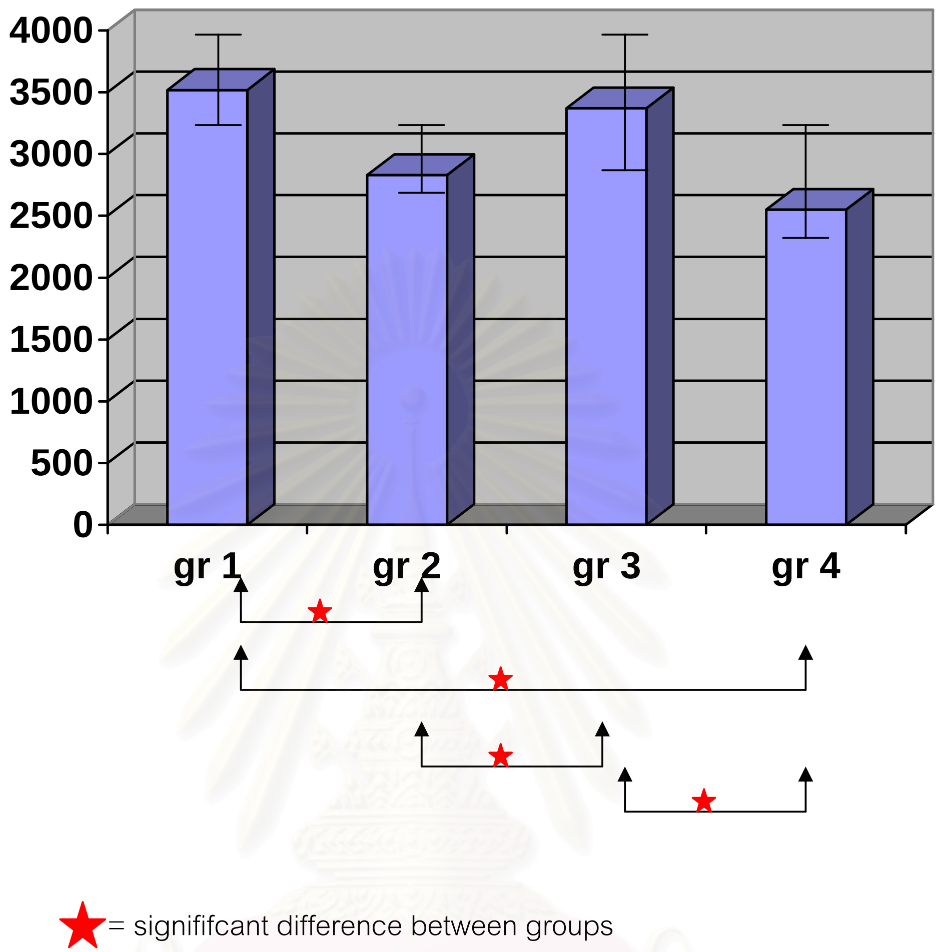


Figure 8 : Bar graph represented means load at fracture ,standard deviation and significant difference between groups

PART II : PATTERN OF FRACTURE AND ROOT DENTIN THICKNESS

The mean thickness of root dentin after mechanical instrumentation and post space preparation was presented in table 4.

Table 4 The cross-sectional thickness of root dentin after mechanical instrumentation and post space preparation, in different level

Level	Mean root dentin thickness (mm)			
	Labial	Palatal	Mesial	Distal
1	2.325	2.825	2.125	2.050
2	1.975	2.300	1.750	1.775
3	1.900	2.025	1.550	1.450
4	1.475	1.750	1.125	1.125

All means of root dentin thickness in labial and palatal were greater than in both proximal site at every level, except only 2 samples at the first cut that the thickness in labial, palatal, mesial and distal are equal. Shape of root canals after mechanical instrumentation and post space preparation were circular. All fracture lines presented vertically between cervical and apical area without deviation to other directions. In addition, there was no fracture line extended futher than the level of post tip. Direction and number of fracture line are summarized in table 5.

Table 5 Number and direction of fracture line distributed in each group

Group	Mesiodistal direction		Labiolingual direction	
	1 Fx line	2 Fx lines	1 Fx line	2 Fx lines
I	1	1	5	3
II	-	2	4	4
III	-	2	4	4
IV	-	1	4	5

The most fractures (33 from 40 roots) were occurred in labiolingual direction, with almost equal distribution between 1 and 2 fracture lines. The mesiodistal fracture occurred only 7 roots. In addition, 20 samples of odd number in group I-IV were sectioned horizontally every 3 mm into 4 levels. Cross-section of the root presented direction of fracture line which corresponded with greater root dentin thickness location (labiolingual). The results are showed in appendix figure 1-4.

PART III : OBSERVATION OF THE FRACTURE SURFACE

The paired number samples in every group were separated into 2 pieces at the fracture surface. The interesting areas were the areas at cement layer around the root canals. Low magnification view of entire fracture surface showed a wide band of cement, especially at cervical portion. The very thin band of cement could be observed at apical portion of the root canal. The higher magnification images demonstrated that all fracture sites were free from intruded cement. There were numbers of void was observed within cement layer in both types of cement. The results from SEM showed longitudinal fracture of dentinal tubules (Fig 9).

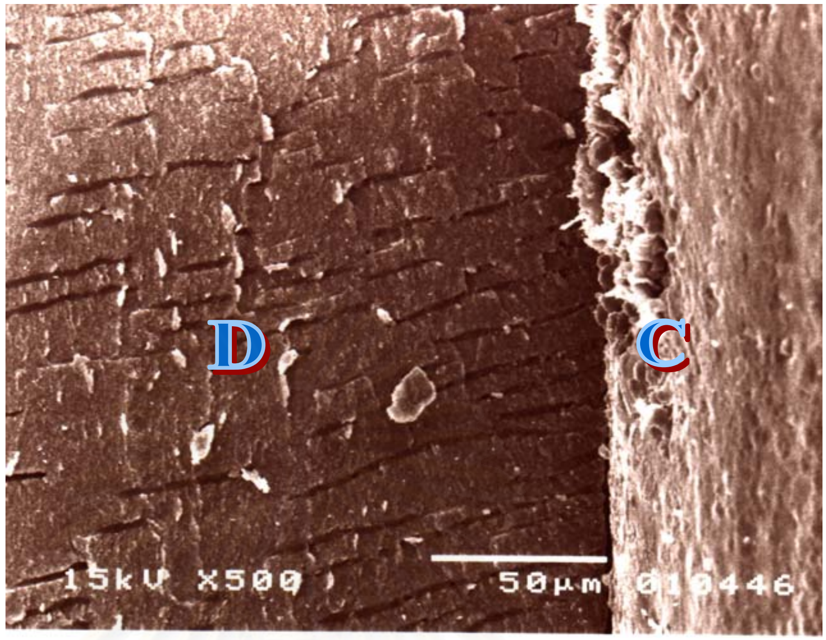


Figure 9 The fracture surface of samples in every group observed under SEM, showing root dentin (D) and cement layer (C) in the same pattern

CHAPTER V

DISCUSSION

This study was designed to investigate the effect of post and cement types on vertical root fracture resistance by comparing vertical root fracture load that was applied vertically to exclude the chance of being fracture in other directions and created vertical root fracture. Extracted maxillary central incisor was used since it has the least root canal variation. Moreover, it has a large and straight root canal that suitable for experimental design. The age of teeth may influence strength of dentin (Tonami and Takahashi, 1997) but the teeth used in this study could not recorded their age before extracted. Previous study showed that the shape and size of root has a great impact on stress distribution to create vertical root fracture (Lertchirakarn *et al.*, 2003). Thus, all samples in this study were selected with similar size and shape to reduce the effect of these samples themselves. Nevertheless, there are still a little variation in size and shape of the teeth that used in this study.

Two types of luting cement and three types of posts were used. Zinc phosphate cement has been used as a luting agent for long time (Rosenstiel *et al.*, 1995). Many studies reported a good performance of this type of cement, not only its acceptable physical properties, but also its clinical application (Phillips, 1991; Diaz-Arnold *et al.*, 1999). Therefore, zinc phosphate cement was used in this study as a standard luting cement. Whereas, tapered cast post represents the customized post that fit to prepared root canal. The other post types were

ParaPost® (stainless steel post) and C-post® (carbon fiber epoxy resin post). ParaPost® represented prefabricated post that made up of metal, while C-post® represented prefabricated post that made up of non-metallic materials. Samples in this study were not placed crown restoration because the placement of crown restoration may change the pattern of the distribution of externally applied load in which the post characteristics will be insignificant and may not create vertical root fracture (Hoag and Dwyer, 1982).

The results in groups that restored with tapered cast post and core (group V: cast post and resin cement; and group VI: cast post and zinc phosphate cement) were different from other experimental groups. Samples in these groups did not failed because of root fracture, but failures occurred due to fracture of dental stone. The root tip was pushed through dental stone that finally touched the base of PVC ring.

Many studies demonstrated that cast post and core did not reinforce the weakened endodontically treated teeth (Sorensen and Martinoff, 1984; Sorensen and Martinoff, 1985; Trope *et al*., 1985). In addition, some studies suggested that tapered metal post created a wedging stress and fracture on the root, both in vitro and *in vivo* studies (Bex *et al*., 1992; Isidor *et al*., 1996; Martinez-Insua *et al*., 1998). This study showed opposite result. The differences between cast post and core and prefabricated post group are their structure and the core material. Cast post and core is always created in single unit with the same material, while prefabricated post needs core built-up. The shoulder of a tapered cast post and core resemble a coping for a cervical root dentin. On the other hands, composite core which was used in prefabricated post group could not provide this action, because resin composite could not resist the applied force and usually broke before the root was fractured. Moreover, the fracture in the case of casting tapered post *in vitro* study occurred in other fracture characteristics such as horizontal or oblique fracture rather than vertical root fracture. This also implies that a pattern of stress produced by tapered cast post and core under vertical loading may not create a vertical root fracture and the direction of applied force effect patterns of fracture as well.

Mean fracture load in teeth restored with carbon fiber post and resin cement (group I) provided the highest value of 3,517.30 ± 354.34 newtons, followed closely by teeth restored with stainless steel post and resin cement (group III) at 3,368.90 ± 382.68 newtons. The teeth restored with stainless steel post and zinc phosphate cement (group IV) demonstrated the lowest mean fracture load (2,549.60 ± 356.19 newtons) which was greatly different from many studies. The minimum inner root canal applied force that required for vertical fracture in maxillary central incisor was reported 9.1 kg (about 89.18 newtons) (Lertchirakarn *et al*., 1999), whereas the mean fracture loads in this study ranged between 2,549.60-3,517.30 newtons. The results showed that the mean fracture load in this study are much higher. This may be the different design of applied force. Lertchirakarn *et al*. (1999) used spreader to produce inner force and push into the canal which most of the spreader contacted to dental wall approximately 1 mm from root apex. The spreader bound at only a small contact area produced a high stress. This may be due to the direct effect of root canal shape that can amplified applied force to critical level of stress that can produce vertical root fracture (Lertchirakarn *et al*., 2003). In contrast, cemented post in this study has a broader contact between post and inner surface of root canal to transfer applied vertical loading.

Moreover, the vertical root fracture load in this study are also greater than the fracture load of endodontically treated teeth that restored with different post and core in previous reports (Barkordar *et al*., 1989; Loney, Moulding and Ristco, 1995; Mendoza *et al*., 1997; Martinez-Insua *et al*., 1998; Al-Hazameh and Gutteridge, 2001). This may be because of the difference in applied force direction. All of former studies applied oblique force, while vertical force was used in this study. Vertical loading direction reduce peak stress value in dentin and no bending action to the tooth structure. Therefore, higher force was required to fracture of the root. These corresponded to Yang *et al.* study in 2001. The previous report by Loney *et al.* (1995) showed that mean failure load increase as load angle parallel to the long axis of the teeth (from 110 to 150 degree). In this study, the author confirmed that an angulation of loading force was a factor affecting failure.

The effect of cement types were analyzed, and it showed a strong effect on vertical root fracture resistance (P value = 0.000). This statistic significance was corresponded with the means fracture load that showed in table 1. Samples with post that cemented with resin cement (group I and III) showed significantly higher fracture load than samples cemented with zinc phosphate cement (group II and IV). Peters *et al.* (1983) suggested that the bonding between the post and the cement appear to be very important parameter to achieve optimal mechanical behavior of the tooth-prosthesis combination. Finite element analysis was used to evaluate the effect of bonding between post and cement (perfectly bonded or friction-held model). The results showed that the overall load of stress in the case of friction model was about 20% higher when compared to the connected interface model. In addition, the axial stress in case of friction increased considerably toward the apex, whereas the connected boundary resulted in uniform distribution of stresses (Peters *et al.,* 1983). Trope *et al.* (1985) demonstrated that fracture resistance of endodontically treated teeth could be increased by using acid etching prior to the used of bonded material in the root canal. Whereas, other *in vitro* studies supported the use of bonding cement in restorative work and claimed that resin cement could prevent root fracture (Mendoza *et al.,* 1997; Al-Hazameh and Gutteridge, 2001). Al-Hazameh and Gutteridge (2001) suggested the used of bonding resin cement in case of endodontically treated teeth without furrule preparation, because their results showed no significant difference of failure load between furrule and non-furrule group if these teeth were cemented with resin cement. Moreover, Mendoza *et al.* (1997) showed ability of resin-bonded post to reinforce teeth that are structurally weak in cervical area against fracture. Roots in which the post were cement with resin cement have significantly more resistance to fracture than those when zinc phosphate cement was used.

Clinical observation also supported the use of resin cement as luting material to prevent root fracture. Ferrari *et al.* (2000) observed success rate in teeth restored with Composipost® and resin cement in 200 patients. No root fracture was found. In group restored with cast post and zinc phosphate cement showed 9% of root fracture. A retrospective study by Fedriksson *et al*. (1998) showed there was only 0.8% of root fracture in teeth restored with Composipost® and resin cement after 2 to 3 years, as well. Unfortunately, no study observed the effect of resin cement on vertical fracture resistance. However, the results from this study suggest that resin cement may reinforce the weaken endodontically treated root and decrease the evidence of vertical root fracture. The possible explanation may be dentin bonding cement such as resin cement in this study provides a chemically bond to both dentin and post, and it create a single unit of tooth-prosthesis combination. On the other hands, zinc phosphate cement is gradually crumbled under compression.

Types of post have a borderline statistical insignificance in this study (P value = 0.051). Similar results could also be observed in studies of King and Satchell (1991) and Dean *et al.* (1998). Even though Joshi *et al.* (2001)

demonstrated that the post materials with low elastic moduli (carbon fiber post) showed significantly less stresses with more favorable stress distribution than those of higher elastic moduli (stainless steel post) in every load direction. From the results of this study may be concluded that the effect of post types was not strong enough to show statically. However, the effect of post showed marginally insignificant. Therefore, resin-reinforced composite post needs more data collection and further study. This type of post is still considered to be an interesting way in reconstruction weaken endodontically treated teeth, especially when resin cement is used as luting agent.

All samples in this study showed fracture lines extended completely from root canal to outer root surface without separation of the root fragments. 80% of the fracture lines presented in labiolingual direction. All fracture lines presented vertically within the post length. This characteristic was different from vertical root fracture produced in other studies. In the studies of Bex *et al.* (1992) and Sirimai, Riis and Morgana (1999), the vertical fracture lines at the apical third deviated to other directions (labially or lingually). This difference may be due to the different direction of applied load. The two latter studies applied lateral force that produced maximum stress concentration at the labial or lingual plate of the root around the dowel apex , whereas during vertical loading force produced well distributed stress around the dowel in vertical direction (Yang *et al*., 2001).

It was interested that although the dentin thickness in faciolingual is greater than in the mesiodistal direction, almost all of samples (33 roots from 40 roots) fractured in faciolingual direction. Whereas, only 7 roots fractured in mesiodistal direction (table 5). Similar observations were also reported in other studies (Walton *et al*., 1984; Holcomb *et al*., 1987; Lertchirakarn *et al.,* 1999). Lertchirakarn *et al.* (2003) demonstrated that outer root morphology and dentin thickness affect stress distribution in the root canal wall by using 3-D finite element model. The effect of outer root morphology and dentin thickness on stress distribution were explained in terms of circumferential stress theory and bending mechanism. The labial and lingual canal wall received a higher tensile stress because the root dentin thicknesses at mesial and distal were thinner than those of labial and ligual, and the radius of root surface curvature in this part is less than that in both labial and lingual root surface. This study can explain the characteristic of vertical root fracture in location very well. Corresponded with the results that the fracture line in this study that did not extend further than the level of post tip. This suggest that the fracture originated at the end of the post region and extended to cervical area because of the influence of the higher tensile stress at the inner root canal wall on both labial and lingual which may higher than the wedging effect of the post itself.

All the SEM samples demonstrated no root canal cement or luting cement on the fracture surface. This result suggested that there was no initial crack or fracture occurred before and during obturation of root canal space, including during post cementation. This result confirmed the pressure used in this study did not create root fracture and vertical root fracture occurred only by vertical force during experiment. However, Meister *et al.* (1980) reported that the secondary cause of vertical root fracture was the forcing or tapping of inlays or posts into places (4 roots from 32 roots). It was suggested that dowels act as a piston, creating severe hydraulic back pressure during post installation. However, if a parallel-sided vented post is used, it is completely passive (Caputo and Standlee, 1987).

Unlike a broken bone, the fracture of tooth will never heal spontaneously. Fracture line provides a path for irritants from oral cavity to invade into root canal system and initiate inflammation especially for vertical root fracture. In spite of new way of treatment such as bonding fracture site with bonding resin, this treatment procedure does not guarantee success in all cases. Refracture, deterioration of periodontal inflammation, and tooth mobility may result in a loss of tooth after some times (Sugaya *et al*., 2001). The prevention or strengthening the endodontically treated root is most significant procedure. The result from this study provided the optional procedure to reduce the chance of vertical root fracture. However, this experimental study may not reflect complex pattern of mastication. Therefore, the further study on vertical root fracture should be performed clinically to investigate the relevance between clinical and laboratory study.

CHAPTER VI

CONCLUSION

Under the condition of this study, the following conclusions are made :

1. All groups showed failure of vertical root fracture, except root that restored with cast post and core.
2. The force need to vertically fracture the roots in resin cement groups was significantly higher than in the zinc phosphate cement groups.
3. Types of cement influence vertical root fracture load. On the other hands, types of post showed marginally effect on vertical fracture load.
4. 33 of 40 samples fractured in labiolingual direction.
5. The fracture lines were extended only within the level of the post length.
6. All SEM samples showed no root canal cement or luting cement on the fracture surface.

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APPENDIX

Table 1 Fracture load of samples in four groups

Sample No.	Experimental group			
	Gr I	Gr II	Gr III	Gr IV
1	3132	2440	2603	2143
2	3208	2506	2965	2169
3	3218	2619	3039	2332
4	3260	2785	3390	2342
5	3350	2885	3426	2426
6	3366	2921	3480	2479
7	3702	2985	3623	2658
8	3927	2986	3678	2721
9	3994	3038	3697	2963
10	4016	3144	3788	3263
Mean±SD	3,517.30±354.34	2,830.90±236.91	3,368.90±382.68	2,549.60±356.19

Table 2 Statistical analysis of multiple comparison using Scheffe test

Group number	Group number	Mean difference	Sig
Gr1	Gr2	686.4	.000
	Gr3	-51.6	.986
	Gr4	967.7	.000
Gr2	Gr1	-686.4	.000
	Gr3	-738.0	.000
	Gr4	281.3	.254
Gr3	Gr1	51.6	.986
	Gr2	738.0	.000
	Gr4	1019.3	.000
Gr4	Gr1	-967.7	.000
	Gr2	-281.3	.254
	Gr3	-1019.3	.000

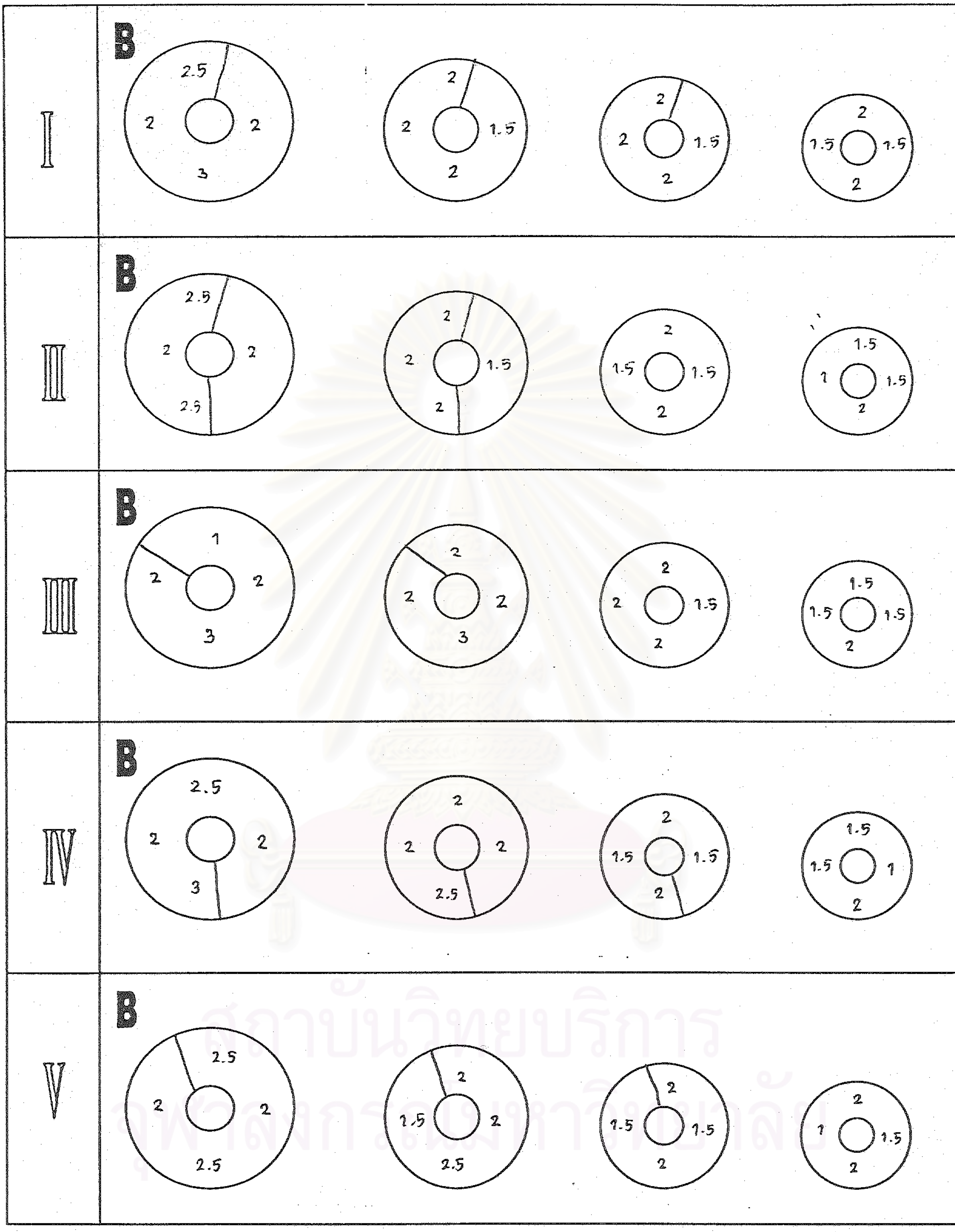

Figure 1 Graphic represented cross sectional of the root

at different level in samples of group I (5 samples); B = Buccal

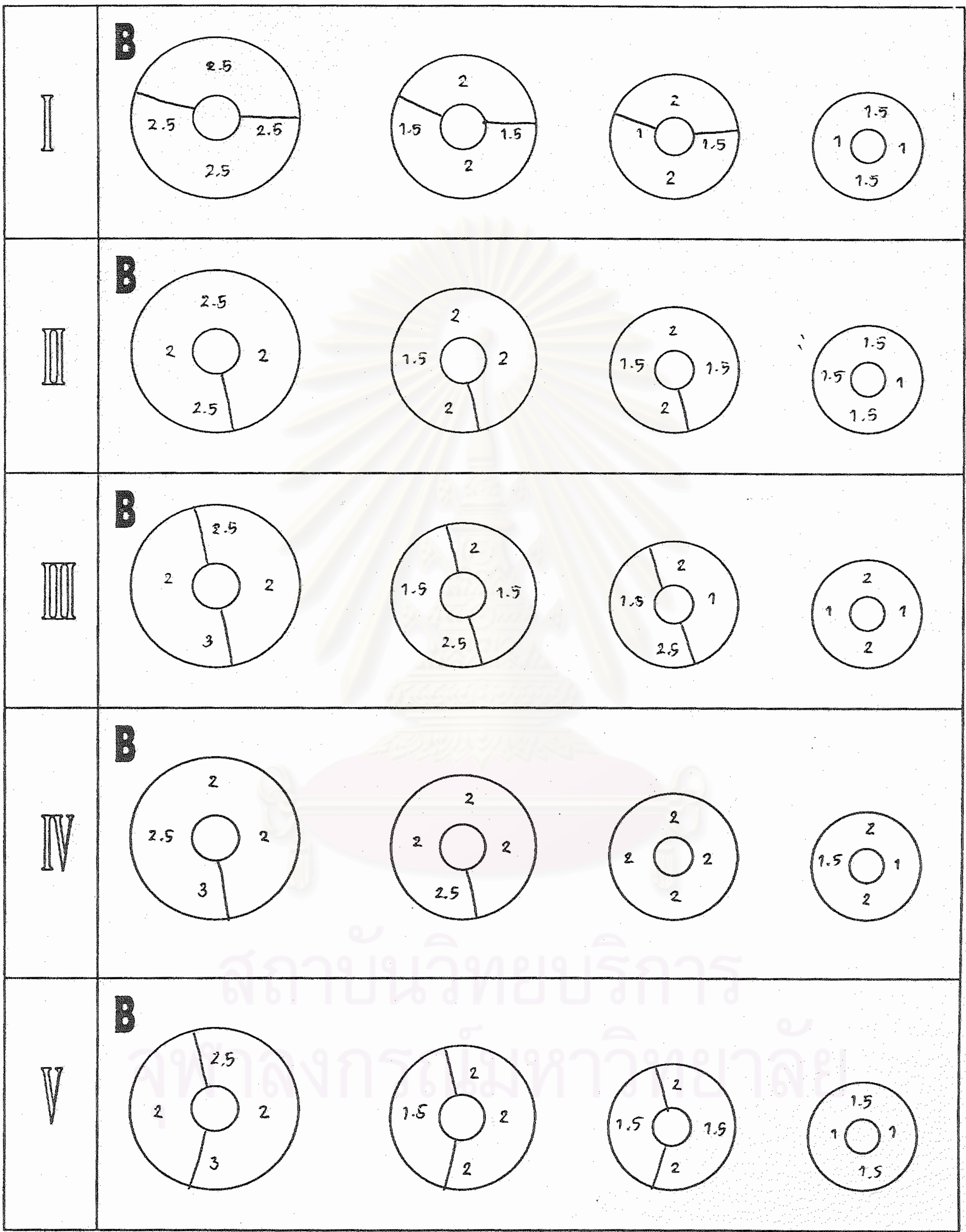

Figure 2 Graphic represented cross sectional of the root

at different level in samples of group II (5 samples); B = Buccal

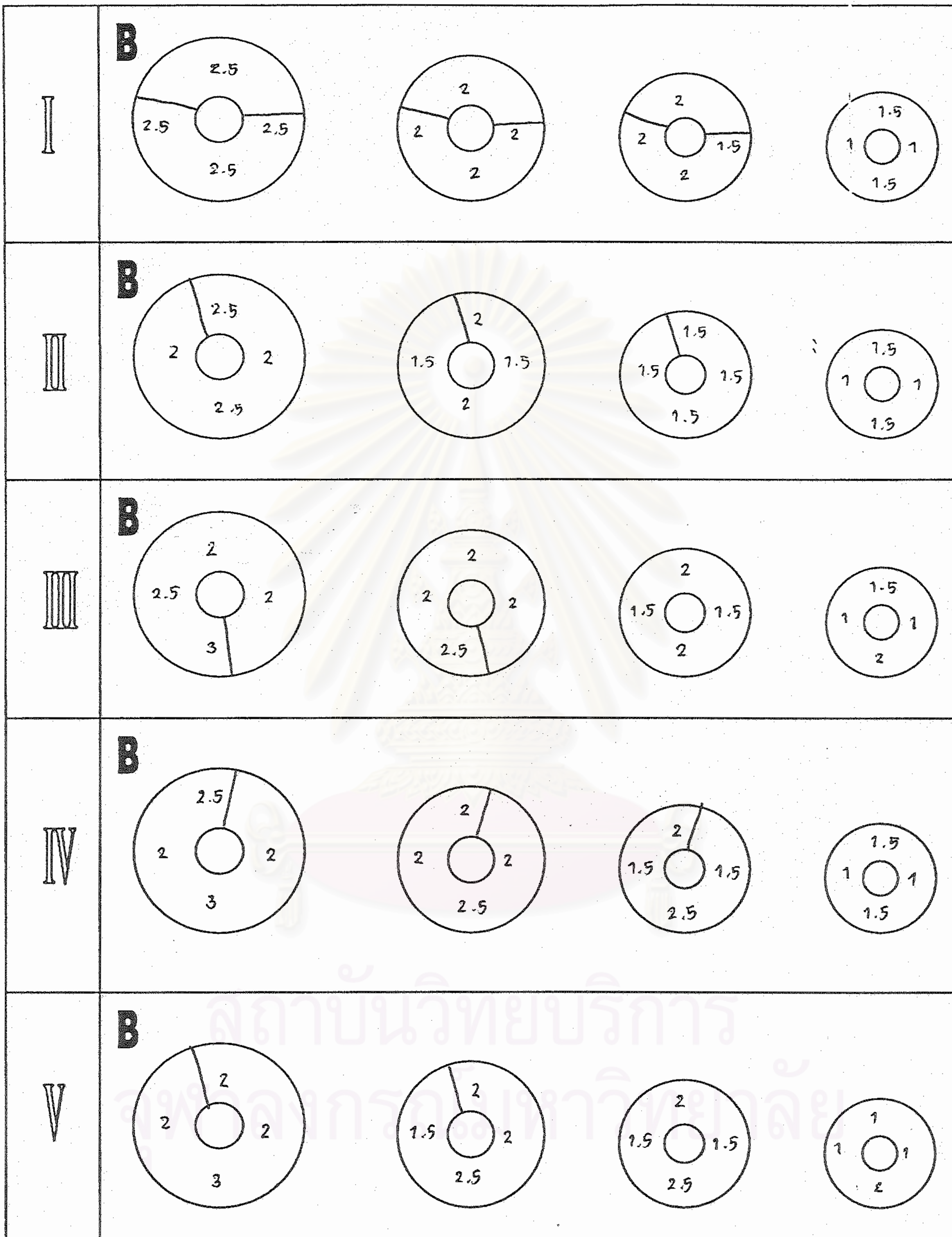

Figure 3 Graphic represented cross sectional of the root
at different level in samples of group III (5 samples); B = Buccal

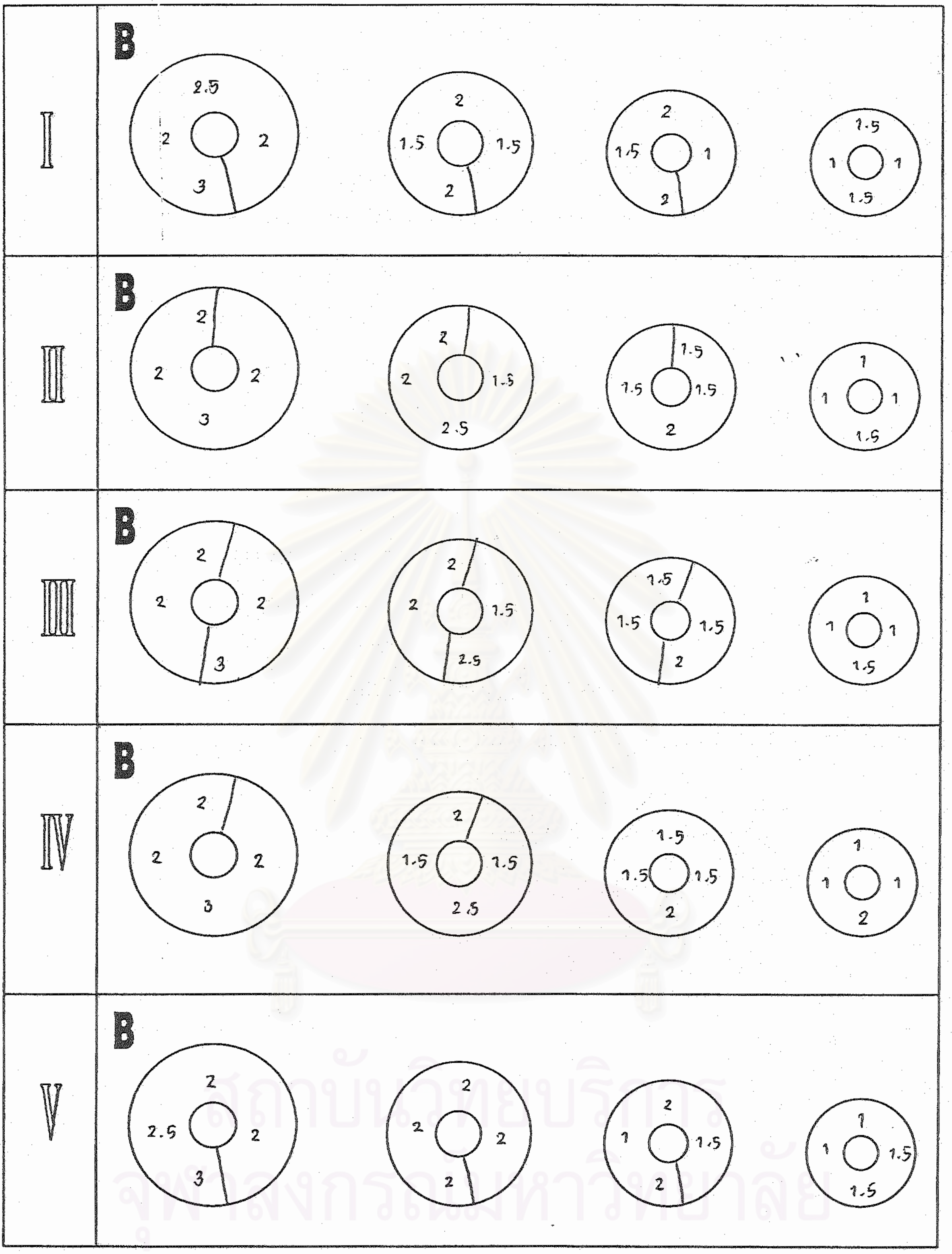

Figure 4 Graphic represented cross sectional of the root at different level in samples of group IV (5 samples); B = Buccal

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- Oral Hygiene Practices and Pattern of Dental Deposite on Tooth Surfaces. Presented on the 4th Dental Research Presentation and Academy Meeting of Thai Dental Faculties Board; 1999 October 27-29; Rayong Resort Hotel, Thailand. (with Phantumavanit, P; Songpaisan, Y; Bongsunant, S and Ratanamalai, W)