Chapter One

Introduction, Aims and Objectives

1.1 Introduction

The restoration of endodontically treated teeth is an important aspect of dental practice that involves a range of treatment options of varying complexity. The challenge may be complicated by substantial loss of coronal tooth structure and the ability to predict restorative success (Pereira, 2006). To prevent further destruction of these teeth, a protective restoration is necessary to create retention, resistance, and an adequate seal (Kivanç et al., 2002).

The major reasons for obturation are to seal vestiges of irritants in the root canal system and to minimize the deleterious effects of both apical and coronal leakage. Current reports have shown that no available filling materials or techniques can produce an adequate seal of the entire root canal system (Siqueira, 2000).

Clinically, microleakage may be identified as a dynamic phenomenon that results in two consequential manifestations. A compromised marginal seal causes hydrodynamic fluid movement through a degrading smear layer into the patent dentinal tubules underneath to result in hypersensitivity to thermal and osmotic stimuli and is referred to as the sensory component of microleakage. Penetration of bacteria and their products through such potential gaps along the axiopuplal floor accounts for the pathologic component of microleakage that result in recurrent caries and subsequent pulpal pathose (Gwinnett et al., 1995).

Coronal microleakage can considerably affect the prognosis of endodontic treatment, since an inadequate coronal seal will allow biologic contamination and penetration of saliva, nutrients, chemicals and importantly microorganisms and their by-products, which can lead to endodontic failure (Aminozarbian et al., 2009). Torabinejad et al. (2001) showed that more than 50% of root canals were completely contaminated when

the coronal surface of their filling were exposed to staphylococcus epidermidis (Vijay and Indira, 2009).

Quite a lot of approaches have been introduced to overcome the problem of polymerization shrinkage and prevent microleakage (Yazici et al., 2008). Mousavinasab et al. (2008) reported that several investigators have suggested painting a low viscosity resin over the debonded tooth–composite resin interface to reseal the restoration margins, particularly at the dentinal margins. The concept of rebonding for sealing marginal gaps consists of applying an unfilled resin-bonding agent over the margins of the finished restorations. This compensates for the adverse effect of the polymerization shrinkage on the tooth-restoration interface and guarantees higher quality and durability of the marginal adaptation.

To achieve a successful endodontic therapy, the most important criterion is the well adaptation of the filling material to dentine walls and to prevent microleakage apically and coronally (Kivanç et al., 2002).

The use of posts in endodontically treated teeth to retain an overlying restoration has a history of at least 300 years (Thongthammachat, 2006). The cast post-and-core procedure has been advocated as one of several restorative options (Salvi, 2007). Additional materials such as the use of prefabricated titanium, stainless steel, zirconia and carbon- or glass fibre reinforced posts have been recommended for root filled teeth (Schwartz and Robbins, 2004). A fibre-reinforced post was introduced to the market that simultaneously serves as an endodontic obturator. The diameter of the apical portion of the post is reduced, and its surface is covered with gutta-percha. It is placed into the prepared canal space with a resin endodontic sealer/cement (Thongthammachat, 2006).

Several in vivo and in vitro studies have reported that prefabricated posts may offer a better prognosis than cast post and core for endodontically treated teeth (Mannocci et al., 2001). When custom-made post and cores are used, a temporary post crown is required while the definitive restorations were being constructed, whereas prefabricated posts can be cemented immediately and this may reduce the possibility of leakage (Fox and Gutteridge, 1997).

Several luting cement materials, such as zinc phosphate, polycarboxylate, glass-ionomer, resin-modified glass-ionomer, compomer and resins, are used to cement posts into the root canal (Ricketts, 2005).

Presently, the progress in adhesive dentistry has led to the improvement of the marginal integrity and consequently the clinical performance of dental restorations (Erdilek et al., 2009). However, the seal provided by the cemented post depends on the seal of the cement used (Min-Kai et al.,1998).

1.1 Aim of the study

This study was carried out to investigate the effectiveness of two different traditional luting cements and one adhesive system on the microleakage in endodontically treated teeth restored with different post systems.

1.3 Objectives

1. To measure the coronal microleakage in endodontically treated teeth restored with different posts and different adhesive systems.

2. To evaluate and compare the sealing effectiveness of the resin luting cement and the traditional cements.

Chapter Two

Literature Review

2.1 Restoration of endodontically treated teeth

Endodontically treated teeth are generally weakened as a result of structure loss due to decay, previous restorative procedures and endodontic access preparation of these teeth (Adanir and Belli, 2007).

Several classic studies have proposed that the dentine in endodontically treated teeth is substantially different than dentine in teeth with vital pulps. It was thought that dentine in endodontically treated teeth was more brittle because of water loss (Yoshiyama et al., 2002) and loss of collagen cross-linking (Rivera and Yamauchi, 1993). In 1991, Huang et al. compared the physical and mechanical properties of dentine specimens from teeth with and without endodontic treatment at different levels of hydration. They concluded that neither dehydration nor endodontic treatment caused degradation of the physical or mechanical properties of dentine.

2.1.1 Restorative factors that affect the prognosis of endodontic treatment

Contamination of the root canal system by saliva, often referred to as "coronal leakage" or "coronal microleakage," is a potential cause of endodontic failure (Saunders and Saunders, 1994). In addition, recurrent caries or fractured restorations may lead to recontamination of the root canal system. Under the best conditions, the oral environment is rich in microorganisms and dental restoration must withstand repeated exposure to physical, chemical, and thermal stressors. It is a difficult environment in which to maintain a hermetically sealed system.

In vitro studies have shown that exposure of coronal gutta-percha to bacterial contamination can lead to migration of bacteria to the apex in a matter of days (Swanson and Madison, 1987).

Contamination of root-canal systems with bacteria must be prevented during and after endodontic treatment. Aseptic treatment techniques should be used, including the use of a rubber dam. Once root-canal treatment is completed, immediate restoration of the tooth is recommended whenever possible. The prognosis of endodontically treated teeth depends not only on the treatment itself, but also on sealing the canal and minimizing the leakage of the oral fluids and bacteria into periradicular areas by prompt placement of coronal restorations (Heling, 2002).

Clinicians strive to totally seal the root canal system in their attempt to ensure endodontic success (Wu and Wesselink, 1993). Despite these efforts, it has been shown that root canal filling leak.

Leonard et al. (1996) stated that presently there is no available material or techniques that provide a complete seal of the canal system. When the coronal portion of the root canal is exposed to the oral environment, the obturated canal is a potential route for microorganisms to gain access to the periapical tissues. This situation may lead to endodontic failure.

2.2 Dentine in bonding

Dentine microstructure and properties are principal determinants of nearly all operations in restorative dentistry. Although significant progress in restorative and preventive dentistry has occurred over the past several decades based on an increased understanding of the caries process and introduction of increasingly effective bonding techniques, a key problem remains in our lack of detailed understanding of dentine itself. This is because dentine is a complex hydrated biological composite structure for which only limited structure-property relationships are available (Marshall, 1993).

Dentine is composed of about 50 vol % mineral in the form of a carbonate rich, calcium deficient apatite; 30 vol % organic matter which is largely type I collagen and about 20 vol % fluid which is similar to plasma but is poorly characterized (Driessens and Verbeeck, 1990).

Dentine is formed by cells called odontoblasts that differentiate from ectomesenchymal cells of the dental papilla. Odontoblasts secrete the organic dentine matrix and regulates mineralization as it move toward the pulp. The odontoblast's cell body is located at the pulp periphery and have processes which extend into the dentinal tubules to about one third of the dentine thickness (Mjor and Ferrari, 2002).

Dentine develops to contain many thousands of microscopic tubes called tubules. These tubules of diameter 0.5–4.0 µm extend roughly parallel to each other from the pulp chamber to the amelo- or cemento-dentinal junctions. They are arranged approximately radially around the pulp in the tooth's transverse plane, with a sigmoid curvature in the axial planes (Bhaskar, 1986). Some of the recognized variations include primary, secondary, reparative or tertiary, sclerotic, transparent, carious, demineralized, remineralized, and hypermineralized dentine. They reflect alterations in the fundamental components of the structure as defined by changes in their arrangement, interrelationships or chemistry. A number of these may have important implications in our ability to develop long lasting adhesion or bonds to this structure (Cox et al., 1992). The marked change in the amount of each structural element with location implies that the nature of the substrate presented for bonding will vary with location.

Generally bond strengths are higher in superficial than deep dentine (Nakamichi et al., 1983). However, there is also evidence that the dependence is likely to be related to the specific bonding agent or mechanism (Causton et al., 1987).

2.2.1 Dentine permeability and dentine adhesion

The relationship between dentine permeability and dentine adhesion has not always been obvious. Early bonding agents were applied directly on smear layers and gave rather low bond strengths (5 MPa) because they did not permeate well in dentine. Careful Scanning Electron Microscopic (SEM) evaluation of both sides of the failed bonds revealed that the 5 MPa 'bond strength' was actually a measure of the cohesive forces holding the smear layer particles together since the failures seemed to occur within the smear layer (Pashley and Carvalho, 1997).

Eick et al. (1992) were among the first to use transmission electron microscopy (TEM) to show that these adhesives only penetrated a few tenths of a micron into the top of the smear layer. They reported that the addition of 2-hydroxyethylmethacrylate (HEMA) to bonding agents improved bond strengths by making them more hydrophilic, thereby facilitating both their ability to spread uniformly on hydrophilic dentine surfaces and to penetrate more deeply into the smear layer. The permeability properties of the smear layer have not been exhaustively studied.

2.2.2 Types of dentine permeability

The major morphologic characteristic of vital dentine is its fluid-filled tubular structure connecting the pulp to the enamel-dentinal junction. According to the hydrodynamic theory (Brannstr and Astriim, 1972), once enamel is lost and dentine is exposed, external stimuli can cause fluid shifts across dentine which activate pulpal nerves and cause pain. This movement of fluid within tubules has been called transdentinal

permeability (Pashley et al., 1993), and is responsible for dentine sensitivity of both exposed dentine and for some types of sensitivity of restored dentine (Brannstr and Astriim, 1972).

Transdentinal permeability is also responsible for the constant wetness of exposed dentine surfaces due to the outward fluid movement from the pulp (Pashley et al., 1993). Penetration of adhesive resin monomers from the surface into tubule lumina is called intratubular dentine permeability, which is a subset of transdentine permeability. It is not necessary for these resins to move across dentine to the pulp. Instead, they need only to permeate a few microns to form resin tags which, if bonded to the tubule walls, seal the tubules and contribute to resin retention (Sano et al., 1995).

The dentine in endodontically treated teeth is substantially different than dentine in teeth with vital pulps. It was thought that dentine in endodontically treated teeth was more brittle because of water loss (Yoshiyama et al., 2002) and loss of collagen cross-linking (Rivera and Yamauchi, 1993). The loss of structural integrity associated with the changes in the dentine lead to a higher occurrence of fractures in endodontically treated teeth compared with vital teeth (Schwartz and Robbins, 2004).

2.2.3 Theoretical model of dentine bonding

Theoretically, bonding to dentine can be accomplished by bonding to its organic component (collagen), its mineral component (hydroxyapatite) or both (Asmussen et al., 1993). Since calcium is abundant in dentine, early generation dentine bonding systems attempted to chemically bond to dentine by ionic bonds to calcium (Eliades et al., 1985).

Although HEMA (2- hydroxyethylmethacrylate) and glutaraldehyde based solutions have been described as capable of chemically bonding to collagen on EDTA-treated dentine (Asmussen et al., 1985), these bonds are now believed to be the result of a micromechanical bonding mechanism to the collagen network (Suzuki and Nakai, 1993).

The mechanical retention provided by resin tags and hybrid layer formation represent the major part of the overall bond strength. Most of the remaining adhesion is due to surface adhesion, while the chemical adhesion, if it exists, seems to contribute very little and may be masked by mechanical bonding (Eliades et al., 1990; Van Meerbeek et al., 1993).

Gwinnett et al. (1993) recently attempted to dissect dentine bonding into its component parts. He reported resin composite bond strengths of about 10 MPa to smear layer-covered dentine. The bond strengths of All Bond 2 (Bisco, Itasca, IL, USA) increased to approximately 20 MPa when the smear layer was removed by air abrasion, exposing sound, intact mineralized intertubular dentine but leaving the tubule lumina occluded with smear plugs. That value was thought to be due to surface adhesion to sound dentine, since neither intratubular nor intertubular interdentinal resin infiltration occurred in the absence of acid-etching.

2.2.4 Dentine permeability and microleakage

While bond strengths provide important information related to retention of resin composites, the ability of bonding agents to seal dentine is also very important. In the case of inadvertent debonding, it is desirable that the hybrid layer and resin tags remain in the dentine surface rather than being pulled away, thereby maintaining a surface seal

which will protect the pulp from external irritants and the dentine surface from demineralization (Sano et al., 1995).

Some studies have reported little or no microleakage at dentine margins when current generation bonding systems were used (Davidson and Gwinnett, 1994).

Nanoleakage has been shown to occur at both the bottom of the hybrid layer and/or scattered along the entire hybrid layer, depending on the bonding system. This leakage occurs within demineralized dentine and is a special type of intertubular dentine permeability. The clinical significance of the nanoleakage is still not clear, but it indirectly reflects the inability of adhesive systems to completely fill the demineralized zone, leaving the hybrid layer with a large amount of porosity. It appears that bonding systems that etch deeper in dentine are more likely to show higher degrees of nanoleakage (Sano, 2006).

2.3 Dentine bonding agent

Dentine bonding mainly consists of three processes; etching, priming and bonding. These steps can be modified to reduce substrate sensitivity into many forms (Pashley, 1992). Generally, the bonding substrate is classified by mechanism of adhesion and steps of application or substrate condition. However, classification also can be based on substrate condition (dry or wet) which tremendously affects the bond strength.

2.3.1 Classification of Dentine bonding agent

It can be classified according to mechanism of adhesion:

- The etch-and- rinse approach:

The etch-and-rinse substrate requires the application of an acid or calcium chelators that decalcify the outer layer of dentine and a separate application of a primer and adhesive. Currently, 35% phosphoric acid is used to remove the smear layer and dentinal tubule plugs, increase dentinal permeability and decalcify the intertubular and peritubular dentine; demineralizing dentine over a depth of 3.0 μm to 5.0 μm, thereby exposing a scaffold of collagen fibrils nearly depleted of hydroxyapatite (Perdigao et al., 1996; Van Meerbeek et al., 1992).

There are 2 types of etch-and-rinse approaches:

- Three step etch-and-rinses:

  Consisted of three separate application steps (etching, priming and adhesive-resin application).

- Two step etch-and-rinses:

In search of simplification, a two step etch-and-rinse was developed. This system combines the priming and adhesive-resin application to one step. Even though, both systems pursue a similar adhesion mechanism, the three step commonly exhibit superior performance over the two step system (Peumans et al., 2005).

After the acid is washed off, the exposed collagen fibrils function as a microretentive network for micromechanical interlocking of resin monomers. In an inadvertent over air-drying situation, re-expansion of the collapsed collagen mesh is especially crucial to improve the bond strength of the adhesive. Primer containing one or more hydrophilic monomers is applied. These primer molecules (i.e. HEMA, BPDM, 4-META) contain two functional groups, a hydrophilic and a hydrophobic group. While the hydrophilic group has an affinity for the water content within dentine, the hydrophobic group has an

affinity for the resin monomer. The primer wets and penetrates the collagen network. Once the primer is applied properly, an adhesive is applied and then light cured. The oxygen inhibiting layer on the surface of bonding will copolymerize with the resin composite restorative material. This layer of polymerized resin intermingled with collagen fibers is defined as the resin- reinforced dentine, resin- reinforced zone, resin infiltration layer, or hybrid layer (Nakabayashi et al.,1982; Van Meerbeek et al., 1992).

The number of resin tags and the peripheral cuff of peritubular hybrid layer, not the length of tags, play a crucial role in retention. Therefore, the thickness of the hybrid layer is not a critical requirement (Yoshiyama et al., 1995). True chemical adhesion between collagen and the resin monomers is unlikely, due to the inert nature of collagen fibrils and the low affinity of the monomers for hydroxyl apatite-depleted collagen (Van Meerbeek et al., 1992; Van Meerbeek et al., 2003).

Consequently, the nano leakage phenomenon, i.e. stained water pathways, can be observed, shown as silver absorption at the nanometer size gap between resin and collagen fibrils (Sano et al., 1995). This process leads to the gradual degradation of the bond which affects bond durability (De Munck, 2005).

- ▪ The self etch approach:

Probably, in regard to user-friendliness and technique-sensitivity, the most promising approach clinically is self-etch. It no longer needs an "etch & rinse" phase, which not only lessens clinical application time, but also significantly reduces technique-sensitivity or the risk of making errors during application and manipulation. Another important advantage of the self-etch approach is that infiltration of resin occurs simultaneously with the self-etching process, by which the risk of discrepancy between both processes is low or non-existent (Tay et al., 2002a; Tay et al., 2002b).

A self-etch approach involves either a one- or two-step application procedure. The self-etch effect should be ascribed to monomers to which one or more carboxylic or phosphate acid groups are grafted (Van Meerbeek et al., 2001). Self etch adhesives can be subdivided by the number of application steps (one-step or two-step) and by their acidity (pH) (mild; pH $\geq$ 2, intermediate pH $\approx$ 1.5, and strong pH $\leq$ 1) (Van Meerbeek et al., 2003).

"Strong"self-etch adhesive usually have a pH of 1 or below. This high acidity results in rather deep demineralization effects. On enamel, the resulting acid-etch pattern resembles a phosphoric-acid treatment following an etch & rinse approach (Inoue et al., 2000; Pashley and Tay, 2001). On dentine, collagen is exposed and nearly all hydroxyapatite is dissolved. Consequently, the underlying bonding mechanism of "strong" self-etch adhesives is primarily diffusion-based, similar to the etch and rinse approach. Such low-pH self-etch adhesives have often been documented with rather low bond strength values especially at dentine and quite a high number of pre-testing failures when tested following a microtensile bond strength approach (Inoue et al.,, 2001; De Munck et al., 2003).

"Mild" self-etch systems, in general, have a pH of around 2 and demineralize dentine only to a depth of 1 μm. This superficial demineralization occurs only partially, keeping residual hydroxyapatite still attached to collagen. Nevertheless, sufficient surface porosity is created to obtain micromechanical interlocking through hybridization (Van Meerbeek et al., 2003). The thickness of hybrid layer is, however, much smaller than that produced by the strong self-etch or etch & rinse approach but has been proven to be minor in importance with regard to actual bonding effectiveness (Inoue et al., 2000 ; De Munck et al., 2003).

Another classification is based on substrate condition; there are 2 major types of bonding substrates namely, dry and wet bonding substrates which can be subdivided to water and ethanol-wet bonding substrates:-

Dry bonding substrate:

Dry bonding substrate provides high resin-enamel bond strength, but low resin-dentine bond strength. This substrate fails to preserve morphological integrity of collagen matrix so that a very thin hybrid layer is created and there is an absence of interfibrillar spaces. While water serves as collagen configuration preserver but after water is evaporated by air drying, H-bonds between collagen fibers are created resulting in collapse of collagen matrix. Once the collagen matrix collapses, interfibrillar spaces are reduced. Consequently, resin monomers cannot penetrate into this collagen matrix and properly form a hybrid layer. Thus, the dry bonding substrate is not suitable for dentine bonding (Tay et al., 1996).

Wet-bonding substrate:

The water-wet bonding substrate helps maintain the normal morphological integrity of dentine matrix. After dentine is etched with phosphoric acid and rinsed with water, demineralized dentine is blotted dry leaving water to moisten dentine collagen and thus preventing any interpeptide H-bonds from forming. Collagen network can be fully expanded with relatively wide interfibrillar spaces. Then, hydrophilic monomers can better infiltrate into this water-saturated dentine replacing the water and creating hybrid layer (Pashley et al., 2007).

Water wet bonding improves the resin-dentine bond strength. Potential disadvantages of wet-bonding include: a compliant matrix that can easily shrink upon solvent evaporation and residual water that may cause phase separation of resin components. The goal is to

coax hydrophobic monomers into a hydrophilic matrix without inducing phase changes. This bond would absorb less water, plasticize less and produce a more durable bond (Ito et al., 2005).

2.4 Microleakage

Microleakage is the marginal permeability to bacterial, chemical and molecular invasion at the interface between the teeth and restorations (Wieczkowski et al., 1992). It may be defined as the diffusion of bacteria, oral fluids, ions and molecules into the tooth-filling interface. Many studies emphasize that margins of restorations are not fixed, inert and impenetrable borders, but dynamic micro crevices which contain a busy traffic of ions and molecules (Going, 1972; Kidd, 1976).

2.4.1 Causes of microleakage

The causes of microleakage are usually associated with polymerization shrinkage, the composite resin used, occlusal load, location of the prepared margins and the technique used (Kubo et al., 2001). Cavity type and design and the localization of the restoration may affect the microleakage pattern (Hilton and Ferracane, 1998). Polymerization shrinkage may induce stresses, which can lead to the breakdown of the bonding at cavity walls, promoting marginal gaps and subsequent microleakage (Davidson et al., 1984).

2.4.2 Consequence of microleakage

Microleakage may lead to problems such as postoperative sensitivity, marginal discoloration and breakdown at the tooth-restoration interface, recurrent caries and pathological changes of the pulp tissue (Going, 1972; Bergenholtz et al., 1982).

2.4.3 Significance of microleakage

Microleakage is a dynamic process that can increase or decrease with time. As a result of long term exposure to saliva, pellicle and bacterial plaque, changes may occur that will serve to obturate the space between tooth substance and restoration (Going, 1972). The effects of bacterial leakage upon the dental pulp are well documented (Brannstrom, 1981; Bergenholtz et al., 1982). Prevention of bacterial access along the margins of restorations is therefore a high priority (Taylor and Lynch, 1992).

2.4.4 Coronal microleakage

Coronal microleakage can considerably affect the prognosis of endodontic treatment. An inadequate coronal seal will allow biologic contamination and penetration of saliva, nutrients, chemicals and microorganisms and their by-products. As result, endodontic failure may occur; coronal seal therefore can be regarded as important as the apical seal (Aminozarbian et al., 2009).

Indira (2009) stated that the exposure of the coronal segments of obturated root canals to artificial saliva have resulted in recontamination of 79% to 85% of the root canal system in as little as 3 days. This type of leakage could be prevented by using a temporary restoration with an acceptable seal against saliva, bacteria, their by-product and foods. Coronal seal is influenced by the restoration thickness, quality of condensation and total contact surface between intact tooth structure and the restoration (Aminozarbian et al., 2009).

However, much emphasis is now being placed on the quality of the final restoration to reduce coronal leakage. Many root canal treated teeth are restored using post and core techniques which provides retention for the coronal restoration (Fox and Gutteridge, 1997)

2.4.5 Microleakage tests

Microleakage tests can provide much useful information about the performance of restorative materials. A variety of different techniques for assessing microleakage have been developed and utilized. Most modern techniques utilize different principles involving biological, chemical, electrical, physical or radioactive components (Gonzalez et al., 1997).

2.4.5.1 Direct observation

The simplest assessment of microleakage involves direct observation of the restoration. No agent or tracer is used to detect microleakage. This may be done tactilely with the use of an explorer, and/or visually by determining the presence of discoloration in adjacent enamel or a gap between tooth and restoration (Osborn and Gale, 1979; Leinfelder et al., 1978).

2.4.5.2 Organic Dyes

The use of organic dyes is one of the most popular techniques using this principle, as well as one of the oldest (Shortall, 1982). Some of the organic dyes used include basic fuchsin, methylene blue, eosin, aniline blue, crystal violet and erythrosine B (Fuks et al., 1992; Prati et al., 1991; Yougson et al., 1990). Percentage concentration currently in use range from 0.5 to 2.0 percent (Ben-Amar et al., 1989; Manders et al., 1990). Most of the early organic dyes used were toxic, precluding their use for in vivo studies (Bauer and Henson, 1984).

Some thermocycled the specimens in dye solution (Leinfelder et al., 1986). Others therrmocycled the specimens in the dye (25 to 200 cycles), followed by immersion in the dye solution for one to 21 days (Ben-Amar et al., 1986; Staninec and Holt, 1988).

Fayyad and Shortall in 1987, assessed dye penetration by using an image analysis apparatus linked to a stereomicroscope. Digital imaging microscopy was used to record the actual length of the dye penetration along the interface. In spite of the disadvantages, the popularity of the organic dyes has not diminished due to ease of use and low cost.

2.4.5.3 Fluorescent dyes

Fluorescing agents have been used in different fields of dental research for almost 40 years to study a wide variety of topics: microleakage and/or adaptation of bonded restorations to preparation walls, characteristics and structure of bonded restoration hybrid layer or the interfacial morphology among different types of restorative materials (D'Alpino, 2006).

Because the fluorescent dye is non-toxic, it offered the advantage of being usable for topical and systemic application for in vivo studies (Gonzalez et al., 1997). However, the in vitro and in vivo results using fluorescent dye have not been found to give identical results in hamsters. They noted that mean microleakage scores obtained from in vivo testing were much lower than those from in vitro testing among human subjects (Gonzalez et al., 1997).

2.4.5.4 Radioisotopes

In 1992, Taylor and Lynch suggested that the use of radioisotopes provides finer detail in leakage studies as the smaller isotopes molecules measure only 40 nm compared with the smaller dye particles (120 nm). Trowbridge in 1987 reported that isotopes such as Ca45 have an affinity for tooth structure or for restorative materials and thus distribution of the isotope may be misleading.

2.4.5.5 Bacterial penetration

The use of bacteria to assess leakage (mainly coronal) is considered to be of greater clinical and biological relevance than the dye penetration methods (Verĭssimo and do Vale, 2006). This method requires a controlled sterile environment to avoid contamination with other bacteria (Gonzalez et al., 1997). Many different strains of bacteria have been used to assess marginal microleakage and this has led to contradictory results, because the methods depend on the type of bacteria used. Moreover, if the sealer has antimicrobial activity, it is unfeasible to employ the bacteria method (Verĭssimo and do Vale, 2006).

2.4.5.6 Fluid filtration or transportation

In this method, the sealing capacity is measured by means of air bubble movement inside a capillary tube. It was developed by Pashley's groups in 1987 and modified by Wu et al. in 1993 for use in root canals (Verĭssimo and do Vale, 2006). It consist of a filled canal that has its coronal portion connected to a tube filled with water under atmospheric pressure and its apex to a 20 μl glass capillary tube 170 mm long and of uniform caliber filled with water. Finally, a pressure of 0.1 atm is applied through the coronal part, which will force the water through the empty space along the root canal (Wu et al., 1994).

2.4.5.7 Dye extraction method

In this method, the teeth are dissolved in acids that release all dyes from the interface and the optical density of the solution measured by a spectrophotometer (Comps and Pashley, 2003). This technique gave similar results to those of fluid filtration, because both take into consideration the porosity of the interface between the filling material and the root (Verĭssimo and do Vale, 2006).

2.5 Luting cements

Luting cements must withstand masticatory and parafunctional stresses for many years in a warm and wet oral environment (Chun and Shane, 1999). A dental cement must be used to act as a barrier against microbial leakage, sealing the interface between tooth and restoration and holding them together through some form of surface attachment (Diaz-Arnold et al., 1999).

In vitro modelling techniques done in 1994 by Kamposiora, have demonstrated that high stresses are imposed on luting cements, particularly in the biologically important marginal areas. Actual stresses imposed on luting cements may be much greater than those estimated by simply dividing applied masticatory loads by the resisting surface area of tooth preparations.

According to Terry (2005) there are five types of commercially available luting agents for the long-term cementation of fixed prostheses which include: zinc phosphate, polycarboxylate, glass ionomer, resin-ionomer and composite resin cements.

2.5.1 Resin luting cement

Resin cements were first developed in the 1950s. The first resin cements had high polymerization shrinkage and increased microleakeage because of their low filler content. They also had high residual amine levels which contributed to significant colour shift after polymerization (Petrich et al., 2004).

Application of resin luting agents has increased considerably over the last few years (Attar et al., 2003). It has been used for cementation of crowns, conventional bridges and resin-bonded bridges and for direct bonding of orthodontic brackets to acid-etched

enamel (Craig and Powers, 2002). They are composed of the same basic components as composite restorative materials but with lower concentration of filler particles. Most of these cements are used in conjunction with the dentine bonding systems (Terry, 2005).

2.5.1.1 Structure

According to John (2003) resin cements are composed of two main parts which are:

Powder:

Resin matrix (diacrylate monomer).

Inorganic fillers.

Coupling agent (organo silane).

Chemical or photo initiators and activator.

Liquid:

Methyl methacrylate.

Tertiary amine.

In the powder/liquid form, the powder is generally a finely divided borosilicate or silica glass together with fine polymer powder and an organic peroxide initiator.

The liquid is a mixture of bis-GMA and/ or other dimethacrylate monomers containing an amine promoter for polymerization (O'Brien, 2008). Since Bis-GMA is quite viscous, it must be thinned by using shorter, more flexible diacrylate monomers, eg, ethyleneglycol dimethacrylate (EGDMA) and triethyleneglycol dimethacrylate (TEGDMA) (Burgess et al., 2002).

2.5.1.2 Classification

Lambrechts classified different luting composites according to their initiation systems or viscosities (Kramer et al., 2000). However, many types of composite cement systems

are available. They come as chemically activated, light activated and dual-cure systems (Gladwin and Bagby, 2009).

2.5.1.2.1 Self/ Auto-cured resin cements

emically activated resin cements are supplied as two-component systems, consisting of either a powder and a liquid or two pastes. The two components are combined by mixing on a paper pad for 20 to 30 sec. (Anusavice, 2003). Once the chemically cured resin cement is mixed, the initiator (benzoyl peroxide or sulfinic acid) and activator (a tertiary amine) contact and the polymerization begins. After a few minutes, the polymerization produces a gel (solid) where the polymer cross-linked enough to form a cohesive mass (Burgess et al., 2002). Kramer et al. (2000) said that the setting time of self-cured resin ranged from 150-200 sec which limited the possibilities of excess removal under difficult clinical conditions. It can be used for cementation of non light transmitting restorations.

2.5.1.2.2 Light-cured resin cements

Whereas the first luting resins were visible light-activated, the tendency is now towards the use of light and optional dual-cured resins. The concern is that visible light curing resins may not cure properly when they are used to bond large inlay, as the light would be unable to penetrate to the full depth of the inlay (Noort, 2007). Light –activated resins should be utilized with indirect ceramic or composite restorations that transmit light and are less than 1.5 mm in thickness (Terry, 2005). The intensity of light-curing can be affected by the distance the light guide is held from the curing site. As the distance from the light source increase, there is a linear decrease in the power density (Burgess et al., 2002).

2.5.1.2.3 Dual-cured resin cements

These types of cements start curing with light and continue with chemical curing. The chemical cure will polymerize more thoroughly than light curing alone. These products are used to cement translucent restorations, such as porcelain and indirect resin restorations (O'Brien, 2008). They seemed to be favorable for indirect tooth-coloured restorations because they provide extended working times and controlled polymerization (Kramer et al., 2000).

2.5.1.3 Properties of resin luting cements:

The physical and biological properties of resin luting agents could vary considerably because of the difference in the quantity and quality of their polymeric and inorganic phases, as well as the efficacy of their setting mechanisms (Attar et al., 2003).

As with resin composite restorative materials, monomer conversion is incomplete, even under optimum cure conditions and thus, manipulation is critical to optimum physical properties (O'Brien, 2008). Since the composition of the resin cement is very similar to that of composite restorative materials, the physical properties are also similar. In particular, the tensile strength is much higher than any of the other classes of conventional cements. In addition to that, they have high bond strength, indicating that these classes of cements as the preferred materials for non-retentive preparation and for cementation of non-metallic prosthetic devices (Dhuru, 2004).

2.5.1.3.1 Adhesion

When using a traditional nonadhesive luting agent such as zinc phosphate, retention is dependent on the geometric form of the tooth preparation that limits the paths of displacement of the cast restoration (Rosenstiel, 1998). Adhesive resins such as Panavia

have shown increased retention when compared with zinc phosphate, glass ionomer or conventional resin cements (Ayad et al., 1997).

Adhesion of resin cements to enamel occurs through the micromechanical interlocking of resin to the hydroxyapatite crystals and rods of etched enamel (Diaz-Arnold et al., 1999). Laboratory measurement of bond strengths of various devices cemented with resin luting cements to dentine yield high values, typically in the 18-30 MPa range (Dhuru, 2004). Adhesion of resin to dentine is more complex, involving penetration of hydrophilic monomers through a collagen layer overlying partially demineralized apatite of etched dentine (Diaz-Arnold et al., 1999).

2.5.1.3.2 Polymerization shrinkage

Resin luting agents shrink during setting, which causes undesirable stresses in the set material. Contraction gaps can occur at the dentine-cement interface that may be in the range of 1.6 to 7.1μm (Rosenstiel, 1998). Burgess et al., in 2002, said that shrinkage of the resin cement can fracture marginal tooth structure, tear the adhesive or cause tooth structure to deform which increase microleakage, postoperative sensitivity, staining and recurrent caries.

2.5.1.3.3 Film thickness

The film thickness of the luting agent can directly affect long-term clinical success (Rosenstiel, 1998). Kramer et al., in 2000, reported that the evaluation of film thickness was highly influenced by the size of the fillers, geometry of the cavity, surface roughness of the bonding substrates, applied pressure, working time and temperature. Many resin cements tend to show unacceptable high values for film thickness (O'Brien, 2008).

2.5.1.3.4 Radiopacity

An ideal luting agent should be radiopaque to enable the practitioner to distinguish between a cement line and recurrent caries, as well as detect cement overhangs (Rosenstiel, 1998). It is important that luting agents have greater radiopacity than dentine because it is difficult to detect a cement line radiographically when the material is not significantly more radiopaque than dentine (Attar et al., 2003). As the radiopacity of the luting agent increases, the detection threshold for marginal overhangs decreases; thus, a luting agent should be chosen that is as radiopaque as possible (Rosenstiel, 1998).

Metal posts used to restore endodontically treated teeth may shine through all-ceramic crowns and thin gingival tissues. When nonprecious alloys are used, corrosion products may lead to discolouration. The shine through of metal post discolouration depends on the thickness and the opacity of luting cement. As the cement opacity increases the grayish colour decreases (Ferrari et al., 2000).

2.5.1.3.5 Biocompatibility

An ideal dental luting agent should be biocompatible, that is, have little interaction with body tissues and fluids, be nontoxic, and have low allergic potential (Craig, 1997). Resin luting agents appear to pose few problems; pulpal pathology may be due to poor seating, polymerization contraction and consequent microleakage. All systems show microleakage, which may contribute to tooth sensitivity and clinical failure (O'Brien, 2008). Allergy to the constituents of resin luting agents has been reported by patients and dental personnel, but it is apparently quite rare (Rosenstiel, 1998).

2.5.1.4 Advantages of resin luting cements

These cements have high strength, low solubility and micromechanical bonding to prepared enamel, dentine, alloys and ceramic surfaces (O'Brien, 2008). They are available in various shades and opacities and their chemistry allow them to adhere to many dental substrates (Diaz-Arnold et al., 1999). In addition, the resin cements are quite resistant to erosion in an acidic aqueous environment (Dhuru, 2004).

2.5.1.5 Disadvantages of resin luting cements

The use of resin luting agent is technique-sensitive and require careful handling/ manipulation during bonding and during the removal of excess material (Attar et al., 2003). Resin luting agents have short working time (Craig and Powers, 2004). They are also more difficult to seal and have a higher film thickness than traditional cements, causing possible leakage and pulpal sensitivity (O'Brien, 2008).

2.5.2 Glass ionomer cement

Wilson and Kent (1972) were the first to describe glass ionomer cements. Their physical properties were an amalgamation of those of silicate and polycarboxylate cements, but their handling characteristics were not ideal. The current glass ionomer cements were introduced following the development of ion-leachable glasses and have better physical and clinical handling properties (Croll and Nicholson, 2002)). Glass ionomer cements were designed to integrate the optical and fluoride-releasing properties of silicate particles with biocompatible and chemically adhesive properties of the polyacrylic acid matrix (Terrry, 2005). On mixing, the polyacrylic acid and tartaric acid will react with the glass, leaching calcium and aluminium ions from the surface which cross-link the polyacid molecules into a gel (O'Brien, 2008).

Originally, the cement was intended for the aesthetic restoration of anterior teeth and it was recommended for use in restoring teeth with Class III and Class V cavity preparations. Because of its adhesive bond to tooth structure and its caries prevention potential, the type of glass ionomers have expanded to include their use as luting agents (Anusavice, 2003). The advantages of glass ionomer cement include its ability to chemically bond to tooth structure, anticariogenic effect, high compressive strength, low solubility and a coefficient of thermal expansion similar to that of tooth structure (Petrich, 2004).

The values for compressive and tensile strength of glass ionomer cements are similar to those of compomer and zinc phosphate cements (Craig et al., 2004). However, the 24-hour compressive strength of glass ionomer cements ranges from 90 to 230 MPa and it increase between 24 hours and one year (Craig and Powers, 2002).

One of glass ionomer cement's disadvantages is the potential for post-cementation sensitivity because of low initial setting pH and the setting reaction sensitivity to moisture contamination/dessication (Petrich, 2004).

However, Terry (2005) stated that to avoid postoperative sensitivity for extensive preparations of freshly cut dentine, an application of a desensitization agent is suggested which hase no negative effect on crown retention.

2.5.3 Zinc phosphate cement

The primary luting cements in current use are zinc phosphate, polycarboxylate, glass-ionomer, resin composite and resin modified glass-ionomer cement.

Despite the introduction of new cement formulations, zinc phosphate was reported amongst the most popular luting agents in current use (Berry et al., 1996). It sets by an acid-base reaction initiated on mixing a powder composed of 90% ZnO and 10% MgO with a liquid that consist of approximately 67% phosphoric acid buffered with aluminum and zinc (Diaz-Arnold et al., 1999).

Unfortunately, the physical, chemical, biological and mechanical properties of the cements are known to be dependent on the mixing ratio. To ensure that cements are produced as close to optimum properties as possible, under uncontrolled temperature and relative humidity conditions normally encountered in clinical practice, it is desirable to establish uniform proportioning and mixing of the cement. Capsulation enables the powder/liquid ratio and mixing regime to be standardized by the manufacturer so that the functional properties of the plastic cement mass will not be susceptible to clinically induced variability (Fleming et al., 1999).

Zinc phosphate does not chemically bond to any substrate and provides a retentive seal by mechanical means only. Microleakage is aggravated by degradation in oral fluids and an initial low setting pH. Several studies have demonstrated significant linear penetration of silver nitrate along the restoration-tooth interface (Diaz-Arnold et al., 1999).

2.6 Post systems

The longevity of endodontically involved teeth has been greatly enhanced by continuing developments made in endodontic therapy and restorative procedures. It has been reported that a large number of endodontically treated teeth are restored to their original function with the use of intraradicular devices (Fernandes et al., 2003).

The construction of post has been used as a means of providing anchorage for restorations for over 250 years (Stewardson, 2001). Despite the lack of data to support its success, post placement in endodontically treated teeth is a common clinical procedure amongst restorative dentists (Fouad, 2004).

2.6.1 Function of a post

The primary purpose of a post is to retain a core in a tooth with extensive loss of coronal tooth structure (Schwartz and Robbins, 2004). According to Stewardson (2001), posts have been used mainly for two reasons which are reinforcement of endodontically treated teeth and retention by providing anchorage for a core upon which a restoration can be placed. A tooth that is restored with a post and core and crown can be readily understood as a group of dissimilar materials that ultimately have to function as a single compound entity (Pitel and Hicks, 2003).

2.6.2 Indication of a post

The need for a post varies greatly between the anterior and posterior teeth. However, the indication for post insertion depends on the dental substance and extent of either destruction or viable structure seen in the teeth being considered for endodontic treatment (Peroz et al., 2005).

Schwartz and Robbins (2004) have shown that anterior teeth with minimal loss of tooth structure may be restored conservatively with a bonded restoration in the access opening.

A post is of little or no benefit in a structurally sound anterior tooth and increases the chances for a nonrestorable failure. If an anterior tooth must be prepared to receive a crown after endodontic treatment because a good amount of tooth structure was lost, a post may be necessary to retain the core so that these teeth can resist functional forces (Cheung, 2005).

Fouad (2004) reported that when complete coverage become mandatory in endodontically treated posterior teeth with extensive loss of coronal tooth structure or when the tooth is serving as abutment, the retention and support are derived from within the canal by using a post.

Premolars are usually bulkier than anterior teeth, but often are single-rooted teeth with relatively small pulp chambers. For these reasons, they require posts more often than molars. In addition, premolars are more likely than molars to be subjected to lateral forces during mastication (Schwartz and Robbins, 2004).

2.6.3 Classification of posts

Posts are categorized a number of different ways. They can be classified according to their shapes and surface characteristics, may be parallel, tapered or parallel-and-tapered combination (Fernandes et al., 2003). Schwartz and Robbins (2004) classified posts according to the way of retention into the active and passive. Active posts are intended to engage the walls of the canal whereas passive posts are retained strictly by the luting agent.

Standlee and Caputo (1992) stated that active posts are more retentive than passive posts, but introduce more stress into the root than passive posts. There are another two main categories of posts which are custom-fabricated and prefabricated (Cheung, 2005). The customized cast post is indicated in teeth with elliptical or excessively flared canals (Fouad, 2004).

Stainless steel, titanium and titanium alloys, gold plated brass, ceramic and fiber-reinforced polymers have been used as materials for prefabricated posts (Cheung, 2005).

Fiber-reinforced composite posts have been introduced as alternative to conventional materials as their biomechanical properties have been reported to be close to that of dentine (Plotino et al., 2007).

Kim et al. (2009) says that using of fibre posts has become popular for restoration of root filled teeth mainly due to their good aesthetics and similar modules to dentine.

2.6.4 Metal posts versus non-metal posts

Traditionally, posts were made of metal alloys. Recently, nonmetallic posts have been introduced (Fernandes et al., 2003). Pitel and Hicks (2003) demonstrated that an irreversible discolouration and damage of the teeth may be created due to the diffusion of the oxidation and corrosion by products of the metallic posts into the root. Therefore, use of metal posts has been reduced. They are visible through the more translucent all-ceramic restorations and even with less translucent restorations cause the marginal gingiva to appear dark (Schwartz and Robbins, 2004).

On the other hand, non-metal posts are metal-free, they do not cause metal allergies or corrode. They offer good aesthetics in easily visible areas of the mouth and can be removed easily in case of an endodontic failure requiring retreatment (Cheung, 2005).

In addition, the technique for removing them in the event of fracture or need for endodontic retreatment is much simpler in comparison with that needed to remove metal posts (Stewardson, 2001)

2.6.5 Post space preparation

Ideally, post space preparation is completed at the appointment when the root canal is filled to minimize microbial entry (Fouad, 2004). However, knowing the root anatomy of different teeth is important before attempting to prepare any canal space for post installation (Cheung, 2005).

2.6.5.1 Post length

The recommended post length is equal to 3⁄4 of root canal length, if possible, or at least equal to the length of the crown. They caution that 4 to 5 mm of gutta-percha should remain apically to maintain an adequate seal (Schwartz and Robbins, 2004). It has been demonstrated that the greater the post length, the better the retention and stress distribution (Fernandes et al., 2003). On the other hand, Peroz et al. (2005) have shown that leakage increases with post-space preparation and a remaining apical filling of less than 3 mm may result in an unpredictable seal.

2.6.5.2 Post diameter

Although a group of investigators reported that increasing the post diameter could increase retention, many researchers confirmed that increasing the post diameter significantly increases internal stress within the tooth (Fouad, 2004).

Fernandes et al. (2003) they proposed that post should be surrounded by a minimum of 1mm of sound dentine. He advocated minimal canal preparation and maintaining as much residual dentine as possible.

2.6.5.3 Post cementation

The retention of post can be influenced by the type of cement used (Pitel and Hicks, 2003). However, zinc phosphate, polycarboxylate and glass ionomer cements were commonly used for post cementation because of their ease of use and their history of clinical success (Fouad, 2004).

Recently, posts are usually cemented by a resin cement in combination with an adhesive system (Kim et al., 2009) because they increase retention , tend to leak less than other cements and provide at least short-term strengthening of the root (Schwartz and Robbins, 2004).

Several methods have been suggested for placement of the cement inside the canal; such as lentulo spiral, paper point, or endodontic explorer but the lentulo spiral is the superior instrument. Four techniques for the cementation of cast post restorations were compared in extracted single-rooted teeth. The techniques used were the lentula spiral, endodontic explorer, paper point, and direct post application. Evaluation was based on the presence of voids in the cement and retention of the post, the lentula spiral technique was performed without voids (Fouad, 2004).

2.6.6 Post aesthetics

The post and core material should be aesthetically compatible with the crown and the surrounding tissues (Fernandes et al., 2003). A metal post alters the transmission of light through the tooth and may show through the tooth especially where the gingival

tissues are thin (Stewardson, 2001). Fibre-reinforced posts consist of some type of mineral or glass fiber embedded in epoxy or resin matrix which offers significant aesthetic advantages than metal posts (Pitel and Hicks, 2003).

2.6.7 Retrievability

It has been estimated that as many as 15% of endodontically treated teeth may eventually require retreatment or re-access to the root canal (Pitel and Hicks, 2003). For this reason, Schwartz and Robbins (2004) suggested that it is important that posts can be retrieved if endodontic retreatment becomes necessary.

In 2001, Stewardson reported that removal of long metal post can be difficult, if not impossible, and may result in tooth fracture. On the other hand, one of the major clinical advantages of fibre-reinforced posts is the ability to remove them conveniently and without trauma (Pitel and Hicks, 2003). In contrast, ceramic and zirconium posts are considered to be very difficult and sometimes impossible to retrieve (Schwartz and Robbins, 2004).