Chapter One
Introduction, Aims and Ojectives

1.1 Introduction

Prosthodontic restoration of an endodontically treated tooth often requires additional support from the root canal by means of a post and core restoration (Christensen, 2004). Endodontically treated teeth are assumed to be more prone to fracture because of desiccation or premature loss of moisture supplied by a vital pulp (Carter et al., 1983). In cases of severe hard tissue loss, posts are frequently needed (Dikbas et al., 2007; Darabi and Namazi, 2008). In recent years more emphasis has been placed on the “ferrule effect” in the restoration of endodontically treated teeth with posts and cores. A ferrule has been described as a key element of tooth preparation when using a post and core (Rosen, 1961). Naumann et al. (2006) stated that the incomplete crown ferrule was associated with greater variation in load capacity.

Endodontically treated teeth with insufficient coronal tooth structure generally require radicular posts to assist in restoring the tooth to function. First introduced in 1990, fibre posts were rapidly accepted by clinicians and provided a viable alternative to cast metal posts for the restoration of root filled teeth. The major advantage of fibre posts is their similar elastic modulus to dentine, producing a stress field similar to that of natural teeth, whereas metal posts exhibit high stress concentrations at the post dentine interface (Vano, 2008).

The length of the post influences stress distribution in the root, and thereby affects its resistance to fracture. When the length of the post is increased the retentive capacity increases (Isidor et al., 1999; Le Bell-Rönnlöf, 2007). A longer post also helps the root to resist bending. However, a long post preparation increases the risk of root perforation particularly in curved roots. There are many guidelines concerning the length of the post. A common recommendation has been that the length of the post should be equal to the length of the crown (Harper et al., 1976) or greater than the length of the crown (Silverstein et al., 1964). Other studies have suggested that the post length should be equal to a certain amount of the root, e.g. half the length of the root, two thirds of the root length or at least half way between the apex of the root and the alveolar crest of supporting bone (Le Bell-Rönnlöf, 2007).

One of the restorative strategies when restoring an endodontically treated tooth with a post-core and a crown is to include a ferrule in the design of the tooth preparation. To date there were no published studies evaluating the effect of ferrule height on fracture resistance of endodontically treated teeth restored with glass fibre posts at different lengths.

1.2 Aim

The purpose of this study is to evaluate the effect of ferrule height and post length on fracture resistance of endodontically treated teeth restored with fibre post luted with a self adhesive resin cement, composite core and a full coverage crown.

1.3 Objectives

1. To determine the effect of ferrule height on fracture resistance of endodontically treated teeth restored with glass fibre post, composite core and crown.
2. To evaluate the effect of post length on failure loads of endodontically treated teeth restored with glass fibre posts.
3. To evaluate effect of ferrule height and post length on the fracture mode of endodontically treated teeth restored with glass fibre posts.

Chapter Two
Literature Review

2.1 Survival rate of endodontically treated teeth

Endodontically treated teeth are usually more susceptible to fracture because they have insufficient coronal tooth structure as a result of caries, trauma or the endodontic procedure itself. The restoration of the endodontically treated teeth has been considered a topic of interest since the use of post and core crowns began early in the 1900s **(**Terry and Swift 2010).

It has been suggested that the dentine in endodontically treated teeth undergoes changes in collagen cross-linking. These changes make them dry with time. Therefore, they become more brittle and may fracture more easily than vital teeth (Baraban, 1967; Helfer, 1972; Sokol, 1987; Olivera et al., 1987; Reeh et al., 1989; Rivera and Yamauchi, 1993). Many studies have been carried out related to this subject, one of them was done by Carter et al. (1983). They tested plano-parallel specimens of human dentine from vital and endodontically treated teeth with the punch shear test. They found significant differences between shear strength and toughness values for the two groups with the endodontically treated teeth showing lower values.

Sedgley and Messer (1992) compared the biomechanical properties (hardness, toughness, punch shear strength and load to fracture) of 23 endodontically treated teeth with their contralateral vital pairs. They found no significant difference between them.

However, the changes in pulpless teeth may be caused by the restorative procedure itself. Reeh et al. (1989) compared the effect of endodontic and restorative procedures to the strength of pulpless teeth. They found that endodontic procedures reduced the relative stiffness by 5% to 20% from occlusal cavity preparation and 63% from MOD cavity preparation.

The longevity of endodontically treated teeth without crown coverage has been investigated as a potential factor when choosing appropriate treatment modalities. In their study, Nagasiri and Chitmongkolsuk (2005) demonstrated that the survival rates of endodontically treated molars without crowns at 1, 2, and 5 years were 96%, 88%, and 36%, respectively. They also found that molar teeth with greater amount of remaining tooth structure after endodontic treatment had a survival rate of 78% at 5 years, and direct composite restorations had a better survival rate than conventional amalgam and reinforced zinc oxide and eugenol with polymethacrylate restorations.

The choice of appropriate definitive restoration of endodontically treated maxillary anterior teeth should be guided by the amount of remaining hard tissues as well as functional and aesthetic considerations. However, in cases of inadequate remaining coronal tooth structure, post-retained cores are often required to support complete crown restorations. (Signore et al., 2009).

2.2 Remaining coronal tooth structure

The survival of a pulpless tooth is directly related to the quantity and quality of the remaining dental tissue (Periera et al., 2005). During restorative procedures sound coronal dentine must be conserved to make the crown margin extending below the junction of the core and the remaining tooth structure. This is to help in retention and resistance of the core by allowing the use of a ferrule preparation designed to decrease stress findings in the cervical third of endodontically treated central incisors (Ahangari et al., 2008).

Remaining coronal tooth structure also influences the fracture resistance of crowned endodontically treated teeth. Therefore, preservation of tooth structure may improve its prognosis because it provides protection against fracture under occlusal loads (Nissan et al., 2008). Pereira et al. (2006) compared the fracture strengths of endodontically treated teeth using posts and cores with different amounts of coronal dentine. They found that the fracture resistance of endodontically treated teeth increased significantly with increased amount of coronal dentine.

Arunpraditkul et al. (2009) studied the fracture resistance of endodontically treated mandibular second premolars between those with four walls and those with three walls of remaining coronal tooth structure and evaluated the effect of the site of the missing coronal wall. They concluded that teeth with ideal tooth preparation are more fracture resistance than teeth with only three walls, and the site of the missing coronal wall had no effect on the fracture resistance of endodontically treated teeth.

To ensure functional longevity, endodontically treated teeth must have at least 5 mm of tooth structure coronal to the crestal bone. Three millimeters are needed to maintain a healthy soft tissue complex, and 2 mm of coronal tooth structure incisal to the preparation finish line to ensure structural integrity. If less than 5 mm in height it can be increased either surgically through a crown lengthening procedure or orthodontically through forced extrusion of the tooth. However, it should not be carried out at the expense of crown-to-root ratio, or the aesthetic outcome (Ng et al., 2006).

Meng et al. (2007) stated that 2 mm of crown lengthening result in a ferrule that reduce fracture strengths for endodontically treated premolars restored using two dowel-core systems and cast metal crowns. Gegauff (2000) observed that the combination of simulated surgical crown-lengthening and crown margin placed more apically to provide a 2 mm crown ferrule on a decoronated mandibular second premolar resulted in a reduction of static load failure for the restored tooth.

Sorensen and Engelman (1990) also recommended surgical crown lengthening or orthodontic extrusion when the existing clinical crown height will not permit the placement of a crown ferrule. However, a number of significant disadvantages may exist, including treatment delay, discomfort and the considerable added cost to an already expensive sequence of procedures.

Studies have been carried out to evaluate the amount of the coronal tooth structure that affect the fracture strength of endodontically treated teeth. Sorensen and Engelman (1990) observed that one millimetre of coronal tooth structure above the crown margin increase the fracture resistance of pulpless teeth while a contra bevel at either the tooth-core junction or the crown margin was of no benefit, and the thickness of axial tooth structure at the crown margin also was ineffective.

Varvara et al. (2007) evaluated the fracture resistance and failure mode of endodontically treated teeth restored with 3 different restorative techniques with varying amounts of remaining dentine heights (0, 2, 4, and 5 mm from the cemento-enamel junction). They concluded that the increased height of residual dentine generally provided greater fracture resistance.

2.3 Ferrule effect

A ferrule has been described as a key element of tooth preparation when using a post and core (Tan et al., 2005; Dikbas et al., 2007). The ferrule effect can be defined by a 360-degree metal crown collar surrounding parallel walls of dentine and extending coronal to the shoulder of the preparation (Sorensen and Engelman, 1990).

Libman and Nicholls (1995) defined it as a metal band or ring used to fit the root or crown of a tooth. They reported the need for a crown ferrule of at least 1.5 mm on maxillary central incisors to successfully endure the cyclic loading they used to simulate chewing.

The use of a ferrule as part of the core or artificial crown may be of benefit in strengthening endodontically treated teeth. It is desirable, but should not be carried out at the expense of the remaining tooth/root structure (Stankiewicz and Wilson, 2002).

Ichim et al. (2006) analysed the effect of ferrule height on the mechanical resistance and stress distribution within a root. They concluded that a ferrule increases the mechanical resistance of a post/core/crown restoration. Isidor et al. (1999) compared the effect of ferrule length and post length on fracture resistance of endodontically treated teeth. They stated that ferrule length was more important than post length in increasing fracture resistance to cyclic loading of crowned teeth.

There is no standard design for preparation of a ferrule, but in order to gain the full benefit of this design, the ferrule must be of a minimum of 1 to 2 mm in height, encircle the tooth completely, have parallel dentine walls, end on sound tooth structure and avoid invasion of the attachment apparatus at the tooth (Wagnild and Mueller, 2002). The prognosis of restored pulpless teeth is determined by factors like the preservation of healthy dentine, ferruling of crown margins on sound tooth structure, and type of intermaxillary relationship (Pilo and Tamse, 2000). Zhi-Yue and Yu-Xing (2003) stated that a 2 mm dentine ferrule was effective in enhancing the fracture strength of endodontically treated maxillary central incisors restored with custom cast post-core.

Tan et al. (2005) investigated the resistance to static loading of endodontically treated teeth with uniform and nonuniform ferrule configurations. They found that central incisors restored with cast dowel/core and crowns with a 2 mm uniform ferrule were more resistant to fracture than central incisors with nonuniform (0.5 to 2 mm) ferrule heights. They also stated that both the 2 mm ferrule and nonuniform ferrule groups were more fracture resistant than the group that lacked a ferrule.

Akkayan (2004) compared the effect of three different ferrule lengths (1.0 mm, 1.5 mm and 2.0 mm) on the fracture resistance and the fracture patterns of endodontically treated teeth restored with 4 different aesthetic dowel systems and a crown. He found that a significant difference existed in the mean fracture loads of the teeth prepared to 2 mm ferrule length compared with 1 mm and 1.5 mm ferrule lengths regardless of the dowel system tested.

However, al-Hazaimeh and Gutteridge (2001) stated that the ferrule preparation has no benefit in terms of resistance to fracture of central incisors with prefabricated post (Parapost) and with a composite core and crown. Dikbas et al. (2007) evaluated the effect of different types of ferrule designs on fracture resistance of endodontically treated maxillary central incisors restored with quartz fibre posts, composite cores, and crowns. They found that there was no difference on the fracture resistance when using different ferrule designs in teeth restored with fibre posts.

2.4 Posts

2.4.1 Indication

Endodontically treated teeth are usually weak due to loss of tooth structure from previous restoration(s), caries or trauma and cavity access during endodontic treatment. Therefore, they are mostly indicated for full coverage restoration with post and core to achieve retention and resistance form for the final restoration (Darabi and Namazi, 2008). There are several factors to be considered in deciding on the restorative techniques and materials to be used in restoring the tooth to normal form and function such as the amount of remaining tooth structure, tooth type, position in the arch, morphology and the periodontal condition of the tooth, the amount of occlusal stress and extent of the destruction of the tooth (Sabbak, 1998).

The chief function of a post is to retain the core. In case where there is extensive loss of coronal tooth structure, retention of the posts is provided by the canal space (Wahab, 2003; Dikbas et al., 2007). It is known that endodontically treated teeth with posts have significantly greater longevity than teeth without post (Wahab, 2003). A study had been carried out by Ferrari et al. (2007) comparing endodontic treated teeth restored with posts and those without posts; they found that the survival rate of posted teeth was higher (92.5%) than those restored without a post.

In the past the general opinion was that a post strengthens the endodontically treated tooth (Bolla et al., 2007). A survey in Sweden revealed that 29% of 505 general practitioners and 17% of 91 prosthodontists who participated in a survey have the opinion that posts do strengthen the root-filled teeth (Eckerbom and Magnusson, 2001). Others stated that posts do not strengthen the endodontically treated teeth (Guzy and Nicholls, 1979; Leary et al., 1987; McDonald et al., 1990). In addition, post placement procedure may be a predisposing factor to root fracture as it removes more remaining dentine from canal walls (Guzy and Nicholls, 1979; Grieznis et al., 2006; Rondo, 2007; González-Lluch et al., 2007). However, posts can protect the remaining tooth structure by distributing the applied load within the root. Thus preventing uncontrolled stress concentration in focal points and thereby affects its resistance to fracture (Le Bell-Rönnlöf, 2007).

There are different causes of failure in prosthodontic treatments such as loss of retention of posts or crowns, secondary caries and root fracture. Teeth that undergo root fracture usually have to be extracted. As a result, root fracture is considered to be the most serious cause of failure (Sadeghi, 2006). Fractured roots are not restorable while if the site of fracture is located within the core or post, repair is possible (Martinez-Insua et al., 1998).

2.4.2 Classification

Posts can be divided into two main groups: active posts and passive posts according to the way that they gain retention. They can be subdivided according to thier shape into cylindrical, tapered or cylindrical with a tapered end, and can be also divided by material compositions (Schwartz and Robbins, 2004; Ricketts et al., 2005).

2.4.2.(a) Active posts

Active posts are prefabricated with threads, they mechanically engage the dentine walls with these threads to gain retention. They can be categorized into two types; self-threading or pretapped. In case of self-threading posts, the post engage dentine by forming threads into the dentine walls as it is "screwed" into the root canal, while the pretapped posts engage dentine by fitting thread-paths preformed into the canal walls by a thread cutter used prior to installing the post (Ricketts et al., 2005).

2.4.2.(b) Passive posts

Luting cement with their close proximity to the prepared dentine walls, are the main factors affecting the retention of passive posts. They are categorised into two groups, custom made posts and prefabricated posts. The prefabricated posts may be with either a smooth or a serrated surface texture (Ricketts et al., 2005).

2.4.3 Material

Posts are made of either metallic or non-metallic posts. The metallic posts are divided into cast posts which are either precious, semi-precious or non-precious posts and prefabricated titanium posts. While the non- metallic types of posts are divided into fibre posts and ceramic posts (Stewardson, 2001).

2.4.3.(a) Tooth-coloured posts

As patients' demand for aesthetic restorations increases, practitioners must keep up with the science as well as the demand. These types of posts have superior aesthetic apearance.

There are two types of non-metallic posts: fibre reinforced and ceramic posts.

2.4.3.(a).(i) Fibre reinforced composite posts

These types of posts consist of two components; the first one is continuous reinforcing fibres (carbon, glass, quartz, composite resin, silica or zircon) which are present in a high percentage and embedded in a polymer matrix which is the second component (Mannocci et al., 2001; Seefeld et al., 2007; Mekayarajjananonth et al., 2009). To connect the fibres and the matrix, a coupling agent, probably silance, is also used (Mannocci et al., 2001). Matrix polymers used are commonly epoxy resins with a highly cross-linked structure and a degree of conversion (Seefeld et al., 2007). The presence of these fibres increases the surface area. Stress will be distributed on a wider surface area and this increases the load threshold to prevent micro-fractures.

The properties of these materials are: high impact resistance, attenuation and softening of vibrations, shock absorption and increased fatigue resistance (Boschian et al., 2002). They are anisotropic materials and have high fatigue and tensile strength. They have low modulus of elasticity which is similar to that of dentine, and thus produce a stress field similar to that of natural teeth (Lassila et al., 2004; D’Arcangelo et al., 2007**).** It is thought that fibre posts tend to flex under load and thus resulting in distribution of stresses along the post and dentine interface. This is considered to be the major advantage of these systems (Naumann et al., 2005; Naumann et al., 2007). In addition, they form a “monobloc” with uniform stress distribution throughout the restored tooth, resulting in lowered core-dentine interface stress and failure rates (Lassila et al., 2004). The mechanical properties of fibre-reinforced composite materials are strongly dependent on the structure of the materials and on the load direction (Mannocci et al., 2001).

The first fibre reinforced composite posts were made of carbon/graphite fibres and were introduced in 1990. The earlier generations of fibre posts posses good mechanical properties (Lassila et al., 2004). They are called composipost dowels which are made of stretched, aligned carbon fibres embedded in an epoxy-resin matrix. In studying the clinical behaviour of this system, it can be considered as a viable alternative to cast metal dowel/cores or metal prefabricated posts (Fazekas et al., 1998; Fredriksson et al., 1998;

Glazer, 2000; Ferrari et al., 2000). However, they have poor aesthetic qualities because they are black in colour (Lassila et al., 2004). As a result, they had some limitations to their universal use, they were also radiolucent and difficult to mask under all-ceramic or composite restorations (Grandini et al., 2005). Due to increasing aesthetic demand, a number of different fibre posts were quickly introduced onto the markets. They were made of glass; electrical glass (E-glass), high strength glass (S-glass) or silica fibres, they are white in colour or translucent (Lassila et al., 2004). Translucent fibre posts clinically show interesting mechanical properties (comparable to the dentine) and superior aesthetic characteristics that enhance a final restoration with an all-ceramic crown with satisfying results (Malferrari et al., 2002; Monticelli et al., 2004). Glass or quartz fibre posts posses high aesthetic advantages and some are light-conducting (Mekayarajjananonth et al., 2009). However, glass fibre posts have a lower flexural strength than posts reinforced with carbon fibres (Novais et al., 2009).

The use of these new tooth-coloured fibre posts together with a matching material for core build-up like resin-based material, is expected to gain a more natural and aesthetic appearance of the final restoration. On the other hand, cores directly built-up with composite resin have shown a fracture resistance comparable to that of cast gold cores regarding the mechanical properties (Monticelli et al., 2004). Naumann et al. (2007) summarized that the rigidity of the post material had no effect on the load resistance of endodontically treated teeth. They also stated that the ferrule preparation together with endodontic post were highly fracture resistant after thermomechanical loading than any other build-up design.

In clinical dentistry, adhesively-retained fibre posts are becoming a popular choice for the restoration of endodontically treated teeth (Ferrari et al., 2000; Foxton et al., 2008). They are easy to place, relatively inexpensive, can be bonded to resin cement, and are easy to remove if the tooth needs to be retreated (Christensen, 2004).

Naumann et al. (2005) studied the survival rate of postendodontic reconstructions of teeth with different degrees of hard tissue loss; they used tapered or parallel-sided post shapes. They concluded that tapered and parallel-sided glass fibre posts after 2 years of clinical service have equal survival rate. Post fractures and loss of post retention were the most frequent types of failure. Similar study was conducted by Signor et al. (2009); they investigated the clinical effectiveness of tapered and parallel-sided glass-fibre posts over up to 8 years in endodontically treated, maxillary anterior teeth covered with full-ceramic crowns. The clinical performance was satisfactory and the survival rate was higher for teeth with remaining four and three coronal walls. However, Mohammadi et al. (2009) stated that endodontically treated maxillary premolars with MOD preparations restored with direct composite resin, with or without fibre post and cusp capping, had the same fracture resistance under static loading. Furthermore, Plotino et al. (2007) investigated the flexural modulus and flexural strength of fibre and metal posts in comparison with human root dentine. They concluded that the elastic modulus of fibre reinforced composite posts was more closely approaches that of dentine while metal posts exhibit modulus of elasticity much higher than that of dentine. Regarding the flexural strength, fibre and metal posts were respectively four and seven times higher than root dentine.

A study using three-point bending test reported that fibre posts must not be in contact with oral fluids as water absorption will lead to degradation of epoxy resin materials, and some fibre-reinforced composites, especially glass and silica fibre-based composites, may be hydrolytically unstable (Mannocci et al., 2001). In addition, they are relatively radiolucent compared with natural tooth structure (Ibrahim et al., 2006).

2.4.3.(a).(ii) Ceramic and Zirconium Posts

Clinical applications of these posts are usually in cases when high-level aesthetics are required as they have excellent optical properties (e.g. translucency, value, chroma) (Ahmad, 1999; Spear and Holloway, 2008). Ceramics with high strength tend to be more opaque and pose a challenge when trying to match natural tooth colour, but they can mask discoloration when present (Spear and Holloway, 2008). The ceramic posts are very stiff and strong, with no plastic behavior (Asmussen et al., 1999). A clinical study by Nothdurft and Pospiech (2006) evaluated pulpless teeth restored with conventionally cemented zirconia posts with observation period ranged from 8 to 44 months. The results demonstrated that there were no signs of failure like loss of retention, fracture of posts, and fracture of teeth.

Paul and Werder (2004) considered that pulpless teeth restored with zirconium oxide posts with direct composite cores were clinically promising, as their success rates were 100% after 57.7 months of clinical service. While those teeth with zirconium oxide posts with indirect glass-ceramic cores displayed a significantly higher failure rate and a high dropout rate after 46.3 months of clinical service, all failures were due to loss of retention.

2.4.3.(b) Metallic posts

These posts are either prefabricated or custom made. The use of cast posts designed to optimally fit the root canal but their use require multiple appointments, also they requires a temporary restoration of the root canal after post preparation and therefore bears the risk of reinfection of the canal due to coronal leakage. while prefabricated posts require one visit and can be cemented immediately after post space preparation (Kremeier et al. 2008). In case of custom made cast posts and cores, a temporary post-crown must be prepared during the construction of definitive restoration; in contrast, the use of prefabricated posts allow a core reconstruction immediately after the post space preparation. Temporary post-crowns cemented with zinc oxide-eugenol (ZOE) cement produced significantly more coronal microleakage than cast or prefabricated post systems (Mannocci et al 2001).

The main disadvantage of metal posts is their tendency to induce vertical root fracture which is considered to be a very urgent problem that needs to be addressed (Abdul Salam, 2006; Hayashi and Ebisu, 2008). These posts exhibit high modulus of elasticity; the stress is transferred from the rigid post to the less rigid dentine. As a consequence fracture will happen due to the excessive stress transferred from the post-core to the remaining tooth (Hayashi and Ebisu, 2008). Furthermore, metal posts and cores are associated with inferior aesthetics, because they do not allow light transmission, possibility of corrosion causing gingival and tooth discoloration, and have possible biocompatibility concerns. Some of them may have difficulty in fabrication and also in fitting, and retrieval is difficult and might lead to tooth and/or root fracture (Al-Wahadni, 2008).

2.4.4 Post length

Post length seems to have different effects in restoration of pulpless teeth, retention is one of these factors, an increase in post length usually corresponds to increased retention (Standlee et al., 1978; Nergiz et al., 2002; Cheung, 2005; Braga et al., 2006). However, the relationship between post length and success of the filling is not necessarily linear. A post that is too short will fail, whereas one that is too long may also fail (Asmussen et al., 1999; Wahab, 2004). Long post may cause perforation if the apical third is curved, tapered or it may damage the seal of the root canal filling (Wahab, 2004).

Peak shear stresses is also affected by post length, it is increased when the length of the post decreased (Holmes et al., 1996). A number of authors studied the effect of post length on fracture resistance. Giovani et al. (2009) evaluated the fracture resistance of roots restored with glass-fibre and metal posts at different lengths; (6, 8 and10 mm). They concluded that the 10 mm long glass-fibre group demonstrated significantly higher values of fracture resistance, while the lowest values achieved by the 6 mm-long glass-fibre group resulting in root fracture. Similar studies by Santos-Filho et al. (2008); McLaren et al. (2009). They used different post lengths, again 10 mm had the highest fracture resistance.

It is important to notice that it may not always be possible to use a long post, especially when the remaining root is short or curved. In addition, a portion of the root canal filling must be removed for post placement, about 3 to 5 mm of apical gutta-percha must be preserved to maintain the apical seal (do Valle et al., 2007). As apical leakage thought to be affected by the level of remaining gutta-percha, Mattison et al. (1984) analyzed the apical leakage quantitatively with varied levels of remaining gutta-percha (3 mm, 5 mm and 7 mm). They observed that when the level of gutta-percha increased to 7 mm the degree of leakage decreased. They advised that the length of the remaining apical gutta-percha of at least 5 mm is necessary for an adequate apical seal. Different recommendations have been made regarding the optimal post length. It was suggested that the post should be equal to or greater than the length of the crown (Sorensen and Martinoff, 1984). Other studies tried to estimate the post length according to a certain amount of the root, e.g. half the length of the root, two thirds of the root length or at least half the length from the apex of the root to the alveolar crest of supporting bone (Le Bell-Rönnlöf, 2007). Others recommended the post length that is longer than the crown or about 1 1/3 the length of the crown or it should be as long as possible without disturbing the apical seal (Stockton, 1999).

2.4.5 Post diameter

Post diameter had no effect on retention (Standlee et al., 1978). However, increasing the diameter of the post raises its stiffness but at the expense of the remaining dentine (Trabert et al., 1978; Asmussen et al., 1999). That is why post diameter must be controlled to preserve radicular dentine in order to reduce the risk of root perforations. In the same time allow the tooth to resist fracture (Trabert et al., 1978) because teeth with a smaller diameter post have an elevated fracture resistance than teeth with a larger diameter post (Grieznis et al., 2006).

Lloyd and Palik (1993) described three different philosophies about the diameter of posts used; One group so-called the "Conservationists" who advocated using the narrowest post possible to conserve the maximum amount of tooth structure remaining after removal of gutta-percha. Another group was the "Proportionists" who recommended a post which has apical diameter that is equal to one third the diameter of the root at its narrowest dimension of the root diameter. The last group was the "Preservationists" who advocated a minimum of 1 mm of dentine encircling the post.

2.4.6 Post design

Post design plays a significant role in the fracture resistance of endodontically treated teeth; poorly designed dowels (too short, too wide or both), can cause vertical root fracture which is considered as failure that leads to tooth extraction (Peciuliene and Rimkuviene, 2004). Cast post and core has been widely used (Maccari, 2003; Nandini and Venkatesh, 2006). They do offer some advantages in special cases such as when multiple teeth require posts by making an impression and fabricating them in the laboratory rather than placing a post and build up in individual teeth as a chair side procedure. Also they may be indicated when a tooth is misaligned and the core should be made at an angle in relation to the post to achieve correct alignment with the adjacent teeth (Nandini and Venkatesh, 2006). However, cast post and core has some disadvantages that may jeopardize long-term success. Their disadvantages include tooth weakness related to the removal of root structure, lack of cement retention, corrosion risks, poor stress distribution leading to root fracture, difficulties in removal of the post, necessity for two appointments to complete the procedure, and laboratory cost (Maccari, 2003). In addition to the custom cast post and core, many commercially prefabricated posts are available. Their axial form is either tapered or parallel, and the surface can be smooth, serrated with or without vents, or threaded using taps or self-threading. They lie in three basic combinations: tapered, (serrated or smooth-sided), parallel-sided (serrated or smooth-sided) and parallel-sided, (threaded and inserted into pre-tapped channels) (Cheung, 2005).

Tapered posts have a good record of clinical success (Weine et al., 1991). The shape of these posts resemble the natural root form and canal configuration, hence preservation of tooth structure at the apical area is obtained. But they posses the tendency to promote root fracture because of the generation of wedging stresses (Whitworth et al., 2003; Fernandes et al., 2003). However, such forces are not as strong as those generated by self-tapping screw systems. The cause of root fracture associated with tapered posts may be due to the type of cases in which such posts are often used, i.e. the wide, thin-walled tapered canal (Whitworth et al., 2003). In addition, they show lower retentive strength (Fernandes et al., 2003).

Parallel posts seem to be more retentive than tapered post (Standlee et al., 1978 and Torbjörner et al., 1995). This is due to the fact that they induce less stress into the root; there is less of a wedging effect and lesser chance of root fracture than tapered post. On the other hand, tapered posts require less dentine removal because most roots are tapered. Thats why they are indicated in teeth with thin roots and delicate morphology (Standlee et al., 1978). Another type of post shape is the parallel-tapered design; in this type the post is parallel all over its length except for the most apical portion, where it is tapered. This design is of two benefits; the former one is the good retention quality because of parallel design and the second one is the preservation of the dentine at the apex because of the taper shaped end (Fernandes et al., 2003).

Albuquerque et al. (2003) compared three post shapes (tapered, cylindrical and two-stage cylindrical) made of three different materials [stainless steel, titanium and carbon fibre on Bisphenol A-Glycidyl Methacrylate (Bis-GMA) matrix] in the stress distribution on an endodontically treated incisor using the finite element method analysis. They found that post materials introduced higher variations on the stress concentrations while post shapes had relatively small effect on them. Torbjörner et al. (1995) reviewed almost 800 posts after four to five years and analyze failure rate and failure characteristics for two post designs; custom-cast tapered posts and parallel-sided serrated posts. They found that parallel posts showed about half the failure rate of custom-cast tapered posts. Teixeira et al. (2006) studied in vitro four types of fibre-reinforced resin-based composite root canal posts with different shapes (parallel fibre glass posts, double-tapered fibre quartz posts, tapered fibre glass posts and two different types of parallel fibre glass posts). They found that parallel shape posts had good retention better than tapered posts when a dual-cured resin-based cement was used.

Signore et al. (2005) observed the clinical effectiveness of both parallel-sided and tapered glass fibre posts in endodontically treated maxillary anterior teeth restored with either hybrid composite or dual-cure composite resin core material, and covered with full ceramic crowns over a period of 8 years. They found that the success rate for parallel-shaped posts and for tapered posts was 98.6% and 96.8% respectively. The success rate for dual-cure composite material was 100% and that of hybrid light-cure composite was 96.8%. This long-term clinical performance showed satisfactory results. Furthermore, they observed that where there is more residual dentine, the mechanical qualities of the build-up material play a less significant role.

Joshi et al. (2001) stated that the selection of the shape of the post should be carried out in a way that maximum coronal dentine is preserved. The surface configuration of the post also influence the retention of a resin-cemented dowel. Standlee et al. (1978) studied three different designs of endodontic posts and thier effects on the retention. They observed that the most retentive type was the threaded, parallel-sided dowels screwed into tapped channels followed by the serrated, parallel-sided dowels cemented in matched cylindrical channels and smooth-sided tapered posts were the least retentive. Furthermore, dowels with transverse serrations or crosshatching exhibited better retention than dowels with longitudinal spirals or threads (Standlee and Caputo, 1993).

The fracture resistance of an endodontically treated tooth may be affected by the surface configuration of the post. Threaded posts are seemed to show the highest incidence of root fractures due to the high stress level generated on installation and loading (Rolf et al., 1992). The use of threaded posts should only be limited in spacial cases such as in curved or short roots that require maximum retention with sufficient dentine thickness (Felton et al., 1991).

The type of material used in the designing of posts and cores play a great role in the success of the final restoration. Some in vitro methods were conducted to analyze specific properties of post-and-core restorations. Materials placed in the tooth should have physical properties as close as possible to those of natural tissues, carbon-epoxy posts seemed to possess such properties (Dietschi et al., 1996).

Numerous studies have been done to evaluate the clinical behavior of different posts materials and compared their survival rates. With the abundance of literature demonstrating that metallic posts have a greater number of disadvantages over the other post systems such as the fibre reinforced composite posts, results showed that the later post systems was favourable, with high retention rates and a lack of root fractures in addition to superior aesthetic quality (Duke, 2002).

Maccari et al. (2003) investigated the effect of composition of prefabricated aesthetic posts in fracture resistance of endodontically treated teeth. They found that teeth restored with glass-fibre and carbon-quartz fibre posts had double fracture resistance than that seen in ceramic posts. They also studied the mode of fracture in these three types of posts, and they observed that the type of fracture seen in zirconiumdioxide posts was root fracture which is the type that is most difficult to repair clinically. While the other two posts presented with favourable fractures.

2.5 Luting cements

Luting cements are used to form the link between a fixed restoration and the supporting tooth structure (Jivraj et al., 2006). The ability of a luting agent to retain a dowel may influence the retention and failure mode of the posts (Sahafi et al., 2004) consiquently it influence the prognosis of a restoration (Ertugrul and Ismail, 2005). Luting cement have an important role in sealing the margin and thus prevents the marginal leakage. The primary purpose of the luting procedure is to achieve a durable bond and to have good marginal adaptation of the luting material to the restoration and tooth (Jivraj et al., 2006).

The ideal luting cement for fixed prostheses should be biocompatible and have good physical and mechanical properties. These includes resistance to microleakage, resist functional force, and high compressive and tensile strength and other mechanical properties (Rosenstiel et al., 1998). It should posses a high fracture toughness, dimensionally stable to decrease stresses during setting procedure, be without porosity defects, be able to flow plastically as it sets and finally it should be able to adhere to the substrates (Mitchell and Orr, 1998).

2.5.1 Luting agents

In the past there are three main types of conventional cements commonly used; zinc phosphate cements, polycarboxylate, and glass ionomer cements. In recent years there are two additional types of luting agents have been used with considerable popularity. These include the resin-modified glass ionomer cements and resin cements (Jivraj et al., 2006). Each type of these luting agents, has its own physical and chemical properties and handling characteristics which are different from each other but no one is consiered as ideal for all types of restorations (Diaz-Arnold et al., 1999).

2.5.1.(a) Resin luting cements

2.5.1.(a).(i) Composition

The composition of the resin luting cements is the same as general composition of composite resin restorative materials; a resin matrix with silane-treated inorganic fillers. The fillers are silica or glass particles and/or colloidal silica. An adhesion promoter was added to the methylmethacrylate monomer so that no seperate bonding agent is needed (Anusavice, 2003).

2.5.1.(a).(ii) Physical and mechanical properties

Physical properties seemed to be of great effect in the durability of luting cements in the mouth. The resistance against dissolution and disintegration is one of the most important of these properties because it may lead to loosening of the fixed prostheses and/or eventual secondary caries (Yoshida, 1998). They are less likely to leak than other cements (Schwartz and Robbins, 2004). Generally, resin cements have superior mechanical properties; in clinical situations where the retention is inadequate they offer increased retention. In addition, they can increase the fracture resistance of overlying ceramic materials (Schwartz and Robbins, 2004; Saskalauskaite et al., 2008).

However, during curing shrinkage of the cement, stress will develope. The film thickness of the lute is of great effect in the amount and nature of the stress development; the thicker the layer, the slower the stress development (Davidson et al.,1991). Abo-Hamar et al. (2005) used a shear bond strength test to study the bonding ability of the new universal self-adhesive cement RelyX Unicem to dentine and enamel compared to four conventional luting agents, with and without thermocycling. They found that RelyX Unicem may be considered as an excellent adhesive system for high-strength situations, especially for luting conventional ceramic crowns with little or no enamel left. In addition, it can be used in one step, thereby, avoiding technique sensitivity that is faced with other different luting materials. Kivanç and Görgül (1995) stated that for luting post systems, self-etching adhesives considered as good alternatives to etch-and-rinse adhesive systems.

2.5.1.(a).(iii) Adhesion

The resin luting cements posses good ability to adhere to enamel and dentine (McComb, 1996; Sahafi et al., 2005; Terry et al., 2007) without the need of a conditioning and/or a bonding system. They exhibit improved micromechanical and chemical bonding not only to tooth structure but also to other substrates like the surfaces of metal-primed or silica-coated, silane-treated ceramic surfaces which is essential for the retention of the restoration and also for the marginal integrity (Terry et al., 2007). This bonding ability of resin luting agents to adhere to different post materials and dentine make the tooth more fracture resistant (Mendoza et al., 1997). Cements with high retentive capacities are believed to be of great influence in post‘s design, surface texture and length. It is of benefit in cases that lack the retention forms such as in shorter parallel-sided and tapered dentatus dowels (Nissan et al., 2001). The adhesive strength of the composite cement seemed to be affected by the contraction stress which is developed during curing shrinkage (Davidson et al., 1991).

2.5.1.(a).(iv) Disadvantages

Resin luting cements are more difficult to use (McComb, 1996). Stresses produced during polymerization shrinkage and problems with adequate access to the root canal hazard the formation of high-strength bonds (Bouillaguet et al., 2003).

2.5.1.(a).(v) Classification of resin luting cements

Resin cements are divided into three categories according to the activation mode, light-cured, dual-cured and chemically cured agents (Jivraj et al., 2006).

Chemically-activated (Auto cured)

Chemically-activated (auto cured) cements are available either in powder and liquid form or in paste-paste system. Generally, the powder is borosilicate or silica glass with fine polymer powder and an organic peroxide initiator. The liquid consist of dimethacrylate monomers containing an amine promoter for polymerization. The paste system consists of the same compositions but with the monomers and fillers combined into two pastes (O'Brien, 2002). On mixing the two components, polymerization occurs resulting in a highly cross-linked structure. That is why the excess must be removed as soon as possible before polymerization become complete as it is difficult to be removed after that. This cement can be used in all types of prosthesis especially if these prosthesis are thicker than 2.5 mm (Anusavice, 2003).

Photo-activated (Light-cured)

Light-polymerized cements are single component luting cement systems. They are indicated in cementation of prosthesis in a thickness of less than 1.5 mm to allow enough light transmition. Again removal of the excess material should not be delayed after polymerizing because once polymerization complete it becomes very hard (Anusavice, 2003).

These cements create more stress generation during polymerization shrinkage and show evidence of less flow than autopolymerized composites. This contraction stress formed might reach above 20 MPa. (Alster et al., 1997).

Dual cured

Dual-cured and self-cured resin cements are two-component system and need to be mixed in a way similar to that of chemically-cured cement (Anusavice, 2003). This type of cement has been recommended to be used for the cementation of fibre posts. They are thought to have the ability to polymerize in areas which cannot be entirely reached by light such as the apical portions of the root. However, light curing was recommended for the initiation of polymerization reaction of dual-cured resin cements because it was reported that some dual-cured cements may not reach an adequate degree of conversion in the absence of light (Radovic et al., 2009). Dual-polymerized resin luting agents had higher or equal flexural strength compared to the autopolymerized mode (Lu et al., 2005).

2.6 Core

A core build up means rebuilding of the coronal part of badly broken-down tooth before the restoration of the tooth with an indirect extracoronal restoration (Chutinan et al., 2004). Different materials can be used for core build up but there are three main types which are amalgam, composite and reinforced glass ionomer materials (Bonilla et al., 2000).

2.6.1 Amalgam

Amalgam is one of the most popular restorative materials. It posseses high fracture toughness to withstand the stresses generated during mastication (Bonilla et al., 2000). Amalgam is strong in tension and fracture resistant (Millstein et al., 1991), and has the highest compressive strength (Larson, 2004). It exhibit an elastic modulus similar to that of dentine (Combe et al., 1999). On the negative side, setting time of amalgam alloys to reach maximal hardness is after 24-hours which made the ability to prepare the tooth for cast restoration at the same appointment is impossible.

Amalgam is considered as undependable core buildup material when there is lack of bulk (Gateau et al., 1999). Another disadvantage of amalgam is that it has no natural adhesive properties and should be used with an adhesive system for buildup (Howdle et al., 2002). Aesthetic is also considered as a disadvantage of amalgam especially in anterior teeth when used with ceramic crowns (Schwartz and Robbins, 2004).

2.6.2 Glass ionomer

The glass-ionomer materials have some favourable characteristics including flouride release and exhibit low coefficient of thermal expansion (Aksoy et al., 2005). They are considered as dimensionally stable in moisture (Cooley et al., 1990). However, this type of material including resin-modified glass ionomer are weak (Millstein et al., 1991) and show less strength than that for resin composites or amalgam when used as a build up material. (Cho et al., 1999; Möllersten et al., 2002; Piwowarczyk et al., 2002). They are contraindicated in cases with extensive loss of tooth structure (Schwartz and Robbins, 2004) and their use should be limited to non stress bearing area (Aksoy et al., 2005).

2.6.3 Composite

Composite resin is the most popular core material and has some characteristics of an ideal build up material. It can be bonded to many of the current posts and to the remaining tooth structure to increase retention compared to amalgam and cast post and cores (Pilo et al., 2002). Composite is strong in tension (Millstein et al., 1991) and it was found to have a significant influence on tensile bond strength (Wrbas et al., 2007). Composite cores posses good fracture resistance with more favourable fracture patterns when they fail (Pilo et al., 2002). They show the best compressive and diametral tensile strengths among the other core materials (Yüzügüllü et al., 1990). It leads to good aesthetical results because it is tooth coloured and can be used under translucent restorations (Pilo et al., 2002). However, during polymerization composite tends to shrink which may lead to gap formation in the areas of the weakest adhesion. After polymerization, it swells because of water absorption, so plastic deformation occurs under repeated loads (Schwartz and Robbins, 2004).

Chapter Three
Materials And Methods

3.1 Materials

Glass fibre reinforced composite post system (RelyX™ fibre post, 3M/ESPE, USA) was used in this study (Fig. 3.1). The length, diameter and components of the RelyX^{TM} post system are listed in Table 3.1. Self-adhesive universal resin cement (RelyX™ Unicem, 3M/ESPE, USA) was used to cement the posts (Fig. 3.2). The compositions of the resin cement are demonstrated in Table 3.2. Cores were fabricated from composite resin (Filtek™ Z350, 3M/ESPE, USA) (Fig. 3.3), then covered with metal crown made from non precious alloy.

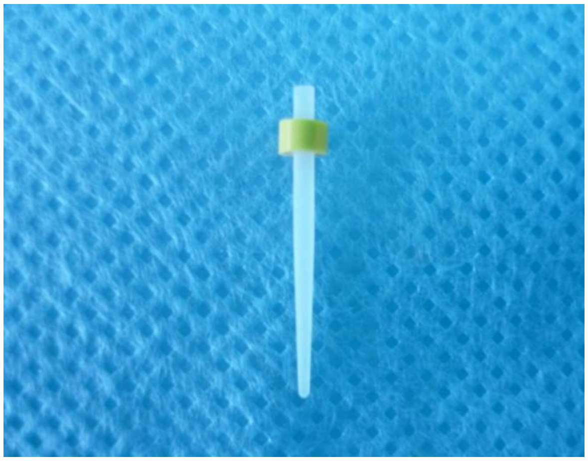

Figure 3.1 RelyX™ fibre post

Table 3.1 The post system used in this study

Post system	Diameter (mm)	Legth (mm)	manufacturer	Components*
Relyx^{TM}	A = 0.7, C = 1.30	20	3M/ESPE, USA	60-70% glass fibres 30-40% epoxy resin

A = Apical end diameter, C = Coronal end diameter
* According to the manufacturer product profile

Figure 3.2 RelyX™ Unicem Aplicap and Elongation tip

Table 3.2 Compositions of resin cement

Cement	components*	manufacturer
RelyX™ Unicem self adhesive resin cement	*Powder*: glass powder, silica, calcium hydroxide, pigment, substituted pyrimidine, peroxy compound, initiator. *Liquid:* methacrylated phosphoric ester, dimethacrylate, acetate, stabilizer, initiator.	3M/ESPE, USA

* According to the manufacturer product profile

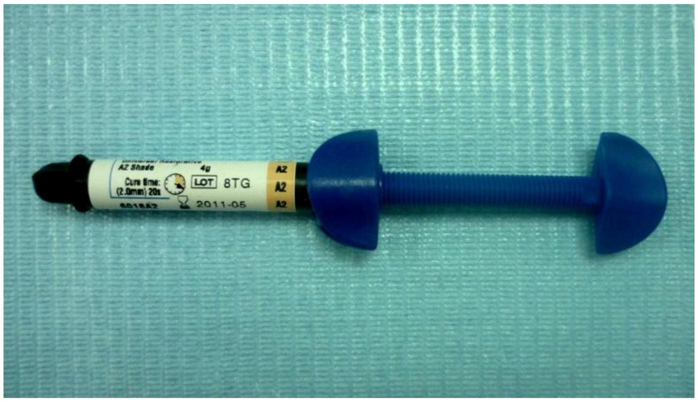

Figure 3.3 Filtek Z350 composite resin build up material

Table 3.3 Compositions of the composite core build up material

Composite type	Compositions*	Manufacturer
Filtek™ Z350	*Filler*: aggregated zirconia/silica cluster, with an average clusterparticles size of 0.6 to 1.4 microns with primary particle size of 5-20 nm and non-agglomerated/non-aggregated, 20 nm silica filler. The inorganic filler loading is 78.5% by weight (59.5% by volume). *Matrix*: bis-GMA, bis-EMA (6), UDMA with small amounts of TEGDMA.	3M/ESPE, USA

* According to the manufacturer product profile

3.2 Methods

3.2.1 Teeth collection

One hundred and forty extracted, single-rooted, human maxillary central incisors were collected (Fig. 3.4). To prevent desiccation, they were stored in 0.9% solution of physiologic normal saline. Disinfection was done to the teeth with 0.5% Chloramine T trihydrate solution for one week. Ultrasonic scaler (Peizon® Master 400, Switzerland) was used to remove the external debries on the teeth. Once cleaned, they were stored in a refrigerator at 4° C in distilled water.

Figure 3.4 The collected teeth

3.2.2 Teeth selection

Ninety maxillary central incisors were then selected from the total number. Digital caliper (Mitutoyo/Digimatic, Japan) was used to measure the faciopalatal and mesiodistal dimensions at the cementoenamel junction (CEJ) of each tooth. Teeth with comparable mesiodistal (6.5-7.0 mm) and faciopalatal (7.0-7.5 mm) dimensions were chosen. The selected teeth were examined at 10X magnification using a stereomicroscope (Olympus, U-CMAD3, Japan) to ensure fracture-free roots. The inclusion criteria for tooth selection were teeth with single canals. Those with root surface caries or crack lines and fractures were excluded from the study. Teeth with previous endodontic treatment were also excluded. The teeth were numbered (Fig. 3.5) and periapical radiographs were taken for each of them to exclude any tooth with internal resorption or canal abnormality.

Figure 3.5 The numbered teeth prepared for x ray

3.2.3 Teeth decoronation

A diamond disc with low speed straight handpiece under constant water irrigation was used to cut the crown of the teeth (Fig. 3.6). To standardize the specimen’s lengths, the crowns of the selected teeth were removed according to ferrule heights F4, F2 and F0 (4 mm = F4, 2 mm = F2 and 0 mm = F0).

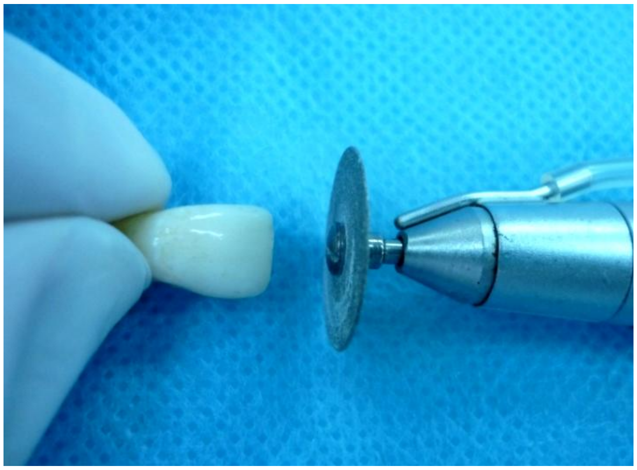

Figure 3.6 Teeth decoronation

By using digital caliper (Mitutoyo/Digimatic, Tokyo, Japan) the specimens’ lengths were assigned as 19 mm, 17 mm and 15 mm from the apical end by a horizontal cut made perpendicular to the long axis of the root (Fig. 3.7). Minute length adjustment and final polishing were done using a grinding machine (Metaserv® 2000, Buehler, USA) (Fig. 3.8).

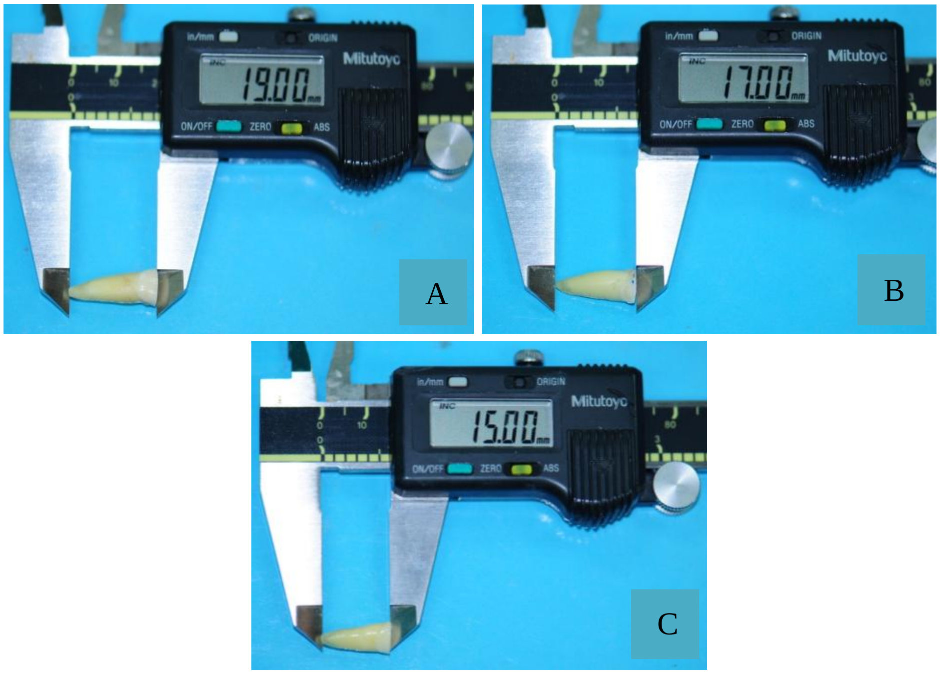

Figure 3.7 Specimen’s lengths were assigned as: (a) 19 mm, (b) 17 mm and (c) 15 mm using digital caliper.

Figure 3.8 Grinding and polishing machine

3.2.4 Canal preparation and obturation

The specimens were mounted in impression compound blocks prior to endodontic preparation to control movements during manipulation. The preparation of the root canals of all teeth were done using the step-back technique with K-files (Dentsply/Maillefer, Switzerland). The pulp extirpation with a barbed broach (Dentsply/Maillefer, Switzerland) was the first step of the root canal preparation. Size 10 K-file was used in order to establish the canal patency by placing it inside the canal with light pressure untill it’s tip appear at the apical foramen; the true working length was shorter of this file's length by 1 mm which was 18 mm, 16 mm and 14 mm according to the groups of the study. (Teeth with large canals were excluded, this was achieved by using size 30 K-file). In case that when the first file that bound to the canal walls was size 30 K-file, the tooth will be included. If this file did not bind to the canal walls, this means that the tooth had a large canal and it would be excluded from the study. Further instrumentation of the apical sections were done with K-files (size 35, 40 and 45). The master apical file used was size 45, at 18 mm at F4 Group, 16 mm at F2 Group and 14 mm at F0 Group. Then the canals were flared out by using size 50 K-file placed 1.0 mm short of the working length. Instrumentation was continued by shortening the working length of each successively larger file by 1.0 mm until reach the final size which was size 60 K-file. For irrigation of the canals 3.0 ml of 1% sodium hypochlorite solution (NaOCl) (Clorox (M) Industries Sdn Bhd, Malaysia) was used after each filing and size 10 K-file was used in order to check the canal patency. After completion of canal preparation irrigation was done with 3.0 ml of 1% Sodium hypochlorite (NaOCl) and then with 3.0 ml of 17% Ethylenediaminetetraacetic acid (EDTA) (SmearClear™, SybronEndo, USA). Then, in order to remove any trace of irrigants from the canals distilled water was used for final irrigation. The teeth were kept in distilled water until the obturation time.

Lateral condensation technique was used for teeth obturation using gutta-percha cones (Dentsply/Asia, Hong Kong) and a resin-based canal sealer (AH-plus®, Dentsply/DeTrey, Germany) (Fig. 3.9). Before obturation, the canals were dried using paper points (Dentsply/Asia, Hong Kong). With the use of a ruler, size 45 gutta-percha master cones were marked and bended to the assigned working length. Then, a trial insertion of the gutta-percha master cones was done inside the canals to the full working length to ensure complete seating. After that the two pastes of the sealer (paste A and B) were mixed on the glass slab using a metal spatula in 1:1 ratio according to the manufacturer's instruction. The prepared canal was coated with a thin layer of the sealer (AH-plus®, Dentsply/DeTrey, Germany) using paper points. The gutta-percha master apical cone was also coated with a thin layer of the sealer and inserted into the canal and seated at full working length. For lateral condensation a finger spreader that reached 1-2 mm short of the working length was selected. Then the accessory fine and medium gutta-percha points (Dentsply/Asia, Hong Kong) were inserted in the space created by the finger spreader.

This process was continued until the spreader could not penetrate more than 1-2 mm into the canal orifice. The flame-heated condenser was used to remove the extra coronal excess of gutta-percha and vertical condensation of gutta-percha at the canal orifice was created with the same heated condenser. Temporary cement (Cavit®, 3M/ESPE, USA) was used for sealing the canals orifices. Finally to ensure full setting of the seal, the teeth were stored in a 100% humid environment at 37° C for 24 hours.

Figure 3.9 AH Plus™ root canal sealer

3.2.5 Grouping

The selected 90 teeth were randomly divided into three groups, each group consist of 30 teeth. A different ferrule height/residual dentine was assigned to each group; 4 mm (F4), 2 mm (F2) and 0 mm (F0) ferrule heights. Each group was further divided into 3 subgroups of 10 teeth; each with a different post length (10 mm = 2/3, 7.5 mm = 1/2 and 5 mm = 1/3 of the root length). The groupings were demonstrated in (Fig. 3.10) and Table 3.4.

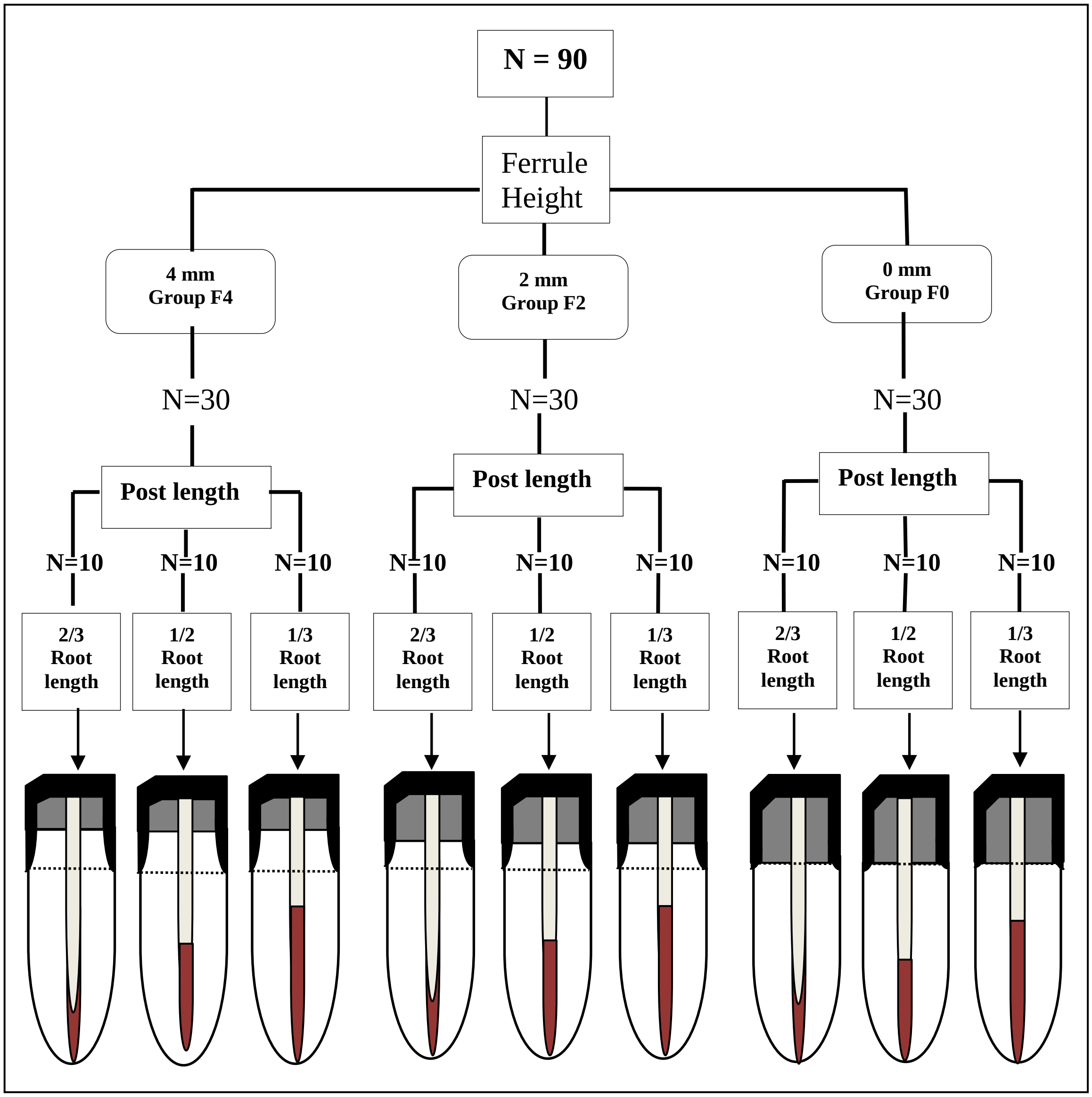

Figure 3.10 Grouping of the specimens

Table 3.4 Ferrule heights and post lengths assigned to the study groups

Group	Ferrule height (mm)	Tooth length (mm)	Post length (mm)	Post length: root length ratio
F4P10	4	19	10	2/3
F4P7.5	4	19	7.5	1/2
F4P5	4	19	5	1/3
F2P10	2	17	10	2/3
F2P7.5	2	17	7.5	1/2
F2P5	2	17	5	1/3
F0P10	0	15	10	2/3
F0P7.5	0	15	7.5	1/2
F0P5	0	15	5	1/3

F = Ferrule heights, P = Post length, Root length = 15 mm.

3.2.6 Removing Gutta-Percha

To prepare the post space, the gutta-percha was first removed from the root canal with Gates-Glidden burs (Dentsply/Maillefer, Switzerland) No. 2 and 3 attached to a low speed handpiece. A light brushing motion was applied on the canal walls during the use of the bur to ensure that all the gutta-percha was removed from the canal. The working lengths of the Gates-Glidden burs were adjusted by using rubber stoppers according to the post length assigned for each group.

3.2.7 Post space preparation

Prefabricated glass fibre reinforced composite posts (RelyX™ Fibre post, 3M/ESPE, USA) of 0.7 mm diameter at their apical section and 1.3 mm diameter at their coronal section (yellow coded) were used. The post spaces for each group were prepared with appropriate low-speed drill which was supplied with the post kit to match the post size (yellow coded) (Fig. 3.11). The length of the drill was modified according to the different post lengths assigned for each experimental group.

The lengths of the fibre posts and their matching drills in P7.5 and P5 groups were modified by cutting their apical end. Rubber stoppers were used to mark the the drill and the post to the assigned length of each group of the study. The cut was done by using a diamond disc placed on a low speed rotary hand piece under a continuous stream of cooling water. This modification is due to the fact that the drills and the posts used are tapered at the apical end and after modification, they fit better to the prepared canal walls than those inserted to the desired length without being cut.

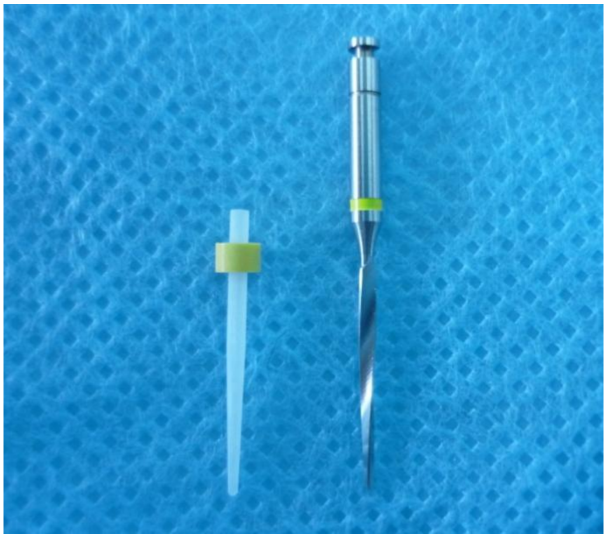

Figure 3.11 Size 1 RelyX™ Fibre post with it's matching drill

3.2.7.(a) F4 Groups (P10, P7.5 and P5)

In these groups, the coronal portion of the posts was extended 2 mm from the sectioned tooth surface so that its length above the CEJ was 6 mm. The length of the post and its matching drill was adjusted by a rubber stopper to match the preplanned length of the post which was different between the three subgroups.

3.2.7.(a) (i) Group P10

The preplanned length of the post inside the canal was 10 mm. The apical section of the post remain intact (Fig. 3.11). The post was marked with a rubber stopper 4 mm below its coronal end. Then the post was cut at the mark with a high speed diamond disc under a stream of cooling water. Thus the total length of the post was 16 mm (10 mm inside the canal plus 6 mm above the CEJ). A rubber stopper was placed in the special drill to adjust the working length of the drill to the desired length. After finishing the preparation of the post spaces, they were rinsed with distilled water and dried with paper points. To ensure full seating of the posts they were trial inserted into prepared canal space before the cementation.

3.2.7.(a) (ii) Group P7.5

The post was cut 2.5 mm from it's apical end. A rubber stopper was used to mark the desired level at which the post will be cut. The cut was done by using a diamond disc placed on a low speed rotary hand piece under a continuous stream of cooling water. The special drill was also modified by cutting its apical end 2.5 mm to match the post shape (Fig 3.12). The coronal portion of the post was cut to the preplaned length which was 7.5 mm inside the canal plus 6 mm above the CEJ. So the total post length was 13.5 mm. The cut was done by the same procedure used in group P10.

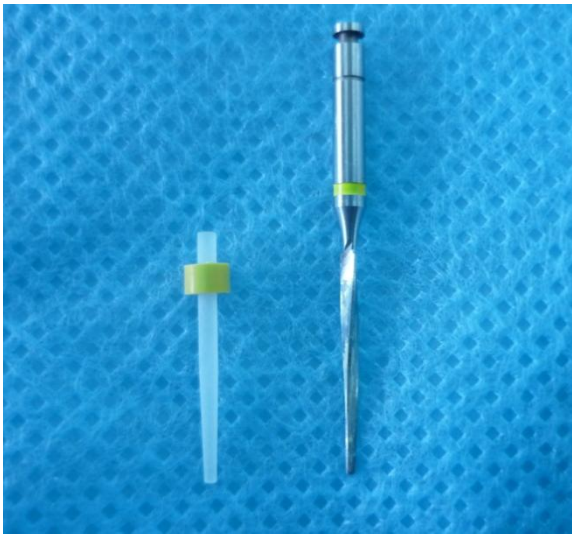

Figure 3.12 RelyX™ Fibre post with it's matching drill were cut 2.5 mm from their apical end.

3.2.7.(a) (iii) Group P5

The post and it's matching special drill was modified by cutting its apical end 5 mm in the same manner that was used in group P7.5. (Fig 3.13). The total post length in this group was 11 mm (5 mm inside the canal and 6 mm above the CEJ).

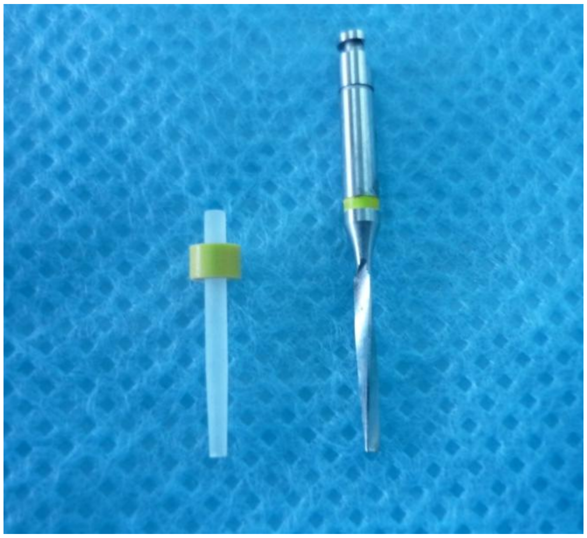

Figure 3.13 RelyX™ Fibre post with it's matching drill were cut 5 mm from their apical end

3.2.7.(b) F2 Groups (P10, P7.5 and P5)

In these groups, the coronal portion of the posts was extended 4 mm from the sectioned tooth surface (6 mm from CEJ). The length of the post and its matching drill were similar to those in the F4 subgroups. They had been modified in the same procedure and same measurements that were used in the F4 subgroups.

3.2.7.(c) F0 Groups (P10, P7.5 and P5)

The difference between this group and the other two groups (F4 and F2) was only in the extending part of the post from the sectioned surface of the tooth which was 6 mm. This is because the cut of the sectioned surface was with the level of CEJ. The other steps of post cutting and the post and drill modifications were done in the same manner that were explained in the previous groups.

3.2.8 Post placement and cementation

Following the manufacturer’s instructions the root canals were flushed with 1% sodium hypochlorite before post cementation. Then distilled water was used to rinse the canals immediately and then dried with paper points (Dentsply/Asia, Hong Kong). The posts were inserted into the canals to check for passive complete seating to a depth corresponding to the post length assigned for each group. A self adhesive resin cement (RelyX™ Unicem, 3M/ESPE) was used for posts cementation. The resin cement capsule (RelyX Unicem self-adhesive universal resin cement) was first activated with an Aplicap™ activator for 4 seconds and then mixed with a high-speed rotary mixing unit (RotoMix, 3MESPE, Germany) for 10 seconds according to the manufacturer's instructions. The canal was then filled with the cement by using elongation tips (RelyX Unicem™ Aplicap Elongation Tips, 3M/ESPE, USA). Post was immediately inserted into the canal and a light curing machine

(Dentsply spectrum™ 800, USA) was used for photoactivation of the cement through the post for 10 seconds to allow initial polymerization. After initial setting scaler was used to remove any excess cement on the sectioned tooth surface. The specimens were left for twenty four hours to allow for complete setting of the cement.

3.2.9 Core build up

Composite resin (Filtek™ Z350, 3M/ESPE, USA) is the material used for core build up. First of all, 37% phosphoric acid gel (Scotchbond™, 3M/ESPE, USA) was used for etching of the sectioned tooth surface for 10 seconds. Then the etchant gel was rinsed using water and gently air-dried using an air syringe. After that, the bonding agent (Adper Single bond 2, 3M/ESPE, USA) was applied to the sectioned root surface in two layers and it was light cured for two seconds using a Spectrum™ 800 (Dentsply/Caulk, USA) light curing unit. A copper band was then seated over the sectioned tooth surface. A layer of composite core material of 2 mm thickness was first applied and condensed and then light cured for 40 seconds. Further increments of composite resin placed within a cylindrical matrix in a vertical direction to form the remainder of the core until the desired height of the core which was 6 mm from the CEJ level covering the coronal end of the post that emmerged from the sectioned tooth surface. The copper band was then removed and additional 40 seconds polymerization was subsequently performed on all around the core to ensure complete setting of the core material.

3.2.10 Tooth mounting

Root surfaces were first marked 3 mm below the facial cemento-enamel junction. To simulate the periodontal ligament, the root surfaces were covered with two layers of 0.075 mm-thick heat-resistant polytetrafluoroethylene adhesive tape. Then each specimen was stabilized on a holder with a vertically moving rod of a milling machine (AF 30 milling and surveying machine, Switzerland) in order to keep the specimen inside the block perpendicular to the horizontal plane (Fig 3.14).

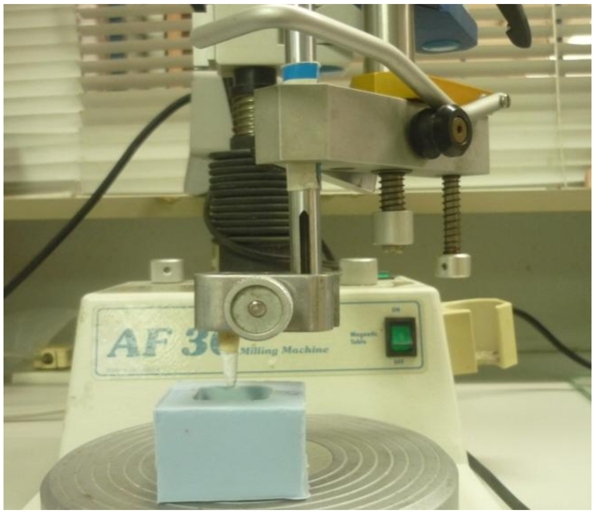

Figure 3.14 A tooth fixed in milling machine

Specimens were then lowered into the centre of a custom made cubic moulds (23 mm width X 23 mm length X 25 mm depth) filled with autopolymerizing acrylic resin (Satex cold cure acrylic, England) at the level previously marked before. Thus the mounted portion of the root was 12 mm (Fig. 3.15). After the first sign of acrylic polymerization, teeth were removed from the resin blocks by moving the rod in an upward direction, and the tape spacers were removed from the root surfaces. Silicone impression material (Densply, Aquasil Ultra XLV, USA) was mixed and injected into the tooth space in the acrylic resin molds, and the teeth were reinserted into the resin molds to produce a standardized silicone layer of 0.15 mm to simulate periodontal ligament. Then specimens were left for 24 hours in room temperature for complete setting of the acrylic resin.

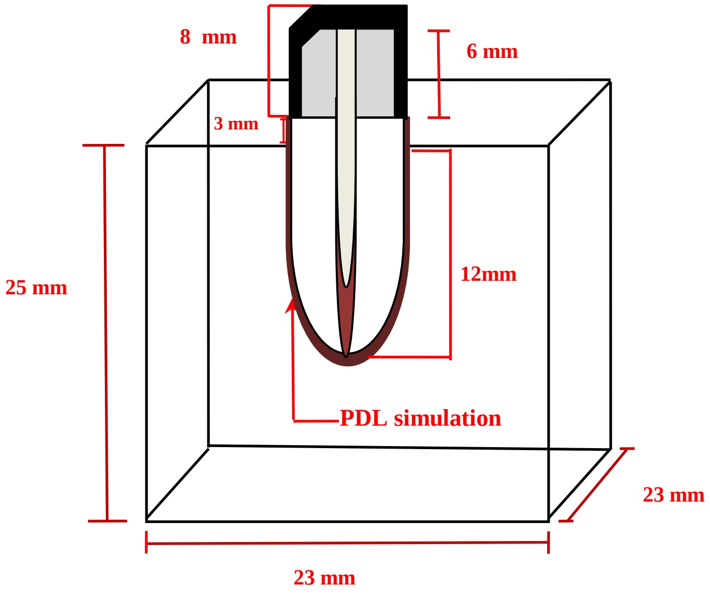

Figure 3.15 Specification of restored tooth in mounting block

3.2.11 Preparation

Each specimen was prepared to receive a non-precious metal coping. To standardise the preparation convergence angle, diamond bur (998FG021 Round ended, tapered with guide pin, NTI-Kahla GmBH, Germany) was attached to a high speed rotary handpiece which was fixed to a paralleling device (Custom-made at the Engineering Department, University of Malaya) in order to make the walls 6^{o} tapered (Fig. 3.16). This produced a preparation with a total occlusal convergence angle of 12 degree and a height of 6 mm from the preparation margin. For all the specimens a chamfer finish of 1 mm in depth was prepared at the level of facial cemento-enamel junction around the circumference of the tooth. A guide pin at the tip of the burs produced a standardised depth of the preparation margin of 1 mm.

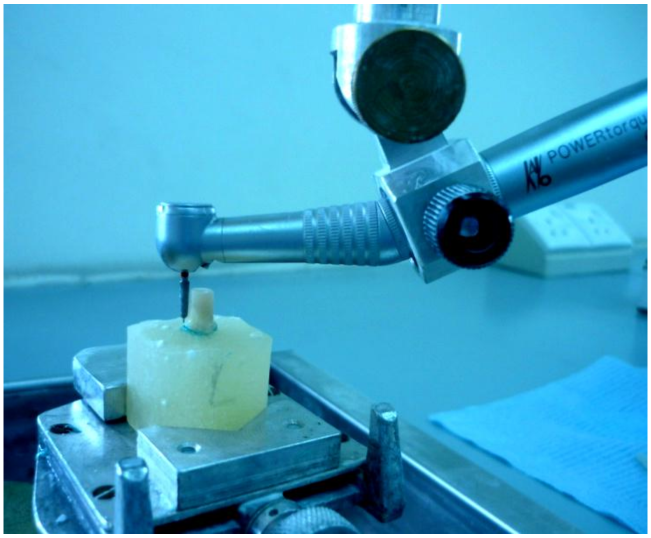

Figure 3.16 Core preparation with paralleling device

A customized metal jig with a 45° plane angle was fabricated as shown in Fig. 3.17. A cubic hole of similar dimensions to those of the resin block was created at the center of the inclined plane. The jig was also provided with a lateral screw to fix the resin block and to prevent any possible movement of the block during loading. When fixed inside the jig, each specimen in the resin block would be aligned 45° to the horizontal plan. A beveled cut was made on the palato-incisal line angle of the coronal core surface to simulate the flat palato-incisal surface of a tooth starting from the incisal edge and extending 5 mm toward the cervical direction. This was done to create a flat palatal surface of the metal coping for the loading tip of the testing machine. The cut was done using a diamond disk with straight handpiece attached to a surveyor (AF 30 milling and surveying machine, Switzerland). The specimens were then ready for the fabrication of metal crowns (Fig. 3.17).

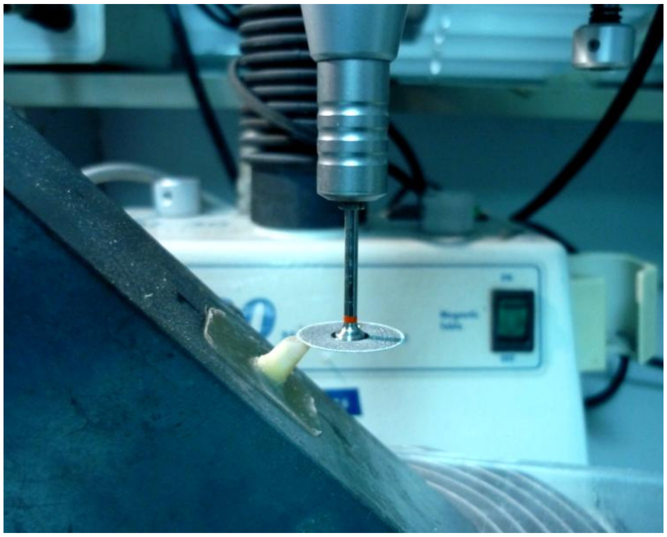

Figure 3.17 The fixed specimen subjected to a horizontal cut by using diamond disc attached the surveyor

3.2.12 Crown fabrication and cementation

Wax pattern was done above the finishing line covering the core in group 0 mm ferrule heights (F0) and the core and remaining tooth structure in group 2 and 4 mm ferrule heights. Each coping was waxed individually so that each prepared specimen will recive its own coping. The wax pattern was done with uniform thickness of 1 mm all arround and 2 mm thickness incisally. The total height of the wax pattern was 8 mm from the facial cemento-enamel junction to the incisal edge. Ninety metal copings were fabricated from non precious alloy to simulate crowns. The thickness of each metal coping was verified with digital crown calliper and adjustment was made where necessary to produce uniform thickness as planned. Then the crowns were adhesively luted to the prepared core with RelyX Unicem (RelyX™ Unicem, 3M/ESPE, USA) according to the manufacturer's instructions.

3.2.13 Thermocycling

Prior to thermocycling the specimens were stored in distilled water at 37° C and 100% humidity for 24 hours. The specimens were placed in a bath filled with water (Custom-made at the Engineering Department, University of Malaya) and it was then thermocycled 500 times from 5 to 55° C using 30 second dwell times with a two seconds transfer interval (Fig. 3.18).

Figure 3.18 Thermocycling machine

3.2.14 Testing procedure

Each mounted specimen was fixed in the customized jig in a way that it aligned the long axis of the tooth at 45° angle to the horizontal plane and 135° to the loading rod tip (Fig. 3.19). This jig was secured to the lower compartment of an Instron universal testing machine (Shimadzu, Autograph AG-X, Japan) (Fig. 3.20). A flat steel tip with round-ended compressive head, 2 mm in diameter, was used to apply the load from a palatal direction. It was fixed to the moving upper compartment of the testing machine. The head was positioned in the middle of the palatal slope for all specimens.

The compressive load was applied at a crosshead speed of 0.5 mm/min until failure occurred. Failure threshold was determined as the point at which the specimen could no longer withstand an increase in load where a sudden sharp drop in the stress-strain curve was displayed on the monitor connected to the Instron testing machine. All specimens were stored in distilled water for failure mode analysis.

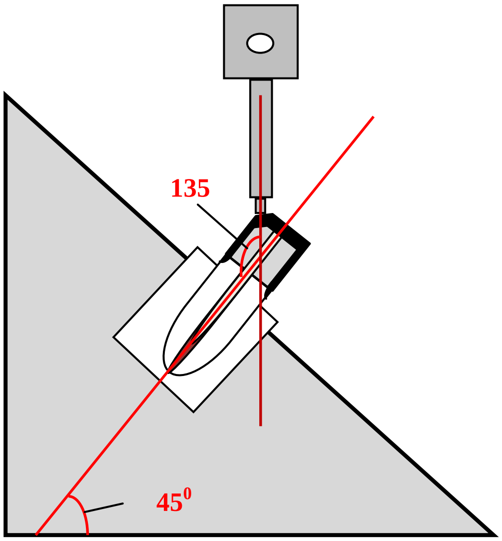

Figure 3.19 Loading angels: A mounted specimen was fixed in this jig at an angle 45° to the horizontal plane and 135° to the loading rod tip.

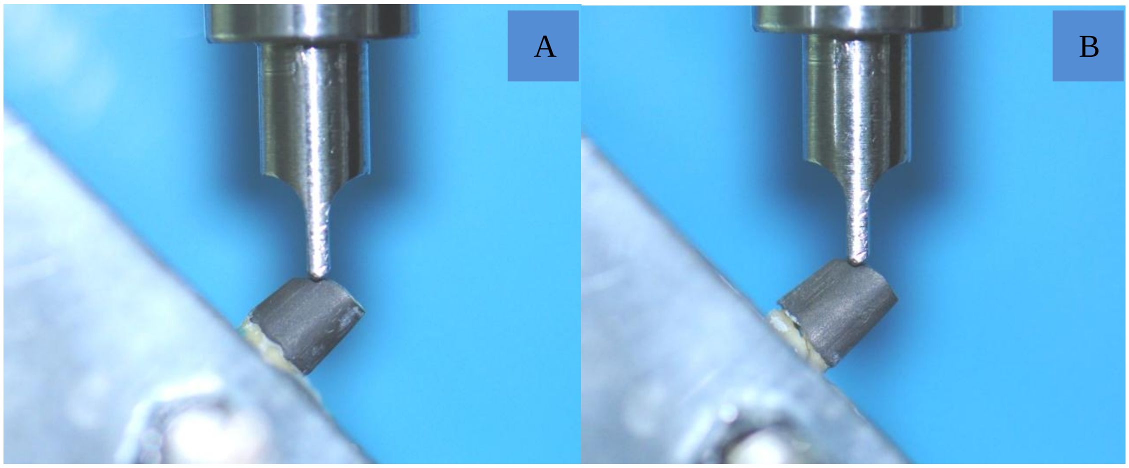

Figure 3.20 Specimens fixed in instron universal testing machine (A) before loading (B) after loading.

3.2.15 Failure mode evaluation

The failure mode was evaluated by visual examination of the specimens to classify its type. Then a stereomicroscope (Olympus, U-CMAD3, Japan) was used for further evaluation of the mode of failure. The failure mode was classified as either favourable (restorable) or unfavourable (catastrophic).

3.2.15.(a) Favourable failure modes

This mode of failure referred to those that take place above the level of the acrylic resin which simulate the bone level. They include either partial or complete post/core/crown debonding or post-core-tooth complex fracture above acrylic resin block (Fig. 3.21).

3.2.15.(b) Unfavourable failure modes

In this category the failure occurs below the level of the acrylic resin. It includes fracture of the post/core/root complex, cracks in the roots or vertical root fractures. To study and evaluate the manner of this type of failure, the specimens were examined by visual inspection (Fig. 3.21).

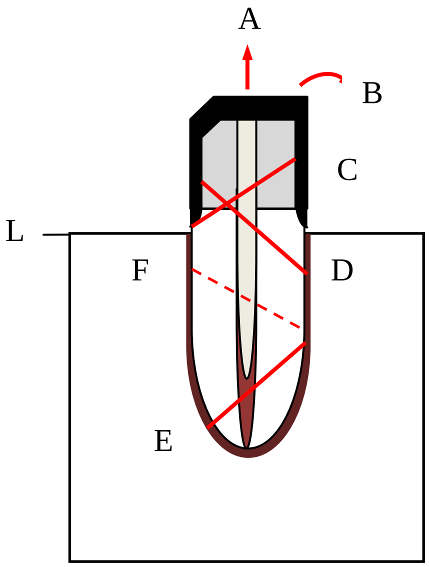

Figure 3.21 Failure modes; L = level of bone simulation, A = complete debonding of the post/core/crown, B = partial debonding of the crown and the core, C = fracture of the post/core/root complex above the simulating bone level, D = fracture of the post/core/root complex below the simulating bone level, E = vertical root fracture and F = cracks below the simulating bone level. (A-C are Favourable, D-F are unfavourable).

3.2.16 Data analysis

The data were subjected to statistical analysis using SPSS (Statistical Programme for Social Sciences); Windows version 12.0 (SPSS Inc.; USA). Two-way analysis of variance (ANOVA), with ferrule height and post length as fixed factors, was used to test the significant of differences in the ferrule heights at each post lenght and in the post lenghts at each ferrule height. When significant, Post-hoc test (Games-Howell) was performed for multiple comparisons. The level of significance was set at p = 0.05 for all the statistical tests. The decriptive statistic was used to record the failure mode.

Chapter Four
Results

4.1 Failure loads

4.1.1 Descriptive statistics for the failure loads

The failure load of each specimen is shown in Appendix III. The means and standard deviations of the failure loads for each post length subgroup at different ferrule heights are presented in Appendix V. Table V.1. The means are also presented in the form of a bar chart (Fig. 4.1).

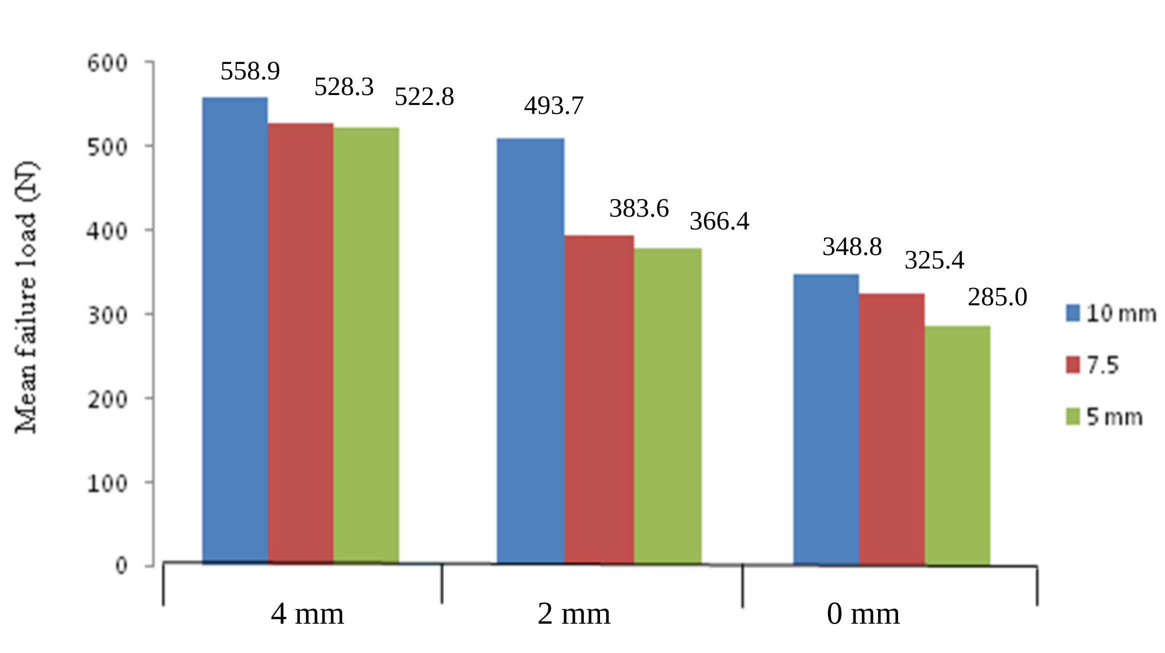

Figure 4.1 The mean failure load for each post length subgroup

The results showed that the highest mean failure load was obtained from 4 mm ferrule height at 10 mm post length group, F4P10 (558.9 N). However the lowest mean failure load was obtained from 0 mm ferrule height with 5 mm post length group, F0P5 (285.0 N).

4.1.2 The effect of ferrule height and post length on fracture load

The assumption of normal distribution of the data was met (appendix IV). Thus Two-way ANOVA test was performed (Table 4.1). Results in Table 4.1 showed that only the ferrule height had significant effect on the failure load ($p < 0.000$). However, the post length was found to have no significant effect on the failure load ($p = 0.102$) (Table 4.1) and Fig. 4.2. No significant interaction between ferrule height and post length was found ($p = 0.801$). This means that the effect of ferrule height on failure load was not affected by post length. Regardless the post length, specimens with 4 mm ferrule height had the highest failure load followed by those with 2 mm ferrule. The lowest failure load was seen when there was no crown ferrule present.

Table 4.1 Two-way ANOVA for the effect of ferrule height and post length on fracture load

Independent variable	N[a]	Mean failure load (N) ± (SD)	F (df)	*P* value
Ferrule Heights				
4	30	536.7 (195.4)		
2	30	414.6 (133)	18.143 (2)	0.000*
0	30	319.8 (54.7)		
Post length				
10	30	467.1 (184.3)		
7.5	30	412.4 (155.6)	2.344 (2)	0.102
5	30	391.4 (148.3)		

a = sample number * The level of significance sited at $p < 0.05$.

Post-hoc multiple comparisons test was performed for the ferrule height groups as indicated by two-way ANOVA. It shows that 4 mm ferrule height group had significantly higher fracture resistance than 2 mm and 0 mm groups. Similarly, 2 mm ferrule had significantly higher fracture resistance than those without ferrule [Table 4.2 and Fig. 4.3 (4 mm >> 2 mm >> 0 mm)].

Table 4.2 Post hoc test multiple comparisons for the ferrule heights

Ferrule heights (mm)	Mean difference (I-J)	95% Confidence interval		*P* value
		Lower Bound	Upper Bound	
4 vs 2	122.1*	17.9	226.3	.018
4 vs 0	216.9*	126.0	307.7	.000
2 vs 0	94.8*	30.7	158.8	.002

* The mean difference is significant at the $p < 0.05$

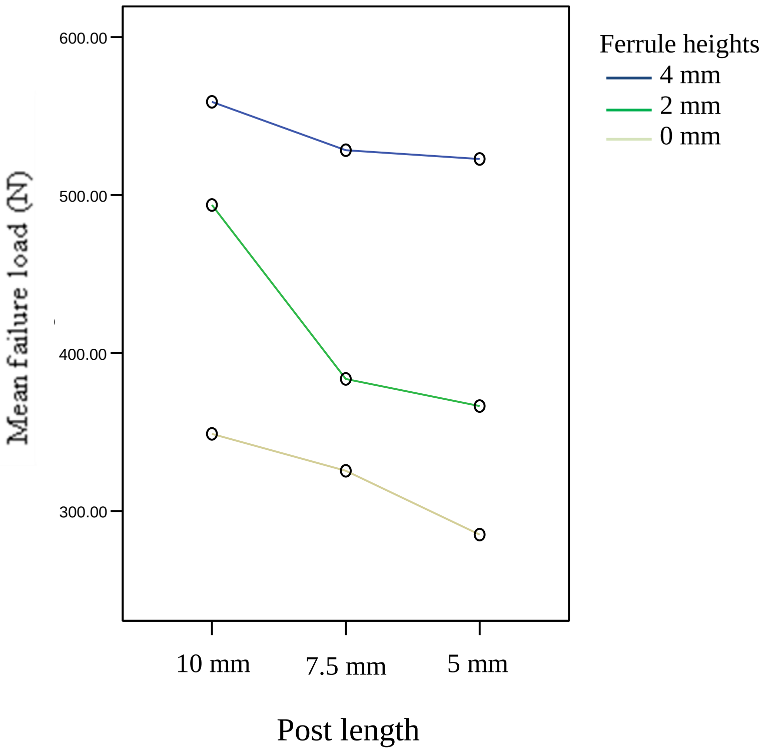

Figure 4.2 Mean failure loads for ferrule height groups

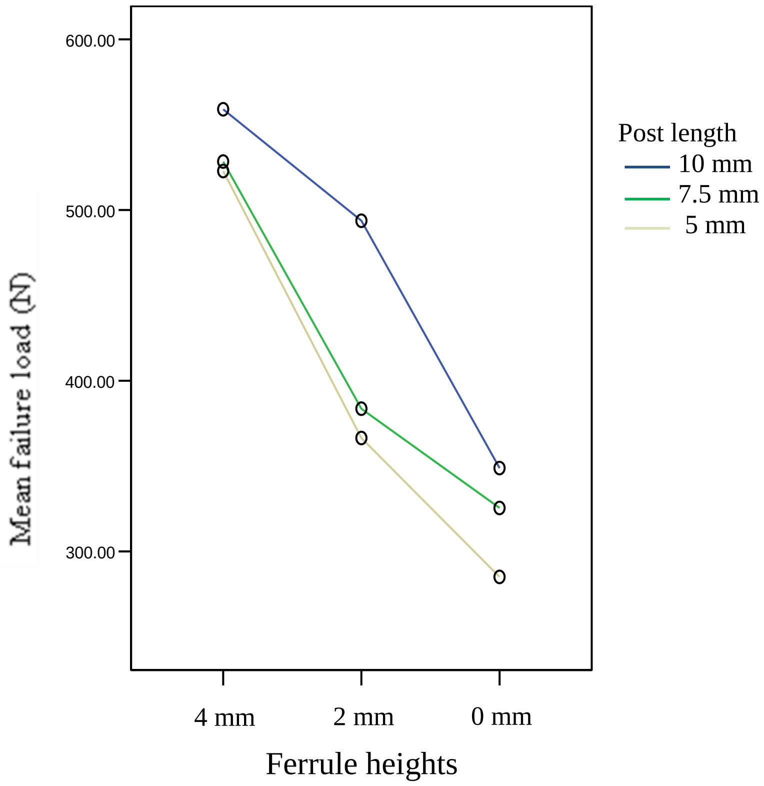

Figure 4.3 Mean failure loads for post length groups

4.2 The effect of ferrule height and post length on failure mode

The failure mode was evaluated and recorded according to the way mentioned in chapter 3 section 2.15. The data for failure modes were analyzed using Chi-square test. While conducting the test, it was found that the assumption for conducting Chi-square was not met. The expected count of less than 5 of cells exceeded 20% for all levels of ferrule height. Therefore, only discriptive statistics were done. The numbers and percentages for both favourable and unfavourable failure modes in each subgroup are presented in Table 4.3. Generally, the favourable failure modes were more than the unfavourable types in almost all the subgroups. It was found that the 4 mm ferrule group had more favourable failure compared to 2 mm and 0 mm ferrule groups, and 2 mm ferrule had more favourable than those without ferrule (4 mm > 2 mm > 0 mm) as shown in Table 4.3.

In post length groups, the heighest number of favourable failure was displayed in 10 mm groups followed by 7.5 mm and lastly 5 mm. The numbers and the percentages of both favourable and unfavourable failures are presented in (Table. 4.3).

Table 4.3 Descriptive statistics of failure modes

Ferrule height	Post length	N	Favourable Freq (%)	Unfavourable Freq (%)
4 mm	10 mm	10	7 (70 %)	3 (30%)
	7.5 mm	10	7 (70%)	3 (30%)
	5 mm	10	6 (60%)	4 (40 %)
	Total	30	20 (66.7%)	10 (33.3)
2 mm	10 mm	10	7 (70%)	3 (30%)
	7.5 mm	10	6 (60%)	4 (40%)
	5 mm	10	5 (50%)	5 (50%)
	Total	30	18 (60%)	12 (40%)
0 mm	10 mm	10	7 (70%)	3 (30 %)
	7.5 mm	10	6 (60%)	4 (40%)
	5 mm	10	4 (40%)	6 (60%)
	Total	30	17 (56.7%)	13 (43.3%)

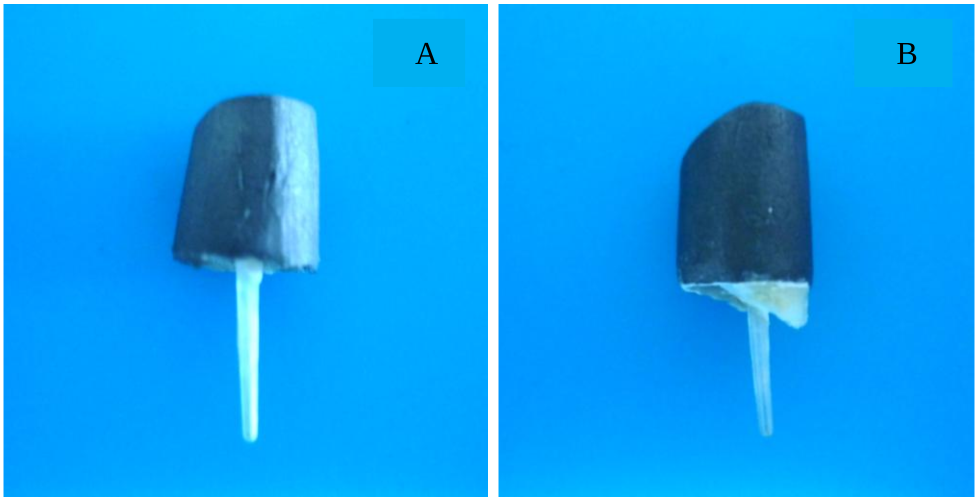

Figure 4.4 Samples of favourable failure modes in F4 group (A) post length 10 mm, (B) post length 7.5 mm subgroups

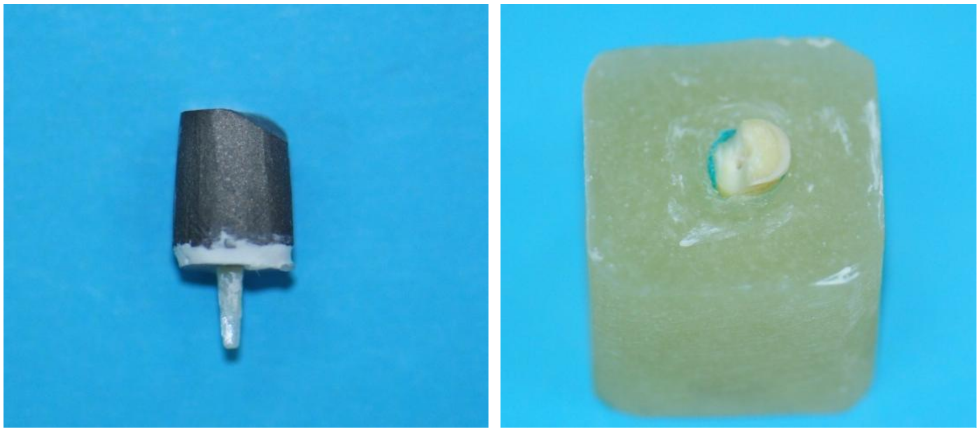

Figure 4.5 Samples of favourable failure modes in F2 group and post length 5 mm susubgroups

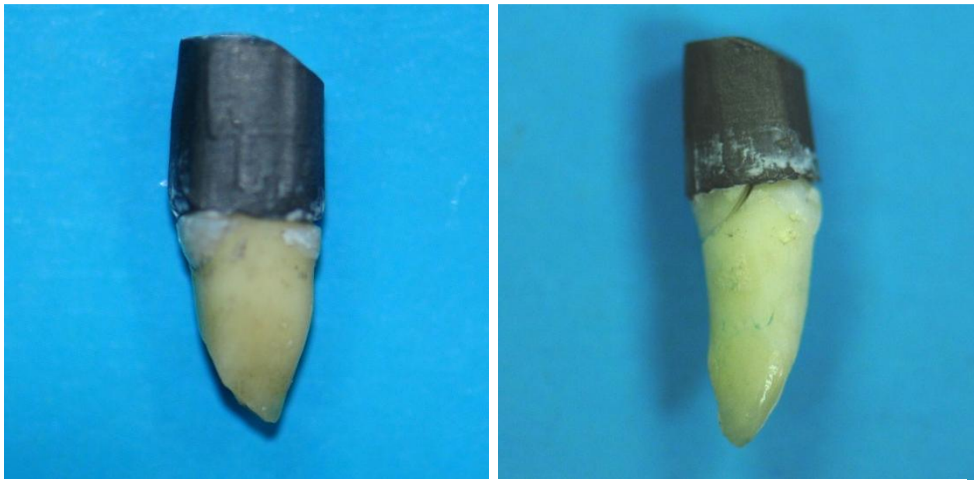

Figure 4.6 Samples of unfavourable failure modes in F0 group and post length 10 mm subgroups

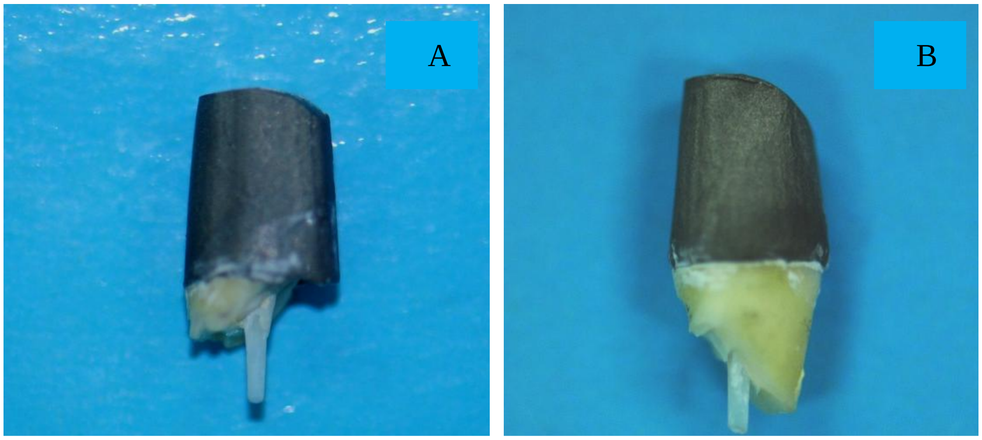

Figure 4.7 Samples of Unfavourable failure modes (A) post length 5 mm (B) post length 7.5 mm subgroups

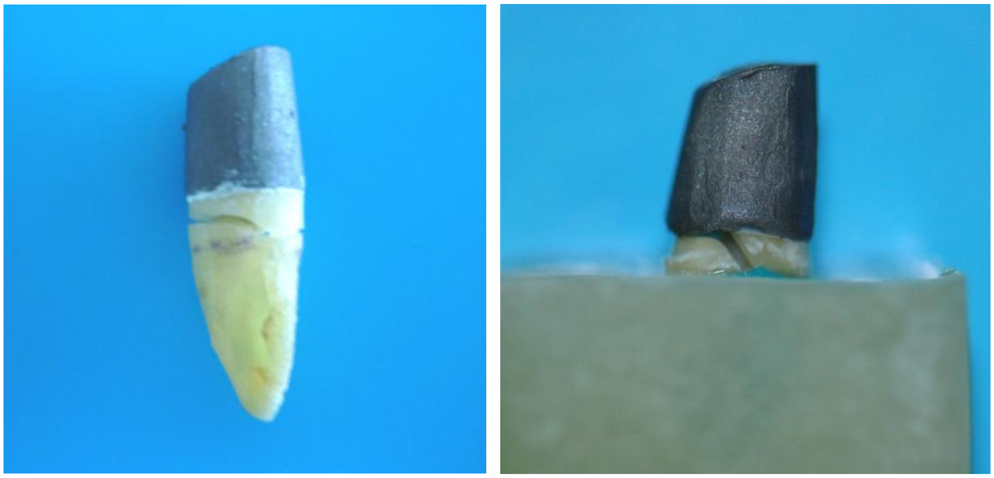

Figure 4.8 Unfavourable failure modes

Chapter Five
Discussion

5.1 Methodology

5.1.1 Teeth collection and selection

In this *in vitro* study, extracted human maxillary central incisors were used to evaluate the fracture resistance of endodontically treated teeth restored with glass fibre post with different lengths and at different ferrule heights. The use of extracted human teeth seemed to be common and acceptable by other studies (Tan et al., 2005). Maxillary central incisors were chosed because the use of fibre posts and composite cores in restoration of endodontically treated maxillary central incisors are getting popular compared to cast post and core. Factors taken into consideration for choosing the teeth in this research include root length, faciopalatal and mesiodistal dimensions. Although the inciso-cervical length is more important than the mesio-distal width, however, they were selected by mesio-distal width rather than the inciso-cervical length because the length was standardised later on in the teeth decoronation section in the methodology. For standardisation, teeth with similar mesio-distal and bucco-lingual dimensions at the cement-enamel junction were chosen. However, it is impossible to standardize their root morphology and canal anatomy which might have some effects on the results. The disinfection was done using 0.5% chloramine T aqueous solution at 4°C for one week, a procedure recommended by (ISO/TS 11405: 2003).

5.1.2 Teeth decoronation

Three ferrule heights were used in this study (0 mm, 2 mm and 4 mm) in order to determine and evaluate the effect of ferrule height on the fracture resistance and failure mode of endodontically treated maxillary central incisors restored with glass fibre post, composite core and full coverage crown.

In our study these ferrule heights had been chosen to compare the results of this study with the results of other similar studies that used different ferrule heights ranging from 0 mm to 5 mm (Isidor et al., 1999; Pereira et al., 2006; Varvara et al., 2007). A standardized method was used to section the crowns of the selected teeth according to the ferrule heights.

5.1.3 Canal preparation and obturation

Sodium hypochlorite (NaOCl) was the main irrigant used in this study; 3.0 mL at a concentration of 1% after each instrumentation. It is the most popular irrigant solution used in endodontic treatment (Saunders W, 2005). A lot of studies found that NaOCl is suitable for debridement of the root canals and exhibit a good antimicrobial effect in different concentrations ranging from 0.5 to 5.25% (Barnard et al., 1996; Krause et al., 2007; Giardino et al., 2009). Sodium hypochlorite was found to have a great effect in the properties of human dentine such as it can decrease its elastic modulus and flexural strength (Sim et al., 2001; Pascon et al., 2009). However, its effects seemed to be concentration-dependent (Sim et al., 2001; Zhang et al., 2010). Because of that, low concentration of the irrigant (1% NaOCl) was used to diminish any possible effects on the physical or mechanical properties of the tooth.

To remove the smear layer, the canals were irrigated with 3.0 mL of 17% Ethylenediaminetetraacetic acid (EDTA) followed with 1% sodium hypochlorite (NaOCl). Czonstkowsky et al. (1999) and Violich and Chandler (2010) stated that 17% EDTA is effective in smear layer removal. It was found that the adhesive properties of self-etching resin cement to root canal dentine was improved by smear layer removal when using fibre post (Gettleman et al., 1999; Wu et al., 2009). As the smear layer removal lead to the opening of the dentinal tubules (Patel et al., 2007) thus the bond strength between them is improved (Gu et al., 2009). Then the final irrigation with 10.0 mL of distilled water was done to remove any remaining irrigating solution. The obturation method used was the lateral condensation technique. It is relatively simple technique and fast to be carried out especially in straight roots (Amditis et al., 1992). It is the technique that was used by similar studies which were investigating the fracture resistance of teeth restored with posts (Kutesa-Mutebi and Osman, 2004; Pereira et al., 2006; Aykent et al., 2006).

A non-eugenol sealer (AH Plus) was used in the present study. It is recommended when the resin luting cement was planned to be used, rather than the eugenol-containing sealers as they might affect the polymerization of this type of luting cements. Studies found that the eugenol affect the bond strength of resin materials to the root canal dentine (Ngoh et al., 2001; Alfredo et al., 2006). However, another study concluded that the eugenol-containing sealer had no effect on the post retention luted with resin cement (Hagge et al., 2002).

5.1.4 Post space preparation

To allow complete setting of the sealer the root treated teeth were stored at 37° C and 100% humidity in an incubator for 24 hours. It has been shown that immediate or delayed post space preparations had no effect in the apical leakage (Abramovitz et al., 2000; Dias et al., 2009).

To remove the gutta percha, size 2 and 3 Gates-Glidden rotary burs placed on a slow speed handpiece was used in this study. To ensure complete removal of sealer and gutta percha at the dentine wall, Gates-Glidden burs were lightly brushed against the dentine walls. Furthermore, since the size of the post drills were slightly bigger than the size of the canals, this would have removed any residual sealers and gutta percha. This was important since any remaining searler and/or gutta percha could have influenced the cementation of the post and subsequently the fracture load.

There are several methods that can be used for the removal of gutta percha; including chemicals, rotary, and heated instruments. However, rotary instruments are preferred since they are efficient and faster than hand instruments as well as relatively easy to manipulate (Saad et al., 2007; Giuliani et al., 2008). The effect of the removal technique on the remaining apical seal was investigated by several studies. It was found that there was no significant difference between removing gutta-percha by rotary instruments or by heated pluggers when 4-5 mm apical seal was left (Hiltner et al., 1992; Grecca et al., 2009).

In the present study, the minimum length of gutta percha preserved apically was 4.0 mm to imitate the true clinical situation. Some studies advocated 4-5 mm apical seal (Mattison et al., 1984; Schwartz and Robbins, 2004). The lengths of the posts in this study were selected to simulate clinical situation where various lengths of post may be indicated. The 10.0 mm post length is equal to two thirds of a 15.0 mm root length. Several researchers recommended this post length (Stockton, 1999; McLaren et al., 2009). The 7.5 mm post is equal to half the root length used in this study. This post length was also preferred by (Llena-Pay, 2001). While, the 5.0 mm length represents an extreme condition where the post is equal to one third the root length. Short posts had been accepted by several researchers (El-Mowafy and Milenkovic, 1994; Nissan et al., 2001).

5.1.5 Post cementation

In the study design, one type of cement was used for post cementation in all the groups of the study, that was the RelyX Unicem™. Yoshida et al., 1998 stated that the bond strength of fibre post to root canal dentine was higher when cemented with RelyX Unicem self-adhesive resin cement which exhibit sealing properties better than the conventional types of cement. Piwowarczyk et al., 2004 and Abo-Hamar, 2005 found that self-adhesive universal resin cement (RelyX Unicem) possessed high bond strengths to different prosthodontic materials like ketac cem.

The application of the cement was done directly into the canal using RelyX Unicem™ elongation tips. According to the manufacturer instructions, the elongation tip allows voids-free cementation in one-single step compared with that when the cement is loaded on the post before seating (3M ESPE RelyX fibre post technical product profile). Following the manufacturer instructions, no pre-treatment was done to the dentine surface before the application of RelyX Unicem. Hikita et al. (2007) stated that when RelyX Unicem was used without dentine pre-treatment, it showed higher bond strength to dentine.

The posts were seated inside the canals to full lengths and the cement was photoactivated via the posts to gain initial polymerization. Sinhoreti et al. (2007) reported that the Rely-X resin cement activated by chemical/physical mode with light curing through a 1.5 mm-thick ceramic layer had high hardness values than that of chemical reaction alone. Lu et al. (2005) demonstrated that the dual-polymerized resin luting agents exhibit higher flexural strength than that of the autopolymerized cement. Fonseca et al. (2005) stated that in the absence of photoactivation, RelyX resin cements demonstrated significant decreases in diametral tensile strength.

5.1.6 Tooth mounting

The biological width of the periodontium was simulated by leaving the coronal 3.0 mm above the level of the acrylic resin as preferred by other studies (Akkayan, 2004). Since that the physiological properties of a periodontal ligament (PDL) in teeth under load can potentially affect the results, PDL simulation was done to be as close as possible to the clinical sitiuation. This procedure was done by several previous studies (Akkayan and Gülmez, 2002; Akkayan, 2004; Pereira et al., 2006; Varvara et al., 2007; Jung et al., 2007; Dikbas et al., 2007; Adanir and Belli, 2008; Salameh et al., 2008; de Oliveira et al., 2008; Hayashi et al., 2008; Preuss et al., 2008; Moosavi et al., 2008; Darabi and Namazi, 2008; McLaren et al., 2009). For this purpose silicon impression material of approximately 0.15 mm was used like most of the studies that simulating the PDL.

5.1.7 Crown fabrication

In the study design, non-precious metal crowns were used with fibre post for anterior teeth rather than metal-ceramic crowns using precious metal or all-ceramic crowns. Non precious alloy was used because of high strength, modulus of elasticity and hardness (Campbell, 1989). This was to ensure that the loading force was tranferred to the post-core-cement-dentine system and that the occurrence of fracture was not influenced by the use of metal coping. Gu et al., 2007 stated that the metal ceramic crowns are recommended in incisors restored with fibre reinforced posts. In addition, it was found that metal crowns are harder than all-ceramic crowns (Campbell, 1989). Moreover, ceramics are brittle, have low tensile strength, and are prone to have less strength in a moist environment (Sobrinho et al., 1998). Similar studies that investigated the fracture resistance of endodontically treated anterior teeth restored with fibre posts also used the metal crown (Akkayan, 2004; Chuang et al., 2005; Varvara et al., 2007; Giovani et al., 2009).

5.1.8 Thermocycling

The specimens were thermocycled according to ISO/TS 11405: 2003. Thermocycling procedure simulates the changes in the temperature and moisture of oral environment, thus it may affect the results. The main reason for thermocycling is to evaluate the long term fatigue of materials to extreme temperature and their effect on degradation. Lassila et al. (2004) and Stewardson et al. (2010) demonstrated that the flexural properties of fibre posts could be affected by thermocycling. D'Amario et al. (2010) observed that thermocycling affect bond strength of RelyX resin cements. Similar Previous studies that investigated the fracture resistance subjected their samples to thermocycling procedure prior to loading them (Sadeghi, 2006; Aykent et al., 2006; D'Arcangelo et al., 2007; Darabi and Namazi, 2008).

5.1.9 Loading

Most of the studies investigating the fracture resistance of anterior teeth tended to use loading angles ranging from 130° to 135° to the long axis of their roots (Zhi-Yue and Yu-Xing, 2003; Akkayan, 2004; Giovani et al., 2009). This angle is similar to the average interincisal angle between maxillary and mandibular incisors in Class I occlusion (Varvara et al., 2007). In this study the teeth were loaded palatally at an angle of 135° to the long axis of their roots using a flat-ended 2.0 mm rod. This type of rod is better than that of the round one which may result in a sliding movement of the loading tip over the tooth surface. As well as the pointed or sharp tip rods are well known to develop stress concentration areas.

In the present study, an increased compressive load was applied at a constant angle and at a standardized direction on a fixed point on the crown until failure occurred. This is due to the fact that the design of this study evaluates the maximum load that could be resisted by endodontically treated maxillary incisors restored with fibre post, composite core and crown. Thus it differed from the real intraoral situation which is characterized by repetitive, multidirectional masticatory loads applied repeatedly to a larger surface area. That’s why the use of the cyclic fatigue testing creates more reasonable replication of the intraoral environment because it evaluates the resistance of the specimen to repetitive compressive loads maintained at regular speed for a fixed number of cycles or in anticipation of failure occurs. In the oral environment, the teeth have to withstand both types of load and both types can induce critical fracture of pulpless teeth. Accordingly, the resistance to monotonic loads is not less important than the fatigue resistance (Dietschi et al., 2008).

5.2 Results

5.2.1 The effect of ferrule height on fracture resistance

In the present study, the fracture resistances of endodontically treated maxillary central incisors with different ferrule heights and different post lengths were stress tested and recorded. The results of this investigation confirmed the general consensus that the endodontically treated teeth with the presence of a ferrule is superior to those that lack of ferrule in the prevention of tooth fracture under a static load. Numerous studies have illustrated the importance of the ferrule effect in the restoration of endodontically treated teeth. The presence of ferrule has been shown to decrease the stress concentration at the core-dentine junction (Zhi-Yue and Yu-Xing, 2003). Ferrule also helps to maintain the integrity of the cement seal of the crown (Libman and Nicholls, 1995). In addition, during the ferrule preparation, the parallel walls are in dentine and that the walls are coronal to the shoulder of the preparation. Sorensen and Engelman (1990) found that 1 mm of parallel dentine above the shoulder preparation increased the fracture resistance of endodontically treated teeth. Same findings were recorded by Aykent et al. (2006). In another study, Sorensen and Martinoff (1984) showed that 1 mm of remaining coronal tooth structure nearly doubled the fracture resistance of the endodontically treated teeth. This supports the idea that the loss of structural integrity associated with crown preparation may lead to a higher occurrence of fractures in endodontically treated teeth.

Our study showed that increasing the ferrule height significantly increased the fracture resistance of endodontically treated teeth restored with glass fibre posts, composite cores and crowns ($P < 0.000$). This is in agreement with other studies (Loney et al., 1990; Cathro et al., 1996; Isidor et al., 1999; Pereira et al., 2006; Varvara et al., 2007). However, clinical question had been raised as to whether the post at any of the ferrule heights tested may work equally well in the clinical situation.

The lowest mean failure load that was recorded from the subgroup that lacking a crown ferrule and with a short post (285.0 N) was higher than the maximum human incisal bite force. It was recorded that this bite force does not exceed 200 N during normal physiological functioning of anterior teeth (Tan et al., 2006). This could be as a result of the design of our study that include periodontal ligament simulation which tend to act as a shock absorber leading to higher values of failure loads.

Additionally, our results indicated that the 4 mm ferrule height group presented significantly with the highest mean failure load (536.7 N) when compared with the 2 mm (414.6 N) and 0 mm (319.8 N) ferrule groups regardless the post length. These differences in failure load between different ferrule height groups may be attributed to several mechanisms of action as explained by Tan et al. (2006). The most reasonable explanation is that when the amount of remaining dentine increased, this allowed for redistribution and dissipation of large force. Besides, more coronal dentine structure may have formed a more stable foundation for the post and core; accordingly, the greater resistance to rotation would be achieved. The results of a combination of these previously mentioned suggestions may lead to increase the fracture resistance.

The findings of this study are in agreement with the results of the study done by Zhi-Yue and Yu-Xing (2003). They confirmed that the fracture strength of endodontically treated maxillary central incisors with 2 mm dentine ferrule restored with posts and cores was significantly higher than that without a ferrule. Pierrisnard et al. (2002) suggested that in the presence of ferrule, the type of the post had no influence in the fracture resistance of endodontically treated teeth.

Our results disagree with the results of study done by al-Hazaimeh and Gutteridge (2001). They investigated the effect of 2 mm ferrule preparation on the fracture resistance of crowned central incisors incorporating a prefabricated metal post (Parapost) cemented with Panavia-Ex and with a composite core. They concluded that the additional use of a ferrule preparation has no benefit in terms of resistance to fracture when composite cement and core materials were utilized with prefabricated Parapost system. It could be concluded that the endodontically treated teeth restored with fibre post and composite core with at least 2 mm of remaining tooth structure (ferrule) is beneficial in increasing fracture resistance.

Another study done by Libman and Nicholls (1995) demonstrated that the 0.5 mm and 1 mm ferrule heights did not increase the fracture resistance compared to 1.5 mm and 2 mm ferrule lengths. In contrast to other study done by de Oliveira et al. (2008) who suggested that the amount of coronal dentine did not significantly increase the fracture resistance of endodontically treated teeth restored with prefabricated carbon fibre post and composite resin core. This contrast results might be due to the differences in study designs as they evaluated the fracture resistance of endodontically treated upper canine restored with prefabricated carbon fibre post. The ferrule lengths used were 0 mm, 1 mm, 2 mm, and 3 mm. The differences between ferrule heights were small as well as small sample size. However, they confirmed that the presence of, at least, 1 mm of coronal structure increased the fracture resistance of the tooth in 24.5% of their study subjects.

The findings of our study were also in disagreement with (Kutesa-Mutebi and Osman, 2004; Dikbas et al, 2007) as they concluded that ferrule designs did not have any influence on the fracture resistance of maxillary central incisors restored with fibre posts, composite cores and full metallic crowns. One explanation might be due to the fact that they evaluated the effect of different ferrule designs and configurations but at the same height. While in the present study, we evaluated the effects of different ferrule heights in the same design. However, Arunpraditkul et al. (2009) confirmed that teeth with four walls of remaining coronal dentine had significantly higher fracture resistance than teeth with only three walls. In addition, Dikbas et al. (2007) did not perform thermocycling and Kutesa-Mutebi and Osman (2004) did not simulate the presence of periodontal ligament. These might be the factors that could affect their results.

5.2.2 The effect of post length on fracture resistance

Previous studies evaluated the post length trying to find the most optimal length. They investigated the effect of post length on retention (Standlee et al., 1978; Stockton, 1999; Nerqiz et al., 2002; Barga et al., 2006) and fracture resistance (McLaren et al., 2009). Our study differs from the others in that we investigated the effect of ferrule height and post length on fracture resistance of endodontically treated maxillary central incisors as well as their failure modes. The fracture resistances of the three fibre post lengths (10 mm, 7.5 mm and 5 mm) were compared in three different ferrule heights (0 mm, 2 mm and 4 mm).

In viewing the results of each post length subgroup in the study (Fig. 4.1), it was found that the highest mean failure load was obtained from the 10 mm post length followed by the 7.5 mm and then the 5 mm post length in all the ferrule height groups. This might be because of the elastic modulus of the glass fibre post which is close to that of dentine. When compressive load was applied to the tooth with a long post (10 mm), it will absorb a great amount of stress so that the force will be distributed in an even way to the radicular dentine while the short length post (5 mm) concentrates the stress to a smaller area of the dentine leading to a higher risk of root fracture. This could be described by the results of a study done by Giovani et al. (2009) who confirmed that the glass fibre post of 10 mm length possessed a higher fracture resistance than the shorter post which may lead to root fracture. Scotti et al. (2006) stated that the length of fibre posts should follow the crown/root ratio; it must be at 1:1 ratio. This means that post must have adequate length to be the same of the crown length.

The observation of the 5.0 mm post having the lowest failure loads might be explained by the observations of Nakamura et al. (2006). In a two-dimensional finite element analysis, they suggested that the long post should be used in order to minimize the stress that might lead to the root fracture. This is because the fibre posts of 1/3 the canal length showed greater stress concentration over a relatively smaller area of the root compared with posts of 2/3 the canal length.

Nevertheless, no statistically significant differences were found between the mean failure loads for the three post lengths used in each of the three ferrule height groups (P = 0.102). In other words, the post length did not significantly affect the fracture resistances of endodontically treated teeth. These findings may be due to the fact that the effect of ferrule was masking the effect of post length. Moreover, in 4 mm ferrule height group, when we look through the mean failure loads of the three post lengths, we notice that the difference between the mean failure loads of 10 mm and 5 mm post length is only 36.1 N. While in 0 mm ferrule height group, the difference between the mean failure loads of 10 mm and 5 mm post length is (63.8 N). This means that in the absence of ferrule we can detect a little post length effect in spite of the fact that there was no significant difference which may be due the small sample size. This fact can be detected when looking through the results of a study done by Isidor et al. (1999) who confirmed that the ferrule length is more important than the post length in term of enhancing the fracture resistance of crowned teeth.

The findings of the present study were in agreement with the results of a study done by do Valle et al. (2007). They evaluated the influence of prefabricated stainless steal post length on the fracture resistance of endodontically treated teeth. The teeth were restored with three different post lengths (10 mm, 7.5 mm and 5 mm), composite cores and metal crowns. They concluded that increasing the post length did not significantly increase the fracture resistance of endodontically treated teeth restored with fibre post.

From the clinical point of view, we can get some benefit from the results of this study in terms of the selection of the post length. When we have adequate tooth structure and good amount of remaining dentinal tissue for more than 2 mm, we can choose the shortest post length (5 mm) especially in cases of short or curved roots. In addition, it can be of a benefit in preserving the tooth structure and protect the intra radicular dentine from excessive removal when using the long post.

Santos-Filho et al. (2008) compared the effect of the lengths of different post types; glass fibre post, prefabricated steel post and cast post and core on the strain and fracture resistance of root filled teeth. They confirmed that there was no significant differences between the three post lengths of glass fibre posts (10 mm, 7.5 mm and 5 mm) and interestingly, the shortest fibre post length (5 mm) showed higher fracture resistance than metal post. Indeed, the results of our study were not in agreement with these results.

5.2.3 Failure mode

The modes of failure of the specimens were examined and inspected in all the subgroups. According to Fokkinga et al. (2004) any fracture of the root below the simulated bone level (acrylic resin level in our study) was defined as unfavourable failures 'catastrophic'. These types of failures are usually irreparable and frequently require the tooth to be extracted. For that reason the failure mode for each subgroup must be taken into consideration since its severity was as important as the fracture resistance and might lead to tooth extraction (Fokkinga et al. 2004).

In this study, the effects of three ferrule heights (4 mm, 2 mm and 0 mm) on the failure mode at three post lengths (10 mm, 7.5 mm and 5 mm) were investigated. In general, more favourable failures were observed in all the specimens except for those restored with short post of 1/3 root length in the absence of ferrule height (residual dentine height). This observation was in agreement with previous studies evaluating the fracture resistance of endodontically treated teeth restored with glass fibre posts (Maccari et al., 2003; Akkayan, 2004; Barjau-Escribano et al., 2006; Arandi et al., 2008). These results may be attributed to the property of glass fibre post which posseses modulus of elasticity closes to that of dentine. This allow it to flex with the tooth under load, and distribute the load evenly to root dentine via resin cement interface resulting in more favourable stress distribution at the interface without concentrating stress at dentine (Boschian et al., 2006). Moreover, the difference in the elastic moduli of the fibre and matrix components of the fibre post might contribute to stress absorption by dissipating stress along their interface (Seefeld et al., 2007). This will partially absorb the load and increase the likelihood of failures at the post/cement/core/tooth interface before the occurrence of root fracture (Fokkinga et al. 2004).

Cormier et al. (2001) found that the type of fracture associated with the fibre post was restorable compared to that associated with the cast posts. Similar results were obtained by Akkayan and Gulmez (2002) who concluded that the glass fibre post when subjected to a compressive load, fractured favourably.

Regardless of the post length, it was found that the 4 mm group showed the highest percentage of favourable failure modes followed by the 2 mm and then 0 mm. Thus our results confirmed that having the ferrule heights of at least 2 mm may result in a more favourable fracture mode. This is in agreement with a review of literature by Shcwartz and Robbins, (2004). They concluded that endodontically treated teeth prepared with a ferrule tend to fail in a more favourable mode.

In our study we use metal crown covering the composite core build up. Actually there is no doubt that the crown create a ferrule effect and a different load distribution when placed over the core build up if the margins encircle a sound dentine collar (Sorensen and Engelman, 1999). This may aid in achieving favourable type of fracture. Moreover, during the inspection of the types of failure of the specimens no crown displacement was found. This might be as a result of adequate preparation of the core and the use of a good adhesive cementation which contributed to minimizing the risk of crown displacement.

In spite of that unfavourable mode of failure were also seen in our results. The explanation behind that may be because of our study design that included different post lengths. It was observed that the higher the post length the more the favourable mode of fracture. In 10 mm and 7.5 mm subgroups, more specimens failed favourably, while the 5 mm post length groups showed the highest catastrophic failure particularly in the absence of ferrule height. This may be due to the fact that when applying a load to the shortest post, it transmits the force and concentrate it to a small area of the root dentine around its apical end leading to root fracture (Giovani et al., 2009). The results of this study are in agreement with Asmussen et al. (2005) and Nakamura et al. (2006). They reported the same findings about the short post length. These findings also agree with a study done by of Fuss et al., (2001). They found that the vertical root fractures were predominant types of failure in short posts that extended to only one third of the root length. Their conclusion was that the longer posts were preferable than the shorter ones.

However, in the presence of 4 mm ferrule height, the specimens restored with short post (1/3 root length) had more favourable failures. These findings may be due to the fact that the greater ferrule effect provided by more residual dentine overcomes the effect of the short post length leading to a more favourable type of failure. It can therefore be suggested that endodontically treated teeth resotred with glass fibre posts may have a tendency for favourable mode of failure especially when restored with post of at least 1/2 the root length in the presence of ferrule height.

Our study also showed that catastrophic (unfavourable) failures occurred at loading forces greater than the normal physiological masticatory force exerted on maxillary cental incisors especially in the presence of at least 2 mm residual dentine heights. These forces were reported by other studies: 146.17 N (Ferrario et al., 2004), 210.5 N (Paphangkorakit and Osborn, 1997) and 235.9 N (Poiate et al., 2009). Therefore, short posts may be indicated in clinical situations where the residual dentine (ferrule) height of at least 2 mm is present.

5.3 Limitations of the study

Although the design of the current study attempted to simulate clinical situations such as having ferrule, simulated periodontal ligament and a cast crown placement. It is difficult to interpret these results directly for the clinical practice. This is because this study had some limitations; it is an in vitro investigation which could not fully replicate oral conditions. Other thing is the type of test used, that is, a static load which was applied on one point in a monostatic pattern that does not represent the intraoral condition. The study also evaluated the maxillary central incisors and therefore, the results can be applied only to that group of teeth.

5.4 Conclusions

Under the limitations of this study, the following conclusions were drawn:

1. Increasing the ferrule height significantly increased the fracture resistance of the endodontically treated maxillary central incisors restored with a glass fibre post luted with RelyX™ Unicem self adhesive resin cement, composite core and crown.
2. The 4 mm ferrule height group had significantly higher fracture resistance compared with the 2 mm and 0 mm ferrule groups, and 2 mm ferrule group had significantly higher fracture resistance than 0 mm ferrule group (FH 4 mm >> FH 2 mm >> FH 0 mm).
3. Post length had no significant effect on the fracture resistance of endodontically treated maxillary central incisors for any given ferrule height.
4. Almost all the subgroups had favourable failure. A more unfavourable failures could be expected with short posts (1/3 root length) than longer post.

Chapter Six

Recommendations for Further Studies

6.1 Recommendations for further studies

1. This study evaluated the effect of ferrule height and post length on the fracture resistance of endodontically treated teeth in vitro. Further in vivo studies are required to investigate the effect of ferrule height and post length on the fracture resistance of endodontically treated teeth.

2. Another study is needed to evaluate the effect of ferrule height and post length on the fracture resistance of endodontically treated posterior teeth.

3. A further study is needed to evaluate the fatigue resistance of different types of posts with different ferrule heights.

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Appendices

APPENDIX I
List of materials used in the study

Table I.1 Materials used in the study

Material	**Manufacturer**
Temporary Filling	Cavit™, 3M ESPE, U.S.A
Bonding Material	Adper™ Single Bond 23M ESPE, St Paul, MN, U.S.A
Composite	Filtek™ Z350, 3M ESPE, U.S.A
Gates Glidden drills	Dentsply/Maillefer, Ballaigues, Switzerland
K-files	Dentsply/Maillefer, Ballaigues, Switzerland
Barbed Broach	Dentsply/Maillefer, Ballaigues, Switzerland
Gutta Percha	Dentsply/Maillefer,Asia, Hong Kong
Resin Cement	RelyX™ Unicem™, 3M ESPE, St Paul, MN, U.S.A
Fiber post	RelyX Fiber Post, 3M ESPE, St Paul, MN, U.S.A
Etchant	Scotchbond™, 3M ESPE, St Paul, MN, U.S.A
polytetrafluoroethylene adhesive tape	Iso 9001 P.T.F.E Tabe 0.075 mm. KITA
Autopolymerizing Acrylic resin for teeth mounting	Satex cold cure acrylic, England.
Disinfectant	Chloramine T, BDH, Laboratory Supplies, Poole, Dorest, England.
Sodium Hypochlorite	Clorox, Clorox (M) Industries, Sdn, Bhd, Malaysia
Ethylenediaminetetraacetic acid (EDTA)	SmearClear™, SybronEndo,USA
Diamond disc	Besco, Germany

APPENDIX II
List of equipments/ instruments used in the study

Table II.1 Equipments/Instruments used in the study

Equipment/Instrument	**Manufacturer**
Ultrasonic Scaler	Peizon® Master 400, Switzerland
Thermocycling Machine	Custom-made at the Engineering Department, University of Malaya
Digital Caliper	Mitutoyo/Digimatic, Tokyo, Japan.
Stereomicroscope	Kyowa Optical SDZ-PL, Kyowa Optical Co., Ltd. Kanagawa, Japan
Hand Piece	KaVo, Warthausen, Germany
Mixing Unit	RotoMix, 3MESPE, Germany
Light Curing Unit	Spectrum™ 800, Dentsply/Caulk, Milford, USA.
Polisher/Grinder	Metaserv® 2000, Buchler, USA
Dental Surveyor	AF 30, Switzerland
paralleling device	Custom-made at the Engineering Department, University of Malaya
Universal Testing Machine	Shimadzu, Autograph AG-X, Japan

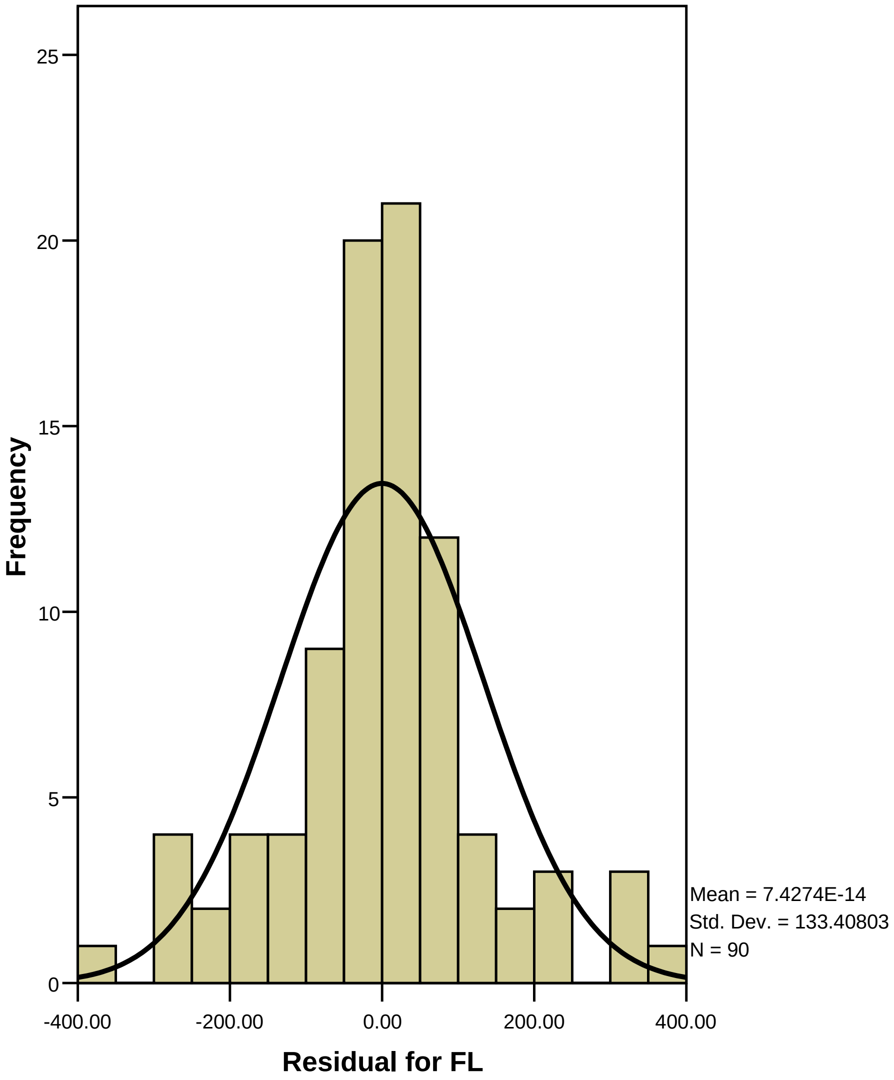
APPENDIX III
Raw data

Table III.1 Raw data

Groups	Sample #	Failure load (N)	Groups	Sample #	Failure load (N)
F4P10	1	586.93	F2P7.5	46	500.89
F4P10	2	658.36	F2P7.5	47	410.85
F4P10	3	283.09	F2P7.5	48	209.21
F4P10	4	388.36	F2P7.5	49	469.07
F4P10	5	765.12	F2P7.5	50	338.01
F4P10	6	534.08	F2P5	51	310.05
F4P10	7	742.76	F2P5	52	349.3
F4P10	8	888.04	F2P5	53	424.58
F4P10	9	539.2	F2P5	54	431.1
F4P10	10	203.95	F2P5	55	303.41
F4P7.5	11	359.15	F2P5	56	341.03
F4P7.5	12	635.45	F2P5	57	403.72
F4P7.5	13	918.97	F2P5	58	360.9
F4P7.5	14	735.55	F2P5	59	427.83
F4P7.5	15	596.36	F2P5	60	312.58
F4P7.5	16	535.34	F0P10	61	312.58
F4P7.5	17	251.88	F0P10	62	350.73
F4P7.5	18	431.94	F0P10	63	344.51
F4P7.5	19	499.61	F0P10	64	339.88
F4P7.5	20	319.35	F0P10	65	385.99
F4P5	21	401.22	F0P10	66	326.52
F4P5	22	556.83	F0P10	67	395.8
F4P5	23	358.75	F0P10	68	401.38
F4P5	24	840.75	F0P10	69	345.39
F4P5	25	455.04	F0P10	70	285.52
F4P5	26	754.39	F0P7.5	71	423.4
F4P5	27	236.47	F0P7.5	72	342.86
F4P5	28	475.29	F0P7.5	73	283.82
F4P5	29	645.66	F0P7.5	74	335.92
F4P5	30	503.9	F0P7.5	75	337.54
F2P10	31	443.4	F0P7.5	76	390.55
F2P10	32	380.2	F0P7.5	77	280.77
F2P10	33	686.16	F0P7.5	78	279.43
F2P10	34	245.49	F0P7.5	79	216.4
F2P10	35	524.86	F0P7.5	80	364.23
F2P10	36	806.86	F0P5	81	289.0
F2P10	37	206.23	F0P5	82	266.48
F2P10	38	512.97	F0P5	83	320.49
F2P10	39	502.43	F0P5	84	314.71
F2P10	40	628.66	F0P5	85	243.4
F2P7.5	41	459.46	F0P5	86	201.06
F2P7.5	42	449.98	F0P5	87	298.71
F2P7.5	43	272.95	F0P5	88	244.65
F2P7.5	44	329.94	F0P5	89	304.58
F2P7.5	45	396.0	F0P5	90	367.72

APPENDIX IV

Homogeneity test



APPENDIX V

Statistical analysis tables for the effect of ferrule height and post length on the failure load by Two-way ANOVA test.

Dependent variable: fracture load

Table V.1 Descriptive statistic

Ferrule heights	Post length	Mean	Std. Deviation	N
4 mm	10 mm	558.988	217.941	10
	7.5 mm	528.359	202.902	10
	5 mm	522.829	183.141	10
	Total	536.725	195.418	30
2 mm	10 mm	493.724	186.906	10
	7.5 mm	383.635	94.125	10
	5 mm	366.449	51.360	10
	Total	414.603	133.036	30
0 mm	10 mm	348. 829	36.942	10
	7.5 mm	325.491	61.131	10
	5 mm	285.079	47.514	10
	Total	319.800	54.785	30
Total	10 mm	467.180	184.351	30
	7.5 mm	412.495	155.603	30
	5 mm	391.452	148.315	30
	Total	423.709	164.806	90

Dependent variable: fracture load

Table V.2 Levene's test of Equality of Error Variances

F	df1	df2	Sig
4.981	8	81	0.000

Dependent variable: fracture load

Table V.3 Test of between-subject effects					
Source	Type III sum of sequares	df	Mean square	F	Sig.
Corrected model	833355.103[a]	8	104169.388	5.327	.000
Intercept	16157687.7	1	16157687.65	826.248	.000
Ferrule heights	709580.708	2	354790.354	18.143	.000
Post legth	91680.681	2	45840.341	2.344	.102
Ferrule height* post length	32093.714	4	8023.429	.410	.801
Error	1583995.499	81	19555.500		
Total	18575038.3	90			
Corrected total	2417350.602	89			

a. R squared = .345 (Adjusted R Squared = .280)

Estimated Marginal Means

Dependent variable: fracture load

Table V. 4 Grand mean			
Mean	Std. Error	95% Confidence Interval	
		Lower Bond	Upper Bound
423.710	14.741	394.381	453.039

Dependent variable: fracture load

Table V.5 Ferrule height				
Ferrule height	Mean	Std. Error	95% Confidence Interval	
			Lower Bond	Upper Bound
4 mm	536.726	25.531	485.926	587.525
2 mm	414.603	25.531	363.804	465.402
0 mm	319.800	25.531	269.001	370.600

Dependent variable: fracture load

Table V.6 Post length

Post length	Mean	Std. Error	95% Confidence Interval	
			Lower Bond	Upper Bound
10 mm	467.181	25.531	416.382	517.980
7.5 mm	412.495	25.531	361.696	463.295
5 mm	391.453	25.531	340.653	442.252

Post Hoc Tests

Multiple comparisons

Table V.7 Ferrule height

(I)Ferrule height	(J) Ferrule height	Mean difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
4 mm	2 mm	122.1227*	43.1613	.018	17.9397	226.3056
	0 mm	216.9253*	37.0539	.000	126.0695	307.7811
2 mm	4 mm	-122.1227*	43.1613	.018	-226.3056	-17.9397
	0 mm	94.8026*	26.2679	.002	30.7772	158.8280
0 mm	4 mm	-216.9253	37.0539	.000	-307.7811	-126.069
	0 mm	-94.8026*	26.2679	.002	-158.8280	-30.7772

Based on observed means.

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

Table V.8 Post length

(I)Post length	(J) Post length	Mean difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
10 mm	7.5 mm	54.6855	44.0446	.434	-51.3339	160.7050
	5 mm	75.7282	43.1983	.195	-28.3022	179.7587
7.5 mm	10 mm	-54.6855	44.0446	.434	-160.7050	51.3339
	5 mm	21.0427	39.2471	.854	-73.3646	115.4500
5 mm	10 mm	-75.7282	43.1983	.195	-179.758	28.3022
	7.5 mm	-21-0427	39.2471	854	-115.4500	73.3646

Based on observed means.

APPENDIX VI

Descriptive statistics table for the effect of ferrule height and post length on the failure mode

Table VI.1 Failure mode* Groups Crosstabulation

Ferrule heights	Post length	Failure mode		Total
		Favourable	unfavourable	
4 mm	10 mm Count	7	3	10
	% within post length	70%	30%	100%
	7.5 mm Count	7	3	10
	% within post length	70%	30%	100%
	5 mm Count	6	4	10
	% within post length	60%	40%	100%
	Total Count	20	10	30
	% within post length	66.7%	33.3%	100%
2 mm	10 mm Count	7	3	10
	% within post length	70%	30%	100%
	7.5 mm Count	6	4	10
	% within post length	60%	40%	100%
	5 mm Count	5	5	10
	% within post length	50%	50%	100%
	Total Count	18	12	30
	% within post length	60%	40%	100%
0 mm	10 mm Count	7	3	10
	% within post length	70%	30%	100%
	7.5 mm Count	6	4	10
	% within post length	60%	40%	100%
	5 mm Count	4	6	10
	% within post length	40%	60%	100%
	Total Count	17	13	30
	% within post length	56.7%	43.3%	100%