CHAPTER THREE

REVIEW OF LITERATURE

3.1. Root canal therapy

3.1.1. Introduction

Endodontic therapy over a period of time has developed into an art and science to retain grossly carious, infected and mutilated teeth whenever possible, hence increasing their longevity in the mouth to the greatest possible extent. Predictable successful endodontic therapy depends on correct diagnosis, effective cleaning and shaping, disinfection, and an adequate obturation of the root canal system (Crump, 1979; Matsumoto et al., 1987). The ultimate aim of endodontic therapy is to provide an environment conducive to healing of the periapical tissues. Healing is possible only when the canal space is obliterated with a chemically inert, biologically compatible and dimensionally stable obturating material (Agarwal and Jayalakshmi, 2002). The correct combination of techniques favors periapical healing and will avoid or at least reduce the possibility of any reinfection of the treated root canal, and thus improve the outcome of endodontic treatment (Pumarola et al., 1992).

3.1.2. Phases of root canal therapy

There are three basic phases in root canal therapy:

1. The diagnostic phase: in which the disease to be treated is determined and the treatment plan developed (Cohen, 1998).
2. The preparatory phase: in which the contents of root canal such as inflamed or necrotic pulp tissue, bacteria, and bacterial products are removed by mechanical preparation with the aid of chemical irrigants. The canal is prepared and shaped in a continuously tapered funnel from the coronal access to the apex, without weakening the remaining dentine and without any perforation, ledging and zipping, which will facilitate root canal obturation (Schilder, 1974; Weine, 1996a).

3. Obliteration phase: in which the canal is filled in three dimensions with an inert material to obtain a hermetic seal as close as possible to the cemento-dentinal junction (Weine, 1996b).

3.1.3. Rationale of root canal therapy

Endodontic therapy includes, but is not limited to, the prevention and treatment of diseases and injuries of the dental pulp and associated periradicular tissues (American Association of Endodontists, 1998).

The rationale of root canal treatment lies in the fact that the non-vital pulp, being non-vascular, has no defense mechanisms. The damaged tissues within the root canal undergo autolysis and the resulting breakdown products will diffuse into the surrounding tissues and cause periradicular irritation associated with the portals of exit (Grossman, 1981a). However, this concept was not supported by Kim (1985) who showed that drainage of waste products was impeded. Also, endodontic therapy includes treatment of the vital and inflamed pulp (Trowbridge, 2002; Teixeira and Trope, 2004).

One of the main goals of endodontics is maximum elimination of microorganisms in the root canal system, particularly in cases of pulp necrosis and apical periodontitis, when the bacterial flora is most plentiful. The most effective way to achieve this aim is by means of instrumentation and irrigation. However, no less important than the biomechanical preparation is an adequate filling of the canal, which facilitates good periapical sealing (Pumarola et al., 1992).

Although the principle of infection had been known for many years, it was in 1965 that Kakehashi and colleagues proved conclusively that periapical lesions do not develop in the absence of bacteria. The presence of microorganisms in the root canal system after

treatment has been identified as the paramount cause of persistent disease (Sjögren et al., 1997). Ray and Trope (1995) implicated coronal leakage. Others merely showed an association between the presence of inadequate fill with the presence of periapical lesions. Ray and Trope (1995) reported 50% and 39% respectively in America, Saunders et al. (1997) reported 59% and 58% respectively in Scotland, Kirkevang et al. (2000) reported 73% and 52% in Denmark, Dugas et al. (2003) reported 43% and 45% in Canada, Segura-Egea et al. (2004) reported 66% and 64% in Spain, and there are innumerable other similar reports across the globe. No causal relationship has been proven.

When the root canal has been treated, the reservoir of bacteria or noxious products has been eliminated and the root canal has been thoroughly obturated, the periradicular lesion will undergo healing (Gulabivala, 2004). Because of the critical role played by microorganisms in the pathogenesis of periradicular lesions, root canal therapy should be considered as clinical management of a microbial disease.

3.2. Preparation of the root canal system

3.2.1. Introduction

Preparation of the root canal system is recognized as one of the most important stages in root canal treatment (Schilder, 1974; Ruddle, 2002). It includes the removal of vital and necrotic tissues from the root canal system, as well as the total elimination of infected pulp tissue from the root canal (Smith et al., 1993; European Society of Endodontology, 2006). According to Walton and Rivera (2002), one aim of root canal instrumentation is to remove the inner layer of dentine from all aspects of the root canal wall. However, in many cases bacteria have penetrated deeply into the dentinal tubules (Armitage et al., 1983; Ando and Hoshino, 1990; Peters et al., 2001b), making it difficult to completely remove them from the dentinal tubules using instruments. Furthermore, it would be more difficult to remove the entire inner layer of dentine in oblong than in round root canals (Wu and Wesselink, 2001). So, filling these recesses may trap the remaining bacteria and isolate them from sources of nutrients (Peters et al., 1995; Sundqvist and Figdor, 1998).

According to Ingle (1961), the major causes of endodontic treatment failure are incorrect canal instrumentation and incomplete obturation of the canal space. Unfortunately, it has been shown by several investigators that no single instrument or instrumentation technique can achieve complete cleanliness of root canal walls (Peters and Barbakow, 2000; Ahlquist et al., 2001). From a biological point of view, the use of irrigation is essential for the removal of the remnant debris and smear layer formed during canal preparation.

Techniques of preparing root canals include manual preparation, automated root canal preparation, sonic and ultrasonic preparation, use of laser systems and non-instrumentation techniques (NITs). Any root canal preparation technique should be

simple, safe and predictable. Many techniques have been described over the years. In principle, these can be split into methods of instrument manipulation (reaming and filing) and preparation philosophies. During root canal treatment, canals are prepared by hand or by engine-driven instruments. Cutting is achieved by rotation or by a circumferential push-pull movement. Flaring the coronal part of the root canal is mandatory in root canal therapy, allowing better access to the apical end, control of the instruments, irrigation and debris removal, and more favorable conditions for obturation (Allison et al., 1979).

Many anatomical and histological studies have demonstrated the complexity of the anatomy of the root canal system (Kuttler, 1955; Vertucci, 1974; Trope et al., 1986; Cunningham and Senia, 1992; Gulabivala et al., 2001). This complexity makes it impossible to sterilize the root canal system completely and quickly. Mechanical instruments of graded sizes are used to remove intracanal dentine together with infected pulp by contacting and planing all root canal walls. In nearly all cases this is impossible to achieve, because the instruments cannot contact all the internal surfaces. Also, removal of the entire thickness of infected dentine is likely to severely weaken the tooth. For this reason, combination of mechanical root canal preparation and irrigants are mandatory to destroy colonies of micro-organisms. Consequently, instrumentation of the root canal is carried out to produce a pathway for the delivery of an antibacterial irrigant to all the ramifications of the root canal system. It also makes space for medicaments and the final root canal filling.

3.2.2. Techniques for root canal preparation

Several different instrumentation techniques have been described in the literature.

3.2.2.1. Standardized technique

Ingle (1961) described the first, systematic root canal preparation technique, which has become known as the ‘standardized technique’. This technique could be considered the classic traditional technique and was used for many years and required each instrument, file or reamer, to be placed to the full working length. The root canal was enlarged until clean white dentine shavings were seen on the apical few millimeters of the instrument (Carrotte, 2004). This technique was designed for single-cone filling techniques. However, it had limitations. For this reason, this approach is no longer taught at most institutions (Walton, 1992). The standardized technique is satisfactory in straight canals, however, a standardized shape cannot be formed in curved canals (Schneider, 1971; Weine et al., 1975). As the size of an instrument increases, it becomes less flexible and this may lead to iatrogenic errors in curved root canals. Common problems encountered are ledging, zipping, elbow formation, perforation and loss of working length owing to compaction of dentine debris (Carrotte, 2004).

3.2.2.2. Step-back technique

Step-back and step-down techniques for long have been the two major approaches to shaping and cleaning the root canal. The step-back technique was first described by Clem in 1969 and was advocated by Mullaney (1979) to overcome the problem of the curved root canal. The step-back technique has generally been reported to be superior over the Standardized technique (Walton, 1976; Bolaňos and Jensen, 1980). Weine (1996a) advocated a step-back technique with a rasping action of files that has several advantages. Apical instrumentation is accomplished using smaller files which are more flexible and thus are able to be advanced to the full working length with minimal tendency to transport the canals. The larger files that are used in the step-back preparation are not extended to the working length to decrease the tendency for transportation.

3.2.2.3. Crown-down techniques

The step-down technique, although not the term step-down, was first suggested by Schilder in 1974, and the technique was described in detail by Goerig et al. (1982). It has been followed by other similar coronal to apical techniques such as the double flared technique (Fava, 1983), and the crown-down pressuresless technique (Morgan and Montgomery, 1984). Crown-down techniques commence preparation using larger instrument sizes at the canal orifice, working down the root canal with progressively smaller instruments. This means the coronal aspect of the root canal is widened and cleaned before the apical part. Major goals of crown-down techniques are reduction of periapically extruded necrotic debris and minimization of root canal straightening. Crown-down techniques have been reported to produce less apically extruded debris than the step-back technique (Ruiz-Hubard et al., 1987; Swindle et al., 1991; Al-Omari and Dummer, 1995; Ferraz et al., 2001). Crown-down techniques are now the most widely used techniques for preparation of root canal systems (Carrotte, 2004).

In many dental schools, students are taught that the apical root canal should be enlarged to three sizes larger than the first file that binds at the working length (Weine, 1996a). The aim of this procedure is to remove the entire layer of predentine from the canal wall. It is thought that this file can gauge the apical diameter, so that after enlargement using three larger files, the inner layer of dentine together with microorganisms can be removed from the entire wall (Wu et al., 2003b).

3.2.2.4. Balanced force technique

Roane et al. (1985) developed the “balanced force” concept of instrumentation. Instrumentation is divided into placement, cutting, and removal using only rotary motions for the files. Placement of files uses clockwise rotation and inward pressure, cutting is accomplished using counterclockwise rotation and inward pressure adjusted to

match the file size, and removal is accomplished using non-cutting clockwise rotations to remove debris. The main advantages of the balanced force technique are good apical control of the file tip as the instrument does not cut over the complete length, good centering of the instrument because of the non-cutting safety tip, and pre-curving the instrument is unnecessary (Ruddle, 2002). It has been used in the preparation of the curved root canal (Wu and Wesselink, 1995). However, it has been found that in the preparation of the coronal two-thirds of oval canals, use of the balanced force method left portions of the root canal wall uninstrumented (Wu and Wesselink, 2001).

The balanced force technique required more working time than preparation with GT Rotary, Lightspeed or ProFile Ni-Ti instruments (Short et al., 1997; Hata et al., 2002).

3.2.2.5. Automated root canal preparation

Walia et al. (1988) described the properties of a file manufactured from nickel-titanium (Ni-Ti) alloy composed of approximately 55% nickel and 45% titanium by mass. These properties are shape memory and superior elasticity. The elastic limit in bending and torsion is two to three times higher for Ni-Ti than stainless-steel instruments; therefore, much lower forces are exerted on radicular wall dentine, compared with stainless-steel instruments (Hülsmann et al., 2005). The superelasticity of nickel-titanium alloy allows these instruments to flex much more than stainless-steel instruments before exceeding their elastic limit, allowing easier instrumentation of curved canals while minimizing canal transportation.

Studies of various nickel-titanium instruments in recent years have focused on their centring ability, maintenance of root canal curvature and safety in use. Many of these studies suggested that root canal preparation with modern rotary nickel-titanium instruments may produce more consistent, uniform, centred and round root canals with no or minimal apical transportation of curved root canals (Glosson et al., 1995; Poulsen

et al., 1995; Thompson and Dummer, 1997a, b; Peters et al., 2001a). However, some studies have also shown superior results when using hand instrumentation for creating well-shaped root canals (Hülsmann and Stryga, 1993; Hülsmann et al., 1997). Unfortunately, only relatively little information is available on their cleaning ability. Kochis et al. (1998) could find no difference in the cleaning ability between Quantec and manual preparation using K-files. Bechelli et al. (1999) described a homogeneous smear layer after Lightspeed preparation. In another study, no differences between Quantec SC and Lightspeed could be found (Hülsmann et al., 2003a). Both systems showed nearly complete removal of debris but left a smear layer in all specimens. In contrast, FlexMaster, ProTaper and HERO 642 showed nearly complete removal of debris, leaving only a thin smear layer with a relatively high percentage of specimens without a smear layer (Hülsmann et al., 2003b; Paqué et al., 2005).

The Anatomic Endodontic Technology (AET) which was introduced more recently includes a new generation of flexible stainless-steel instruments, a series of disposable syringes and 30-gauge needle tips specifically designed to maintain the natural shape of the root canal during preparation (White, 2002). Zmener et al. (2005b) concluded that although better instrumentation scores were obtained in root canals prepared with Anatomic Endodontic Technology (AET), complete cleanliness was not achieved by any of the techniques and instruments investigated.

3.2.2.6. Sonic and ultrasonic preparation

Richman (1957) reported the first use of ultrasonics in endodontics. In 1976, Howard Martin developed a device for preparation and cleaning of root canals and named this technique as ‘endosonics’. The cleaning and disinfecting capacity of ultrasonics is still a subject of controversy. Several studies have demonstrated enhanced root canal cleanliness including improved removal of smear layer compared with conventional

irrigation techniques (Cunningham and Martin, 1982; Sabins et al., 2003). Other studies have reported similar results for ultrasonic and conventional preparation/irrigation (Langeland et al., 1986; Lim et al., 1987; Ahmad et al., 1987; Baker et al., 1988; Goldman et al., 1988; Mandel et al., 1990; Spoleti et al., 2003).

3.2.2.7. Other methods

Laser systems are recommended by some authors for disinfection but at present are not suited for the preparation of root canal systems. The selection of appropriate irradiation parameters is mandatory, but these parameters have not yet been defined for all laser systems. In addition, different tip designs such as flexible and side-emitting probes need to be developed (Hülsmann et al., 2005).

A non-instrumental technique (NIT) was developed by Lussi et al. (1993). The technique uses a vacuum pump and an electrically driven piston, generating alternating pressure and bubbles in the irrigation solution inside the root canal. It relies exclusively on activated disinfecting and tissue-dissolving solutions may be preferred (Lussi et al., 1995). Unfortunately, a recent clinical evaluation revealed that only 21% of the tested roots were sufficiently cleaned with this method, indicating a need for further modifications before this technique can be used in routine clinical practice (Attin et al., 2002).

3.2.3. Preparation of oval canals

Ingle et al. (1994b) described the shape of the mandibular premolar root as ovoid at the cervical level, round or ovoid at the mid-root level, and round in the apical third. Wu et al. (2000d) reported that most oval-shaped canals have long bucco-lingual but short mesio-distal diameters. An attempt to extend the preparation of oval root canals in a certain direction to include canal recesses or fins of oval root canals may also lead to complications like ledges, zips, elbows, and dangerous zones (Weine et al., 1976;

Calhoun and Montgomery, 1988). Wu et al. (2000b) reported that when curved oval canals are prepared, rotation of instruments produces less apical transportation than a push-pull filing movement. However, recesses in oval canals may not be included in a round preparation created by rotation of instruments, and thus they remain unprepared. One perception is that circumferential filing with a small file may instrument these recesses (Wu and Wesselink, 2001).

As reported by Wu and Wesselink (2001) and more recently by Zmener et al. (2005b), the long oval canal is more frequently seen at 5-10 mm distance from the apex of mandibular incisors and maxillary and mandibular premolars, which logically would indicate that these areas are more prone to be out of reach of rotary instruments. Likewise, in oval canals a circular cut using rotary instruments left approximately 65% of the root canal unprepared at a level of 5 mm from the apex (Wu et al., 2000d). Hence, a circular preparation would require instruments of a large size that may perforate or significantly weaken the roots in a mesial-distal direction (Wu et al., 2000d). Weiger et al. (2002) calculated the ratio of prepared to unprepared outlines of oval root canals in mandibular molars and incisors. Preparation using Hedström files and HERO 642 rotary Ni-Ti preparation showed better results than Lightspeed preparation. Barbizam et al. (2002) confirmed these findings in a study of preparation of flattened root canals in mandibular incisors. They reported superior results in terms of root canal cleanliness for the manual crown-down pressureless technique using stainless-steel K-files compared with ProFile 0.04 rotary preparation. In another investigation, Rödig et al. (2002) prepared oval distal root canals in mandibular molars using nickel-titanium instruments. They found no significant differences concerning root canal cleanliness among three Ni-Ti systems (Lightspeed, Quantec SC, ProFile 0.04). All three systems performed relatively poorly in the coronal two-thirds of the root canals probably because of their flexibility, frequently not allowing the operator to force them into lateral extensions.

Peters and Barbakow (2000), Schäfer and Zapke (2000), Ahlquist et al. (2001) and Zmener et al. (2005b) also reported that the design of ProFile as well as other nickel titanium rotary instruments are not suitable for exertion of lateral pressure. When viewed in cross-section, the ProFile tends to form a round shape during preparation of most oval-shaped canals (Short et al., 1997). Cleaning of recesses in oval canals may be enhanced by use of sonic and ultrasonic irrigation with vibrating files. When an ultrasonic unit is used for irrigation, the file is best directed towards the extensions and away from danger zones (Lumley et al., 1993).

3.3. Obturation of the root canal system

3.3.1. Introduction

The root canal system is complex and consists of many irregularities, which include fins, apical deltas, isthmuses, and accessory and lateral canals. Hence, the objectives of obturating the prepared canal are to seal the root canal system entombing any irritants left behind in the canal after cleaning and shaping and to eliminate all avenues of leakage from the oral cavity and the periradicular tissues into the canal system (Gutmann and Witherspoon, 2002). A maximum volume of gutta-percha and a thin layer of sealer are preferred because sealer may shrink during setting and dissolve, thus causing leakage (Kontakiotis, 1997; DuLac et al., 1999). A three-dimensionally well-filled root canal system does the following (Nguyen, 1991):

1. It prevents percolation and microleakage of peripheral exudates into the root canal space.
2. It prevents re-infection of the root canal through sealing of the apical foramen against microorganisms or their toxins.
3. It creates a favorable biological environment for the process of tissue healing to take place.

It is generally accepted that the ideal terminus of the root canal filling is at the histological cemento-dentinal junction (Holland and de Souza, 1985). Kuttler (1955) found that the cemento-dentinal junction is approximately 0.5 mm from the apical foramen in young people and 0.75 mm in older individuals. He concluded that the root canal should be filled as far as 0.5 mm from the apical foramen.

Undue reliance on a coronal seal is probably unacceptable without first filling the canal system (Dugas et al., 2003). Filling materials may control the infection directly, by actively killing microorganisms which remain (Saleh et al., 2004; Nair et al., 2005), or

which gain later entry to the pulp space, and indirectly, by denying nutrition, space to multiply, and correct conditions for the establishment of significant bio-mass of individual microbes, or the development of harmful climax communities. The complete three-dimensional obturation of the root canal system is crucial to successful root canal therapy. Over the years, various obturation techniques and different obturation materials have been developed, refined, and studied for improving the filling of the root canal system.

3.4. Materials for root canal obturation

3.4.1. Introduction

According to Ørstavik (2005), endodontic filling materials may be considered true implants as they touch and are based in vital tissues of the body, and protrude to meet the external surface directly or, more appropriately, indirectly via another surface restoration. It follows that the materials must possess several different properties relative to their functions and location, ranging from biocompatibility to mechanical sealing ability. A plethora of materials have been advocated over the past 150 years for root canal obturation. Grossman (1981b) had delineated ten requirements for an ideal root canal filling material; these are:

1. It should be easily introduced into root canal.
2. It should seal the canal laterally as well as apically.
3. It should be radiopaque.
4. It should not irritate periradicular tissue.
5. It should be bacteriostatic, or at least not encourage bacterial growth.
6. It should not shrink after being inserted.
7. It should be impervious to moisture.
8. It should not stain the tooth structure.

9. It should be sterile, or easily and quickly sterilized immediately before insertion.
10. It should be removed easily from the canal if necessary.

3.4.2. Dental gutta-percha

Gutta-percha is the trans isomer of polyisoprene differing dramatically in its tensile properties from natural rubber, the cis isomer. Whereas natural rubber is essentially amorphorus, gutta-percha is approximately 60% crystalline. This fact largely accounts for the difference in their respective mechanical properties. Although natural rubber is typical of an elastomeric material, the crystalline nature of gutta-percha results in mechanical behavior similar to a partially crystalline polymer such as polyethylene (Friedman et al., 1975).

Gutta-percha is obtained from a number of tropical trees. Gutta-percha is used in various techniques for obturation of the root canal system. Chemically pure gutta-percha exists in two crystalline forms, alpha and beta. The alpha form is the material that comes from the natural tree product. The two forms are interchangeable depending on the temperature of the material. When heated, the initial beta form changes to the alpha form. When cooled, it can change back into the beta form (Schilder et al., 1974b). The alpha form has adhesive characteristics and a low viscosity. The beta form has no adhesive characteristics but has a higher viscosity. Most commercially available form is the beta structure at 37ºC, which transforms to the alpha phase when heated to 46-48ºC. The alpha phase begins to change to the amorphous phase (molten phase) at 56-62ºC (Schilder et al., 1974a). The effect of heating on the volumetric change of gutta-percha is important to dentistry. Gutta-percha expands slightly on heating, a desirable trait for an endodontic filling material (Gurney et al., 1971). This physical property manifests itself as an increased volume of material that may be compacted into a root canal cavity. The term “compaction” is preferred to “condensation” because clinically, gutta-percha

cannot be condensed, compressed or concentrated, which implies packing of molecules and to make denser (Schilder et al., 1974b).

Gutta-percha is the most commonly used material to obturate the root canal system since its introduction in dentistry over 100 years ago (Dummer, 1997). Modern dental gutta-percha materials are composed of 20% natural gutta-percha and 65-75% zinc oxide of the material. The zinc oxide content provides a major part of the radiopacity of endodontic gutta-percha. The remaining 5-10% consists of various resins, waxes and metal sulfates (Spångberg, 2002). For root canal obturation, gutta-percha core material is manufactured in the form of cones in both standardized and non-standardized sizes. The standardized sizes match with ISO sizes of root canal files and are used primarily as the main core material for obturation. The non-standardized sizes are more tapered from the tip and are usually designated for use as accessory or auxiliary cones during lateral compaction, as extra-fine, fine-fine, medium-fine, fine, fine-medium, medium, medium-large, large and extra-large sizes (Gutmann and Witherspoon, 2002). For injectable thermoplastic obturation techniques, gutta-percha may come in either pellet form or in cannules. For some thermoplastic techniques, it is available in a heatable syringe. Carrier coated with a layer of α-phase gutta-percha is also available.

Seltzer (1988a) found gutta-percha to be non-irritating to the apical tissues. Holland et al. (1982) investigated the long-term reaction of rat connective tissue to silver and gutta-percha points over a period of one year. One brand of gutta-percha and the silver points were well tolerated. The other brand of gutta-percha points caused pronounced effects with thick fibrous capsules and severe chronic inflammation of the surrounding connective tissue. This observation is in line with the inflammatory potential of gutta-percha as shown in the study by Serene et al. (1988). Gutta-percha has been shown to produce an intense localized tissue response in subcutaneous tissue when placed in fine

particle form or when it has been altered with softening agents; however, large gutta-percha particles were well encapsulated and the surrounding tissue was free of inflammation (Sjögren et al., 1995). Although “pure, raw gutta-percha” is non-toxic, there is some evidence of cytotoxicity from endodontic gutta-percha materials; this may be related to the high content of zinc oxide that is known to be an irritant (Pascon and Spångberg, 1990). Wolfson and Seltzer (1975) found that with the exception of a calcium hydroxide and a chloroform-containing product, the toxic effects of naturally occurring gutta-percha (trans-polyisoprene) are similar to those of commercial gutta-percha. Munaco et al. (1978) and Pascon and Spångberg (1990) regarded the cytotoxic effect of commercial gutta-percha to be due to the high content of zinc oxide.

Calcium hydroxide-containing gutta-percha cones and their efficacy comparable with calcium hydroxide pastes have been demonstrated (Holland et al., 1996). The Roeko Company introduced gutta-percha core materials that contain calcium hydroxide instead of zinc oxide at a concentration of 50-51% by weight to overcome the irritant effect of zinc oxide (Economides et al., 1999). In an *in vitro* study by Podbielski et al. (2000), calcium hydroxide containing gutta-percha core materials demonstrated good inhibitory action on the bacterial growth of three of the four test organisms. Iodoform-containing gutta-percha materials, introduced by Martin and Martin (1999), had a negligible effect on *Enterococcus faecalis*, but demonstrated a significant inhibitory effect on *Streptococcus sanguis* (Silver et al., 2000).

Gutta-percha becomes brittle as it ages, probably through oxidation (Oliet and Sorin, 1977). Storage under artificial light accelerates their deterioration (Johansson, 1980). Therefore, it should be stored in a cool, dry place for a longer shelf-life. Methods of rejuvenating aged gutta-percha have also been suggested (Sorin et al., 1979).

3.4.3. Root canal sealers

3.4.3.1. Overview

Sealers are responsible for the principal function of the final root canal filling which include sealing off of the root canal system and entombment of remaining bacteria (Ørstavik, 2005). Root canal sealers are used primarily to form a fluid-tight seal at the apex by filling the minor intricacies between the solid material and canal walls, and also by filling patent accessory canals and multiple foramina. They also act as a binding agent to cement gutta-percha cone materials to canal walls, and in cold compaction of gutta-percha amongst the cones themselves. They also act as a lubricant to facilitate the seating of the primary core into the canal. Therefore, sealers play an important role in sealing the root canal. Without sealers, root canal fillings leak (Michanowicz and Czonstkowsky, 1984; ElDeeb, 1985; Hata et al., 1992; Wu et al., 2000a).

Conventional sealers are recognized as more serious irritants to periradicular tissues than gutta-percha (Langeland, 1974). This statement was supported by a number of cell culture experiments which showed that all sealers are toxic to various degrees (Munaco et al., 1978; Syrjänen et al., 1985; Guigand et al., 1999). However, the small amount of sealer forced into the periapical region during compaction is normally resorbed (Peters, 1986; Augsburger and Peters, 1990). *In vivo* implantation experiments on animals proved that most sealers induce an initial severe tissue response, which eventually subsides (Wennberg, 1980; Ørstavik and Mjör, 1988). Ideally, the root canal wall should be covered completely with sealer after obturation. Many techniques have been used to place sealers into root canals, including the use of files or reamers, gutta-percha core materials, paper points, lentulo spirals or ultrasonic files.

3.4.3.2. Types of root canal sealers

Many types and brands of sealers are available. Sealers that are commonly used may be grouped into zinc oxide and eugenol-based sealers, calcium hydroxide-based sealers, epoxy-resin sealers, glass ionomer-based sealers, silicone-based sealers and urethane methacrylates.

3.4.3.2(a). Zinc oxide and eugenol-based sealers

Many zinc oxide and eugenol-based sealers are available (Grossman's, Roth, ProcoSol, Tubliseal and Kerr Pulp Canal Sealer).

Zinc oxide eugenol materials have dominated the past 70 to 80 years. These sealers are simply zinc oxide eugenol (ZnOE) cements modified for endodontic use. The liquid for these materials is eugenol whilst the powder contains finely sifted zinc oxide (ZnO) to enhance the flow of the cement. Zinc oxide eugenol-based sealers have some antibacterial activity of their own, but will also exhibit some toxicity when placed directly on vital tissues (Ørstavik, 2005). In a study by Serene et al. (1988), it was found that zinc oxide eugenol (ZnOE) sealers activated the complement system and thus an inflammatory reaction. Additionally, Guigand et al. (1999) found these sealers to be severely cytotoxic in fibroblast cultures. These properties are mainly attributed to the eugenol component. The toxic potency of eugenol has been demonstrated by Araki et al. (1993, 1994) who found that the sealer, Canals (Syowa Yakuhin Kako Ltd, Tokyo, Japan), with eugenol as the liquid component was significantly more cytotoxic in permanent L929 cells and primary human periodontal ligament fibroblasts than the material, Canals-N (Syowa Yakuhin Kako Ltd, Tokyo, Japan), with an identical powder as Canals but with fatty acids replacing eugenol as the liquid component.

3.4.3.2(b). Calcium hydroxide-based sealers

The success of calcium hydroxide as a pulp protecting and capping agent, and as interappointment dressing prompted its use also in sealer cement formulations (Ørstavik, 2005). There are several commercial sealers containing calcium hydroxide (Sealapex, CRCS and Apexit). These materials have been shown to have similar sealing ability to zinc oxide and eugenol preparations; however, long-term exposure to tissue fluid may possibly lead to dissolution of the material as calcium hydroxide is leached out (Pitt Ford et al., 2002).

In vivo studies have demonstrated that Sealapex and CRCS easily disintegrate in the tissue (Soares et al., 1990), and may cause chronic inflammation (Tronstad et al., 1988). Calcium hydroxide sealers are generally characterized as having good cytocompatibility (Geurtsen et al., 1998; Osorio et al., 1998; Ersev et al., 1999; Telli et al., 1999). Specific histocompatibility was tested in dog root canals to compare the periapical reaction to four calcium hydroxide-containing sealers by Leonardo et al. (1997). They found that inflammatory reactions were related to an incomplete adaptation of the root canal fillings.

3.4.3.2(c). Epoxy-resin sealers

Epoxy-resins are well established as effective root canal sealers, displaying acceptable biocompatibility (Kaplan et al., 2003; Miletić et al., 2003), insolubility and dimensional stability (McMichen et al., 2003). Epoxy-resins also have good sealing properties and adhesive and antibacterial activities (Pitt Ford et al., 2002), but gave an initial severe inflammatory reaction (Ørstavik and Mjör, 1988). The initial reaction subsided after some weeks and the material was then tolerated well by the periradicular tissues (Erausquin and Muruzábal, 1968; Ørstavik and Mjör, 1988).

AH-26 and AH-Plus™ are classic examples with proven track records of clinical use (Ørstavik and Horsted-Bindslev, 1993; Leonardo et al., 2003). *In vitro* tests have demonstrated comparable seal in thin and thick sections (Kontakiotis et al., 1997; Kardon et al., 2003). Some studies reported that epoxy resin demonstrated better sealing ability than other root canal sealers (Wu et al., 1995; Kontakiotis et al., 1997).

Like most sealers, AH-26 is very toxic when freshly prepared (Spångberg, 1969; Pascon et al., 1991). The toxicity of AH-26 sealer is attributed to the release of a very small amount of formaldehyde as a result of the chemical setting process. This brief release of formaldehyde, however, is thousand times lower than the long-term release from conventional formaldehyde-containing sealers such as N2 (Spångberg et al., 1993). After the initial setting, AH-26 exerts little toxic effect *in vitro* and *in vivo* (Pascon and Spångberg, 1990).

According to the manufacturer, AH-Plus™ is a modified formulation of AH-26 in which formaldehyde is not released. Spångberg et al. (1993) and Leonardo et al. (1999) showed that AH-26 released formaldehyde after setting, but only a minimum release was observed for AH-Plus™. The cytotoxicity of AH-26 and AH-Plus™ were evaluated *in vitro* (Koulaouzidou et al., 1998). AH-26 had a severe cytotoxic effect whilst AH-Plus™ showed a markedly lower toxic influence on the cells throughout the experimental period. AH-Plus™ also exhibited a lower cytotoxicity potential compared to AH-26 in the study by Huang et al. (2002).

3.4.3.2(d). Glass ionomer-based sealers

Glass ionomer cements have been introduced as endodontic sealers (e.g. Ketac-Endo), because of its ability to adhere to dentine (Pitt Ford et al., 2002; Whitworth, 2005). Glass ionomer cement modified for endodontic use is known to cause a minor tissue irritation (Zetterqvist et al., 1987; Zetterqvist et al., 1988) and low toxicity *in vitro*

(Pissiotis et al., 1991). However, evidence on root reinforcement was equivocal (Johnson et al., 2000; Lertchirakarn et al., 2002; De Bruyne and De Moor, 2004) and concerns have been expressed about long-term solubility (Schäfer and Zandbiglari, 2003).

There may be some difficulty removing set glass ionomer cement from the root canal system when carrying out root canal retreatment (Pitt Ford et al., 2002). Since their introduction some 20 years ago, they have been used despite laboratory findings of leakage and disintegration (Friedman et al., 1995; Schäfer and Zandbiglari, 2003).

3.4.3.2(e). Silicone-based sealers

Lee Endo-Fill (Lee Pharmaceuticals, El Monte, CA, USA) was an early attempt at utilizing the water-repellant, chemical stability and adhesive properties of silicone materials in endodontics (Nixon et al., 1991). RoekoSeal (Roeko, Langenau, Germany) is a white, fluid paste, whereas GuttaFlow (Roeko) appears to be based on RoekoSeal, with the addition of powdered gutta-percha (Whitworth, 2005).

Laboratory studies indicated a 0.2% setting expansion (Ørstavik et al., 2001), biocompatibility (Bouillaguet et al., 2004), and acceptable wall coverage (Ardila et al., 2003). Also, silicone-based sealers showed impressive biological performance (Miletic et al., 2005). A clinical trial comparing silicone sealer with zinc-oxide eugenol in lateral compaction revealed comparable healing outcomes (Huumonen et al., 2003).

3.4.3.2(f). Urethane methacrylates

EndoRez (Ultradent, South Jordan, UT, USA) is a hydrophilic urethane methacrylate resin capable of good canal wetting and flow into dentinal tubules (Whitworth, 2005). Many laboratory investigations reported acceptable biocompatibility (Bouillaguet et al., 2004; Zmener, 2004; Zmener et al., 2005a) and ability to seal as well as other

established sealers (Kardon et al., 2003). However, the combination of gutta-percha cone materials and methacrylate resin sealer has shown reduced apical sealing ability compared with gutta-percha cone materials and an epoxy-resin sealer (Kardon et al., 2003; Sevimay and Kalayci, 2005).

Tay et al. (2005b) have examined the use of resin-coated gutta-percha cone materials with a dual-curing EndoRez in an effort to enhance bond and seal. Resin tags were demonstrated impregnating canal walls, but interfacial leakage was not prevented.

3.4.4. Resin obturation materials

A complete sealing of the root canal system is expected by using root filling materials that bond to the canal wall. No such materials for endodontic use are commercially available. However, various types of dentine-bonding agents and composite resins are available in restorative dentistry and have been examined for the root canal filling (Zidan and ElDeeb, 1985; Leonard et al., 1996; Ahlberg and Tay, 1998).

Dentine bonding used in restorative dentistry has been applied to endodontic treatment with promising results reported, particularly in the form of resin sealers (Leonard et al., 1996). A few studies have evaluated the potential of using dentine bonding agents and resins as obturation materials in non-surgical root canal treatment (Tidmarsh, 1978; Zidan and ElDeeb, 1985). According to Rawlinson (1989), reasons for not using resins as obturation materials were difficult and unpredictable methods of delivery of the material into the root canal and the inability to retreat the canal if necessary. However, it has been acknowledged that these materials may have the potential to enhance the root canal seal by reducing microleakage from both apical and coronal directions.

Anic et al. (1995) evaluated, by scanning electron microscopy, a composite resin photopolymerized by argon laser, as a root canal filling material. They observed that

resin penetrated into the tubules, but the contraction that occurred during polymerization affected the adhesion in some cases. Leonard et al. (1996) reported that a new dentine-bonding agent and C & B Metabond resin (Parkell) was comparable, as a root canal filling material, to single gutta-percha cone with a glass ionomer sealer. As described by Tidmarsh (1978) and Goldman et al. (1984), adhesive systems can be used in endodontics for two purposes:

1. To seal the endodontic space as a root canal filling material.
2. To bond-lute posts in root canals in combination with resin cement.

Imai and Komabayashi (2003) tested a new type of root canal filling resin for its ability to adhere to dentine. The authors found that the resin material had properties desirable for root canal filling, such as adhesion to dentine, good sealing ability and removability. Some authors have investigated the apical third morphology after root canal preparation and acid etching (Ferrari et al., 2000; Mjör et al., 2001). Mjör et al. (2001) concluded that obturation techniques based on the penetration of adhesives into dentinal tubules are unlikely to be successful, and adhesive techniques must depend on the impregnation of a hybrid layer.

In 2003, Pentron Corporation introduced Resilon™ obturation core materials and a resin sealer that is a self-etch primer after smear layer removal. The combination is claimed to allow creation of a solid “mono-block” (a material which is contiguous from its resin tags in cleared dentinal tubules through sealer to the core canal filler). According to the manufacturer, the material not only fully obturates canal anatomy, it diminishes coronal microleakage through bonding to the cleared dentinal tubules. Resilon™ (RealSeal™, SybronEndo, Orange, CA, USA; Epiphany™, Pentron Clinical Technologies, Wallingford, CT, USA) was developed in the hope to replace gutta-percha and traditional sealers for root canal obturation.

3.4.4.1. Composition of the Resilon™ obturation system

This system comprises:

1. Resilon primer™, a self-etch primer, which contains a sulfonic acid-terminated functional monomer, HEMA, water and a polymerization initiator.

2. Resilon sealer™, a dual curable, resin-based composite sealer. The resin matrix consists of BisGMA, ethoxylated BisGMA, UDMA, and hydrophilic difunctional methacrylates. It contains fillers of calcium hydroxide, barium sulphate, barium glass, bismuth oxychloride, and silica. The total filler content is approximately 70 percent by weight.

3. Resilon™ core material, a thermoplastic synthetic polymer based root canal filling material. Based on a polyester, Resilon™ core material contains bioactive glass, bismuth oxychloride and barium sulphate. The filler content is approximately 65 percent by weight.

It performs like gutta-percha, has the same handling properties, and for retreatment purposes may be softened with heat, or dissolved with solvents like chloroform. Similar to gutta-percha, master cones in all ISO sizes and accessory cones in various sizes are available. In addition, Resilon™ pellets of this material are available for use with the Obtura II unit (Spartan-Obtura, Fenton, MO). Additionally, it is available in cartridge form for the Extruder side of the Elements™ Obturation Unit (SybronEndo, Orange, CA, USA).

These new materials have been shown to be biocompatible, non-cytotoxic, and non-mutagenic and have been approved for endodontic use by the Food and Drug Administration (USA). Toxikon Corporation (ISO project no. 01- 4421-G1) performed *Salmonella typhimurium* and *Escherichia coli* reverse mutation assay, which demonstrated that Resilon™ is non-mutagenic. The Epiphany™ sealant has been

evaluated and scored using the skin sensitization Kligman maximization test and received a grade one reaction, which is considered not significant according to Magnusson and Kligman (1969). Li et al. (2005) concluded that Epiphany™ root canal sealant with primer has significant antimicrobial effects on *Streptococcus mutans* and *Enterococcus faecalis*.

Chivian (2004) stated that "using the Resilon™ system does not require you to alter the filling technique you currently use and requires a minimal learning curve. The only change is the substitution of Resilon™ core materials and sealer for your present gutta-percha and sealer. Minor alterations to the technique are required because you are bonding the root filling and creating a monoblock rather than cementing core materials into the root canal".

There have been several studies conducted to show the advantages and disadvantages of the Resilon™ obturation material.

Tay et al. (2005c) studied the susceptibility of the Resilon™ filling material to alkaline hydrolysis. They showed that Resilon™ is susceptible to alkaline hydrolysis in 20% sodium ethoxide. The group also showed that Resilon™ is susceptible to biodegradation by bacterial and salivary enzymes (Tay et al., 2005d).

Gesi et al. (2005) compared the interfacial strength of Resilon™/Epiphany™ sealer and gutta-percha/AH-Plus™ using a thin-slice push-out test design. Their study found both groups to have similar low interfacial strengths, and they concluded that this result challenges the concept of strengthening root-filled teeth with Resilon™ as reported by Teixeira et al. (2004b).

Pitout et al. (2006) concluded that bacterial micro-leakage of a root canal sealed using Resilon™ and Epiphany™ sealer is similar to that of a root canal sealed using gutta-

percha and Roth root canal cement, when using either the cold lateral compaction technique or the System B technique. These new materials also allowed similar amounts of dye penetration to occur regardless of which of the two techniques, cold lateral compaction or System B, was used.

Stratton et al. (2006) showed in their study that the Resilon™ groups with self-etch primer and Epiphany™ resin root canal sealer were significantly more resistant to fluid movement than the gutta-percha and AH-Plus™ sealer groups.

Tunga and Bodrumlu (2006) concluded that the Epiphany™ obturation system allowed the least leakage. They showed that the Epiphany™ obturation system is a promising root canal sealer with good sealing ability.

Ungor et al. (2006) compared the bond strength of the Resilon™/Epiphany™ with gutta-percha/AH-Plus™. They found that the Resilon™/Epiphany™ combination was not superior to that of the gutta-percha/AH-Plus™ combination.

Versiani et al. (2006) concluded that setting time, flow and film thickness of Epiphany™ and AH-Plus™ conform to American National Standards specifications for endodontic filling materials (ANSI/ADA 2000). However, the solubility and dimensional alteration values of Epiphany™ sealer, and dimensional alteration values of AH-Plus™ were higher than those considered acceptable for the ANSI/ADA specifications (ANSI/ADA 2000).

Wilkinson et al. (2007) evaluated the fracture resistance gained by filling root canals of simulated immature teeth with either Resilon™, gutta-percha, a self-curing flowable composite resin. They showed that the composite resin was the only material significantly more fracture resistant.

Resilon™ is a relatively new material and obviously there needs to be more research conducted to determine if it is a suitable replacement for gutta-percha. Although, studies have shown that Resilon™ has several advantages over gutta-percha, further research is needed to confirm and support these advantages.

3.5. Methods of filling the root canal

The two most commonly employed techniques are lateral and vertical compaction. Other methods are variations of warmed gutta-percha techniques (Ingle and West, 1994).

3.5.1. Lateral compaction technique

Cold lateral compaction of gutta-percha is used by many clinicians worldwide to fill root canals, and is taught at many dental institutes due to its simplicity and adaptability to most cases (Qualtrough et al., 1999). Lateral compaction of gutta-percha cones with sealer has long been the standard against which other methods of canal obturation have been judged.

In this technique (Ingle and West, 1994), the primary cone is selected to match the size of the last instrument used to the working length. It is then positioned and tested visually and radiographically to ensure optimum fit at the apical 2-3 mm of the canal. After placing the sealer into the canal, the primary master cone material is coated with sealer and seated into the canal to the full working length. A pre-selected spreader is then introduced into the canal, and with controlled vertical motion is slowly moved apically to full penetration. The master cone is compacted laterally by the spreader to create space for an accessory filling cone material. The spreader is then removed with the same reciprocating motion, and the first accessory cone is then inserted to the full depth of the space left by the spreader. The sequence of spreader application and accessory cone insertion continues until the spreader can only penetrate 2-3 mm beyond

the cementoenamel junction (CEJ). The protruding cones are then severed at the orifice of the canal with a very hot instrument.

The lateral compaction technique is relatively uncomplicated and requires a simple armamentarium. It seals and obturates as any other techniques in conventional situations (Sakkal et al., 1991).

However, there are some disadvantages of this technique. It rarely fills canal fins and irregularities, lateral canals, has poor canal replication ability (Brayton et al., 1973) and relies on sealer to fill accessory anatomy (Dummer, 1997). In addition, excessive force during lateral compaction was found to be a common cause of vertical fracture (Meister et al., 1980).

3.5.1.1. Variants of cold lateral compaction

A number of methods have been reported to enhance gutta-percha adaptation and density in the lateral compaction technique. These methods were reported in the literature as follows:

1. Warm lateral compaction of gutta-percha by Endotec device (Martin and Fischer, 1990).
2. Softening gutta-percha with heat before insertion of the cold spreader (Himel and Cain, 1993).
3. Lateral compaction of gutta-percha by ultrasonically energized spreader (Zmener and Banegas, 1999).
4. Mechanical activation of finger spreaders in an endodontic reciprocating handpiece (Gound et al., 2000; Jarrett et al., 2004).
5. Softening the apical 2 to 3 mm gutta-percha chemically followed by adaptation (Gutmann and Witherspoon, 2002).

6. Lateral compaction of gutta-percha to the canal orifice, followed by a segmental removal of gutta-percha with concomitant vertical compaction to the apical third of the canal. The coronal two thirds are then refilled with either lateral or vertical compaction (Gutmann and Witherspoon, 2002).
7. Lateral compaction of gutta-percha in the apical third only, followed by the searing off of the extended cones and obturation of the coronal two-thirds of the canal with either vertical compaction or the injection of softened gutta-percha (Gutmann and Witherspoon, 2002).
8. Warming spreaders before each use in a hot-bead sterilizer (Whitworth, 2005).

Luccy et al. (1990) studied the apical seal obtained from cold lateral compaction and two warmed lateral compaction techniques. The analysis showed no statistically significant differences for the dye leakage scores.

Reader et al. (1993) compared three techniques, lateral compaction, warmed lateral and warmed vertical compaction, for the obturation of lateral canals and the principal canal. They observed the presence of sealer in lateral canals for lateral compaction groups, but for warm vertical compaction, more cases of gutta-percha was found there. As for the principal canal, statistically significant differences were not found among the techniques when the gutta-percha filling was analyzed for the presence of empty spaces (i.e. voids).

3.5.2. Vertical compaction technique

Philosophical battles have long been waged between advocates of the cold lateral compaction technique and warm vertical compaction technique, presenting compelling cases on the benefits and shortcomings of each (Weine and Buchanan, 1996).

Schilder (1967) introduced a concept of cleaning and shaping root canals to a conical shape, then obturating the space three-dimensionally with gutta-percha. This technique

utilizes a system of varying sized pluggers to burn off and compact the warmed gutta-percha apically. A master cone material is selected, fitted for size, coated with sealer and inserted into the root canal. The master cone material should fit at 0.5 to 1 mm short of the radiographic terminus and should fit tightly in the apical third of the canal. After heating gutta-percha in the root canal using an electric device, Touch 'n Heat (Analytic Technologies, Redmond, WA, USA), the gutta-percha is vertically compacted by means of pre-fitted pluggers. This process is repeated and continued with smaller pluggers until 3-4 mm of gutta-percha remains in the root canal. At this stage, the space can be left if a post space is required, or backfilled with another technique. The warm vertical compaction technique has been shown to be effective in filling canal irregularities and lateral canals (Schilder, 1967).

The adaptation of gutta-percha achieved by this technique has been found to be superior to that provided by cold lateral compaction (Smith et al., 2000; Wu et al., 2001b).

The "continuous wave of condensation" technique was introduced by Buchanan in 1994. This technique utilizes the System B electrical heat source (Analytic Technologies/SybronEndo, Orange, CA, USA) to obturate the root canal system with a single continuous wave of thermoplasticized gutta-percha (Buchanan, 1996). The tips of the System B act as both a heat carrier and a plugger which allow for simultaneous warming and compaction of gutta-percha. The "continuous wave of condensation" technique has been reported to simplify and speed up the vertical compaction of gutta-percha. This technique serves as a hybrid of the cold lateral and warm vertical techniques (Buchanan, 1994). The System B has been shown to be comparable to vertical compaction in producing a root filling consisting of a high percentage of gutta-percha (Silver et al., 1999) and a similar apical seal (Pommel and Camps, 2001). Also, the "continuous wave of condensation" provides less microbial coronal leakage

(Jacobson and Baumgartner, 2002), and the gutta-percha better adapts to grooves and depressions of the canal wall and lateral canals than in the lateral compaction technique (DuLac et al., 1999; Goldberg et al., 2001). A thermoplasticized gutta-percha injection system, e.g. Obtura II, can be used effectively to backfill the root canal (McRobert and Lumley, 1997).

When utilizing warm vertical compaction or "continuous wave of condensation" techniques, there is a concern that the heat needed to thermoplasticized gutta-percha could cause damage to the periodontium. A temperature rise of 10ºC above normal body temperature is regarded as a critical level at which periodontal tissues could be adversely affected (Fors et al., 1985; Gutmann et al., 1987). Lipski (2005) studied the root surface temperature rise during root canal obturation using the System B with an infrared thermal imaging camera. He found that the System B produced temperature changes on the outer root surfaces. In the case of teeth with relatively thin dentinal walls, the temperature reached high values. Lee et al. (1998) compared root surface temperatures produced during warm vertical compaction using the System B, Touch 'n Heat, and flame-heated carrier. They found that the System B should not damage the periradicular tissues, but caution should be used when utilizing Touch 'n Heat or flame-heated carrier. Silver et al. (1999) also compared the System B to the Touch 'n Heat, and found that the Touch 'n Heat elevated the external root surface temperature more than 10ºC, but the System B produced significantly less temperature change during preparation.

There have been several studies conducted to compare various obturation techniques. Some of these comparative studies have evaluated the ability of these techniques to reproduce canal anatomy, fill lateral canals and prevent leakage.

Brothman (1981) compared the vertical compaction with the lateral compaction technique radiographically and for the obturation of lateral canals. Vertical compaction presented approximately twice as many obturated lateral canals when compared to lateral compaction. Relating to the apical third of the canal, both techniques gave similar results.

Mendoza et al. (2000) compared two heated gutta-percha and sealer obturation techniques in canines of dogs and found radiographically that the heated lateral method appeared to have a better endodontic fill; there was however significantly greater apical dye leakage in teeth obturated with the heated lateral gutta-percha. There was also extrusion of sealer and root fracture associated with the heated lateral technique. The warm vertical compaction technique appears to provide a better apical seal in the short term, with fewer obturation complications when compared to the heated lateral method.

Various modifications in materials or procedures have been developed to improve obturation. These include thermoplasticized injection, thermocompaction, and combination of both vertical and lateral compaction methods (Lee et al., 1997).

3.5.3. Thermocompaction technique

A new concept of softening (by frictional heat) and compacting gutta-percha was introduced by McSpadden in 1979. The device was initially called the McSpadden compactor. It resembled a reverse Hedstroem file, spinning in a latch-type handpiece at up to 20,000 rpm (Ingle and West, 1994). The frictional heat generated plasticized the gutta-percha and the reverse screw design of the compactor forced the softened gutta-percha towards the canal walls and apically. In the hand of an inexperienced clinician, the compactor could fracture; vertical root canal fractures, inadvertent cutting of dentine and excessive heat generation and gross overfill could also occur (Harris et al., 1982; Saunders, 1990). Despite improvements in the compactor design, it was impossible to

rotate such an instrument in the narrow confines of the apical section of a curved canal without the risk of fracture (Cohen, 1982). McSpadden had redesigned the compactor as a gentler lower-speed instrument made of nickel titanium, and renamed it as NT condenser (Ingle and West, 1994). Gilhooly et al. (2000) found that it produced significantly more extrusion of sealer and gutta-percha, had less apical dye leakage and worse scores for radiographic quality than lateral compaction.

3.5.4. Thermoplasticized injection technique

The concept of root canal obturation with injectable thermoplasticized gutta-percha was first introduced by Yee et al. (1977). Further studies (Moreno, 1977; Torabinejad et al., 1978; Marlin et al., 1981; Budd et al., 1991) have supported this achievement in that the thermoplasticized gutta-percha was shown to replicate the intricacies of the root canal system and achieve a seal which is equal to, if not superior to, that produced by other obturation methods in a significantly shorter time (Michanowicz and Czonstkowsky, 1984; Czonstkowsky et al., 1985; ElDeeb, 1985; Evans and Simon, 1986; Mann and McWalter, 1987). The concept is marketed as the Obtura II (Spartan-Obtura, Fenton, MO) which heats the gutta-percha to 160-200ºC, and the Ultrafil system (Hygenic, Akron, OH) which works at 70ºC. The Obtura II may be used alone or for back filling. When used on its own, the tip of the needle should reach 3-4 mm short of the canal terminus. A small amount of softened gutta-percha is extruded into the canal at this level and compacted vertically with a prefitted root canal plugger to form an apical plug. Subsequently, Obtura II is used to backfill the remainder of the canal in segments (Glickman and Gutmann, 1992). Obtura II was judged by some studies to have the best overall adaptation to canal walls and was able to reproduce the prepared root canal anatomy *in vitro* (Budd et al., 1991; Weller et al., 1997; Goldberg et al., 2000; Smith et al., 2000). However, LaCombe et al. (1988) reported serious overfilling and apical extrusion of gutta-percha after using this technique.

Greene et al. (1990) compared the apical seal produced by the Canal Finder System, lateral compaction, the Ultrafil system, and the sectional warm gutta-percha technique. They reported no significant difference in leakage among the four groups.

Jacobsen and BeGole (1992) compared the presence of empty spaces in the obturation mass for four techniques (Obtura, Kloroperka, thermocompaction and warmed lateral compaction) by using computerized methods of internal surface analysis. The authors observed similar results when the apical third of the canal was evaluated, whereas voids were found in the middle third when the thermocompaction technique was used.

Veis et al. (1994) evaluated the sealing ability of thermoplasticized and lateral compaction techniques. The study demonstrated no statistically significant difference between the two.

Weller et al. (1997) compared three different techniques (Thermafil, Obtura II and cold lateral compaction) for the adaptation of obturation material to canal walls. The Obtura II system showed better results, followed by Thermafil and lateral compaction.

3.5.5. Core carrier technique

Thermafil (Tulsa Dental Products, Tulsa, OK, USA) is an obturation system in which the gutta-percha is pre-applied onto a carrier that resembles a finger spreader. Thermafil consists of a flexible central carrier coated with a layer of α-phase gutta-percha. According to the manufacturer, this gutta-percha coated obturator is heated in a special oven to the appropriate softness, and the obturation is done with the complete device. A sealer must be used. Thermafil was first described by Johnson (1978) who claimed that it is effective in filling all canal spaces and isthmuses. Further development of the original Thermafil led to the production of Thermafil Plus that uses a plastic carrier for carrying the gutta-percha (Gulabivala and Leung, 1994).

There have been a number of laboratory studies comparing the apical sealing ability of Thermafil and lateral compaction, the majority of which reported either a similar or significantly better seal with Thermafil (Beatty et al. 1989; Bhambhani and Sprechman, 1994; Dummer et al., 1994; Gulabivala et al., 1998; De Moor and De Boever 2000; Gençoğlu et al., 2002). Thermafil also seemed to be more effective than lateral compaction in filling lateral canals (Reader et al., 1993; DuLac et al., 1999; Goldberg et al., 2001), and produced a homogenous mass of gutta-percha in the root canal compared with lateral condensation (Gençoğlu et al., 1993b). More recent studies (Gençoğlu et al., 2002; Jarrett et al., 2004; De Deus et al., 2006) found that the Thermafil is capable of producing a homogenous mass in the root canal with a better core/sealer ratio than that achieved with cold lateral compaction. However, contrary to the above findings, a dye leakage study by Ravanshad and Torabinejad (1992) showed that the Thermafil group leaked more than the cold lateral compaction or warm vertical compaction technique. Fan et al. (2000) also compared the leakage of warm vertical condensation and Thermafil in the apical portion of curved canals and showed that the Thermafil group leaked more. Dalat and Spångberg (1994) found that Thermafil provides a superior seal with an epoxy resin sealer. Chohayeb (1992) and Clark and ElDeeb (1993) found no statistical difference in dye leakage between Thermafil plastic and metal obturators, before post space preparation. In the study by Ricci and Kessler (1994) of the effect of post space preparation on teeth obturated with plastic versus metal Thermafil carriers, the plastic obturators leaked more. They inferred that the method of post space preparation probably caused the loss of the apical integrity of the plastic Thermafil group.

The Thermafil is intended to make filling easier and faster. However, a minor disadvantage of leaving a plastic core material in the root canal is the problem of

removing it, should retreatment be required. The retained plastic material is not always easy to remove (Ibarrola et al., 1993; Frajlich et al., 1998).

Another system, the SimpliFill obturation system (LightSpeed Technologies, San Antonio, TX, USA) was introduced in 1999, and was designed to be used with the Lightspeed instrumentation system. According to the manufacturer, the technique is based on a match-sized plug of gutta-percha or Resilon™, five mm long, attached to the end of a carrier. After sealer has been placed, the appropriate size SimpliFill is placed to working length and the carrier is removed, leaving the apical segment obturated and the coronal segment open. Sealer is then injected with a syringe into the coronal segment, and a single core material (gutta-percha or Resilon™) or a post is inserted.

Santos et al. (1999) compared the leakage of SimpliFill with cold lateral condensation in an apical-to-coronal direction and found no statistical difference between the two techniques.

Jarrett et al. (2004) concluded *in vitro* that SimpliFill, Thermafil, mechanical lateral condensation, and warm vertical condensation techniques created more complete obturation at the 2 mm and 4 mm levels than cold lateral condensation, “continuous wave of condensation” and a modified SimpliFill technique.

Gopikrishna and Parameswaren (2006) found that the sectional obturation techniques of SimpliFill, Thermafil and warm vertical compaction provide superior seal to lateral compaction when a tooth requires a post space after obturation.

3.6. Evaluation of the quality of root canal obturation

3.6.1. Overview

A three-dimensional obturation of the root canal space will prevent fluid percolating from a periapical source acting as a culture medium for any bacteria that may remain following preparation. It will also prevent ingress of bacteria and fluids from the oral environment (Madison et al., 1987).

Numerous studies have dealt with the evaluation of the sealing efficiency of various filling materials and techniques. Many techniques have been devised to test the sealing properties of root canal fillings both *in vitro* and *in vivo*. Endodontic obturation techniques and filling materials can be assessed in clinical investigations but such studies require long observation periods to be meaningful. Clinical investigations are also difficult to standardize and the results may vary due to differences in the skills of operators as well as differences in the criteria used for evaluation of the results. Therefore, various *in vitro* methods have been introduced with the objective of evaluating the sealing ability of different obturation techniques and materials used (Al-Ghamdi and Wennberg, 1994).

3.6.2. Microleakage of root filling materials

Microleakage in the root canal is the movement of periradicular tissue fluids, microorganisms, and their associated toxins along the interface of the dentinal walls and the root filling material (Hovland and Dumsha, 1985; Wu and Wesselink, 1993; American Association of Endodontists, 1994). Leakage along root canal fillings can occur apically from the tooth crown, and is described as coronal leakage (Swanson and Madison, 1987; Torabinejad et al., 1990). If leakage occurs from the apex upwards to the crown, it is defined as apical leakage. Many authors have measured microleakage from the apical 2-3 mm of the canal system (Evans and Simon, 1986; Haddix et al.,

1991), because the presence of the apical foramen and accessory communications in the apical third (De Deus, 1975; Vertucci, 1984) provides a favourable route for leakage to occur.

According to Wu and Wesselink (1993), the most common method used to assess leakage is still the measurement of dye penetration but it often yields a large variation in terms of results. There is conflicting evidence from numerous studies and sometimes in the same study regarding the sealing ability of root canal filling materials and techniques. In addition, it is apparent that there is no universally accepted method for performing apical microleakage investigations. The same authors also stated that it is difficult to draw firm conclusions despite the number of publications on leakage. There are very contradictory results between leakage studies even when the same filling materials have been studied. It has been suggested that research should be done on leakage methodology instead of continuing to evaluate different materials and techniques by methods that give little relevant information (Wu and Wesselink, 1993). This raises the question regarding the clinical relevance of leakage evaluation *in vitro*. As an example, the cold lateral compaction technique has been found clinically successful (~90%) as reported by Seltzer (1988b). However, dye penetration studies of laterally compacted root canal fillings, *in vitro*, generally report significant leakage. Thus, correlation is lacking between the sealing quality of root fillings determined *in vitro* and tissue response observed *in vivo* (Pitt Ford, 1983; Wu and Wesselink, 1993). This has become clear, when Pitt Ford (1983) failed to demonstrate a correlation between the sealing quality of root fillings determined *in vitro* and the tissue response observed *in vivo*, that the usefulness of most leakage tests is questionable.

The advantages and disadvantages of each test method that has been used to assess microleakage of various root filling materials are summarized in Table 3.1. Results of

comparative studies that have revealed poor correlation between different methods used to assess microleakage are summarized in Table 3.2.

dvantages and disadvantages of microleakage evaluation methods

Methods	Advantages and accuracy	Disadvantages, problems and criticisms	References
1. Dye penetration	1. It is a simple and inexpensive technique. 2. It is readily detected under visible light. 3. It easily penetrates the water compartment of the tooth. 4. Methylene blue penetrates farther than any of the isotope tracers. 5. Methylene blue appears to be comparable with that of low molecular weight materials (e.g. butyric acid).	1. It often yields a large variation in terms of results, is hardly reproducible and comparable. 2. Its results are subjectively assessed and the extent of leakage depends on plane of section.	Matloff et al. (1982); Kersten and Mooror (1989); Wu and Wesselink (1993); Al-Ghamdi and Wennberg (1994).
2. Staining technique	1. Provides accuracy and excellent definition for determining the extent and location of leakage. 2. Safer. 3. Teeth are observed directly in a microscope. 4. More objective method.	1. This technique has similar problems to that of dye leakage studies, especially for interpretation of results.	Wu et al. (1983); Hovland and Dumsha (1985); Crim (1987).
3. Radioactive isotopes	1. Able to detect minute amounts of leakage. 2. Penetrates deeply into defects.	1. Destructive. 2. Requires sophisticated materials and apparatus. 3. Radiation hazard. 4. Results evaluated subjectively.	Going (1964); Xu et al. (2005).

Continued ….

Table 3.1 Continued

4. Electrochemical technique	1. Measures microleakage quantitatively and rapidly. 2. Continuous measurements can be made over time in individual specimens.	1. May lead to a false negative reading. 2. The reading may change over time. 3. Requires sophisticated materials and apparatus. 4. Results for linear dye penetration may be influenced by prior testing using this technique.	Mattison and von Fraunhofer (1983); Amiditid et al. (1992); Xu et al. (2005).
5. Air pressure method	1. Measures microleakage quantitatively 2. Nondestructive	1. Difficults to photograph the location of the leakage.	Möller et al. (1983); Taylor and Lynch (1992).
6. Liquid pressure technique	1.Measures microleakage quantitatively 2. Nondestructive. 3. Obtains measurement of leakage over extended time period. 4. Measurement of leakage reflects the entire sample. 5. Sensitive for detection of leakage.	1. No standardization of this method, such as the measurement of time, the applied pressure, the diameter of the tube containing the bubble, and the length of the bubble, which might influence the results.	Derkson et al. (1986); Wu et al. (1993, 1994a, b); Xu et al. (2005).

Continued ….

Table 3.1 Continued

7. Bacteria	1. More clinically and biologically relevant.	1. Results assessed qualitatively. 2. May produce erratic results. 3. Difficulty in maintaining aseptic condition thorough steps of experimental stage. 4. Conclusion might vary with the bacterial species used.	Kidd (1976); Al-Ghamdi and Wennberg (1984); Xu et al. (2005).

Table 3.2 Results of comparative microleakage studies

Methods	Results of comparative studies	References
Dye penetration or radioisotopes and electrochemical technique.	This study compared the electrochemical method to the dye penetration or the radioisotope method. They found a correlation, but only at the two ends of the electric score range.	Delivanis and Chapman (1982).
Radioisotopes and dye penetration.	Methylene blue penetrated deeper than any of the isotope tracers. In addition, both ^{45}Ca and ^{125}I-labeled albumin penetrated approximately half as far as methylene blue, however, the carbon-14-labeled urea penetrated farther than the ^{45}Ca and ^{125}I-labeled albumin. In the same way, they compared dye penetration to that of an isotope tracer. They found a correlation between methylene blue and C-urea and correlation between methylene blue and ^{125}I-albumin, but not between $CaCl_2$ and methylene blue.	Matloff et al. (1982).
Size of particles and molecules in endodontic leakage.	More leakage was seen with the small particles, butyric acid, valeric acid, methylene blue than with the large sized molecules.	Kersten and Moorer (1989).

Continued ….

Table 3.2 Continued

Dye penetration and electrochemical technique.	Results for linear dye penetration may have been influenced by the prior testing of leakage with the electrochemical technique.	Amditis et al. (1992).
Bacterial penetration and fluid transport.	This study compared bacterial penetration to fluid transport along root canal fillings. As expected, one of the two specimens that showed bacterial penetration fell into the gross leakage category, but the second one fell into the slight leakage category.	Wu et al. (1993).
Fluid filtration and dye penetration.	This study compared fluid filtration and dye penetration methods and found fluid transport was a more sensitive method for detecting voids along root canal fillings than dye penetration.	Wu et al. (1994a).
Bacterial leakage and dye leakage.	This study preformed on 96 teeth showed no correlation between bacterial leakage and dye leakage: 37 teeth leaked to *Staphylococcus epidermidis*, 18 leaked to basic fuchsin, and only 12 teeth leaked to both bacteria and dye.	Barthel et al. (1999).

Continued ….

Table 3.2 Continued

Fluid filtration method, dye penetration method and electrochemical method.	This study compared fluid filtration, electro-chemical and dye penetration methods for evaluating the apical sealing ability of single-cone, Thermafil and vertical condensation techniques, using the same teeth, and found no correlation among the methods.	Pommel et al. (2001).
Passive dye penetration, fluid filtration and volumetric dye leakage methods.	This study evaluated the reliability of passive dye penetration, fluid filtration and volumetric dye leakage and showed no correlation among the results.	Camps and Pashley (2003).
Fluid filtration method, vacuum dye leakage method, bacterial microleakage method and electrochemical method.	Compared four different tests for the assessment of leakage of root canal fillings and demonstrated poor correlation among various methods to evaluate hydraulic leakage. The clinical significance of leakage tests *in vitro* is questionable.	Karagenç et al. (2006).

3.7. Methods for evaluation of the quality of root canal obturation

Methods that have been used to evaluate the quality of root canal obturation are:

1. Tooth sectioning.

2. Scanning electron microscopy.

3. Tooth-clearing technique.

4. Radiographic detection method.

3.7.1. Tooth sectioning

3.7.1.1. Introduction

Excellent obturation quality at the apical portion of the canal is essential to maintain the apical seal. A key of clinical success is complete closure of the dentinal wall-obturation interface especially in the apical part to achieve the best apical seal. Most endodontic sealers are soluble and shrink slightly on setting; so, it is best to rely as little as possible on sealers and more on solid-core filling materials (Peters, 1986; Kontakiotis et al., 1997; Wu et al., 2002b). The seal has to be perfect to protect the treated surface, while incomplete obturation is a major cause of endodontic treatment failure. Examination of tooth sections have shown areas of voids and pulp tissue remnants (Reader et al., 1993; Wu and Wesselink 2001; Wu et al., 2001a). These areas allow microorganisms left in the canal to multiply to cause or to maintain inflammation and disease and provide avenues for leakage or fluid to stagnate.

The assessment of the quality of a root canal filling has been advocated by several authors by either evaluation of longitudinal tooth sections (ElDeeb, 1985; Limkangwalmongkol et al., 1992; Manogue et al., 1994) or horizontal sections (Silver et al., 1999; Wu et al., 2000c; Wu et al., 2001b; Gençoğlu et al., 2002; Cathro and Love, 2003; Keçeci et al., 2005; Gordon et al., 2005).

3.7.1.2. Cross-sections

Cross-sections may be examined at various levels along the length of the obturated root canals. According to Langeland (1974), an area of at least 90% gutta-percha is biologically acceptable because sealers are more serious irritants to periradicular tissues. Thus, many investigators evaluated the quality of a root canal filling at various levels by calculating the percentage of gutta-percha, sealer or voids to compare various obturation techniques. Beer et al. (1987) sectioned roots at 1 mm from the apex and studied the cross-section of the obturated root canal under a stereomicroscope. Silver et al. (1999) sectioned roots perpendicular to the axis of the main root canal at 1, 2, 3, 4, 5 and 6 mm from the working length. They compared the area occupied by gutta-percha, sealer and voids of two vertical condensation techniques: Touch ’n Heat and System B. Wu et al. (2000c) sectioned roots horizontally at 3 and 6 mm from the apex and studied the sealer distribution in the root canals obturated by three techniques. Wu and Wesselink (2001) studied the percentage of gutta-percha in oval-shaped canals by cross-sectioning the root canal at 3 and 5 mm from the apex. Wu et al. (2002b) measured the area percentage of gutta-percha at 1.5 mm from the apical foramen. Recently, Gordon et al. (2005) examined the percentage of gutta-percha, sealer or voids in a 0.06 tapered rotary preparation of curved root canals after filling with lateral condensation of matched-sized, single gutta-percha cones. Cross-sections of root canals filled by cold lateral compaction contained 93.6% of gutta-percha as reported by Wu et al. (2001b). Gençoğlu et al. (2002) reported 81.2% and Jarrett et al. (2004) reported 93.8%. For warm vertical compaction, Gençoğlu et al. (2002) used the System B and the gutta-percha percentage was 86.7%, whereas Jarrett et al. (2004) reported 91.85% for warm vertical ”continuous wave” technique.

Wu and Wesselink (2001) measured the mean percentage of filling area, which included the area of gutta-percha and sealer. Areas of voids and pulp tissue remnants were also

found in tooth sections. Silver et al. (1999) presented their results on the percentages of the area occupied by gutta-percha, sealer and voids. Generally, the highest percentage of filling core material, minimal amount of sealer and the relative absence of voids were suggested to obtain good adaptation, produce acceptable root filling and provide long term success of root canal treatment. However, the relative increase in the percentage of sealer and voids within the root canal at the level of accessory gutta-percha core materials indicated that the root filling may be subject to leakage in the critical apical third of the canal, particularly after sealer shrinkage or dissolution (Silver et al., 1999). However, Harris et al. (1982) questioned the accuracy of measuring areas of gutta-percha in the situation where sealer and gutta-percha were “mixed” together when the thermomechanical obturation technique was used. According to Eguchi et al. (1985), white sealer and voids could be clearly distinguished from pink gutta-percha. Whereas Wu et al. (2000c) added black carbon powder into sealer to make it more visible. Keçeci et al. (2005) distinguished clearly the borders of sealer, gutta-percha and voids by using different colors. However, some authors advised non-utilization of sealer in order to prevent methodological problems such as non-standardization in the volume of sealer (Smith et al., 2000; Wu et al., 2002b; De Deus et al., 2006).

Some authors measured the percentages of filled area using a digital imaging technique (Silver et al., 1999; Wu et al., 2000c; Wu et al., 2001b; Gordon et al., 2005). The computer accurately mapped out the area of interest and after counting the number of pixels in the area, the percentage value was presented. Other authors used a planimeter (Beer et al., 1987) or a digitizer (Eguchi et al., 1985).

Other investigators have used cross-sections for determining voids between material and root surface or within the material itself. Eguchi et al. (1985) sectioned the specimens at 1.5, 2.3, 4 and 6 mm from the apex for comparison of the area of the canal space

occupied by gutta-percha following four gutta-percha obturation techniques using Procosol sealer (Den-tal-ez, Lancaster, PA, USA). Wolcott et al. (1997) used microscopy to determine the area of voids when sectioning the teeth at 0.8, 1.6 and 2.4 mm from the canal apex. An area of voids was measured as a percentage of peripheral canal wall involvement. Also, Mannocci et al. (1998) used the stereomicroscope to study the presence of root filling materials and voids present in the coronal, middle, and apical thirds of root canal fillings. Recently, Keçeci et al. (2005) sectioned teeth at 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5 and 7.5 mm respectively from the apex to measure the percentage of gutta-percha, sealer and voids.

Cross-sections of the root canal were also used to determine apical leakage (Beyer Olsen et al., 1983; Limkangwalmongkol et al., 1991; Veis et al., 1994). After immersing in dye, horizontal cuts were made at 1 mm intervals and the extent of dye penetration was measured to the nearest millimetre. According to Limkangwalmongkol et al. (1991), the advantages of this method are:

1. The quality of the root canal filling could be evaluated at the level of each cut specimen. If dye existed in that section, then the entire root canal filling at that level could be examined.
2. Any lateral canals, secondary canals, or cracks could be seen if the tooth happened to be cut at the level where they existed.

However, this method has some disadvantages in that some of the tooth structures and dye are lost during each cut due to the thickness of the cutting blade, and only allows one to determine whether or not there is penetration of dye up to that section (Limkangwalmongkol et al., 1991; Ahlberg et al., 1995; Lucena-Martín et al., 2002).

3.7.1.3. Longitudinal sections

The longitudinal sectioning method enables examination of the exposed filling material and any dye penetration into the material and at the interface with the dentinal wall on one side (Ahlberg et al., 1995). According to Manogue et al. (1994), the examination of a single longitudinal section can give results comparable to those obtained from serial cross-sections. Ahlberg et al. (1995) suggested a variation of this technique, whereby the roots are ground longitudinally with a cylindrical diamond bur to visualize the leakage through a thin layer of dentine, thus reducing the risk of dye dissolution during sectioning. They also affirmed that this technique provides more reliable information about the real leakage pattern than transverse sections. According to Limkangwalmongkol et al. (1992), Camps and Pashley (2003), the disadvantage of the longitudinal sectioning method are:

1. The quality of the root canal fillings can not be assessed since only one plane of the root canal filling can be examined.
2. Any lateral canals, secondary canals, and cracks are difficult to detect.
3. Additional cuts may be needed to obtain the correct direction to cut through any canal curvatures.
4. The random choice of the cut axis and the very low probability of the sections being made through the deepest dye penetration point may result in underestimating the leakage and recording unreliable data.

3.7.2. Scanning electron microscopy

The scanning electron microscopy has been used in dental research to study normal and inflamed gingival tissue, plaque structure, caries formation, the effects of etching on marginal adaptation of various restorative materials and the interface between tooth structure and restorative materials. In endodontics, a number of investigators have utilized scanning electron microscopy (SEM) because of its high magnification and

depth of focus to investigate the adaptation of filling materials to root canal walls and the influence of the smear layer on depth of penetration into canal walls (Baumgardner and Krell, 1990; Gençoğlu et al., 1993a; Pallarés et al., 1995; Kouvas et al., 1998; Mannocci et al., 1998; Sevimay and Dalat, 2003).

Other authors (Torabinejad et al., 1978; Lugassy and Yee, 1982) evaluated the apical seal by observing the interface of canal wall and obturation material with the scanning electron microscope. The methods that employ scanning electron microscopy to observe the interface between the filling material and root canal walls are useful for the study of presence of the material in the root canal space (e.g. flow, penetration of lateral canals, homogeneity of the material), but they do not allow quantification of the leakage (Canalda-Sahli et al., 1992).

3.7.3. Tooth-clearing technique

The tooth-clearing technique has been employed to obtain information on various aspects of endodontic treatment including morphology (Vertucci, 1978; Kasahara et al., 1990), canal instrumentation techniques (Tagger et al., 1994; Ibarrola et al., 1997), the effect of post design and its influence in tooth fracture (Felton et al., 1991), the penetration of human saliva through dentinal tubules (Berutti et al., 1996), sealer placement techniques in the curved canal (Hall et al., 1996) and the microleakage of root canal sealers (Sleder et al., 1991; Smith and Steiman, 1994). In addition, the clearing procedure allows not only linear leakage measurement, but it also allows for examiner observation of the distribution, homogeneity, adaptation of the filling material to dentinal walls and for evaluating root canal fillings (Robertson and Leeb, 1982; Lloyd et al., 1995; Gulabivala et al., 1998; Lussi et al., 1999; Kytridou et al., 1999; Johanson and Bond, 1999).

Several techniques have been used to demineralize and clear teeth, including 5-11% nitric acid (Kasahara et al., 1990; Tagger et al., 1994; Berutti, 1996; Ibarrola et al., 1997); formic acid (O'Neill et al., 1983); 40% solution of ion exchange resin and formic acid (Felton et al., 1991) or 5% hydrochloric acid (Vertucci, 1978). The most common method uses an aggressive demineralizing solution, i.e. 5-11% nitric acid (Robertson et al., 1980; Tagger et al., 1994), with the aim of reducing the time for demineralization (Kasahara et al., 1990; Ibarrola et al., 1997). It has been reported that the demineralization process may be enhanced by using higher concentrations of the acid solution or by raising the temperature, but in both cases this might result in excessive demineralization shrinkage and damage of the organic component may also occur (Robertson et al., 1980; Kwan and Harrington, 1981). The use of weak organic acids allows a better control of shrinkage of the organic tooth structure (Robertson et al., 1980).

However, Pathomvanich and Edmunds (1996) criticized the study of root filling adaptation by examining cleared teeth as an unacceptable method because adaptation of the root canal material to the canal walls cannot be examined directly and only inferred from the amount of the leakage. O'Neill et al. (1983) found no correlation between the microscopic appearance of gutta-percha adaptation in cleared teeth and the degree of apical leakage.

3.7.4. Radiographic method

Radiographic evaluation is the only method available clinically for assessing the adaptation of the root filling to the canal wall (Amditis et al., 1992). Exposing radiographs from different angles based on the buccal object rule (Chenail et al., 1983) is essential in clinical endodontics to assess the quality of the treatment achieved. Kersten et al. (1987) in their *in vitro* study has shown that the use of the proximal

radiograph (i.e. mesial-distal direction) gives a better prediction of the quality of gutta-percha adaptation and compaction. However, proximal radiographs, whilst desirable, are impossible in the clinical setting.

Based on the clinical guideline for successful root canal obturation by the American Association of Endodontists (1994), there should be a radiographically dense filling which extends as close as possible to the cemento-dentinal junction. The presence of overextension of filling materials into the periradicular tissue, under-condensed patent canals or underfills is undesirable. In general, a root canal is considered to be optimally obturated if a continuous radiopaque mass in the canal is observed on the radiograph, free from voids or entrapped air bubbles, well adapted against the outline of the root canal, and ends slightly short of the apex (Kersten et al., 1987). Radiographically, detectable voids may be places into which tissue fluid and bacteria may leak, stagnate and cause inflammation (Beyer-Olsen et al., 1983). The same authors reported a significant association between the radiographically satisfactory root filling and resistance to leakage. EIDeeb et al. (1985) have shown that there was a definite correlation between radiographic density and leakage, particularly in the middle third of the root canal.

Radiographic studies have a number of limitations imposed by the orientation of the tooth and the angulations of the X-ray beam which can result in an acceptable radiographic appearance of a poorly condensed or adapted root filling (Kersten et al., 1987). In addition, significant disagreement has been observed between different observers during the interpretation of radiographs or even by the same observer who re-examines the same film (Goldman et al., 1972, 1974; Zakariasen et al., 1984).

3.8. Summary

Root canal therapy includes instrumentation, disinfection, and complete obturation of the root canal system. It is believed that proper obturation of the root canal system is dependent on first obtaining adequate cleaning and shaping. The complete three-dimensional obturation of the root canal system is widely accepted as a critical factor for long-term success of endodontic therapy. Major advances have been made in the techniques and materials used to obturate the root canal system during endodontic therapy over the last half century.

Gutta-percha is the most commonly used filling material to obturate root canals, and is the standard to which other filling materials are compared due to its biocompatibility, dimensional stability, compactibility, thermoplasticity, and ease of removal. Sealer is used along with gutta-percha to fill the root canal system. Root canal sealer performs several functions to attain and maintain the root canal seal. These functions concern the filling of spaces where the primary root canal filling material failed to reach, as well as patent accessory canals. In addition, the sealer acts as a binding agent between root canal walls and the main filling material, and thus the interface between either sealer and gutta-percha or sealer and dentine is of prime clinical importance. The gutta-percha fills the majority of the root canal system and acts as a carrier for the sealer, but these materials cannot be relied on to create a dependable seal.

In 2003, Pentron Corporation introduced the Resilon™ obturation system in the hope of replacing gutta-percha and traditional sealers for root canal obturation. This system consists of a self-etch dentine primer, a dual-cure resin sealer, and polyester cones. It performs like gutta-percha, has the same handling properties, and for retreatment purposes may be softened with heat, or dissolved with solvents like chloroform. Similar to gutta-percha, master cones in all ISO sizes and accessory cones in various sizes are

available. In addition, Resilon™ pellets of this material are available for use with the Obtura II unit. Additionally, it is available in cartridge form for the Extruder side of the Elements™ Obturation Unit. The technique for using Resilon™ is similar to most other bonding systems.

Obturation techniques and armamentarium have evolved greatly to allow practitioners more efficient, reliable and predictable ways to obturate root canals. Cold lateral compaction is still the most common technique used by practitioners and the most commonly taught technique in dental schools. Lateral compaction of gutta-percha has long been the standard against which other methods of canal obturation have been judged. Schilder described the warm vertical compaction technique in 1967 and since then, modifications to this technique have flooded the endodontic literature. The "continuous wave of condensation" technique developed by Dr. L. Stephen Buchanan, serves as a hybrid of the cold lateral and warm vertical compaction and it has shown much promise in three-dimensional filling of the root canal system. The thermoplasticized injection technique was introduced by Yee et al. (1977) with the hope of achieving a more dense three-dimensional root canal fill. This injectable technique was shown to replicate the intricacies of the root canal system and was able to achieve a seal equal or better to that of other techniques.

The quality of a root canal filling can be assessed by a number of methods. Many techniques have been devised to test the sealing properties of root canal fillings both *in vitro* and *in vivo*. *In vivo* investigations require long observation periods to be meaningful. Therefore, various *in vitro* methods have been introduced with the objective of evaluating the obturation quality of different obturation techniques and materials used, one of which methods is cross-sectional area analysis. In this method, the quality of obturation at each level of cut can be evaluated by measuring the cross-sectional area occupied by the core filling material, sealer and voids.