Chapter One

Introduction, Aim and Objectives

1.1 Introduction

Endodontically treated teeth are structurally compromised. Whether because of decay, previous restoration, fractures or the wearing away of sound enamel and dentin, these teeth required careful and immediate attention in reconstruction to ensure their longevity as functioning and aesthetic members of the dental arch.

Aesthetic demands of full ceramic restoration in anterior region can be achieved with the use of fibre post due to its natural translucency. Due to its elastic properties similar to dentine, fibre post can significantly reduce the risk of root fractures compared with metal post (Dean *et al.*, 1998; Cormier *et al.*, 2001b; Fokkinga *et al.*, 2004; Dietschi *et al.*, 2008). Another added advantage of the use of fibre post is the ease of removal in the case of endodontic retreatment (Cormier *et al.*, 2001b).

Endodontically treated anterior teeth restored with fibre post exhibited higher failure loads than teeth restored with zirconia and titanium posts and fracture patterns favoring a retreatment were observed in teeth restored with fibre post. Hence, fibre posts are preferred to restore endodontically treated anterior teeth (Akkayan and Gulmez, 2002; Bitter and Kielbassa, 2007; Jung *et al.*, 2007; Kivanc and Gorgul, 2008).

A post system should fit the requirements of both the tooth and the restoration. Posts cemented into the canal space provide core retention and should not be used with the intention of reinforcing the tooth (Fernandes and Dessai, 2001). Hence, minimum post space should be prepared consistent with the core retention. Grieznis et al (2006) reported that post and core significantly reduced the fracture resistance of the tooth and should be used only to secure retention and resistance form for full coverage crowns. Teeth with larger diameter cast post have a reduced fracture resistance than teeth with a smaller diameter post (Grieznis *et al.*, 2006).

Lloyd & Palik (1993) reviewed the literature regarding the diameter of post and identified three distinct philosophies of post space preparation. They concluded that a combination of a post space with an apical diameter equaled to 1/3 of the narrowest root terminus and at least 1.0mm of sound dentine surrounding the entire post space yielded a practical guideline for post space preparation (Lloyd and Palik, 1993).

One of the disadvantages of fibre post is that it is prefabricated and only available in sizes predetermined by the manufacturer which do not fit the entire canal. Therefore, post space need to be created using the corresponding drill. In daily clinical practice, the clinician needs to make his judgment on the diameter of the post to be used.

1.2 Aim of Study

The aim of this study is to evaluate the effect of fibre post diameter on the fracture resistance of endodontically treated teeth.

1.3 Objectives of Study

- To determine the effect of glass fibre posts of different diameter on the failure load of endodontically treated teeth with :

    i. different remaining dentine; and
    ii. different thicknesses of reinforcing resin composite.

- To determine the mode of fracture in each group.

1.4 Rationale

Glass fibre post and resin composite have moduli of elasticity close to that of dentine and are bonded adhesively into the canal space creating a monoblock within the root-post-core assembly. Therefore, Null Hypothesis (Ho) states that there is no difference in the failure load and mode of fracture regardless of (1) the amount of remaining dentine, (2) fibre post diameter and (3) the thickness of reinforcing resin composite in the root.

Chapter Two

Literature Review

2.1 Biomechanical Properties of Endodontically Treated Teeth

It is a common perception that endodontically treated teeth are more susceptible to fracture than vital teeth. Studies as early as in the 1970's have proposed that there is significant different in the dentin properties between endodontically treated teeth and vital teeth (Helfer *et al.*, 1972; Stern and Hirshfeld, 1973; Carter *et al.*, 1983; Rivera and Yamauchi, 1993)**.** The dentine in endodontically treated teeth are thought to be more brittle due to the loss of moisture content (Helfer *et al.*, 1972) and loss of collagen cross-linkage (Rivera and Yamauchi, 1993). These findings have been disputed by Huang et al (1992), Sedgley and Messer (1992) and Papa et al (1994).

Huang et al (1992) compared the mechanical properties of human dentin from treated pulpless teeth and dentine from normal vital teeth. They concluded that dehydration after endodontic treatment per se does not weaken dentine structure in terms of compressive and tensile strengths while the mean values of Young's modulus and proportional limit in compression tests appear to be lower.

Segley and Messer (1992) compared biomechanical properties (punch shear strength, toughness, hardness, and load to fracture) of 23 endodontically treated teeth (mean time since endodontic treatment: 10.1 yr) and their contra lateral vital pairs. Aside from a slight difference in hardness, there's no significant different in the biomechanical properties. They concluded that the similarity between the biomechanical properties of endodontically treated teeth and their contra lateral vital pairs indicates that teeth do not become more brittle following endodontic treatment.

Review of studies by Dietschi et al.(2007) concluded that only negligible alterations in tissue moisture and composition attributable to vitality loss or endodontic therapy were reported. Loss of vitality followed by proper endodontic therapy proved to affect tooth biomechanical behaviour only to a limited extent. Conversely, tooth strength is reduced in proportion to coronal tissue loss due to either caries lesion or restorative procedures.

Therefore, it is the loss of structural integrity associated with the access preparation, rather than the changes in the dentine, that lead to a higher occurrence of fracture in endodontically treated teeth compared with vital teeth (Reeh *et al.*, 1989a; Gutmann, 1992; Panitvisai and Messer, 1995).

Randow and Glantz (1986) reported that teeth have a protective feedback mechanism that is lost following removal of dental pulp and could affect the patient’s ability to detect functional overload, which may contribute to higher incidence of tooth fracture.

Taken into consideration from these studies, it is therefore recommended that the clinician restore endodontically treated teeth with the aim of enhancing the structural integrity to prevent fracture by heavy masticatory loading force.

2.2 Restoration of Endodontically Treated Teeth

Restoration of an endodontically treated tooth having minimal coronal tooth structure is generally accomplished using some type of post and core and a full crown. Besides the remaining tooth structure, the choice of permanent restoration is also dependent on the morphology and position of the tooth, functional loading and aesthetic consideration (Tait *et al.*, 2005).

Endodontically treated anterior teeth with minimal loss of coronal tooth structure should be restored conservatively with a bonded restoration in the access cavity (Sorensen and Martinoff, 1984b; Heydecke *et al.*, 2001; Cheung, 2005). In a structurally sound anterior tooth, placement of post has little or no benefit in strengthening the tooth (Guzy and Nicholls, 1979; Trope *et al.*, 1985; Heydecke *et al.*, 2001). Posts and crowns are only indicated when there is extensive loss of tooth structure as a result of caries or trauma, since the remaining tooth structure is the main contributing factor in fracture resistance of endodontically treated teeth (Oliveira Fde *et al.*, 1987; Reeh *et al.*, 1989b). Anterior teeth have small pulp chambers and are subjected to lateral and oblique force as they are placed at an angle to the occlusal plane (Mentink *et al.*, 1993). This makes the teeth susceptible to fracture when unfavourable directional load is applied, and the pulp chambers are too small to provide adequate retention and resistance without a post. Therefore, a post is often indicated along with crown if the amount of remaining tooth structure is inadequate.

Posterior teeth are subjected to greater loading than anterior teeth due to their position closer to the insertion of the masticatory muscle (Fernandes and Dessai, 2001). Access preparation prior to endodontic treatment resulted in increased cuspal deflection during function (Gutmann, 1992; Panitvisai and Messer, 1995). Therefore, it is recommended to restore posterior teeth with already existing restoration involving the marginal ridge or those with extensive loss of tooth structure with cuspal coverage (Sorensen and Martinoff, 1984b; Costa *et al.*, 1997; Cheung and Chan, 2003; Tait *et al.*, 2005). Unless the destruction of the coronal tooth structure is extensive, the pulp chamber and canal provide adequate retention for core buildup (Kane and Burgess, 1991).

2.3 Endodontic Post

Placement of endodontic post and core is a conventional method for restoring endodontically treated teeth with inadequate remaining tooth structure. The main function of the post is to provide retention for the core, not to improve fracture resistance of the endodontically treated teeth (Fernandes and Dessai, 2001; Tan *et al.*, 2005; Stricker and Gohring, 2006).

Posts can be classified according to their shapes and surfaces. According to their shape, they may be parallel, tapered, parallel-tapered combination and anatomical. They may be active or passive based on their surface characteristics. Dallari and Rovatti (1996) have made the following classification for endodontic posts: (1) first generation posts (self-threaded posts, screw posts, serrated-carved posts) or commonly known as active posts; (2) second generation posts (passive posts); (3) third generation posts (nonmetallic passive posts) (Dallari and Rovatti, 1996).

2.3.1 Active Post

Active posts are threaded and gain retention by engaging the walls of the canal. Active posts are more retentive then passive posts, but there is a concern of more stress introduced into the root compared to passive posts (Burns *et al.*, 1990; Felton *et al.*, 1991; Standlee and Caputo, 1992). However, they can be used safely in roots with maximum remaining dentin (Felton *et al.*, 1991) and should be limited to short roots in which maximum retention is needed. To reduce the stress induced by active posts, some techniques, like pre-trapping the post channel, reduced number of threads and counter rotating the post by one half turn after its full engagement are advocated (Ross *et al.*, 1991).

2.3.2 Passive Post

The passive post depends on the luting cement and its close adaptation to the canal wall for its retention. It may be custom casted or prefabricated. It may have either a smooth or a serrated surface texture (Ricketts *et al.*, 2005).

2.3.2(a) Custom Cast Post and Cores

Cast post and cores have an excellent approximation to the root canal wall and were widely used for decades and are still used by some clinician. They lost popularity because they require two appointments, temporization and a laboratory fee. Cast post and cores can still be judged as the gold standard for restorations of teeth with great loss of substance. A retrospective study revealed a success rate of 90.6% over 6 years using cast post and core (Bergman *et al.*, 1989).

2.3.2(b) Prefabricated Metal Post

Prefabricated posts are typically made of stainless steel, nickel chromium alloy or titanium alloy. They are very rigid and strong (except titanium alloy). Passive, tapered prefabricated posts required minimal removal of canal wall dentin because of their resemblance of the canal morphology but offer least retention. Additional retention can be achieved by using parallel post (Standlee *et al.*, 1978) and by the use of resin cement (Junge *et al.*, 1998).

2.3.3 Nonmetallic Passive Post

The increased aesthetic demands for metal free crown has reduced the use of metal posts. Metallic post can create a significant aesthetic issue as a result of “shine through”, as well as the interference with the natural light transmission through the tooth and the gingival complex. There are now several alternatives to metal post that offer functional, as well as aesthetic benefits.

High strength all ceramic posts were introduced with the thought of higher strength and aesthetics in mind. They are developed from materials such as zirconium oxide. Due to their white or tooth colour, they provide limited aesthetic benefit. However these posts are relatively radiopaque compared with fibre posts, but cannot be etched; therefore it is not possible to bond a composite core material to the post, making core retention a problem. Their elastic modulus is identical to that of metal posts and possessed risk of fracture of the root.

2.3.3(a) Fibre Reinforced Composite Post

Fibre-reinforced composite (FRC) posts consist of high volume percentage of continuous reinforcing fibers embedded in a polymer matrix. Matrix polymers are commonly epoxy resins or other polymers with a high degree of conversion and a highly cross-linked structure (Terry *et al.*, 2001; Grandini *et al.*, 2005).

Carbon fiber posts are introduced in 1990 (Duret *et al.*, 1990). They are made from unidirectional pre-tensed carbon fiber in epoxy matrix. Though the original version of carbon fibre post would not corrode like metal and offered exceptional functional benefits, it possessed a black (carbon) colour. Hence, improved versions of the carbon fibre post were offered with a white mineral coating/ sheath surrounding a black carbon fibre core.

Aesthetic requirements were fulfilled with the development of quartz and glass fibre post (Goldberg and Burstone, 1992). Glass fibre posts can be made of different types of glasses. Electrical glass (E-glass) is the most commonly used glass type in which the amorphous phase is a mixture of SiO_2, CaO, B_2O_3, Al_2O_3 and some other oxides of alkali metals. High strength glass (S-glass) is also amorphous but differs in composition ie. alumino silicate glass without CaO but with high MgO content providing high tensile strength (Lassila *et al.*, 2004). Additionally, quartz-fibre can be used to make glass fibre posts. Quartz is a pure silica in crystallized form. It is an inert material with low coefficient of thermal expansion (Murphy, 1998).

The fibers are silanated to the matrix of bisGMA polymers or PMMA. While the fibres provide high tensile strength, the matrix supports and combines the reinforcing fibers and should be considered to be the part which withstand compressive strength, due to the high portion of marco- and microfiller in the resin matrix (Seefeld *et al.*, 2007).

Three-point bending test was the most common method used to measure the the flexural strength and modulus of FRC post specimens. Plotino et al. (2007) compared the flexural modulus and flexural strength of three different types of FRC posts and three metal post with dentin bar and concluded that FRC posts have an elastics modulus that more closely approached that of dentine (Plotino *et al.*, 2007). Whilst its lower flexural strength compared with metal posts, FRC posts provide favourable biomechanical properties and stress distribution (Rodriguez-Cervantes *et al.*, 2007).

Besides its favourable mechanical properties, translucent fibre post allows intra-canal light transmission and consequent light cure depth up to 11.0mm (Lui, 1994b). This would increase the conversion degree of dual cured composite resin cement with a consequent improvement of their mechanical properties such as modulus of elasticity and flexural strength.(Giachetti *et al.*, 2004). The problematic handling and limited working time of autocured resin cement can be overcome by the used of translucent fiber post with light cured or dual cured resin cement. Hence, the reinforcement and rehabilitation of thin-walled roots can be achieved using light activated composite resin (Lui, 1994a; Godder *et al.*, 1994).

Other advantages of fiber posts are free of cytotoxic effects (Torbjorner *et al.*, 1996) and the fiber posts are readily retrievable after failure (Cormier *et al.*, 2001b).

The most commonly reported or perceived drawback to the fibre reinforced posts has been their lack of radio-opacity (Ibrahim *et al.*, 2006).

2.4 ‘Monoblock’ Concept

The term monoblock, literally meaning a single unit, has been employed in dentistry since early 1900’s. Two prerequisites are simultaneously required for a monoblock to function successfully as a mechanically homogenous unit. First, the materials that constitute a monoblock should have the ability to bond strongly and mutually to one another, as well as to the substrate that the monoblock is intended to reinforce. Secondly, these materials should have a modulus of elasticity that is similar to that of the substrate (Tay and Pashley, 2007). Modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region (Askeland, 2006).

A tooth that is restored with a post-core and crown can be assumed as a group of dissimilar materials that ultimately have to function as a single compound entity. Each of the individual materials will have a different mechanical property. When two components of significantly different elastic modulus form an interface, the component with the higher elastic modulus will tend to transfer functional stresses to the component with lower elastic modulus (Torbjorner *et al.*, 1996). When all of the components have a similar elastic modulus, a more uniform stress distribution throughout the restored tooth with lowered interfacial stress and chance for failure are observed (Dietschi *et al.*, 1997).

When restoring endodontically treated teeth, the residual dentin remained the most important component. Since the elastic modulus of the dentin is obviously invariant, to achieved a monoblock, all the other materials which interfaced with it should have a elastic modulus as close as possible to that of the dentin. Hence, the components move, flex and stress as one assembly – a monoblock.

Finite element analyses of tooth restored with fibre post by Pegoretti (2002) showed that the gold cast post-and-core (with a elastic modulus 7 to 10 times higher) produces the greatest stress concentration at the post-dentin interface. Fibre-reinforced composite posts do present quite high stresses in the cervical region due to their flexibility and also to the presence of a less stiff core material. However, the glass fibre composite shows the lowest peak stresses inside the root because its stiffness is much similar to dentin. Except for the force concentration at the cervical margin, the glass fibre composite post induces a stress field quite similar to that of the natural tooth (Pegoretti *et al.*, 2002).

The elastic moduli of different components in post-core and crown restored tooth were obtained from literature and presented in Table 2.1

Table 2.1 Elastic Moduli of Different Components

Component	Elastic Modulus (GPa)	Reference
Dentin	15	(Rees and Jacobsen, 1995)
Glass Fibre Post	48	(Ivoclar Vivadent, Liechtenstein) product profile
Resin Luting Cement (Dual Cure)	7	(Ivoclar Vivadent, Liechtenstein) product profile
Composite Resin Core	11	(Ivoclar Vivadent, Liechtenstein) product profile
Ni-Cr Crown	226	(Wakabayashi and Anusavice, 2000)

2.5 Fracture Resistance of Post-Restored Teeth

A persistent problem that occurs in restorative dentistry is fractures that occur in vital and endodontically treated teeth (Yeh, 1997; Ferrari *et al.*, 2000b). Tooth fracture remained the third common cause of tooth loss after dental caries and periodontal disease (Ellis *et al.*, 1999).

Different factors may influence the clinical outcomes of the post-restored teeth, such as tooth structure preservation, the ferrule effect, post length, diameter, design and material.

2.5.1 Tooth Structure Preservation

Whenever possible, coronal and radicular tooth structure should be conserved as the enlargement of post space will weaken the root (Heydecke *et al.*, 2001). In a recent study by Marchi et al.(2008), who evaluated the influence of remaining dentine thickness around post and core systems and the thermo-mechanical stresses on fracture resistance of bovine roots. They found that the remaining dentine thickness significantly increased the fracture resistance of roots restored with custom cast cores (Marchi *et al.*, 2008). Therefore, the preservation of tooth structure is the utmost essential factor in the fracture resistance of the post-restored teeth (Joseph and Ramachandran, 1990; Marchi *et al.*, 2008; Massa *et al.*, 2010).

2.5.2 The Ferrule Effect

The design of the final restoration is considered to have an effect on the prognosis of restored endodontically treated teeth. It has been proposed that an important design principle of crown preparation is the provision of a ferrule. Libman and Nicholls (1995) defined ferrule as a metal band or ring used to fit the root or crown of a tooth. Sorensen and Engelman (1990) suggested that this "ferrule effect" be defined by a 360-degree metal crown collar surrounding parallel walls of dentine and extending coronal to the shoulder of the preparation.

The ferrule or encircling band of cast metal around the coronal surface has been suggested to reinforce the coronal aspect of the post preparation and acts as an anti rotatory device (DeSort, 1983). It is consider to counteract the functional lever forces (Caputo and Hokama, 1987), the wedging effect of tapered posts, and the lateral forces exerted during insertion and function (Standlee *et al.*, 1972).

Loney et al. (1990) found that the collar had a significant effect on stress distribution. He suggested that the ferrule may help to unite different portions of the tooth. Libman and Nicholls (1995) suggested that to achieve the full benefits of the ferrule effect it should be a minimum of 1.5 mm in height and have parallel dentine walls, totally encircle the tooth, end on sound tooth structure and avoid invasion of the attachment apparatus of the tooth (Libman and Nicholls, 1995).

Akkayan (2004) evaluated the effect of 3 different ferrule lengths (1.0 mm, 1.5 mm, and 2.0 mm) on the fracture resistance and fracture patterns of crowned endodontically treated teeth restored with 4 different esthetic dowel systems (quartz fiber, glass fiber, glass fiber plus zirconia, and zirconia). Regardless of the presence of post or post type, teeth prepared with 2.0-mm ferrules demonstrated significantly higher fracture resistance (Akkayan, 2004; Lima *et al.*, 2010).

Ng et al. (2004) investigated how the absence of a ferrule affected the failure load of teeth that had been restored with bonded fiber posts and resin cores. They found that a 2 mm ferrule significantly increased fracture resistence compared with teeth restored without ferrule. For the ferrule group, root fracture was the predominant mode of failure, whereas in the non ferrule group, debonding failures were predominant.

Pereira et al. (2006) compared the fracture strengths of endodontically treated teeth using posts and cores and variable quantities of coronal dentin located apical to core foundations with corresponding ferrule designs (1-, 2-, and 3-mm ferrule) incorporated into cast restorations, respectively. They found that an increased amount of coronal dentin significantly increases the fracture resistance of endodontically treated teeth. The direct post failed due to core fracture, whereas the cast posts failed due to root fracture. Tan et al. (2005) investigated the effect of a nonuniform circumferential ferrule height on fracture resistance. The results demonstrated that central incisors restored with cast post and core and crowns with a 2-mm uniform ferrule were more fracture resistant compared to central incisors with nonuniform (0.5 to 2 mm) ferrule heights. Both the 2-mm ferrule and nonuniform ferrule groups were more fracture resistant than the group that lacked a ferrule.

In 2009, Meng et al. evaluated the effect of ferrule preparation length on the fracture resistence after simulated surgical crown lengthening and after forced tooth eruption. They found that increased apical ferrule preparation length resulted in significantly increased fracture resistance for simulated forced tooth eruption but not for simulated crown lengthening.

The ferrule effect proved to increase tooth resistance to fracture (Barkhordar *et al.*, 1989; Sorensen and Engelman, 1990b; Hemmings *et al.*, 1991; Gluskin *et al.*, 1995; Libman and Nicholls, 1995; Cathro *et al.*, 1996).

2.5.3 Post length

Several guidelines had been suggested in order to establish the more advantageous post length. According to literature, it should be (1) equal to half of the root length (Baraban, 1967), (2) equal to two-third of the root length (Bartlett, 1968), (3) equal to the length of the clinical crown (Goldrich, 1970); and (4) the post should extend as long as possible, leaving 3mm of gutta-percha to provide a reliable apical seal (Abramovitz *et al.*, 2001). These statements referred to cast metal posts which have an elastic moduli different from that of dentine or fibre post and only frictional retention in the canal (Sorensen and Martinoff, 1984a).

The most common criteria reported in the literature recommended a post length equal to ¾ of the root canal length or at least equal to the length of the crown leaving at least 4 mm of gutta-percha to achieve reliable apical (Camp and Todd, 1983; Zillich and Corcoran, 1984). The preservation of an intact apical seal must always prevail over the post length (Morgano *et al.*, 2004).

Reporting these criteria to fibre post could be considered erroneous, due to the different mechanical behavior of the post itself. Fibre post length has an effect on the amount of root dentin to be removed, potentially weaken the root (Morgano, 1996). The deeper the post insertion is, the more difficult it is to obtain a reliable bond, due to both anatomic reason i.e. reduction of dentinal tubules in apical direction and technical reason i.e. limited cleansing and accumulation of canal wall debris in the apical third of the canal (Innella *et al.*, 2005).

Stress analysis studies showed better stress distribution when longer FRC posts were used (Davy *et al.*, 1981; Asmussen *et al.*, 2005). Therefore, longer FRC post length increased the fracture resistance of post restored teeth (Sokol, 1984; Buttel *et al.*, 2009).

Buttel et al., (2009) investigated (i) the impact of post fit (form-congruence) and (ii) the influence of glass fibre post length of 6 mm and 3 mm on the fracture resistance of severely damaged root filled extracted teeth. They found the fracture resistance of teeth restored with FRC posts and direct resin composite crowns without ferrules was not influenced by post fit within the root canal. Both groups with post insertion depths of 6 mm resulted in significantly higher mean failure loads than the groups with post space preparation of 3 mm. These results implied that excessive post space preparation aimed at producing an optimal circumferential post fit was not required to improve fracture resistance of roots (Buttel *et al.*, 2009).

Santos-Filho et al. (2008) investigated exvivo the effects of different post systems and lengths of 5.0 mm; 7.5 mm and 10.0 mm on the strain and fracture resistance of root-filled bovine teeth. For all posts, decreased lengths resulted in increased microstrain values. However, the fibre posts were associated with lower increase when compared with cast post and cores and prefabricated steel posts, which showed microstrain values two times higher when the post length was 5.0 mm. The two-way analyses of fracture resistance values revealed that post length was statistically significant for the metal posts and not significant for the fibre post. The fracture mode analysis indicated that all groups tended to demonstrate root fractures in groups restored with metal posts and resin core fractures in groups restored with fibre posts. They concluded that the cast post and core when the length was 10.0 mm had the highest fracture resistance; however, the fibre post was effective with the three post lengths, with higher fracture resistance than metal posts when the length was 5.0 mm (Santos-Filho *et al.*, 2008).

Adanir and Belli (2008) evaluated the influence of different post lengths of 6 mm (shorter than 1/1 clinical crown length), 9 mm (1/1 clinical crown length), and 12 mm (longer than 1/1 clinical crown length) upon root fracture resistance. They found that posts shorter than clinical crown length, demonstrated root fracture under significantly lower loading forces ($P<.05$). They recommended that the usage of posts shorter than clinical crowns should be avoided to eliminate clinical failure (Adanir and Belli, 2008).

Besides increased fracture resistance, improvement of post retention occurred with the increase of the post length due to the increased surfaces for bonding of post and canal wall (Macedo *et al.*, 2010).

However, a study reported minimal effect of the post length on stress distribution within dentine (Burns *et al.*, 1990) and was supported by other studies which found no effect of the post length on fracture resistance on restored teeth (Lambjerg-Hansen and Asmussen, 1997; Isidor *et al.*, 1999; Cecchin *et al.*, 2010; Schiavetti *et al.*, 2010; Schmitter *et al.*, 2010a).

Nissan et al. (2008) examined the influence of a reduced post length sealed with a titanium-reinforced composite luting agent on the fracture resistance of crowned endodontically treated teeth with a 2-mm ferrule on healthy tooth structure. They concluded that post length did not influence the fracture resistance of such crowned endodontically treated teeth with a 2-mm ferrule on healthy tooth structure and suggested that prosthesis design was more important than post characteristics in fracture resistance (Nissan *et al.*, 2008).

In conclusion, the optimum post length depends on several factors such as root length, crown height, level of bone support and technique of cementation. Adhesive cements, ferrule effect, and full coronal restoration may reduce the effect of post length on the tooth facture resistance (Leary *et al.*, 1987; Nissan *et al.*, 2001).

2.5.4 Post Diameter

The use of smaller post diameter is recommended to minimize the loss of dentine during preparation of post space, which in turn enhances the fracture resistance of the post-restored tooth (Tjan and Whang, 1985; Sorensen and Engelman, 1990a). Increased radicular dentinal stresses were observed when a post diameter was increased (Mattison, 1982; de Castro Albuquerque *et al.*, 2003).

Lloyd and Palik (1993) reviewed the literature regarding the diameter of posts and identified three distinct philosophies of post space preparation. One group, the “Conservationist” advocated the narrowest diameter for fabrication of a post to a desired length (Robbins, 1990). Another group, the “Proportionist” recommended a post space with an apical diameter equal to one third of the narrowest dimension of the root at the terminus of the post (Tilk *et al.*, 1979). A third group, the “Preservationist” advised that at least 1 mm of sound dentin should surround the entire surface of the post (Caputo and Standlee, 1976). They recommended that a combination of the one third and 1 mm minimal philosophies yielded a practical guideline for post space preparation, particularly in aged teeth (Lloyd and Palik, 1993).

In a recent study to investigate the optimum diameter for the tapered post of a cast alloy post-core system relative to the root diameter, researchers recommended the optimum post to root diameter ratio to minimize failures was approximately 1:4 (Mou *et al.*, 2009).

In the case of badly damaged endodontically treated teeth with flared canals, the use of composite resins as reinforcing buildup materials has been advocated. Compromised root-filled teeth restored with resin-reinforced post and core system were reported to be more resistant to facture than those restored with a morphologic cast post and core (Saupe *et al.*, 1996).

2.5.5 Post Design

Post design has been the subject of much study, experiment and disagreement. A post should (1) have a design that provides for good retention and resistance to dislodgement; (2) apply stress evenly and minimally to the remaining tooth structure;

(3) require a conservative, minimally invasive preparation of remaining tooth structure; and (4) have a good approximation to the root canal walls. The overall post designs are classified as parallel, tapered and anatomical. The parallel and tapered designs are normally available in prefabricated posts while the anatomical shape is traditionally only possible with a custom cast post. Custom cast post have an excellent approximation to the root canal walls but, because of their rigidity, it is most likely to induce root fracture (Martinez-Insua *et al.*, 1998; Ferrari *et al.*, 2000a).

Tapered metal post cause greater cervical stress concentration that parallel posts (Davy *et al.*, 1981; Standlee and Caputo, 1992). This was attributed to the wedging effect introduced by tapered posts and a higher incidence of root fracture was reported when tapered posts were used (Sorensen and Engelman, 1990a).

Parallel posts have been generally accepted as a preferred design in terms of prevention of root fractures (Standlee *et al.*, 1982) However, since most root canals naturally possess a tapered shape or are tapered after instrumentation, the placement of a parallel post into tapered canal must usually accomplished by post preparation that removes critical tooth structure, especially in the apical portion of the canal. Hence, apical stress tend to be higher when parallel posts are used (Reinhardt *et al.*, 1983).

To overcome these problems, parallel tapered-end post design was introduced. The post has a parallel shaft and tapering at the apical end which offers the advantages of enhance retention and minimal apical tooth structure removal (Cooney *et al.*, 1986).

Silva et al. (2009) used finite element analysis (FEA) to evaluate stress distribution on endodontically treated maxillary central incisors that have been restored with different prefabricated posts. They found that fiber posts show more homogeneous stress distribution than metallic posts. They concluded that post material seems to be more relevant for the stress distribution in endodontically treated teeth than the posts' external configuration (Silva *et al.*, 2009).

A retrospective study to investigate the clinical effectiveness over up to 8 years of parallel-sided and of tapered glass-fiber posts showed that the survival rate of parallel-sided glass fibre posts (98.6%) was comparable to that recorded for tapered ones (96.8%) (Signore *et al.*, 2009).

Besides the design of the posts, the surface configuration of the post also influences the fracture resistance of post-restored tooth. Threaded post exhibits unfavourable patterns of stress distribution on placement and during function. The concentration of stresses is seen at the dentinal thread interface (Zmener, 1980). Compared with the smooth or serrated parallel of tapered posts, threaded posts have a higher incidence of root fracture (Deutsch *et al.*, 1985). The use of these posts should be confined to short or curved roots that required maximum retention with sufficient dentine thickness (Felton *et al.*, 1991; Schwartz and Robbins, 2004).

2.5.6 Post Material

There exists a definite correlation between post material and fracture resistance of post-restored tooth. Posts with higher modulus of elasticity like metals were associated with higher failure loads (Martinez-Insua *et al.*, 1998; Sirimai *et al.*, 1999; Fokkinga *et al.*, 2004; Al-Omiri and Al-Wahadni, 2006; Al-Wahadni *et al.*, 2008; McLaren *et al.*, 2009). However, they tend to cause catastrophic and irreparable root fracture (Saupe *et al.*, 1996; Akkayan and Caniklioglu, 1998; Martinez-Insua *et al.*, 1998; Fokkinga *et al.*, 2004; Al-Wahadni *et al.*, 2008; Hajizadeh *et al.*, 2009).

Fibre post with a similar modulus of elasticity to dentine can distribute stresses more evenly along the post-dentine interface and cause less root fractures (Assif *et al.*, 1993; de Castro Albuquerque *et al.*, 2003; Spazzin *et al.*, 2009). When the fibre posts failed, favourable failure modes were observed (Sidoli *et al.*, 1997; Dean *et al.*, 1998; Martinez-Insua *et al.*, 1998; Cormier *et al.*, 2001b; Akkayan and Gulmez, 2002).

Some studies showed teeth restored with fibre posts to have similar (King and Setchell, 1990; Dean *et al.*, 1998; Raygot *et al.*, 2001) or even higher (Akkayan and Gulmez, 2002, Gu and Kern, 2007) fracture resistance than those restored with metal posts.

The inconsistency of the in vitro studies results might be due to different post types, study design, tooth selection and various materials used in each study.

2.5.7 In vitro Studies

Few randomized controlled clinical trials studies have investigated the fracture resistance of teeth restored with post and core restoration. This might be attributed to the difficulties encountered in controlling related factors clinically such as force magnitude and direction, teeth geometry and remaining tooth structures (Fernandes and Dessai, 2001). In vitro studies, on the other hand, are easier to control and conduct, but their recommendations should be interpreted with caution because of their limitations and conflicting results. Three methods have been frequently used in these studies including fracture load testing, photoelastic analysis and finite element analysis.

Photoelastic analysis were used to study the pattern of stress distribution within post restored tooth. But, it is difficult to prepare a complex model mimic the oral environment and to find model material that exactly matches the modulus of elasticity of tooth structure.

The finite element method, however, has an advantage over photoelastic analysis which can provide information about the complete state of stress in a nonhomogenous body. Deformations and stresses in any point of the model can be evaluated and the stressed areas can be visualized (Pegoretti *et al.*, 2002). But assumptions related to material properties of simulated structures (ie. Isotropy homogeneity and linear elasticity) are not usually an absolute representation of the structure. In reality, the structures modeled (ie. bone, tooth, post, core and crown) are much more dynamic. In addition, the physical characteristics of the tissues vary from site to site and from individual to individual. Hence, the direct application of photoelastic and finite element methods to clinical situation is limited.

A commonly used in vitro design for investigating post-and-core restorations is fracture load testing. Extracted teeth, especially incisors and premolars, were used in these studies. Variations that may not have been considered in tooth selection were canal morphology and dentinal changes. Dentinal changes can be attributed by water content, patient age, pulpal condition and dentin composition. The above factors can affect its elasticity, thereby influent the force and fracture pattern during loading.

In these studies, the teeth are mounted for load testing in materials that have limited resiliency. But clinically, teeth have a viable periodontal ligament and are suspended in alveolar bone which is resilient. The materials used were auto-polymerized resin or dental stones. These materials set by exothermic reaction which in time may lead to decreased moisture content, crazing and weakening of the samples, hence would directly affect the fracture resistance value.

Universal testing machines were commonly used in fracture load studies. Static loading at a constant angle was applied to restored teeth. This may not be representative of the in vivo situation as actual masticatory forces are multidirectional and repeatedly applied on larger areas. This design has been criticized due to the relatively high standard deviations regarding the measured fracture load (Asmussen *et al.*, 2005).

In recent years, cyclic or intermittent loading has become more popular, because of being more representative of the forces that occurs in vivo (Drummond and Bapna, 2003). Cyclic loading is continued until failure, or to a specified number of cycles, and the result are reported as the number of cycles to failure, or as the number of failures when cycling loading was stopped. Some of these studies also reported on failure mode.

Results from studies showed that the in vitro forces responsible for failure are much higher that the maximal physiologic forces (Sorensen and Engelman, 1990b; Assif *et al.*, 1993; Isidor *et al.*, 1996). A wide range of force was obtained from studies as shown in Table 2.2.

A structured literature review aimed to elucidate test parameters for in vitro testing of post-endodontic restorations was conducted by Nauman et al. (2009). The literature search revealed 125 abstracts. Sixty-nine studies were included. 57 % of the studies investigated maxillary incisors only. The restorative stage as complex of tooth, post, core, and crown and post-and-core restored specimens without crowns were used most frequently. 59% of the studies used static loading. Only 15% of the studies performed thermocycling and mechanical loading (TCML). However, the number of thermo- and load cycles varied. The cross-head speed of linear loading after TCML ranged from 0.01 to 150 mm min (-1). The reviewed studies were heterogeneous in test design regarding the used test parameters. They recommended a methodological standardization of in vitro testing of post-endodontic restoration (Naumann *et al.*, 2009).

Therefore, the direct extrapolation of the clinical recommendations from an in vitro study must always be made with caution. Although the direct clinical application of in vitro studies is difficult, the recommendation can be used as guidelines.

Table 2.2 In vitro studies on fracture resistance of endodontically treated teeth restored with glass fibre-reinforced composite (FRC) post

Study	Load Type	Tooth Type	n	Cross head speed	Mean Failure Load (SD)N			Comments
					Group / Post Type	Failure Load(SD)N	Unfavourable failure (%)	
(Mangold and Kern, 2011)	Cyclic & Static	Mandibular Premolar	8	1 mm/ min	Glass– W3+post W0-post	 1066(211) 336(40)	 100% 0%	Ni-Cr Crown restored. Fracture resistance dependant on the number of dentin walls. FRC post strengthen teeth with 1 or no remaining wall.
(Schiavetti *et al.*, 2010)	Static	Single root premolar	10	0.75mm/ min	Glass- 5 mm 9 mm	 41(3) 45(7)	 - -	No statistically significant differences among the groups.
(Giovani *et al.*, 2009)	Static	Maxillary canine	10	1 mm/ min	Cast Glass	17(5) 32(13)	100% 30%	FRC post has higher fracture resistance than glass post at 10mm length.
(Forberger and Gohring, 2008)	Static	Mandibular premolar	8	0.5 mm/ min	Glass Zirconia Gold	1092(308) 1253(227) 1101(183)	50% 63% 37%	Ceramic crowns restored. Post-and-core foundation is recommended which demonstrated significantly greater resistance to thermal and dynamic loading stresses.
(Al-Wahadni *et al.*, 2008)	Static	Single root anterior Teeth	10	10 mm / min	Titanium Carbon Glass	572(80) 421(103) 394(124)	100% 60% 100%	Titanium posts demonstrated higher resistance to fracture when compared to carbon fiber post and glass fiber post.
(Qing *et al.*, 2007)	Static	Paired single root	11	0.5 mm/ min	Glass+Zr Cast	-261±237[1]	100% 100%	Glass fiber + zircon posts and composite resin cores exhibited

		teeth						significantly lower failure loads than those with cast post and core.
(Stricker and Gohring, 2006)	Cyclic & Static	Mandibular premolar	8	0.5 mm/ min	Glass Zirconia Cast	873(159) 482(148) 451(183)	50% 50% 38%	Composite crowns show less dramatic failure modes than those described for metal or all-ceramic crowns, irrespective of the post used.
(Gu and Kern, 2006)	Static	Maxillary central incisors	10	1.5mm/ min	Glass Titanium Cast	535(146) 500(168) 413(99)	20% 60% 80%	Restored with metal ceramic crown. Fibre posts can be recommended as an alternative to cast and prefabricated metallic posts.
(Newman *et al.*, 2003)	Static	Maxillary central incisors	10	0.5mm/ min	Glass(N)[2] Glass(F)[3] Steel(N)[2]	129(16) 129(27) 183(33)	0% 0% 30%	Stainless steel posts were more fracture resistant. Fibre post had more favourable failure modes.
(Akkayan and Gulmez, 2002)	Static	Maxillary canines	10	1mm/ min	Titanium Quartz Glass Zirconia	670(83) 912(100) 759(58) 789(80)	100% 20% 40% 70%	Support the use of fibre posts over titanium and zirconia.
(Cormier *et al.*, 2001b)	Static	Mandibular premolar	10	0.05 inch/ min	Carbon Glass Quartz Titanium Cast	176(23) 108(6) 183(10) 204(11) 185(12)	40% 0% 30% 60% 90%	Glass Fibre posts were weaker than all other tested materials but were readily retrievable after failure.

[1] The mean failure load of paired differences.

[2] Narrow canal group, post spaces were prepared with the corresponding reamer.

[3] Flared canals group, thin-walled canals were simulated; were restored with the same posts but were cemented into tapered 2 mm wide canals created with a tapered diamond bur.

Chapter Three

Materials and Methods

3.1 Materials

3.1.1 Glass Fibre Post

The fibre post system used is FRC ProstecPlus fibre post (Ivoclar Vivadent, Liechtenstein) (Fig.3.1). FRC ProstecPlus is a light-conducting, radiopaque root canal post made of glass fibres. Fig. 3.2 showed the SEM image of the longitudinal and cross section of FRC Prostec Plus. Its composition and physical properties are shown in Table 3.1. The diameter of the FRC Prostec Plus are shown in Table 3.2

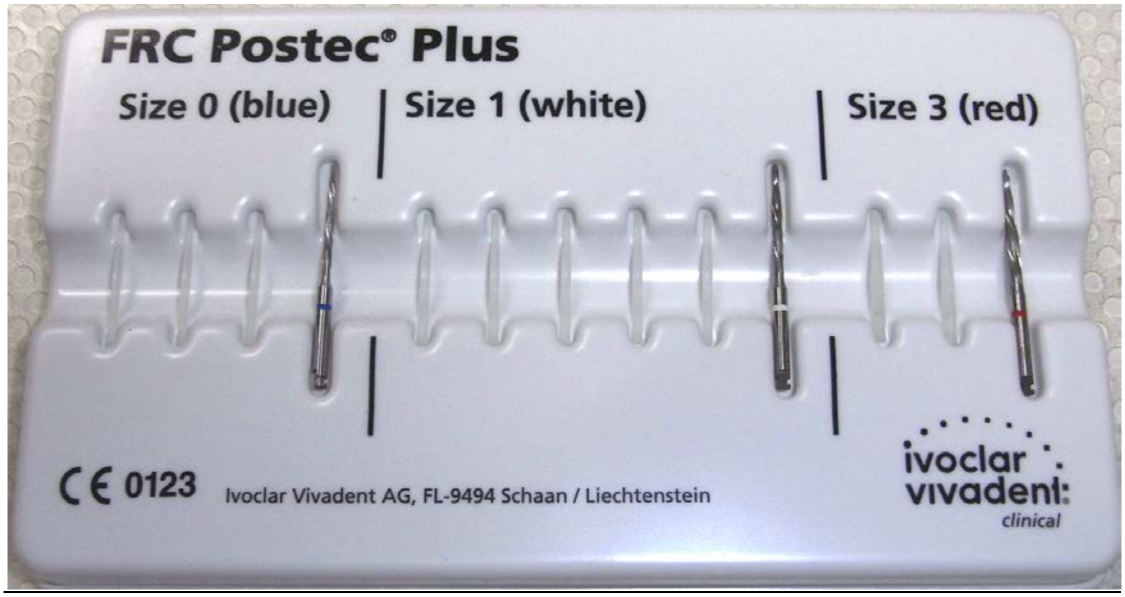
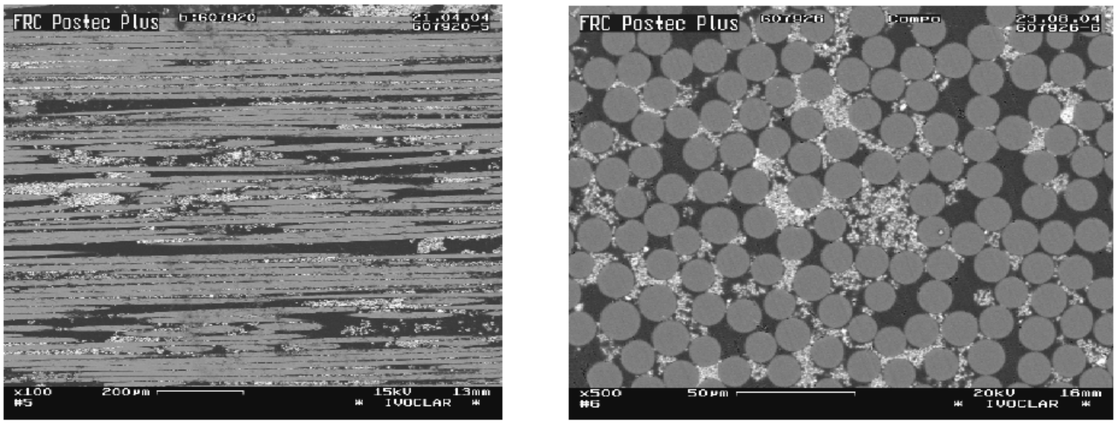


Figure 3.1 FRC Prostec Plus Fibre Post



SEM image: Longitudinal section of FRC Prostec Plus
Longitudinal direction of glass fibres embedded in a polymer matrix

SEM image: Cross section of FRC Prostec
Even distribution of the fibres in the matrix

Figure 3.2 Longitudinal and Cross Section of FRC Prostec Plus
(Adopted from manufacturer's product profiles)

Table 3.1 Composition and Physical Properties of FRC Prostec Plus Fibre Post*

Composition (in wt%)	
Dimethacrylates	approx. 21%
Ytterbium fluoride	approx. 9%
Glass fibres	approx. 70%
Catalysts and stabilizers	< 0.5%
Physical properties	
Flexural strength	1050 ± 50 MPa
Modulus of elasticity	48 ± 2 GPa
Water sorption	17 ± 1 µg/mm³
Water solubility	2.5 ± 0.25 µg/mm³
Radiopacity (Size 1/White)	330 ± 10 %Al
Radiopacity (Size 3/Red)	510 ± 20 %Al

Table 3.2 Diameter of FRC Prostec Plus Fibre Post*

Post colour code	Blue	White	Red
Diameter of apical post end (mm)	0.60	0.80	1.00
Diameter of coronal post end (mm)	1.30	1.50	2.00
Taper	5°18′	5°18′	5°18′
Length	20mm	20mm	20mm

*According to the manufacturer’s product profiles.

3.1.2 Luting Cement

The luting cement used for cementation of both fibre post and full metal crown was Multilink N (Ivoclar Vivadent, Liechtenstein) (Fig 3.3). Multilink N consists of a composite and Multilink N Primer A and B. The corresponding initiator system permits chemical curing (self-curing), which is accelerated by the contact of the composite with the primer. Furthermore, the presence of a photoinitiator provides the possibility of final polymerization with light. The composition of Multilink N are listed in Table 3.3 and the physical properties are listed in Table 3.4.

Table 3.3 Composition of Multilink N (% by weight)

Multilink N	Base	Catalyst
Dimethacrylate and HEMA	30.5	30.2
Barium glass filler and Silicon dioxide filler	45.5	45.5
Ytterbiumtrifluoride	23.0	23.0
Catalysts and stabilizer	1.0	1.3
Pigments	<0.01	-
Multilink N Primer A		
Water	85.7	
Initiators	14.3	
Multilink N Primer B		
Phosphonic acid acrylate	48.1	
Hydroxyethyl methacrylate	48.1	
Methacrylate mod. Polyacrylic acid	3.8	
Stabilizers	< 0.02	
Meta / Zirconia Primer		
Solvent	88.0	
Phosphonic acid acrylate	5.0	
Ethoxylated Bis-EMA	5.0	
Initiators and stabilizers	2.0	
Monobond- S		
3-Metacryloxypropyltrimethoxysilane	1.0	
Aethyl alcohol	52.0	
Distilled water	47.0	

Table 3.4 Physical Properties of Multilink N

Physical Properties	**Self-curing**	**Dual-curing**	
Working time (37 °C)	3 – 4		min
Setting time	7 – 9		min
Film thickness	< 20	< 20	µm
Water absorption (7 days)	< 25	< 25	µg/mm³
Water solubility (7 days)	< 3.0	< 3.0	µg/mm³
Radiopacity	350	350	% Al
Flexural strength	70 ± 20	110 ± 10	MPa
Modulus of elasticity	3250 ± 400	7000 ± 400	MPa
Compressive strength	240 ± 20	280 ± 20	MPa
Transparency Base transp. and cat.	12 ± 1.5	12± 1.5	%
yellow and cat.	10 ± 1.5	10 ± 1.5	%
opaque and cat.	2 ± 0.5	2 ± 0.5	%
Vickers hardness (HV 0.5/30)	370 ± 30	440 ± 30	MPa
Shear bond strength Dentin / 24h	17±5	21±2	MPa
Enamel / 24h	18±3	23±4	MPa

In compliance with ISO 4049:2000 – Polymer-based filling, restorative and luting materials. Mixing ratio of base and catalyst (1:1)
* According to manufacturer's product profile

Figure 3.3 Luting Cement and Resin Composite

3.1.3 Core Buildup And Canal Reinforcement Material

The core buildup and canal reinforcement material used was Tetric N-Ceram (Ivoclar Vivadent, Liechtenstein)(Fig 3.4), a light-curing, radiopaque nano-hybrid composite. The total content of inorganic fillers is 55-57 vol %. The particle size of inorganic fillers is between 40 nm and 3000 nm.

Table 3.5 Composition and Physical Properties of Tetric N-Ceram

Standard composition (wt%)	
Urethane dimethacrylate, Bis-GMA	15.0
Ethoxylated Bis-EMA	3.8
Barium glass, ytterbium trifluoride,	
mixed oxide, silicon dioxide	63.5
Prepolymers	17.0
Additives, stabilizers, catalysts,	
Pigments	0.7
Physical properties	
Flexural strength (MPa)	30,110
Modulus of elasticity (MPa)	10,800
Compressive strength (MPa)	267
Vickers hardness (MPa)	630
Water absorption (µg·mm-3)	24
Water solubility (µg·mm-3)	< 1
1Radiopacity (%Al)	400
Depth of cure (mm)	> 1.5
Transparency (%), depending on shade	6.5 - 20
Density (g·cm-3)	2.16

***** According to manufacturer's profile.

3.2 Methods

3.2.1 Tooth Collection

97 recently extracted, intact, human maxillary central incisors were collected from government dental clinic in the state of Selangor and Wilayah Persekutuan Kuala Lumpur, Malaysia and were stored in 0.9 % physiologic normal saline. Prior to use, the teeth were disinfected in 0.5% Chloramine T trihydrate solution for 7 days following ISO/TS 11405:2003 specification. The teeth were cleaned with ultrasonic scaler (Satelec, France) and external root attached tissue were removed with Gracet no 5/6 (Dentsply,USA). The teeth were placed in normal saline and stored in a refrigerator at 4°C when not in use.

3.2.2 Tooth Selection

50 intact maxillary central incisor teeth with comparable coronal and root dimension were selected from the number collected. Digital caliper (Mitutoyo, Japan) was used to measure the coronal and root length as well as faciopalatal and mesiodistal root width at cementoenamel junction (CEJ). The coronal height was limited to 10 ± 1 mm, and the root length was limited to 12.5 ± 1 mm. The faciopalatal and mesiodistal dimensions at the CEJ were limited to 6.75 ± 0.25 mm and 6.25 ± 0.25 mm respectively. The selected specimens were examined stereoscopically at x 10 magnification with stereoscopic microscope (Kyowa Optical, Japan) to verify the absence of cracks. Periapical radiograph of each specimen was taken to ensure uniformity of canal and absence of internal resorption or calcification of canal.

3.2.3 Tooth Decoronation

The crown of the specimens were decoronated perpendicular to their long axis 2.0 mm coronal to the buccal CEJ with diamond disc (Giflax, Germany) under water coolant.

3.2.4 Canal Preparation And Obturation

Standardized root canal preparation using step back technique was performed on the specimens using K-files (SybronEndo, USA). Barbed broaches (SybronEndo, USA) were used for pulp extirpation. A size 10 K-file was used to establish canal patency and the file was inserted until its tips was visible at the apical foramen. The working length was set at 1.0 mm short of the file length. The canal was first instrumented with size 15 K-files followed by #20, #25, # 30, #35, #40 and #45. Therefore, the master apical file was size 45. A size 50 K-file was inserted into the canal and if it could reached the working length, the specimen was excluded due to its large canal. The canals were further prepared using step back technique until size 60 K-file.

Sodium hypochlorite solution 2.6% (Clorox, Malaysia) was used to irrigate the canal throughout instrumentation. When the canals were fully instrumented, paper points was used to dry the canals and the canals were filled with 17 % ethylenediaminetetraacetic acid (EDTA) (Smear Clear, SybroEndo, USA) and left for 60 seconds. Final irrigation was done using distilled water to remove all of the remaining irrigant.

The instrumented teeth were obturated by lateral condensation technique with gutta-percha cones (SybronEndo, USA) and a resin based sealer (AH 26, Dentsply, Germany). The canals were thoroughly dried with size 45 paper point (SybronEndo, USA). A size 45 gutta-percha cone was inserted to full working length to ensure complete fitting. The powder and liquid of AH26 were mixed on a glass slab using a metal spatula. Two volume units of powder were mixed with one volume unit of resin and mixed to a homogeneous consistency which breaks when lifted 1.5 cm above the glass slab. The mixed cement were applied onto the tip of a lentulo spiral (SybronEndo, USA) and the lentulo spiral was slowly advanced to the apex running at very low speed and withdrew very slowly still running at low speed. The gutta-percha cone was dipped into AH26 and with pumping motion, slowly pushed into the canal. Finger spreaders (SybronEndo, USA) were used for lateral condensation and the space created were filled with accessory Fine and Medium Fine gutta-percha (SybronEndo, USA) until the spreader could not penetrate more than 2mm into the canal orifice. The gutta percha were removed using a flame-heated endodontic condenser (Dentsply, Germany) and vertical condensation was perfomed.

The canal orifices were filled with Cavit (3M ESPE, USA). The obturated teeth were stored in distilled water at 37°C for 24 hour for the full setting of the sealer.

3.2.5 Grouping

The 50 selected, root treated teeth were randomly assigned to five groups of 10 teeth each which are Group B,W,R, BR and WR according to the size of glass fibre post used.

For group B,W and R the post spaces were prepared up to the corresponding size of the post used [FRC ProstecPlus fibre post (Ivoclar Vivadent, Liechtenstein)]. Whereas, for group BR the post space was prepared up to size 3(Red) and the glass fibre post used was size 0(Blue). For group WR the post space was prepared up to size 3(Red) and the glass fibre post used was size 1(White). The groups were illustrated in the Table 3.6 and Figure 3.4.

Table 3.6 Grouping of The Specimens

Group	**Post space diameter(mm)**	**Post diameter (mm)**
B	A= 0.60 ; C= 1.30	A= 0.60 ; C= 1.30
W	A= 0.80 ; C= 1.50	A= 0.80 ; C= 1.50
R	A=1.00 ; C=2.00	A= 1.00 ; C= 2.00
WR	A=1.00 ; C=2.00	A= 0.6 ; C= 1.30
BR	A=1.00 ; C=2.00	A= 0.8 ; C= 1.50

A= Apical section diameter; C= Coronal section diameter

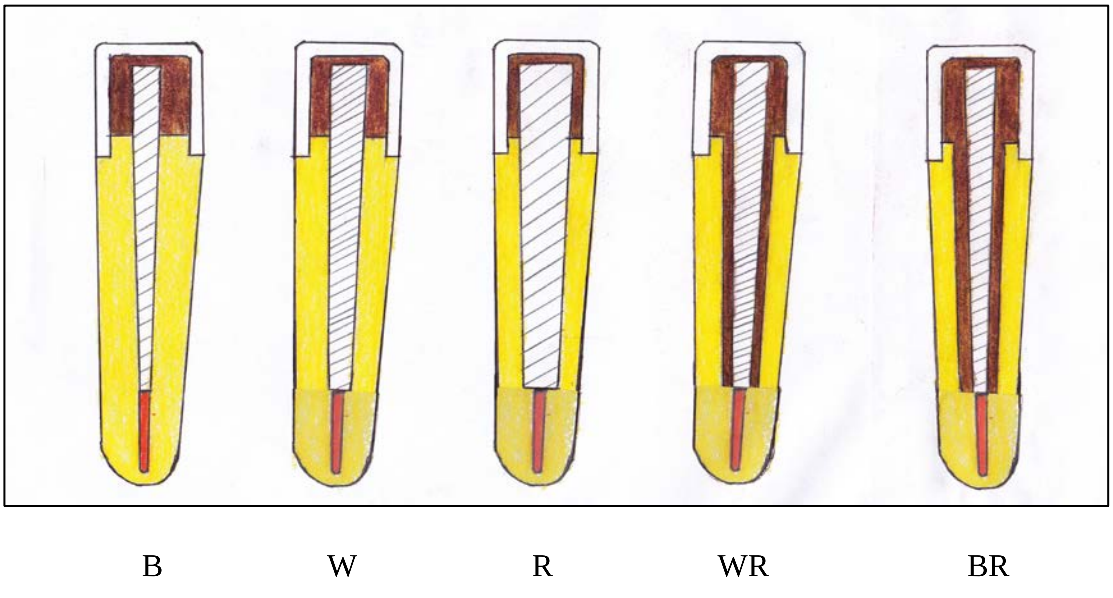


Figure 3.4 Grouping of The Specimens

3.2.6 Post Space Preparation

The gutta-percha were first removed using Gates Glidden burs size 3 and 4 (Dentsply Maillefer, Switzerland) 4.0 mm short of working length. The required preparation depth was determined and marked on the corresponding drill by using silicone stopper. The post spaces of the teeth were prepared using the low speed driven drill provided in the post system up to 4.0 mm apical gutta-percha remained.

For teeth in Group B, the size 0 (Blue colour coded) drill was used to prepare the post space. For teeth in Group W, the size 1(White colour coded) drill was used to prepared the post space. Whereas for teeth in Groups R, BR and WR the size 3 (Red colour coded) drill was used to prepare the post space.

Periapical radiograph of each specimens was taken to ensure correct post space preparation without weakening of roots and absence of gutta-percha.

3.2.7 Post Placement And Cementation

In group B, W and R, the fibre posts were cemented with a self curing resin luting cement Multilink N Primers A/B and Multilink N (Ivoclar Vivadent, Liechtenstein).

The fibre posts were tried into the post space to check proper fit of the post. The fibre posts were cleaned with 37 % phosphoric acid (Total Etch, Ivoclar Vivadent, Liechtenstein). The etching gel were left for 60 seconds before thoroughly rinsing with water and dried with dry, oil-free air. The fibre post was silanated using (Monobond S, Ivoclar Vivadent, Liechtenstein) for 60 seconds and dried with dry, oil-free air. Care was taken not to touch the silanated surface with fingers.

The prepared teeth were irrigated with sodium hypochlorite solution 2.6% (Clorox, Malaysia) and final irrigation was done using distilled water to remove all of the remaining irrigant and dried with paper point.

The two Multilink N Primer liquid A and B were mixed in a 1:1 mixing ratio. The mixed Primer A/B was applied to the post space with elongated micro-brush provided and left for 15 seconds. Paper point size 80 was used to absorb the excess primer.

A new automix tip was placed on the syringe of Multilink N and the cement was dispensed and applied directly to the fibre post making sure full coverage of cement onto the apical 2/3 of the fibre post. The cement-coated fibre post was inserted slowly into post space with a clockwise rotation up to the desired length marked with silicone stopper. Excess cement was briefly cured for 2 seconds with light cure (Spectrum 800, Dentsply, USA). The excess cement were removed with a probe. Subsequently, the cemented post was further light cured for 40 seconds with a light intensity of 800 mW/cm^2 by positioning the light guide tip at a distance of 1-2 mm from the post space openings .

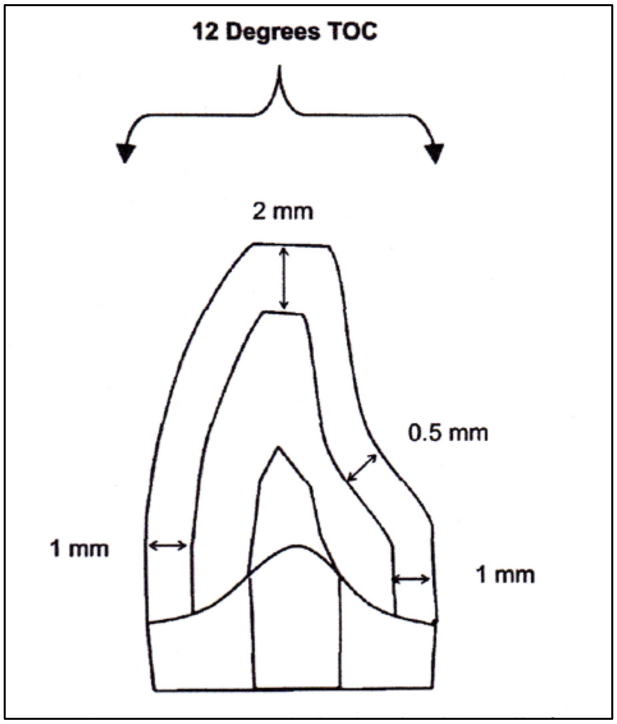
In groups RW and RB, the preparation of fibre post and post space were the same except the post spaces were filled with Tetric N-Ceram (Ivoclar Vivadent, Liechtenstein) in cavifil form before the post was placed. The resin composite was injected into the post space until the post space was fully filled with resin composite. Immediately, the post was inserted in a clockwise rotation until full length marked by silicone stopper. The excess resin was briefly light cured for 5 seconds and excess was removed with a probe. Subsequently, the cemented post was further light cured for 40 seconds with light intensity of 800 mW/cm².

3.2.8 Core Build Up

Composite cores were built up using Tetric N-Ceram (Ivoclar Vivadent, Liechtenstein). The post cemented teeth were applied with mixed Multilink N Primer A/B and left for 15 seconds and dried with dry, oil-free air. The composite cores were built up with a core heights of 6.5 mm measured from the buccal tooth margin. The composite cores were built according to the morphological shape of maxillary central incisor. The composite cores were light cured for 20 seconds with light intensity of 800 mW/cm².

3.2.9 Tooth Preparation for Cast Crown

Tooth reduction for crown preparation was performed to standardized specification as shown in Figure 3.5. The crown margin was designed to follow the simulated contours of the free gingival tissue with the facial and lingual extent of the margin 1.5 mm more apical compared to the proximal margins. The margin was 1 mm wide with a 12 degree total occlusal convergence as well as 1.0 mm of facial reduction with a round shoulder diamond bur. The lingual reduction was 0.5mm. Ferrule of 2.0mm was created at facio-lingual margin and a ferrule of 0.5mm was created at the proximal margin. The core height of 6 mm was prepared with facio-lingual thickness of 1 mm at incisal edge. A plastic crown former PD 171 (Product Dentaire, Switzerland) was used as reduction guide. Figure 3.6 showed the prepared tooth following the above specification.



TOC = Total occlusal convergence

Figure 3.5 Standardized Specification of Crown Preparation.

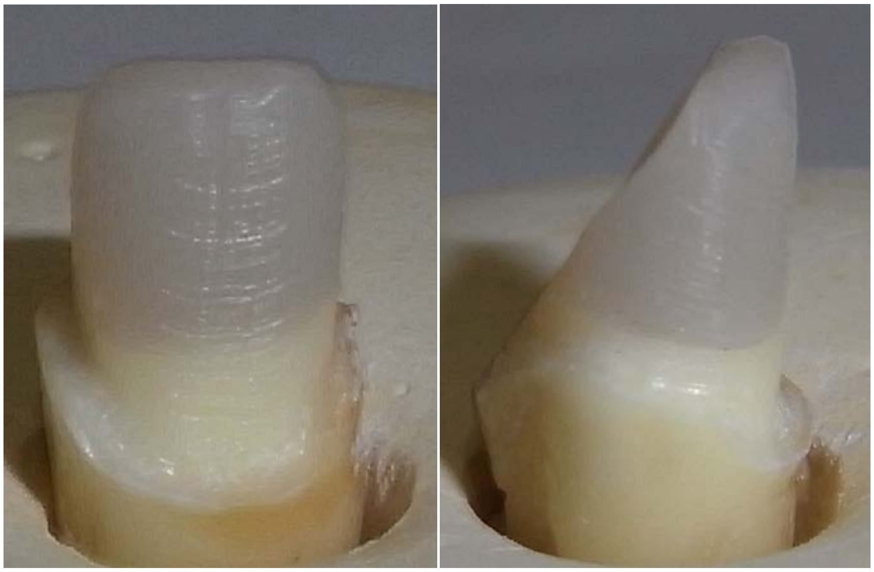


Figure 3.6 Prepared Tooth

3.2.10 Impression Taking And Cast Crown Fabrication

The root of the prepared teeth were lightly coated with petroleum oil (Vaseline, USA) and 5 teeth were invested into a dental stone mould modified with disposable impression tray and secured with sticky wax. The dental stone were poured into the mould to cover the roots of the teeth and left for 60 minutes before removed from the mould. Impression was made with silicone impression material (Aquasil, Dentsply, USA) using disposable dental impression tray. The impressions were invested with dental stone and wax patterns were then made following the plastic crown former PD 171 (Produits Dentaires, Switzerland) to create the standardized crown contour. Wax pattern of each tooth was invested and the investment was placed in a preheated burnout oven and left for 45 minutes. The wax pattern was cast in Ni-Cr Alloy (System KN, Adentatec, Gemany) with the aid of centrifugal casting machine.

3.2.11 Cementation of Crown

Crowns were seated to prepared tooth to ensure good marginal fitting. The inner surface of the crown was air blast and cleaned with water followed with dry, oil free air before coated with Metal/Zircornia Primer (Ivoclar Vivadent, Liechtenstein). The primer was left for 180 seconds before dried with dry, oil free air.

The prepared teeth were coated with mixed Multilink Primer A/B and left for 15 seconds before dried with dry, oil free air. Multilink N (Ivoclar Vivadent, Liechtenstein) was dispensed fully to the inner surface of the cast crown and fitted to the tooth. Excess cement was briefly cured for 2 seconds with light cure (Spectrum 800, Dentsply, USA). The excess cement were removed with a probe. The fitted crown were left for 360 seconds to set.

3.2.12 Tooth mounting

The teeth are first removed from stone block. The roots were cleaned and marked 3.0 mm from the crown margin. The roots were coated with a 0.1-0.2mm thin layer of vinyl polysiloxane silicone (Aquasil, Dentsply, USA), to simulate the periodontal ligament. The teeth were embedded, 3.0mm apical to crown margin, in a block of self cure resin epoxy resin (Mirapox 950, Malaysia) with a custom made cubic mold (23 mm width x 23 mm length x 25 mm height). The teeth was surveyed with dental surveyor to ensure the long axis of the root was perpendicular to the horizontal plane before been secured on the mould by two metal wire and sticky wax. The specimens were left for 24 hours to allow complete setting. Figure 3.7 showed the mounted specimen.

Figure 3.7 Mounted Specimen

3.2.13 Thermocycling

The mounted teeth were stored in distilled water at 37°C and 100 % humidity for 24 hours prior to thermocycling in a thermocycling machine (Fabricated by Faculty of Engineering, University of Malaya, Malaysia). The teeth were placed in a wired mesh attached to the machine arm and were thermocycled 500 times from 5 to 55°C with 30 second dwell time with two seconds transfer interval according to ISO/TS 11405:2003.

3.2.14 Failure Load Testing And Failure Mode Identification

The specimens were fixed in a customized jig fabricated to align the long axis of the tooth at an angle 45° to the horizontal plane and 135° to the loading rod tip. This jig was secured to the lower compartment of a high precision universal testing machine (Shimadzu, Japan). A unidirectional static load was applied on the centre of lingual surface of the crown (5.0mm from incisor edge) using a flat end rod (2.0mm x 10.0 mm) at a crosshead speed of 0.5 mm/min (Figure 3.8). The load was applied until failure occur as measured by a sudden drop of the stress-strain curve which was displayed on the computer monitor connected to the machine.

Figure 3.8 Failure Load Testing With Universal Testing Machine

The mode of failure for each of the specimens was noted by visual inspection. The failure mode was classified into either favourable or unfavourable (Fokkinga et al., 2004). The favourable failure modes were complete or partial post and core debonding or post-core tooth complex fracture above the epoxy resin level. Whereas, the unfavourable failure mode were fracture of the post-core-tooth complex below the epoxy resin, vertical root fracture or tooth cracks below the epoxy resin level.

3.2.14 Statistical analysis

All data were analyzed using Statistical Programme for Social Science (SPSS) for Windows version 12.0 (SPSS Inc., USA). One way analysis of variance(ANOVA) was used to detect the presence of groups differences. The post-hoc (Bonferroni) test was used for multiple comparisons. The probability level for statistical significance was set at α=0.05.

Chapter Four

Results

4.1 Failure Loads

4.1.1 Descriptive Analysis of the Failure Loads

The raw data of the load at failure of each specimen is shown in Appendix I. The mean and standard deviation values for the load at failure for each group are shown in Table 4.1. Figure 4.1 shows the mean failure load in the form of graph.

Table 4.1 Mean failure load and standard deviation for each group

Group	Mean failure load (N) ± (SD)
B	1406(376)
W	1259(379)
R	1085(528)
WR	959(200)
BR	816(298)

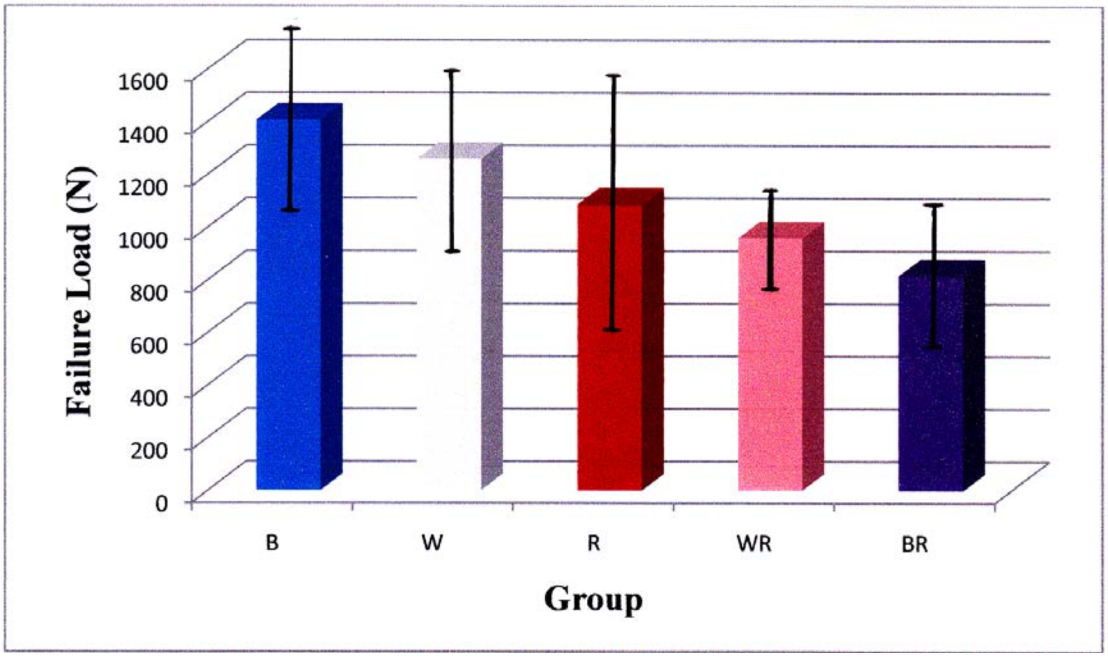


Figure 4.1 Mean failure loads for each group

Group B had the highest mean failure load (1406 N) and Group BR had the lowest mean failure load (816 N).

4.1.2 Statistical analysis for the mean failure loads

Histogram of all specimens and Levene's test were used to test the assumptions of normality and homogeneity before comparing the means (Appendix 5). The histogram for all specimens were normally distributed, Levene's test was not significant as P>0.05. Assumption of equal or homogeneity of variance was met. Therefore One Way ANOVA was used to determine the differences among groups (Table 4.2).

Table 4.2 One-way Analysis of Variance (ANOVA)

Failure Load

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2196456.358	4	549114.089	3.959	0.008
Within Groups	6241494.862	45	138699.886		
Total	8437951.220	49			

The ANOVA test was significant (P<0.05), suggested that at least one pair of the groups was significantly different. Post-hoc (Bonferroni) pairwise comparisons were conducted to test the differences between each pair of means (Table 4.3).

Pairwise comparisons showed that there was a statistically significant difference in failure load between Group B and Group BR (p<0.05) with mean difference 590.15 and 95 % CI = 98.45, 1081.83. While there was no statistically significant difference between other groups, the Null hypothesis was rejected since P < 0.05 and 95% CI did not include 1.

Table 4.3 Post-Hoc (Bonferroni) Multiple Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
B	W	147.29800	166.55323	1.000	-344.3803	638.9763
	R	321.51100	166.55323	.599	-170.1673	813.1893
	BR	590.14800(*)	166.55323	.009	98.4697	1081.8263
	WR	447.26470	166.55323	.101	-44.4136	938.9430
W	B	-147.29800	166.55323	1.000	-638.9763	344.3803
	R	174.21300	166.55323	1.000	-317.4653	665.8913
	BR	442.85000	166.55323	.108	-48.8283	934.5283
	WR	299.96670	166.55323	.784	-191.7116	791.6450
R	B	-321.51100	166.55323	.599	-813.1893	170.1673
	W	-174.21300	166.55323	1.000	-665.8913	317.4653
	BR	268.63700	166.55323	1.000	-223.0413	760.3153
	WR	125.75370	166.55323	1.000	-365.9246	617.4320
BR	B	-590.14800(*)	166.55323	.009	-1081.8263	-98.4697
	W	-442.85000	166.55323	.108	-934.5283	48.8283
	R	-268.63700	166.55323	1.000	-760.3153	223.0413
	WR	-142.88330	166.55323	1.000	-634.5616	348.7950
WR	B	-447.26470	166.55323	.101	-938.9430	44.4136
	W	-299.96670	166.55323	.784	-791.6450	191.7116
	R	-125.75370	166.55323	1.000	-617.4320	365.9246
	BR	142.88330	166.55323	1.000	-348.7950	634.5616

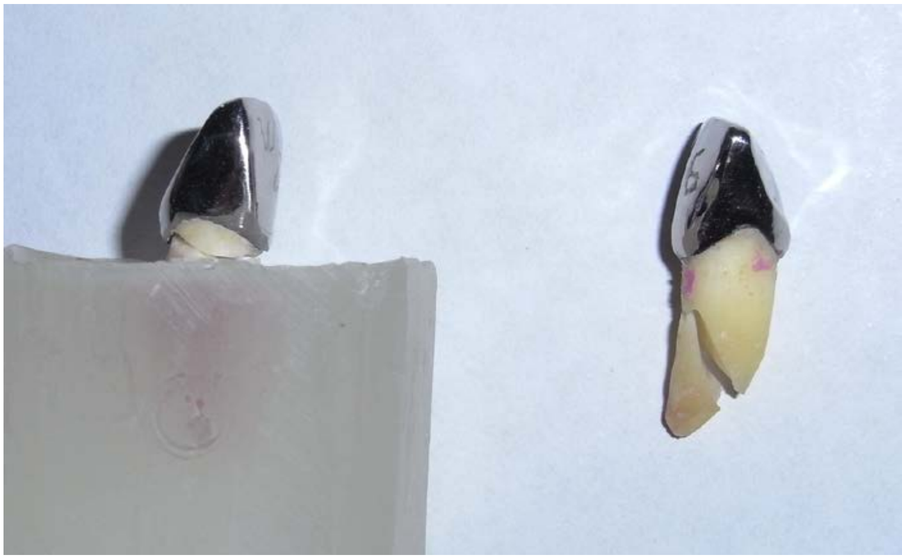
* The mean difference is significant at the 0.05 level.

4.2 Failure Modes

Failure modes for each specimen were recorded according to classification previously mentioned in section 3.2.14. For all of the unfavourable failure, the fracture patent was oblique fracture from cervical to the root (Figure 4.2). Table 4.4 and Figure 4.3

showed the number and percentage of both favourable and unfavourable failure mode in each group.

Group BR had the highest percentage of unfavourable failure. Group B had the lowest unfavourable failure.



Favourable Unfavourable

Figure 4.2 Failure Mode of Specimen

Table 4.4 Failure mode

Group	n	Favourable Failure, n (%)	Unfavourable Failure, n (%)
B	10	7 (70%)	3 (30%)
W	10	6 (60%)	4 (40%)
R	10	4 (40%)	6 (60%)
WR	10	4 (40%)	6 (60%)
BR	10	3 (30%)	7 (70%)

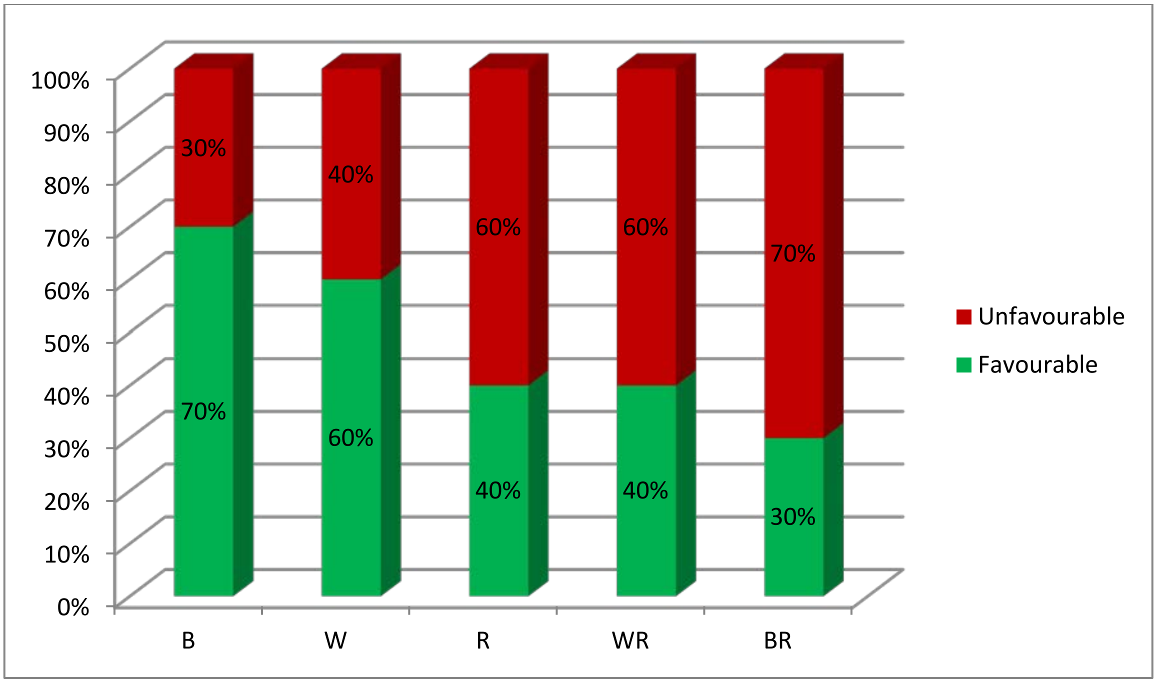


Figure 4.3 Percentage of Failure Mode

Chapter Five

Discussion

5.1 Methodology

5.1.1 Tooth selection and storage

The selection of intact human central incisors represents the best possible option to simulate the clinical situation for endodontically treated teeth. Previous studies had reported their use as an acceptable way to research post restored teeth (Martinez-Insua *et al.*, 1998; King and Setchell, 1990). The main disadvantage of using human teeth was the relatively large variation in size and mechanical properties (Morgano and Milot, 1993), often resulting in large standard deviations. In addition, there was also dentinal variation due to difference in water content, pulpal conditions before extraction, patient age and composition of the dentine itself.

On the other hand, artificial roots cannot mimic natural dentine and their adhesion to the post is unrealistic and not similar to the clinical situations. Rosentritt *et al.*(2009) reported that no artificial tooth substitute made of metal and resin showed fracture patterns similar to those of natural incisors and the range of artificial tooth substitutes suitable for the replacement of human incisors was limited by load capability (Rosentritt *et al.*, 2009).

In this study, the teeth were carefully selected for standardized size as this was reported as an important variation in the resistance to fracture of the specimen (Sirimai *et al.*, 1999). Root length, faciopalatal and mesiodistal dimensions were standardized to minimize the dimensional variation in the specimens. This was also similarly observed for fabrication of standardized core build-ups and full coverage crowns.

The freshly extracted teeth were disinfected using 0.5% Chloramine T aqueous solution for one week as recommended by ISO/TS 11405:2003. Study by Naumann et al. (2010) showed that there was no statistical significant difference in the median fracture load values after static loading without and with 1year of storage in 0.5% chloramine solution (Naumann *et al.*, 2010). The teeth were placed in normal saline and stored in a refrigerator at 4°C when not in use to preserve the water content.

5.1.2 Canal Preparation and Obturation

In this study, the canals were prepared using step back technique with K-file which was a common practice in endodontic treatment. The canals were irrigated with 2.6% sodium hypochlorite solution throughout instrumentation. Studies have reported sodium hypochlorite can reduce the flexural strength and elastic modulus of dentine by depleting the organic content of dentine which was concentration-dependent (Sim *et al.*, 2001; Marending *et al.*, 2007). On the other hand, antimicrobial effect of sodium hypochlorite was also concentration-dependent (Radcliffe *et al.*, 2004; Vianna *et al.*, 2004; Carson *et al.*, 2005). Therefore, 2.6% sodium hypochlorite was used in this study as it was proven equally effective in antimicrobial effect at this concentration (Harrison *et al.*, 1990).

The working length was set at 1 mm short of the apical foramen as a previous study had shown that this length might produce fewer cracks in the apical region (Adorno *et al.*, 2010).

17% Ethelenediaminetretraacetic acid (EDTA) was used for final irrigation of instrumentation to remove smear layer from the root canal wall (da Silva *et al.*, 2008; Mello *et al.*, 2008). The use of EDTA also improved the resistance of the resin-dentine bond sites to chemical degradation and resulted in more durable resin-dentine bonds (Miyasaka and Nakabayashi, 2001; Sauro *et al.*, 2009).

The prepared canals were obturated using lateral condensation technique which was proven to be an efficient technique (Peli *et al.*, 1990). But care was taken as over-force and improper operation are both dangerous that can give rise to vertical root fracture (Hong *et al.*, 2003).

The sealer used in this study was a resin based sealer which was eugenol free to eliminate any possible effect on the polymerization of resin luting cement or resin composite planned for cementation of glass fibre post (Hagge *et al.*, 2002; Alfredo *et al.*, 2006; Dias *et al.*, 2009).

5.1.3 Post space preparation

The obturated teeth were stored in an incubator at 37^{o} C and 100% humidity for 24 hours to allow the complete set of the sealer. In this study, post space preparation was performed 24 hours after obturation as studies showed no significant difference among the delayed or immediate space preparation on apical seal (Aydemir *et al.*, 2009; Grecca *et al.*, 2009).

The gutta-percha was removed with Gates Glidden burs size 3 and 4 as this method was more efficient and relatively easy to manipulate (Schwartz and Robbins, 2004; Grecca *et al.*, 2009). Studies has shown no significant difference among techniques of gutta-percha removal when 4-5 mm of gutta-percha was left (Camp and Todd, 1983; Hiltner *et al.*, 1992), with the exception of a study which stated that mechanical method is the most desirable for gutta-percha removal in post preparation (Mattison *et al.*, 1984).

In this study, 4 mm of gutta-percha were left to provide sufficient apical seal (Raiden and Gendelman, 1994). With this amount of gutta-percha left in the canal, the post length in this study was 8.5 mm±1.0 mm or closed to ¾ of the root length which was recommended by literatures (Camp and Todd, 1983; Zillich and Corcoran, 1984).

This post length was also closed to the clinical crown length of 10 mm to provide better fracture resistance (Adanir and Belli, 2008).

5.1.4 Grouping

In this study, the teeth were randomly assigned to five groups of 10 teeth each. For groups B,W and R, post spaces were carefully prepared using the corresponding reamer which resulted in a close fit of the post to the canal walls. The ratio of the apical diameter of fibre post were B:W = 1:1.33, B:R = 1: 1.67 and W:R = 1:1.25.

For groups BR and WR, the post spaces were prepared using the largest reamer with a diameter of 1.00 mm and 2.00mm at the apical and cervical respectively. The fibre posts used in groups WR and BR had a 20% and 40% reduction in apical diameter respectively. Therefore, a flared canal was simulated in these groups.

5.1.5 Post Placement And Cementation

The fibre posts used in this study were acid etched with 37% phosphoric acid and silanated. Silanization of fibre post proved to improve the retention of composites around etched fibre post with minimal nanoleakage (Monticelli *et al.*, 2006; Cheleux *et al.*, 2007; Rathke *et al.*, 2009).

For groups B,W and R, the fibre posts were cemented using a dual cure resin cement . This adhesive system was applied together with the self etching, self curing primer. The use of self etching adhesives were recommended by Kivanc and Gorgul (2008) although not Pereira et al. (2010) stated that neither the adhesive nor the post space region influenced the degree of conversion and bond strength of the dual cure resin cement. It was also reported that the use of a self-activating dual-curing adhesive system in combination with a dual-curing cement enables effective luting of fibre posts regardless of the amount of light transmitted through the post (Vichi *et al.*, 2011).

The cemented posts were light cured for 40 seconds with light intensity of 800 mW/cm^2 which exceeded the acceptable light density of 600 mW/cm^2 (Oto *et al.*, 2009). With the mechanical properties of the teeth would be enhance as the dual-polymerized resin luting agents used had higher or equal flexural strength compared to the autopolymerized mode (Lu *et al.*, 2005). Photo-initiated polymerization of the adhesive resin and dual-cure resin composite was also found to be necessary to achieve good bonding to root canal dentine (Foxton *et al.*, 2003).

For groups BR and WR, flared canals were simulated. The canal walls were also applied with the same primer but the resin luting cement was replaced by light curing resin composite. The void between the fibre post and canal wall was thus filled with resin composite to serve as reinforcement for the canal. The use of resin composite to strengthen weakened roots was first recommended by Lui in 1987. Boschian Pest et al. (2002) studied the bond strength between luting materials, root dentine and fiber posts and they concluded that the bond strength tests and SEM observations showed that, in vitro, composite resins performed better than resin cements and recommended the use of these materials which may significantly reinforce residual tooth structure; therefore reducing the risk for fracture and debonding (Boschian Pest *et al.*, 2002). However, although hybrid composites showed superior bond strengths in oversized canals, they were still not as high as those of posts in precisely fitting post spaces using common resin cements (Schmage *et al.*, 2009).

In this study, the use of light-curing resin composite was used even though the post length was 8.0mm as study has shown that complete cure of resin composites with light transmitting posts can be achieved at this length (Anoorshiravani and Nathanson, 1996).

5.1.6 Core Build-Up

For this study, the core was built up with hybrid composite, with a modulus of elasticity of 11GPa, which was very similar to the modulus of elasticity of dentine (15 GPa) and was thus able to realize a tooth-post-core monoblock that could homogeneously distribute masticatory loads and reduce stress (Dallari and Rovatti, 1996). The core build-up was done without any matrix as a study showed that when hybrid composites were used to build up a core onto a fiber post, a higher homogeneity of the abutment and a better post-core integration were achieved if the build-up was done in the absence of any matrix (Monticelli *et al.*, 2004). Although core built up with flowable composites showed the highest integrity and the best adaptation onto the post (Monticelli *et al.*, 2005), bond strength to fibre post remained relatively weak. Therefore, core build-up with hybrid composites were better alternatives to flowable composites as core build-up materials (Sadek *et al.*, 2007).

5.1.7 Coronal Restoration

The teeth in this study were restored with Ni-Cr cast crown. The crown of teeth were decoronated perpendicular to their long axes 2.0mm coronal to the buccal CEJ, it was possible to design the prepared crown margin to follow the simulated contours of the free gingival tissues with facial and lingual extended 1.5mm more apical than the proximal margin. Therefore, the ferrule was created 2 mm at facio-lingual margin and 0.5 mm at proximal margin. It has been a common practice that, when there is extensive tooth lost with remaining structure of 2mm above CEJ, a crown restoration will be indicated. Thus, the study design resembled the in vivo condition allowing extrapolation of the results to the clinical situation (Sorensen and Engelman, 1990b; Milot and Stein, 1992; Assif *et al.*, 1993; Mannocci *et al.*, 1999; Sirimai *et al.*, 1999).

However, there were studies which had shown that different ferrule designs did not have any significant influence on the fracture resistance of teeth restored with fibre posts (Dikbas *et al.*, 2007; de Oliveira *et al.*, 2008; Lima *et al.*, 2010; Sherfudhin *et al.*, 2011). This in contrast with other studies which showed that increased ferrule length improved the mechanical behaviour of teeth restored with metal crowns, irrespective of post or core type (Akkayan, 2004; Naumann *et al.*, 2007; da Silva *et al.*, 2010). Hu et al. (2005) concluded that using FRC post might get a long fatigue life in restoring pulpless teeth with flared canals and that dentine ferrule preparation was necessary to enhance resistance of the restorations to cyclic fatigue. Besides, the insertion of a fibre post could reduce the percentage of catastrophic failure of these restorations under function (Meng *et al.*, 2007; Sherfudhin *et al.*, 2011). Additionally, Schmitter et al. (2010) found that increased ferrule height and resin bonding of the crown resulted in higher fracture loads. They concluded that crowns, especially those with a small ferrule height, should be resin bonded. It was also reported that, centrally positioned fiber-reinforced posts did not contribute to load transfer as long as the bond between the tooth and composite core was intact (Schmitter *et al.*, 2010b). Therefore, fiber posts can safely be used for their reinforcing properties regardless of ferrule height. The property of these types of posts is an additional advantage in clinical practice (Dikbas *et al.*, 2007).

5.1.8 Tooth mounting

In this study, the biological width of the periodontium was simulated by embedding the teeth 3.0mm apical to the crown margin in a block of self cure epoxy resin (Cormier *et al.*, 2001b). It was believed that the use of a rigid material to embed extracted teeth could lead to distorted load values and possibly affect the mode of failure of the specimens (Sirimai *et al.*, 1999). Therefore, the roots were coated with a 0.1-0.2mm thin layer of vinyl polysiloxane silicone to simulate the periodontal ligament (Sirimai *et al.*, 1999). The moduli of elasticity of these materials therefore approximated those of the viscoelastic periodontal ligament and the alveolar bone respectively (Bourauel *et al.*, 1999). On the other hand, however, this simulation of periodontal ligament might have limitations due to its complex viscoelastic nature in vivo (King and Setchell, 1990) and thus might cause uncontrolled tooth movement under load (Guzy and Nicholls, 1979). However, the design of this study was similar to other studies that simulate the periodontal ligament of natural teeth (Newman *et al.*, 2003; Moosavi *et al.*, 2008; Nakajima *et al.*, 2010; Toman *et al.*, 2010).

5.1.9 Thermocycling

The thermocycled specimens were carried out according to ISO/TS 11405(2003). Specimens which underwent thermocycling gave more meaningful results as the moisture and temperature changes in the oral environment were simulated. In relation to bond strength of resin cement, various studies showed a significant increase after thermocycling (Tezvergil *et al.*, 2003; Bitter *et al.*, 2006; Albashaireh *et al.*, 2010; Mazzitelli *et al.*, 2011). However, in relation to fracture resistance, no such studies have been reported in the literature.

5.1.10 Loading angle

In this study, the loading angle was set at 135˚ to the long axis of the teeth (Figure 5.1). The average interincisal angle between maxillary and mandibular incisors in class I occlusion was simulated (Ceylan *et al.*, 2002).

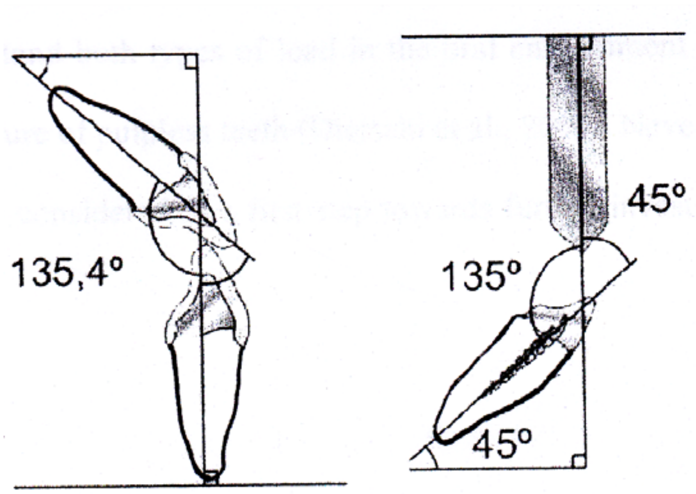


Figure 5.1 Loading Angle (Adopted from Melo et al., 2005)

5.1.11 Static Loading Vs. Cyclic Loading

In this study, the teeth were loaded with an increasing, unidirectional static load applied at a standardized fixed point of the metal crowns until failure occurred. Most of the in vitro studies comparing fracture resistance of post-restored teeth used static loading (Cormier *et al.*, 2001a; Akkayan and Gulmez, 2002; Newman *et al.*, 2003; Gu and Kern, 2006; Qing *et al.*, 2007; Al-Wahadni *et al.*, 2008; Forberger and Gohring, 2008; Giovani *et al.*, 2009; Schiavetti *et al.*, 2010). However, this might not be representative of the actual in vivo situation as the masticatory forces are multidirectional and repeatedly applied on larger area. Therefore, cyclic loading test give a more realistic simulation of the oral environment. Nonetheless, the design of this study provided a baseline on the maximum clenching or parafunctional masticatory force a post-restored tooth could withstand either as a single tooth or a fixed prosthesis.

5.2 Results

5.2.1 Failure Loads

On the basis of the statistical analysis of the data, the null hypothesis was rejected. There was a significant difference among the groups studied. The results show that the failure load for group B (most dentine thickness) was significantly higher than those in group BR (least dentine thickness and thickest reinforcing resin composite). The descending order of fracture strength for the tested groups was B>W>R>WR>BR. These results suggested that the lower load value obtained for the BR group were due in part, to the decrease in remaining dentine and, instead of a fully fitting glass fibre post, reinforcing resin composite was used as replacement. On the other hand, although numerically different, there were no significant differences between the other groups. The result of the mean failure load was consistent with the results of a study by Bonfante et al. (2007) with fracture load ranging from 745 to 920 N. The fibre post system used (FRC Prostec) probably contributed to the greater strength as similarly displayed in this study (Soares *et al.*, 2010).

Comparison between groups B, W and R, which had no reinforcing resin composite, it showed that there was no significant differences in mean failure load. Group B with the largest amount of remaining dentine provided highest fracture resistance and more favourable failure mode. The enlargement of post space therfore decreased the fracture resistance. However, this decrease was not statistically significant.

The effect of the intraradicular reinforcement with resin composite on the fracture resistance of the teeth was one of the interests of this study. Under the conditions of this study, the increased thickness of reinforcing composite had no effect on the fracture resistance of enlarged canals. Though the results of this study somewhat differed from those reported by Saupe et al. (1996), however it was noted that the teeth were restored with metallic posts after intraradicular reconstruction with composite rather than fiber posts as used in this study, where the monoblock effect might have contributed to the difference.

Comparison between groups R, BR and WR which had the same post space but different glass fiber post diameters and reinforcing resin composite thicknesses in groups BR and WR, showed no significant differences in mean failure load. Group BR with the largest amount of reinforcing resin composite displayed the the lowest fracture resistance. The increase of the thickness of reinforcing resin composite decreased the fracture resistance but this difference was not statistically significant.

In comparing between groups W and WR which had the same fiber post diameter but different dentine thicknesses, there was no significant difference in mean failure load. The lost of remaining dentine was replaced with reinforcing resin composite resulting in a decreased in fracture resistance. However, this difference was also not statistically significant.

However, comparison between groups B and BR with the same glass fibre post diameter but different dentine thicknesses showed significant differences in mean failure load. The lost of remaining dentine was replaced with reinforcing resin composite resulting in a significant decrease in fracture resistance. The dentine in group B was the thickest whilst the reinforcing resin composites in group BR was the thickest in this study.

One of the possible explanations was the generation of large lacunae or bubbles in the reinforcing resin due to insertion of a large volume of resin composite in the post spaces in a single increment in this particular resin reinforcement group. There could be reduced cohesive resistance of cement and even reduced bond strength to dentine although a study showed that the increased cement thickness surrounding the FRC post did not impair the bond strength (Perez *et al.*, 2006). Insertion of a large volume of resin composite in the post space in a single increment in this group might also induced a high stress at the adhesive interface, due to the high polymerization shrinkage and impaired control of formation of lacunae in the resin, possibly resulting in reduction in cohesive strength of the resin and bond strength to dentine.

Another possible explanation for the decreased fracture resistance was the curing of the reinforcing resin composite at the most apical part of the post space. It was reported that the larger the post diameter, the greater was the depth of cure (Lui, 1994b). This could explain why the fracture load was significantly different between groups B and BR but not between groups B and WR, since the post diameter in WR was larger than in BR.

The maximal occluding force for male exerted by a maxillary incisor tooth was 146±44 N (Goodacre et al. 2003). The load required to cause failure in this study was higher than that observed in normal functional activity at the anterior region ranging from 166.1 to 264.77N (Mannocci *et al.*, 1999; Strub *et al.*, 2001). Despite group BR being the weakest in fracture resistance, the failure load was still higher than the failure load of a similar study using cast post and core with a mean failure load of 600 N (Tan et al, 2005). This was consistent with studies which showed higher fracture resistance in teeth restored with glass fiber post than those restored with metal posts (Akkayan and Gulmez, 2002; Gu *et al.*, 2007). Also, it had been shown that cast post and core showed lower strain values than groups with glass fiber posts when restored with metal crowns (da Silva *et al.*, 2010).

The results from this study showed that the strength of the teeth is directly proportional to the amount of remaining dentine. The diameter of glass fibre post and reinforcing resin composite thicknesses should not have an effect on the fracture resistance when the remaining dentine thicknesses were similar. The result was thus consistent with the study by Rodgriguez-Cervantes et al. (2007). They concluded that the post diameter had a significant effect on the biomechanical performance of teeth restored with stainless steel posts. Lower failure loads were found as post diameter increased. However, the post diameters of those teeth restored with glass fibre posts had no significant effect. They therefore proposed the use of glass fibre posts to achieve a restorative technique that was less sensitive to post dimensions (Rodriguez-Cervantes *et al.*, 2007).

The results in this study, however were in contrast with other studies which showed low fracture strength values in the groups with narrower diameter (Porciani *et al.*, 2008; Amaral *et al.*, 2009). These studies however did not include a crown and the force was applied directly to the core or post. Therefore, in such studies, they found that the narrower posts had lower fracture resistance than the wider posts.

5.2.2 Failure Modes

One advantage of the use of glass fibre posts was the reported similar modulus of elasticity to dentine (Dietschi *et al.*, 1997; Martinez-Insua *et al.*, 1998). It was believed that the creation of a monoblock dentine-post-core system would transmit and distribute functional stresses across the bonding interface to the tooth more effectively, with the potential to reinforce weakened tooth structure. Therefore if excessive load were applied to the tooth, the post would be able to absorb the stresses thus reducing the possibility of root fracture. The modulus of elasticity of the glass fibre posts used in this study was 48 GPa which was three times the modulus of elasticity of dentine (15 GPa). The vast differences of moduli of elasticity of the materials would yield a high stress concentration in the root. This explained why more unfavourable failures were observed in this study compared to other similar studies.

Differences were observed among groups in relation to the mode of failure. Evaluation of the roots after testing revealed 30% of unfavourable root fractured in Group B and the incidence of such fracture increased with the enlargement of post space. When the post space was enlarged to size 3 in groups R,WR and BR, the percentage of root fracture increased to 70%. This might be attributed to the fact that because more tooth structure was removed during post space enlargement, the resistance to loading force was diminished and the possibility of fracture increased. In addition, endodontic treatment and preparing the root canal preparation to receive a post might lead to cracks and defects that could also concentrate stresses and increased the possibility of root fracture (Cailleteau *et al.*, 1992).

This study somewhat differed from Newman et al. (2003) who reported no root fracture for all the specimens restored with fibre post. These inconsistencies might be attributed to the design of their study where the force was directly applied on the fibre post, whereas in this study, the teeth were prepared with ferrule and restored with core and metal crown. The force was thus distributed via the ferrule and transmitted to the root rather directly to the post.

For teeth restored with reinforcing resin composite, the stresses from polymerization shrinkage of the resin composite could affect the failure mode (Ausiello *et al.*, 2002). This could mean that although using reinforcing resin composite might not directly increase fracture resistance, it might instead create a higher incidence of more favourable and restorable failure mode compared to enlargement of post space to accommodate a larger glass fibre post. The efficacy of these techniques should be evaluated in longitudinal clinical studies.

Adhesively luted resin/fibre posts with composite cores appeared to be the best currently available option in terms of tooth fracture and biomechanical behavior (Al-Omiri *et al.*, 2010). However, controlled clinical studies showing their performance in a long term situation are required.

5.3 Limitations of the study

The limitations of this study should be noted and mentioned as possible area for future research. Only maxillary central incisors were used; therefore, these results could only be applied to that group of teeth.

On the basis of the conditions of the study, it remained uncertain whether complete light-polymerization of the reinforcing resin composite at the most apical portion was achieved. However, the manufacturer's recommended technique was strictly followed.

Because the static laboratory tests measuring fracture resistance in the manner carried out in this study, it did not completely simulate dynamic conditions in which the forces were constantly changing their rate, magnitude and direction, long term clinical evaluation of this correlation should therefore be carried out.

Chapter Six

Conclusion And Clinical Relevance

6.1 Conclusions

On the basis of the condition of this study and within its limitations, the following conclusions were made:

1. Endodontically treated maxillary central incisors restored with crowns in Group B were significantly more fracture resistant than those in Group BR ($p<0.05$).
2. There was no statistically significant effect of glass fibre post diameter on fracture resistance of endodontically treated central incisors restored with crowns with the same thickness of the remaining dentinal wall ($p>0.05$).
3. Enlarged post spaces caused more unfavourable failure regardless of the diameters of the glass fibre posts and reinforcing resin composite thicknesses.

6.2 Clinical Relevance

Remaining dentine wall is more critical in resisting fracture than the diameter of glass fibre post and reinforcing resin composites thicknesses. The use of smaller diameter glass fibre post and reinforcing resin composite are recommended rather than enlargement of post spaces to accurately fit a larger glass fibre post as the enlargement of post spaces increases the risk of unfavourable failure.

Chapter Seven

Suggestions For Further Studies

7.1 Suggestion For Further Studies

1. This study evaluated the effect of fibre post diameter on the fracture resistance of endodontically treated central incisors. The results and conclusion from the study can only be applied to this group of teeth. Further studies are needed to investigate other type of teeth eg. premolars and molars.
2. A further study is needed to evaluate the fatigue resistance of the specimens fabricated using the same protocol. A comparison between the static load and fatigue load could also be conducted to investigate any correlation between the results obtained.
3. Another study can be suggested to replace the metal crown to full ceramic crown as they are more relevant especially in the aesthetic zone.