CHAPTER II

LITERATURE REVIEW

Endodontically treated teeth are generally weakened as a result of decay, previous restorative procedures and endodontic access preparation. These teeth, especially anterior teeth, the remaining coronal tooth structure is quite thin after it has received root canal treatment and been prepared for complete coverage restoration. Anterior teeth must resist lateral and shearing types of forces, and the pulp chambers are too small to provide adequate retention and resistance without post. The amount of remaining coronal tooth structure and the functional requirement of the tooth determine whether an anterior tooth requires a post. In most cases, they are often required placement of root canal post for anchorage and retention of the crown reconstruction. Retrospective clinical study revealed that post did not strengthen the teeth. Restoration with post and core would cause root fracture, post fracture or post dislodgement (25, 26). Schwartz et al. (27) had presented the important principles for the posts as below.

Retention and Resistance

Post retention refers to the ability of the post to resist vertical dislodging forces. Retention is influenced by the post's length, diameter and taper, the luting cement used, and whether a post is active or passive (28, 29). Increasing the length and diameter of the post can increase retention. Parallel posts are more retentive than tapered posts (29, 30). Active posts are more retentive than passive posts (29). Diameter is less important than the other factors listed (31). Even though retention can be increased slightly by enlarging the post diameter, the loss of tooth structure resulted from enlargement weakens the tooth. Therefore, this is not a recommended method to increase retention. Resistance refers to the ability of the post and tooth to withstand lateral and rotational forces. It is influenced by remaining tooth structure, the post's length and rigidity, the presence of antirotation features, and the presence of a ferrule. A restoration lacking resistance form is not likely to achieve long-term success, regardless of the retentive of the post (32).

Failure Mode

An important factor related to resistance is failure mode. All post systems have some percentage of clinical failure. However, some posts cause a higher percentage of failures which are nonrestorable. For example, teeth restored with less rigid post, such as fiber posts, tend to have failures that are more likely to be restorable (2, 4, 33). Teeth prepared with ferrule also tend to fail in a more favorable mode (34). Pilo et al. (35) reported that composite cores tended to fail more favorably than amalgam or gold.

Preservation of Tooth Structure

Whenever possible, coronal and radicular tooth structure should be conserved. In most cases, preparation of a post space should require minimal removal of additional radicular dentin beyond the requirements for root canal treatment. Further enlargement only weakens the root (36). It has been shown that cemented metal posts do not strengthen the root (26). Bonded posts are reported to strengthen the root initially (37), but this strengthening effect is probably lost over time as the tooth is exposed to functional stresses and the resin bond to dentin weakens (36). Minimal enlargement of the post space means the post must be made of a strong material that can withstand functional and parafunctional forces.

Retrievability

Although nonsurgical endodontic treatment enjoys a reputation as a highly successful treatment, some studies have reported lower rate of success (38, 39). For this reason, it is important that posts can be retrieved if endodontic retreatment becomes necessary. In most cases, metal posts can be removed effectively and safely. A case series by Abbott (40) reported only one root fracture of 1600 posts removed. Most fiber posts also are reported to be easy to retrieve (41). In contrast, ceramic and zirconium posts are considered to be very difficult and sometimes impossible to retrieve. Retrievability should be considered when treatment planning a post.

In 1990, both dentist and dental materials companies noticed that metallic posts were too stiff when compared to dentin, leading to a critical transmission of loads to teeth previously weakened by instrumentation, dental caries, and extensive restorations. This led to the development of fiber post, which have been replacing the older methods for restoring endodontically treated teeth that required large coronal destruction (metallic posts, crowns, and nonadhesive cements) (27). Considering the principles of minimally invasive adhesive dentistry, adhesively luted, prefabricated root canal posts seem to be better and meet the requirements of minimal intervention (42).

The modulus of elasticity of fibre posts closely match to the sound root dentin, allowing more uniform absorption and distribution of stress to the remaining root structure, instead of concentrating the stresses (43, 44, 45). Other attractive features of fibre posts include resistance to corrosion, aesthetic appearance, and nonhypersensitivity (46). Akkayan et al (2) revealed that quartz fibre post demonstrated the highest mean resistance to fracture compared to titanium post, glass fibre post and zirconia post. Quartz fibre posts have low elastic modulus (18 to 47 GPa) similar to that of dentin, which may explain the favorable fracture pattern and high fracture loads threshold. Mannocci et al. (37) also reported that quartz fiber posts were able to reduce the risk of root fractures to a minimum.

Luting agents comprise of a broad category of material used to attach and seal dental restorations with prostheses to teeth. New luting agents, particularly with adhesive capability, are being introduced in an attempt to improve the clinical outcomes. The choice of a luting agent depends on the clinical situation combined with the physical, biologic, and handling properties of the luting agent. For more than a century, zinc phosphate cement has been the most widely used luting agent, in spite of some well-documented disadvantages, including high clinical solubility, lack of adhesion, and low setting pH (47, 48). Recently there has been considerable interest in luting materials with adhesive capabilities and therapeutic potential. Conventional glass ionomer luting agents have fluoride ion release (49). Resin-modified glass ionomer cements also release fluoride and contain resin components for improved physical and mechanical properties (50). Resin luting agents have superior mechanical properties and demonstrate increased retentive capabilities (51). Resin may be bonded to some types of posts, so theoretically, the dentin/resin/post can be joined via resin adhesion into one unit, at least for a period of time. Application of resin luting agents have increased considerably over the recently years.

Bonding to dentin with resin materials is more complex than bonding to enamel. Dentin consists of approximately 50 % inorganic mineral (hydroxyapatite) by volume, 30% organic components (primarily type 1 collagen) and 20% fluid (52). The wet environment and relative lack of a mineralize surface made it a challenge to develop materials that bonded to dentin. Current strategies for dentin adhesion were first described by Nakabayashi in 1982 (53). Nakabayashi showed that resin bonding to dentin could be obtained by applying an acid to expose the collagen matrix and dentinal tubules, applying a hydrophilic resin material to the demineralized surface and polymerizing the resin in situ. The collagen matrix and dentinal tubules provided mechánical retention for the resin. Although not as durable and reliable as enamel bonding, steady improvements have been made in dentin bonding and in simplifying dentin-bonding procedures. Dentin adhesive system utilizes an acid as the first step of the bonding process to remove or penetrate through the smear layer and demineralize the dentin surface. The smear layer covers the surface of ground dentin and consists of ground up collagen, hydroxyapatite, bacteria, and salivary component (54). Most dentin adhesive system can be categorized as "etch and rinse" or "self etching" based on the acid etching process (54).

"Etch and Rinse" adhesives

Most of the "etch and rinse" adhesive systems utilize a strong acid such as 30 to 40% phosphoric acid. When phosphoric acid is applied to dentin, the surface is demineralized to a depth of about 5μm. The acid is rinsed off after about 15 sec, removing the smear layer and exposing the collagen matrix and network of dentinal tubules for resin bonding. A hydrophilic primer is then applied to the surface to infiltrate the collagen matrix and tubules. The primer contains a resinous material in a volatile carrier/solvent, such as alcohol or acetone, which carries the resinous material into the collagen matrix and dentinal tubules. The surface must be wet (moist) for the primer to penetrate effectively. After the primer is in the place, a stream air is used to evaporate the carrier and leave the resin behind. A hydrophobic resin monomer (adhesive) is then applied and polymerized, which adheres to the infiltrated resin from primer. A "hybrid layer" or "interdiffusion zone" is formed that consists of resin, collagen and hydroxyapatite crystals (54). It bonds the hydrophobic restorative materials to the underlying hydrophilic dentin. Excessive etching can cause poor bond strength and increase in microleakage (55). The same is true if residual carrier/solvent is left behind, which makes the bond more subject to hydrolytic breakdown (56).

"Self- Etching" Adhesives

Most of the "self-etching" products combine an acid with the primer. Rather than removing the smear layer, they penetrate through it and incorporate it into the "hybrid layer". The acidic primer is applied to the dentin surface and dried with a stream of air. There is no rinsing step. A resin adhesive is then applied and polymerized, follow by the restorative material. The "self-etching" systems can be categorized as "strong" or "aggressive" ($pH<1$), "moderate" (pH 1-2) or "mild" ($pH>2$) (54, 57). The strong "self-etching" systems form a hybrid layer of approximately 5 μm in thickness, similar to phosphoric acid, whereas the mild systems form a hybrid layer of about 1 μm. There does not appear to be clinical significance to this difference in thickness (57).

A further reduction in working steps has been accomplished with the recent introduction of self-adhesive cements that do not require pre-treatment of tooth substrates. This system was designed with the purpose of combining the favorable characteristics of different cements into a single product, in an attempt to satisfy demands for simplification of luting procedures and to overcome the technique sensitivity of multi-step systems (58).

Wet Bonding

Most adhesive systems utilize "wet bonding". If the etched dentin surface is excessively dried, the collagen matrix will collapse and prevents effective infiltration of the primer. This results in low bond strengths and excessive microleakage (59). Excessive moisture has similar negative effect on adhesion (60). An effective method in providing the proper amount of moisture is to dry the surface thoroughly and then rewet with moist sponge, so that the surface is damp, with no visible pooling (59).

Glass-Ionomer Cements

Traditional glass-ionomer cements consist primarily of alumina, silica, and polyalkenoic acid. They are the only restorative material in which the primary bonding mechanism is chemical (61). They form an ionic bond to the hydroxyapatite at the dentin surface and obtain micromechanical retention to etched surface of the hydroxyapatite crystals. Like adhesive resins, glass-ionomer cement loses bond strength over time. When placing glass-ionomer cements, the surface is cleaned and then treated with weak acid (62). The acid removes debris from the dentin surface, removes the smear layer, and exposes hydroxyapatite crystals. It etches the hydroxyapatite, but there is minimal dissolution (61). Because glass-ionomer cements rely on ionic bonding to the hydroxyapatite, strong acids should be avoided because they can cause almost total elimination of mineral from the dentin surface. Removal of the smear has generally been shown to improve the bond of glass-ionomer cement to dentin (63).

Most of the current glass-ionomer restorative materials contain resin and are referred to as resin modified glass-ionomer materials. They obtain a light- cure resin which provides for rapid polymerization on the surface. The resin also protects the glass ionomer cement from dehydration, and improves the physical and mechanical characteristics and optical properties. Most resin modified glass ionomers utilize the same bonding mechanism as traditional glass ionomers and do not require a dentin-bonding agent.

Selecting an appropriate adhesive and luting procedure for bonding posts to root dentin is challenging because of anatomy and limitations in physical and mechanical properties of the adhesive materials. Adhesive materials are frequently compared using bond strength and microleakage tests. Bond strength refers to the force per unit area required to break the bond between the adhesive material and dentin. It is usually described in megapascals (MPa) that is Newtons per square millimeter. Microleakage is perhaps more important for endodontic applications than bond strength. Even if a material has relatively low bond strength to dentin, it may be a good obturating material if it is effective in preventing microleakage. None of the current adhesive materials provides a leak proof seal (64).

The eugenol containing endodontic sealer affected adhesive resin bonding agent and cement (65). This compromised the post retention when using resin as luting agent. However, acid etching and alcohol were advocated in solving the detrimental effect of eugenol and restoring the retentive strength of resin to dentin (66).

Results on effectiveness of self-etching adhesive systems when compared with etch & rinses are contradictory (67, 68). Some studies showed similarities between these systems (68, 69), while others suggest a superiority of etch and rinse materials (67, 70). In a confocal laser scanning microscopy study, the application of etch & rinse and adhesive resulted in a thicker layer compared with self-etching adhesive systems (14).

The structure of dentin is one of an important factor that should be taken into account in terms of bonding (71). The adhesion of luting cements can be influenced by the anatomical and histological characteristics of root canal, including the orientation of the dentinal tubules. Dentinal tubules in the root region are straight, less divergent (72), and not as numerous as in the crown region (73). Moreover, as the number of dentinal tubules also decreases from the cervical to the apical part of the root (74), dentine bonding can vary amongst different areas of the same root canal (7).

One of the most important factors in the strength and stability of the resin/dentin bond is a completeness of resin infiltration into the demineralized dentin. If the resin does not completely infiltrate, fluid movement between the hybrid layer and unaffected dentin speeds the degradation of the bond (75). Water ingress can cause hydrolysis and plasticizing of the resin components. Plasticization is a process in which fluid absorbed by resins, causing them to swell, resulting in degradation of their mechanical properties (75). Hydrolysis can break the covalent bonds within collagen fibrils and the resin polymers. This process is enhanced by enzymes released by bacteria and from dentin itself (76). The breakdown products diffuse out of the interfacial area, which weakens the bond, and allows more fluid to ingress.

Resin luting agents are now available in auto-polymerization, light-polymerization, and dual-polymerization formulations. Many of the limitations of them are related to polymerization shrinkage. When resin based materials polymerized, individual monomer molecules join to form chains that contract as the chains grow and interwine, and the mass undergoes volumetric shrinkage. Resin based restorative materials shrink from 2 to 7%, depending on the volume occupied by filler particles and the test method (77). The force of polymerization contraction often exceeds the bond strength of dentin adhesives to dentin, resulting in gap formation along the surfaces with the weakest bonds (75, 77). Separation often occurs within the hybrid layer (41), but can occur in other area. Resins in thin layers generate very high forces from polymerization contraction (77).

Clinical evidence indicates that the majority of fractures occurred in prosthodontic structure after the period of many years. Such failures generally are not related to an acute overload but result from cyclic loading. This failure is explained by the development of microscopic cracks in areas of stress concentration. With continued loading, these cracks fuse to an over-growing fissure that finally weakens the restoration (23). A commonly used in vitro design for investigating post and core restoration is fracture load testing. Irrespectively, this design has been criticized due to the relatively high standard deviations regarding the measured fracture loads (78). Moreover, static loading used in an in vitro study may not be the representative of the in vivo situation. Overall, in vitro testing of post systems investigating the fracture load revealed controversial results after cyclic loading. A recent overview (27) demonstrated conflicting results revealing a slight tendency towards higher fracture resistance of metallic posts compared to FRC posts: at the same time, a favorable failure mode for FRC posts was revealed. A modulus of elasticity close to that of dentin decreased the incidence of root fracture (33). The teeth reconstructed with FRC posts are more likely to be restorable (2).

Another factor that should be considered in bonding post to root canal dentin is the deterioration of the resin over time. This is a process that is well documented in vitro (55, 75) and in vivo (79). Loss of bond strength is first detectable in the laboratory at 3 months. Interfacial leakage increases as the bond degrades. Functional forces have been shown to contribute to the degradation of resin bond in restorative application. This is also applied in the root canal system where torsional and flexural forces repeatedly stress the dentin/resin interface during function and parafunction. Repeated stress causes microfractures and cracks within the resin. Unpolymerized resin also contributes to the breakdown of the bond. The three steps etch and rinse adhesives exhibit less degradation than the other adhesives (75). However, a study showed that cyclic loading did not affect bonding between the FRC post and root canal dentin, while zirconia post showed decrease in bonding using the total etch system (24). However, there were not many studies compared effect of cyclic loading to bond strength between root canal dentine and FRC post by using different luting cements.

Considering the relative weakness of the post-root bond, the push out test has been considered the most appropriate method to assess the adhesion of luted posts to root canal dentin. The use of thin sections of the restored root segment for testing allows a more uniform distribution of the load applied throughout the bonded interface. Moreover, it permits the evaluation of the pattern of bond failure in loaded specimens (5).

To achieve a successful endodontic therapy, the most important criteria is the well adaptation of the filling material to dentin wall which provides free of microleakage apically and coronally. Microleakage is the diffusion of substances, such as bacteria, oral fluids, molecules and/or ions into a fluid-filled gap or into a structural defect that is present or one that occurs between restorative materials and tooth structure (80). As described by McComb and Smith (81), the smear layer is a combination of organic and inorganic debris presented on the root canal wall after instrumentation. Its presence may act as a path for the ingress and growth of bacteria (82). If the smear layer is not removed, the bacterial byproducts such as acids and enzymes may slowly disintegrate and dissolve the filling material (83). Considering the technical aspect, the smear layer also interferes with the adhesion and penetration of root canal sealers or luting cements into dentinal tubules. Moradi et al. (84) demonstrated that the presence or absence of smear layer had no effect on sealing ability of the "etch and rinse" luting cement. Britto et al. (85) reported similar result with self-etching luting cement. Dissolution of the sealer may increase leakage (86). Polymerization shrinkage is a main factor that causes microgaps between adhesive surfaces of luting cement and root dentin which increases microleakage. There was a study revealed that the micro gap was found between luting cement and root dentin which was a consequence of light- polymerization shrinkage which happened fast (87). The use of organic dyes as a tracer is one of the oldest and most common methods of detecting leakage in vitro. In general, this method for detecting microleakage in vitro involves placing a restoration in an extracted tooth and immersing it in dye solution, after coating the unfilled parts of the tooth with a waterproof vanish. After a certain or a period of time the specimen is removed, washed, and sectioned before visual examination. Penetration of dye is depended on the concentration of dye and the time of immersion. Dentin permeability is also another factor to be considered. Practically, it is undesirable to use dye particles that has a diameter greater than that of the internal diameter of the dentinal tubules (1-4μm) (88).