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IN VITRO EVALUATION OF ROOT CANALS OBTURATED WITH FOUR DIFFERENT TECHNIQUES

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DECLARATION

I, Carel van der Merwe, declare that this thesis entitled "*In Vitro* evaluation of root canals obturated with four different techniques", which I herewith submit to the University of Pretoria for a MSc (Odont), is my own original work, and has never been submitted for any academic award to any other institution of higher learning.

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CAREL VAN DER MERWE **DATE**

SUMMARY

After cleaning and shaping of the root canal the final objective of the endodontic procedure is to obtain a three-dimensional obturation of the root canal space with a fluid-tight seal at the apical foramen.

The objective of this *in vitro* study was to evaluate four different obturation techniques in respect of:

- the radiographic quality of root canal obturation,
- apical leakage and
- the potential of these techniques to obdurate lateral canals

One hundred and sixty canals were prepared by using RaCe nickel titanium rotary files to a size 30 with 6% taper. During preparation irrigation was done with TopClear Solution (17% EDTA and 0.2% cetremide) and ChlorXTRA (6% sodium hypochlorite). The canals were divided in four groups of forty canals each and were obturated using the Hybrid Root SEAL technique, the EndoREZ technique, the System B/Obtura technique and the Thermafil technique.

<u>The Radiographic Quality of Root Canal Obturation</u>: Digital radiographs were taken of the four groups of obturated canals from a buccolingual and a mesiodistal direction. The quality of obturation was determined for the coronal and apical halves of each canal and scored according to radiographic appearances. The data was tabulated and statistically analyzed using the Mann-Whitney U test.

The Hybrid Root SEAL technique demonstrated a statistically significant higher number of radiographic defects in the coronal aspects of the root canals when compared to the System B/Obtura and Thermafil techniques ($p<0.05$). There was no statistically significant difference between the radiographic defects in the coronal aspects of the root canals between Hybrid Root SEAL and EndoREZ techniques ($p>0.05$). The Hybrid Root SEAL technique demonstrated a statistically

significantly higher number of radiographic defects in the apical aspects of the root canals compared to all the other groups ($p<0.05$).

Apical Leakage: Twenty obturated canals of each of the four groups were processed for evaluation of apical leakage. The root surfaces were coated with nail varnish and sticky wax, leaving 4.0 mm around the apical foramen exposed. Specimens were immersed in 2% methylene blue dye for 48 hours, rinsed in distilled water and embedded in clear acrylic resin.

Specimens were sectioned horizontally in 1 mm increments and the extent of dye penetration was measured to the nearest millimeter using a stereomicroscope. The data was tabulated and statistically analyzed using the Man-Whitney U test.

The specimens that were obturated with the EndoREZ technique demonstrated the least apical leakage compared to all the other groups tested in this study. However, there was only a statistically significant difference when the EndoREZ technique was compared to the Hybrid Root SEAL and System B/Obtura techniques ($p<0.05$). The specimens that were obturated with the System B/Obtura technique demonstrated the most apical leakage compared to all the other groups tested in this study. However, there was only a statistically significant difference when the System B/Obtura technique was compared to the EndoREZ and Thermafil techniques ($p<0.05$).

The Potential to Seal Lateral Canals: Twenty obturated canals of each of the four groups were processed for evaluation of the potential to seal lateral canals. The specimens were subjected to a clearing technique and a morphological analysis was performed using a stereomicroscope. Lateral canals were counted and graded within the coronal, middle and apical thirds of the roots. The data was tabulated and statistically analyzed using the Man-Whitney U test.

The Thermafil technique demonstrated the greatest number of filled lateral canals. However, there was no statistically significant difference between the Thermafil technique and all the other techniques ($p<0.05$).

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In Vitro Evaluation of Root Canals Obturated with Four Different Techniques

by

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Those who do not read books have no advantage over those that can not read them

- Mark Twain

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 History of Endodontics

Since the earliest mention of endodontics in the 17th century, there have been numerous advances and developments as a result of continuous research.

Pierre Fauchard (1678-1761), who was considered the founder of modern dentistry, accurately described the dental pulp in his textbook (Monica, 1972). In 1725 the oil of cloves for its sedative properties was introduced by Lazare Riviere (Grossman, 1980) while in 1746 Pierre Fauchard described the removal of pulp tissue (Castellucci, 2005a). Exposed pulp tissue was cauterized with a heated instrument and protected with lead foil, by Leonard Koecker in 1820 (Koch, 1909) and in 1836 Shearjasub Spooner devitalized pulp using arsenic trioxide (Castellucci, 2005a). The first root canal instrument was created in 1838 by Edwin Maynard and in 1847 Edwin Truman introduced gutta-percha as a root-filling material (Castelluci, 2005a).

Barnum isolated a tooth with a thin rubber leaf in 1864 (Koch, 1909) and in 1873 introduced the rubber dam clamp forceps. Gutta-percha cones as the sole material for root canal obturation was used by Bowman in 1867, and during the same year Magitot suggested the use of an electrical current to test pulp vitality (Tagger, 1967).

The first dental radiograph was taken in late 1895 by Otto Walkhoff, a German dentist soon after the discovery of x-rays by Röntgen earlier that year. In 1900 periapical radiolucencies was described by Price as "blind abscesses" and he advised that radiographs were used to diagnose pulpless teeth (Tagger, 1967). A technique for determining canal length and level of obturation was introduced by Dr. Meyer L. Rein in 1908 (Cruse and Bellizzi, 1980). At about the same time G.V. Black suggested length determination and apical gauging to prevent overfilling of root canals (Coolidge, 1960).

The apparent relationship between oral sepsis and bacterial endocarditis was pointed out by Frank Billings in 1904 (Coolidge, 1960) and a few years later one of his students, E.C. Rosenow developed the theory of "focal infection", where he found streptococci to be present in many diseased organs and the fact that they could cause infection at some distant site by hematogenous spread (Coolidge, 1960). In 1909 Mayrhofer indicated that streptococci were present in about 96 percent of pulpal infection cases studied (Prinz, 1917).

In October of 1909, William Hunter, an English physician and pathologist, gave a lecture at the University of Montreal on focal infection. He criticized the standard of prosthetic dentistry which was widely interpreted as an indictment of the pulpless tooth (Duke, 1918). Consequently, for almost 40 years dentists continued to extract any devitalized teeth. The theory of focal infection therefore reigned for many years, instead of an attempt to improve current procedures (Grossman, 1980).

After 1910 safe and effective local anesthetics were developed and radiographic machines improved. With the improvement of technology a small group of dentists fortunately improved their current procedures by using aseptic techniques, bacteriological and histological methods and radiographs for diagnostic purposes. In the late 1940s or early 1950s researchers proved the theory of focal infection to be incorrect (Grossman, 1980). As a result of their findings, endodontic techniques continued to develop and improve, with endodontics establishing its precise role in the field of dentistry (Castellucci, 2005a).

1.2 Principles of Endodontic Treatment

1.2.1 Objective of Endodontics

The objective of endodontic therapy is the restoration of a treated tooth to its proper morphology and physiology in the masticatory apparatus. The treated tooth should be in an acceptable state of health (Weine, 1982).

1.2.2 Phases of Endodontic Therapy

Endodontic treatment entails three phases. The first is the diagnostic phase during which the disease process is diagnosed and the treatment plan determined. The second is the shaping and cleaning phase where the canal is shaped as closely as possible to its original anatomical shape. The objective of this phase is also to remove most of the root canal contents. The third is the obturarion phase where the root canal system is obturated with a stable and biocompatible material to obtain an hermetic seal as close to the cemento-dentinal junction as possible (Weine, 1982).

1.2.3 Significance of Debridement

The debridement procedure in endodontics is the removal of irritants from the canal and periapical tissues, such irritants being detrimental to a successful endodontic treatment. Debridement can be done in various ways. This may include instrumentation or irrigation of the root canal, placement of medicaments, and electrolysis or surgery. Proper preparation of the root canal simplifies obturation and increases the success rate of the endodontic treatment (Weine, 1982).

1.2.4 Respect for Periapical Tissues

Shaping, cleaning and obturation procedures should be limited to the root canal system, although techniques exist that advocate intentional periapical irrigation. Caustic drugs, toxic irrigating solutions and over-instrumentation can all cause post-operative pain (Weine, 1982).

1.2.5 Adequate Coronal Restoration after Root Canal Treatment

Coronal leakage and tooth fracture due to inadequate restorations are common causes for a large number of endodontically treated teeth to be lost. Over the past 15 years there has been significant focus on contamination of the root canal system via the coronal route due to an inadequate restoration (Saunders and Saunders, 1997). Obturation forms a barrier against the re-entry of bacterial irritants and must be supplemented as soon as possible by an adequate coronal restoration (Davalou et al., 1999). This will optimize the outcome of the endodontic therapy. Adequate restoration of the endodontically treated tooth is an integral part of root canal therapy and must be understood by to the patient as constituting part of the treatment plan (Weine, 1982).

1.2.6 Postoperative Observation

Inevitably some root canal-treated teeth will fail, despite the high degree of endodontic success. Requirements for successful endodontic therapy can vary from stringent (radiographic and clinical normalcy) to lenient (clinical normalcy only) (Friedman, 1998; Friedman, 2002). In a follow-up study by Friedman after endodontic initial treatment and re-treatment, 78 percent complete healing (radiographic and clinical normalcy) and 16 percent incomplete healing (clinical normalcy combined with reduced radiolucency) was reported (Friedman et al., 1995). The success rate can be interpreted as 78 percent using the stringent definition, or 94 percent using the more lenient definition. With recall observation some of these possible failures can be intercepted at an early stage. Success is achieved in a high percentage of re-treatment, while some may need apical surgery or at the worst, extraction (Weine, 1982). The most appropriate form of endodontic therapy should be attempted whenever feasible, and is generally preferred above tooth extraction and replacement (Friedman and Mor, 2004).

1.3 Obturation of the Root Canal System

After the endodontic space has been completely cleaned, shaped and disinfected, a three-dimensional obturation of this space will be the ultimate objective of endodontic therapy. With a durable three-dimensional obturation any communication with the periodontium will be eliminated and prevented (Ingle, 1985).

1.3.1 Historic Perspectives

In ancient Egypt, a god of wisdom, learning and magic, known as Hermes Trismegistus, is credited with the term "hermetic seal" (Seltzer, 1988). With this invention the preservation of oils, spices, aromatics, grains and other necessities was effected by a simple wax seal of previously porous walls of earthenware vessels. However, terms such as fluid-tight, fluid-impervious or bacteria-tight seals are more appropriate endodontically speaking (Cohen and Hargreaves, 2006).

Prior to 1800 obturation of root canals resulted in varying degrees of success and satisfaction by first using gold, followed by various metals, oxychloride of zinc, paraffin and amalgam (Koch and Thorpe, 1909). In 1847 the first gutta-percha root canal filling material was developed, patented in 1848 and introduced into the dental profession. This was known as "Hill's Stopping" and consisted of bleached gutta-percha together with carbonate of lime and quartz (Koch and Thorpe, 1909). This did not discourage Bowman from claiming in 1867, the first use of gutta-percha for filling of root canals (Fulton, 1938).

In 1883 Perry claimed the first use of gold wire wrapped with soft gutta-percha. This could very well be the forerunner of the carrier based technique (Perry, 1883). He also began using rolled gutta-percha which was packed into canals (Johnson and Gutmann, 2006). In 1887 the S.S. White Company began manufacturing gutta-percha points (Keane, 1944). The adding of vermilion (pure oxide of mercury) to gutta-percha by Rollins in 1893, was criticized as being dangerous, considering the quantities he suggested (Weinberger, 1948).

It was only realized that canals were not cylindrical once radiography was introduced into the assessment of root canal obturations. Attempts to fill the observed voids led to the development of a multitude of various pastes, sealers and cements (Johnson and Gutmann, 2006).

1.3.2 **Timing of Obturation**

In order to determine the appropriate time to obturate a tooth the following factors must be taken into consideration: the signs and symptoms of the patient; the pulpal and periradicular status; the degree of difficulty and patient management (Johnson and Gutmann, 2006).

1.3.2.1 Vital Pulp Tissue

In cases where the root canal system contains vital pulp tissue, the current consensus is a one-step treatment procedure (Trope and Bergenholtz, 2002). Because of the absence of bacterial contamination a successful outcome can be expected when the normal or inflamed pulp tissue is removed under aseptic conditions. Contamination between visits is precluded when obturation is done at the first visit (Johnson and Gutmann, 2006).

1.3.2.2 Necrotic Pulp Tissue

Currently the consensus is that the success rates of single and multiple visits in treating necrotic pulpal conditions are similar (Peters and Wesselink, 2002). In a prospective clinical study the effect of calcium hydroxide as an inter-appointment dressing was evaluated. The periapical healing of lesions associated with necrotic pulps showed no significant difference between the group obturated at the first visit as compared with the group treated over two visits, with calcium hydroxide as the intracanal medicament (Weiger et al., 2000).

A possible contraindication for first visit obturation is the possibility of not properly drying the canal after cleaning and shaping procedures. In these necrotic cases where exudation from the periapical tissues is present in the canal, it is recommended that calcium hydroxide is placed as an antimicrobial medicament and temporary obturant (Sjøgren et al., 1990).

1.3.3 Apical Limit of Obturation

The dentino-cemental junction has been identified as the apical limit for obturation from studies done during the 1930s (Orban, 1930; Skillen 1930).

Traditionally the apical point of termination has been 1 mm from the radiographic apex. The apical anatomy comprises a minor diameter at the constriction and a major diameter at the foramen, where the narrowest portion of the canal is called the apical constriction (Kuttler, 1955).

Various studies confirmed the average distance from the foramen to the constriction to be 0.5 to 1 mm (Chapman, 1969; Swartz et al., 1983). Based on these findings it appears that canals filled to the radiographic apex are actually overextended and such lack of length control in obturation will lead to extrusion of materials.

In a clinical study of 1007 endodontically treated teeth with 1770 canals, at recall intervals of 6 months, 1 year, 2 years, 5 years and 10 years for radiographic and clinical evaluation, it was found that overfilled cases resulted in a four times greater failure rate than in those cases filled short (Swartz et al., 1983). Another study found that in necrotic cases a better success rate was achieved when procedures terminated at or within 2 mm of the radiographic apex (Wu et al., 2000).

1.3.4 **Smear Layer Management**

The smear layer is an amorphous irregular layer consisting of organic pulpal material and inorganic dentinal debris that accumulate on the canal walls during the cleaning and shaping procedure (McComb and Smith, 1975). This layer, with a thickness of 1 to 5 µm can be packed into the dentinal tubules at varying distances (Orstavik and Haapasalo, 1990; Aguirre et al., 1997). The smear layer can interfere with the action of irrigants used as disinfectants (Gutmann, 1993). It also decreases adhesion and interferes with the penetration of root canal sealers and gutta-percha into the dentinal tubules during thermoplastic obturation techniques (Pashley, 1984).

Removal of the smear layer is generally accomplished by irrigating the canal with chelators to remove the inorganic components and sodium hypochlorite (NaOCl) to remove the remaining organic components (Baumgartner and Mader, 1987).

EDTA (ethylenediamine tetra-acetic acid) is an example of a chelating solution customarily used in endodontic treatment to remove the inorganic component of the smear layer. It is available in both liquid and paste forms with common concentrations between 15 percent and 17 percent (Hulsmann et al., 2003). A detergent is frequently added to the liquid to decrease surface tension, to increase the cleaning ability and to enhance the bactericidal action of the solution (Von der Fehr and Nygaard-Østby, 1963). A new irrigating solution that can be used to remove the smear layer is MTAD (BioPure, Tulsa/Dentsply, Tulsa, OK, USA), which is a mixture of a tetracycline isomer, citric acid and a detergent (Torabinejad et al., 2003).

Sodium hypochlorite is an alkaline solution with a pH of 11 to 12 and is the most widely used irrigant in endodontics (Pataky et al., 2002). The effectiveness in dissolving organic tissue remnants and disinfecting the root canal system with sodium hypochlorite, especially when used in high concentrations, is well known (Goldman et al., 1982; Ayhan et al., 1999). Disadvantages include the possible irritation of periodontal and periapical tissues (Brown et al., 1995) and the cytotoxicity to all cells when extruded through the apex (Pashley et al., 1985). It is recommended that EDTA or NaOCl solutions not be extruded through the apex during shaping and cleaning phases of root canal treatment (Filho et al., 2002).

1.4 **The Ideal Root Canal Filling Material**

In 1958 Grossman wrote: "I doubt very much whether there is any hollow cavity in the body that has been plugged with as many different materials as the root canal of a tooth" (Grossman, 1958).

Various endodontic materials have been advocated for obturation of the radicular space. Biologically acceptable semi-solid or solid materials are used in conjunction with root canal sealers to establish an adequate fluid-tight seal of the root canal system (Musikant, 2008).

Suggested requirements (West, 1975) for the ideal root canal filling material include:

1. Good adaptation to the prepared root canal walls;
2. Dimensional stability;
3. Lack of irritation to surrounding tissue and being non-resorbable for an indefinite period of time;
4. Bacteriostatic;
5. Does not discolour teeth;
6. Semi-solid upon insertion and solid afterwards;
7. Capable of lateral and apical sealing;
8. Impervious to moisture;

9. Radiopaque;
10. Sterile or sterilizable;
11. Easily removable;
12. Easily manipulable;
13. A non-conductor of thermal changes;
14. Slightly expandable after placement;
15. Set in a reasonable period of time.

1.5 Composition of Endodontic Filling Materials

1.5.1 Core Materials

A variety of core materials have been used in conjunction with a sealer/cement for obturation of the root canal systems. Gutta-percha is the most commonly used semi-solid material and silver points the most commonly used solid material.

1.5.1.1 Solid Materials

More than 60 years ago Jasper introduced the use of cones made of silver in dentistry (Jasper, 1941). He proposed that particularly narrow and tortuous canals can be obturated with silver points, specifically because of the rigidity that simplifies placement and length control. This resulted in clinicians often failing to properly clean and shape the canal before obturation.

Disadvantages are the inability of silver points to adapt to all surrounding endodontic anatomy, resulting in insufficient filling of irregularly shaped root canal systems (Schilder, 1978; Weine, 1982), as well as corrosion products produced when silver cones come into contact with tissue fluids or saliva (Brady and del Rio, 1975). These products have been found to be cytotoxic and either produce pathosis or impede periapical healing (Seltzer et al., 1972).

1.5.1.2 Semi-Solid Materials

The most popular semi-solid core material used for obturation of root canals is gutta-percha. It exists in two crystalline forms, *alpha* and *beta* (Goodman et al., 1974). In the *beta* phase the gutta-percha is an unheated compactable solid mass and when heated is transformed into the *alpha* phase that is tacky and pliable, but shrinks on setting (Schilder et al., 1985).

Gutta-percha cones consist of approximately 20 percent gutta-percha, 65 percent zinc oxide, 10 percent radiopacifiers and 5 percent plasticizers (Friedman et al., 1977). Cones are available in different standardized sizes and tapers to match the technique used. Unfortunately, the actual cone size varies due to non-uniformity in manufacture (Goldberg et al., 1979; Mayne et al., 1971).

A disadvantage of gutta-percha points is that it cannot be heat sterilized. However, it was found that when placed in 5.25 percent NaOCl for as little as 60 seconds even the most resistant *Bacillus subtilis* spores can be eliminated (Siqueira et al., 1998).

1.5.1.3 Resin-Based Core Filling Materials

For many decades synthetic resins have been discussed and tested for use as endodontic core filling materials (Spångberg et al., 1993).

An apparently viable alternative to gutta-percha emerged when Epiphany/Resilon (Pentron Clinical Technologies, Wallingford, CT, USA) material points were introduced. It is a polyester core material with bioactive glass, bismuth and barium salts as fillers (Zmener and Pameijer, 2004). It can be used with the lateral condensation technique as well as with the thermoplastic vertical condensation technique.

Resilon has similar physical and handling characteristics as gutta-percha. The main advantage of thermoplastic resin as core material will be the extent to which it can be bonded to the canal walls by means of adhesive resin cement. When the Resilon core bonds with the resin sealer which is attached to the etched root surface, a "monoblock" is formed and the result is a gutta-percha sealer interface together with a tooth-sealer interface. This bonding may strengthen the root and appears to provide a better coronal seal (Orstavik, 2005).

1.5.2 Root Canal Sealers

Root canal sealers have become indispensable in the obturation procedure. They seal the space between the dentinal wall and the obturating core interface, fill voids and irregularities, lateral and accessory canals and also fill spaces between gutta-percha points when the lateral condensation technique is used. The properties of an ideal sealer are outlined by Grossman (1988), although no sealer exists that currently satisfies all the criteria. When freshly mixed, all sealers exhibit toxicity but this is reduced upon setting (Langeland, 1974). Ideally extrusion of sealers into the periradicular tissues should be avoided.

The most commonly used endodontic sealers are zinc oxide-eugenol formulations, calcium hydroxides, glass-ionomers, resins-based and silicone-based sealers.

1.5.2.1 Zinc Oxide-Eugenol-Based Sealers

Zinc oxide-eugenol sealers have been used successfully over an extended period of time. The main advantage includes their excellent antimicrobial properties (Mickel et al., 2003) and the fact that it will resorb if extruded into the periapical tissues (Augsburger and Peters, 1990). They have the disadvantage of a slow setting time (Allan et al., 2001); exhibit shrinkage on setting (Kazemi et al., 1993) and can stain tooth structure (Davis et al., 2002).

Common brand names of zinc oxide-eugenol-based sealers are: Roth's (Roth Inc., Chicago, IL, USA) comprising zinc oxide-eugenol, colophony, bismuth and barium salts; Pulp Canal Sealer/Rickert's (Kerr, Romulus, MI, USA) comprising zinc oxide-eugenol, thymol and silver; Tubli-Seal (Kerr, Romulus, MI, USA) as a non-staining alternative, with barium salt instead of silver; Procosol/Grossman's (Den-tal-ez, Lancaster, PA, USA) with the same com-position as Roth's; Endomethasone (Septodont, Saint-Maur des Fosssés, France) comprising zinc oxide-eugenol and paraformaldehyde (Orstavik, 2005).

Sealers containing paraformaldehyde are unacceptable in any clinical endodontic procedure because of the severe and permanent toxic effects on periradicular tissues (Serper et al., 1998). Osteomyelitis and parasthesia have been reported after this material has been extruded into periapical tissues (Kleier and Averbach, 1988; Erisen et al., 1989).

1.5.2.2 Calcium Hydroxide-Based Sealers

Calcium hydroxide sealers were developed for therapeutic activity. The antimicrobial activity and osteogenic-cementogenic potential demonstrated by these sealers was less than originally expected (Mickel et al., 2003; Miyagak et al., 2006). In order for the release of calcium hydroxide to sustain activity, the sealer needs to be soluble. This is inconsistent with the main purpose of a sealer (McMichen et al., 2003). They exhibit a slow setting time (Allan et al., 2001) and can cause slight staining of tooth structure (Parsons et al., 2001).

Common brand names of calcium hydroxide-based sealers are: Sealapex (Kerr, Romulus, MI, USA) consisting of toluene salicylate and calcium oxide and Apexit (Ivoclar Vivadent, Schaan, Lichtenstein, Switzerland) comprising salicylates and calcium hydroxide (Orstavik, 2005).

Calcium hydroxide has been shown to encourage cementogenesis and osteogenesis and promotes apexification after thorough cleaning and shaping (Holland et al., 1977; Holland et al., 1979). Calcium hydroxide can effect an alkaline pH in the surrounding dentinal tubules, kill bacteria and neutralize endotoxin, a potent inflammatory stimulator (Trope et al., 1995). A disadvantage of calcium hydroxide sealers is that it provokes a chronic inflammatory reaction in the periodontal ligament (Holland and de Souza, 1985).

1.5.2.3 Glass-Ionomer-Based Sealers

Glass-ionomer sealers are polyalkenoate cements that were advocated for use during root canal obturation because they were considered to be biocompatible and demonstrated some adhesion to dentine (Ray and Trope, 1995; Najar et al., 2003). The removal of glass-ionomer sealers if re-treatment is required proved to be very difficult if not impossible (Loest, 1993). This group of sealers exhibits minimal antimicrobial activity (Heling, 1996) and was proved to leak and disintegrate (Friedman et al., 1995; Schäfer and Zandbiglari, 2003). Ketac-Endo (3M, ESPE, St. Paul, MN, USA) is an example of a glass-ionomer-based sealer.

1.5.2.4 Resin-Based Sealers

Resin-based sealers have a long history of use and provide adhesion to gutta-percha and dentine (Lee et al., 2002). They do not contain eugenol and cause a dose-dependant increase in genotoxicity (Huang et al., 2001). Resin-based sealers display deeper and more consistent penetration into the dentinal tubules as compared with all the other types of sealers (Mamootil and Messer, 2007).

AH26 (Dentsply Maillefer, Ballaigues, Switzerland) depended on methenamine polymerization which released formaldehyde during setting. This resulted in the development of AH Plus. AH Plus/Topseal

(Dentsply Maillefer, Ballaigues, Switzerland), are bis-phenol resins using adamantine for polymerization (Spångberg et al., 1993).

EndoREZ (Ultradent, South Jordan, UT, USA) is based on urethane dimethacrylate (UDMA) resin (Zmener and Pameijer, 2004) and has some hydrophilic properties assumed to improve performance even in the presence of moisture. Resin-coated gutta-percha points are used and bonding to the sealer supposedly gives better adhesion and seal throughout the filling mass (Tay et al., 2005).

Epiphany/Resilon (Pentron, Wallingford, CT, USA) improved the EndoREZ concept (Shipper et al., 2004). Following the removal of the smear layer with a chelator, a self-etching primer is applied to the dentine surface. A dual-curing sealer based on Bisphenol-A-glycidyldimethacrylate (BisGMA), UDMA and hydrophilic methacrylates with radiopaque fillers, is used to coat the primed dentine. Insertion of resin cones or thermally plasticized resin core material completes the obturation of the root canal space. This gives rise to the concept of a homogeneous 'monoblock' root filling with little or no voids and adhesion to dentine (Hefferman et al., 2005).

1.5.2.5 Silicone-Based Sealers

Endo-Fill (Lee Pharmaceuticals, El Monte, CA, USA) was developed to utilize the water-repellant, chemical stability and adhesive properties of silicone materials in endodontics (Nixon et al., 1991; Gambarini et al., 2003).

Roeko-Seal (Roeko/Coltene/Whaledent, Langenau, Germany) is a poly-dimethalsiloxane with silicone oil and zirconium oxide (platinum as catalyzing agent) that was developed to polymerize without shrinkage. Impressive biological performance was obtained in clinical follow-up studies (Huumonen et al., 2003; Miletić et al., 2005).

Gutta-Flow (Roeko/Coltene/Whaledent, Langenau, Germany) consists of the same composition of Roeko-Seal with gutta-percha added. Gutta-percha was milled to a low grained size and mixed into the components of the silicone sealer, incorporating the filling qualities of gutta-percha. Gutta-Flow is a eugenol-free sealer and is a cold flowable gutta-percha system for the obturation of root canals (Orstavik, 2005).

1.5.2.6 Self-etching Resin Cements

Hybrid Root SEAL (J Morita, Dietzenbach, Germany) is a dual-cure, self-etching resin cement for root canal obturation. It contains 4-methacryloyloxyethy trimellitate anhydride (4-META), a high performance adhesive monomer that decalcifies tooth substrate and penetrates through the smear layer to form a hybrid layer, creating high polymerization, especially in the interface between root canal walls and cement. Hybrid Root SEAL shows high bond strength to dentine, biocompatibility and good sealability. In a comparative evaluation it showed similar sealing performance as the resin-based sealer, AH Plus (Belli et al., 2008).

1.6 Techniques for Root Canal Obturation with Gutta-Percha

Many techniques have been advocated to achieve an adequate three-dimensional root canal seal. Over the years, considerable controversy existed between lateral condensation (Frank et al., 1983) and vertical condensation techniques (Schilder, 1983). Because it is physically impossible to condense purely laterally or vertically, Schilder (1983) suggested that the true difference between the two techniques depends on whether "cold compaction" or "warm compaction" is used.

1.6.1 Lateral Compaction

This technique is a common method used for root canal obturation. A master cone of gutta-percha that fits well to the apical preparation is placed to the correct length with a small amount of sealer. A spreader, which is a cold rigid metallic and smooth conical shaped instrument, is introduced between the dentine and gutta-percha to create a space into which an auxiliary cone can be placed. This is repeated until a dense, well-adapted filling is obtained (Castellucci, 2005b).

This technique can be used in most clinical situations and provides length control of obturation material during compaction (Gilhooly et al., 2001). Disadvantages are not being able to fill canal irregularities (Collins et al., 2006) or lateral canals (Reader et al., 1993) and the risk of root fracture due to considerable lateral force that is exerted by the spreader (Gimlin et al., 1986). Being a cold obturation technique, the gutta-percha cones are always separated by a certain amount of sealer and never merge into a homogenous, compact mass necessary for a three-dimensional obturation (Brothman, 1981).

1.6.2 **Single Cone Technique**

With this technique a single gutta-percha cone, preferably tapered to match the preparation taper, is placed with various types of sealers (Gordon et al., 2005). Single cone obturation when used with a zinc oxide-eugenol-based sealer has demonstrated a large amount of leakage because the sealer is more prone to cement washout over time (Pommel and Camps, 2001). Although, when used in combination with an epoxy-resin sealer, the apical leakage compares favorably with thermoplastcized techniques (Cohen et al., 1998; Hata et al., 2002).

Research has demonstrated that when the single cone technique is used with epoxy-resin cements, accessory and lateral canals can be filled predictably, provided that the canals have been debrided both mechanically and chemically (Musikant, 2002). The epoxy-resin has good adhesion to both dentine and the gutta-percha cone (Zidan et al., 1987) and by employing this technique root fracture and temperature rise in the tooth and ligament as experienced with thermoplastic techniques is eliminated (Saw and Messer, 1995).

1.6.3 Warm Vertical Compaction

This method of obturating the radicular space in three dimensions was introduced by Schilder (Wu et al., 2001). It requires a canal prepared with a continuous taper and also that the apical foramen is kept as small as possible.

A master cone, that replicates the canal taper, is placed with a sealer 0.5-2 mm short of the apex. This ensures that the cone diameter is larger than the prepared canal. Pluggers come in a variety of sizes with increasing diameters. Heat is applied with a heated plugger or spreader to remove the coronal portion of the gutta-percha. The Touch 'n 'Heat Unit (SybronEndo, Kerr, Romulus, MI, USA) permits temperature control and is an alternative to a flame heated instrument. The remaining softened material in the canal is then condensed with a plugger, forcing the plasticized material apically. This is repeated until the apical portion is filled. The canal is back-filled with 3-4 mm sections of gutta-percha, heated and condensed thereafter (Cohen and Hargreaves, 2006).

Obturating canal irregularities and accessory canals is an advantage of this technique (Wu et al., 2001). Disadvantages are the risk of vertical root fractures, inability of total length control that can cause extrusion of material into the periraducular tissues and the difficulty of negotiating curved canals with the rigid pluggers (Blum et al., 1998a; Blum et al., 1998b).

1.6.4 Continuous Wave of Obturation Technique

The continuous wave of obturation technique is a variation of the warm vertical compaction technique (Buchanan, 1998). This technique employs a heat source, the System B unit (SybronEndo, Kerr, Romulus, MI, USA), and hollow stainless steel pluggers that have insulated copper wire soldered to their tips, with tip diameters of 0.5 mm, and tapers that vary from 6-12 per cent. A plugger is pre-fitted within 5 to 7 mm of the working length. This point of binding is where the hydraulic forces on the gutta-percha decreases and the forces on the root increase. The quality of obturation and filling of canal irregularities are related to the depth the heated plugger is placed (Bowman, 2002; Wu et al., 2002). The recommended temperature setting for the System B unit is 200°C. An increase of temperature setting does not increase the effectiveness of obturation (Jung et al., 2003). After fitting an appropriate master cone, the excess coronal material is removed with the heated plugger, then the System B unit being in the "touch mode". The cold metal plugger is then placed against the gutta-percha in the canal orifice and firm pressure is applied. While the heat is activated in the System B unit, the plugger is pushed to within 3 mm of the binding point. The heat is then inactivated while firm pressure is maintained on the plugger for 5 to 10 seconds. Once the gutta-percha mass has cooled, heat is applied for 1 second to separate the plugger from the apical portion of gutta-percha. The compacted mass of gutta-percha will not be dislodged because the pluggers are designed to heat from the tip to the shank. Backfilling can be accomplished by using a thermoplastic injection technique, using the Obtura II unit (Spartan, Fenton, USA) or the BeeFill unit (VDW GmbH, München, Germany).

The effect on periodontal tissues when using heat-softened gutta-percha techniques continues to raise concern. In a study done by Romero et al., (2000) on extracted teeth with artificial periodontal ligaments, the System B obturation technique was used at 200°C setting. Significantly lower root surface temperature increases were found than were previously reported by Hardie (1987). Subsequent studies have confirmed that root surface temperature changes of less than 10°C, result in no detriment to periodontal tissue adjacent to root surfaces (Lipski, 2004; Lipski, 2006).

1.6.5 Warm Lateral Compaction

This technique is similar to lateral compaction, the difference being that a heated spreader is used. The Endotec II (Caulk, Dentsply, Ballaigues, Switzerland) consist of a heat source and tips of various tapers and diameters. A master cone of gutta-percha is placed to the working length; the appropriate tip is selected and with the device activated, the tip is inserted beside the master cone, using light pressure, to within 2 to 4 mm from the apex. The tip is rotated for 5 to 8 seconds and removed cold. The accessory cone is placed after the space is determined by an unheated spreader. This process is continued until the canal is adequately filled.

This technique provides the clinician with the ability to employ length control; produces a fusion of the gutta-percha into a solid homogeneous mass (Jacobson and BeGole, 1992); creates less stress during obturation than standard lateral compaction (Martin and Fischer, 1990) and does not cause heat related damage to the periodontal tissues (Castelli et al., 1991).

1.6.6 Warm Lateral and Vertical Condensation

A new device, the EndoTwin (MDCL N.V. Corporation, Amsterdam), was developed for both warm lateral and vertical condensation (Castellucci, 2005b). With this device the application of heat and vibration are combined. Pluggers are available in the Standard and Ultrasoft series, with a 0.5 mm diameter and a range of fine, fine medium, medium large, and large. The Ultrasoft series can easily be pre-bent and for narrow and curved canals another tip, with a 0.3 mm diameter tip and a 4 percent taper, is available. The theory is that heat combined with vibration will give the gutta-percha better flow properties, resulting in a higher percentage of gutta-percha. Experimental literature and clinical documentation are currently not available.

1.6.7 **Thermoplastic Injection Techniques**

Thermoplastic gutta-percha techniques consist of injecting gutta-percha, heated outside the mouth by an electrical device, into the prepared root canal (Yee et al., 1977; Marlin et al., 1981). The Obtura II unit (Spartan, Fenton, USA), Ultrafil 3D (Coltene/Whaledent Inc., Cuyahoga Falls, USA) and BeeFill (VDW GmbH, München, Germany) are examples of such devices.

The Obtura II (Spartan, Fenton, USA) is an instrument that looks like a gun and is loaded with gutta-percha pellets. It heats the gutta-percha to a recommended 180°C and has a silver needle attached (varying gauges available) to deliver the thermoplasticized material into the root canal. Canal preparation is similar to other obturation techniques and a sealer is placed with a paper point or the last file used. The delivery needle is placed 3 to 5 mm from the apex and the trigger of the device is gently squeezed until the needle backs out from the canal. The apical portion is then compacted with a plugger dipped in alcohol. This process is repeated until the canal is totally obturated.

BeeFill (VDW GmbH, München, Germany) is a device with a handpiece that is handled like a pen. A cartridge, containing gutta-percha, is placed in the handpiece and the gutta-percha is heated to 180°C. The cartridge has a flexible, heat-conductive, silver alloy cannula to deliver the thermoplasticized gutta-percha into the canal. Sealer placement and thermoplasticized material delivery is similar to the technique utilized with Obtura II unit.

The Ultrafil 3D (Coltene/Whaledent Inc., Cuyahoga Falls, USA) utilizes a heating unit in which gutta-percha cannulas are heated to the recommended 70°C. Cannulas are fitted with 22-gauge stainless steel needles measuring 21 mm in length. An injection syringe is employed to deliver the heated material into the prepared canal. Three types of gutta-percha cannulas are employed with this system. The low-viscosity materials are: Regular Set that requires 30 minutes to set and Firm Set require 4 minutes to set. Endoset is a higher viscosity material and requires 2 minutes to set.

These thermoplasticized techniques demonstrate very good adaptation of the heated gutta-percha to the prepared root canal walls with minimal heat transmission (Weller et al., 1997) and non-damaging heat to the periodontal tissues (Sweatman et al., 2001). Thermoplasticized injection of gutta-percha can be used to backfill canals when the continuous wave of obturation technique is employed.

1.6.8 **Carrier Based Gutta-Percha**

Thermafil (Dentsply-Tulsa Dental, Tulsa, OK, USA) obturation technique was derived from the original idea of Dr. W.B. Johnson described in 1978 (Johnson, 1978). The obturator consists of two parts, a plastic carrier covered with gutta-percha (Cantatore, 2001). The plastic of the carrier is a derivative of polysulfone, perfectly inert and biocompatible if it accidentally comes into contact with the periapical tissues (Glickman et al., 1992). The gutta-percha is an alpha-phase gutta-percha with a fusion heat of 56° C (Malagnino et al., 1994).

Shaping and cleaning of canals are similar to previous techniques and must allow for easy insertion of the carrier leaving sufficient space for the flow of sealer and gutta-percha (Cantatore and Cochet, 1998). All zinc oxide-eugenol sealers with medium to long working times, or polymer resin sealers can be used with the Thermafil system. Small amounts of sealer are placed with paper points until it is reduced to a paper thin layer (Lee et al., 1998). Thermafil obturators are available in 17 sizes with tapers between 4-5 percent. Verifiers are used to verify the canal size and to select the correct obturator (Cantatore and Cochet, 1998; Cantatore, 2001). The bare plastic carrier can also be used to select the correct size obturator. By keeping the tip of the plastic carrier shorter than the working length, gutta-percha and sealer alone will fill the apical area thus increasing the hermeticity of the apical seal (Castellucci A, 2005b). Since the amount of gutta-percha varies at the tip of the plastic carrier it has been advised to remove gutta-percha until the plastic carrier becomes visible, thereby obtaining the same amount of gutta-percha covering the obturators and reducing the risk of apical extrusion (Castellucci A, 2005b).

The selected obturator is heated in a ThermaPrep Plus Oven (Dentsply-Tulsa Dental, Tulsa, OK, USA) and slowly introduced into the canal until it reaches its final position. Pressure on the periapical tissues by the air in the canal being compressed by the heated gutta-percha can result in pain for the patient (Cantatore, 2001). Sealing ability of lateral and accessory canals with this technique is an advantage (Wolcott et al., 1997) but the extrusion of material beyond the apical extent of the preparation is a disadvantage of this technique (Kytridou et al., 1999).

1.6.9 Thermo-Mechanical Compaction

McSpadden introduced an instrument with the design of an inverted Hedstrom file that would generate friction when activated in a slow speed handpiece, with the result that softened gutta-percha is moved apically in the canal. The flexibility of these compactors increases when made of nickel-titanium (McSpadden, 1993).

A master cone with sealer is placed short of the prepared length. A compactor, conforming to the preparation size is selected and placed 3 to 4 mm from the prepared length. Activating the handpiece will initiate friction and transfers heat to the gutta-percha. The pliable mass of gutta-percha is compacted apically and laterally as the instrument is withdrawn from the canal (McSpadden, 1993).

The simplicity and the ability to fill canal irregularities are advantages, (Kersten et al., 1986) while extrusion of material, instrument fracture, canal wall gouging, inability to utilize in curved canals and heat generation are common disadvantages of this technique (Saunders, 1989; Mc Cullagh et al., 1997).

1.7 Objectives of Research Project

The objectives of this *in vitro* study were to evaluate four different root canal obturation techniques in respect of:

- the radiographic quality of root canal obturation,
- apical leakage and
- the potential of these techniques to obturate lateral canals.

CHAPTER 2

MATERIALS AND METHODS

2.1 Selection of Teeth

Ninety six non-carious, recently extracted human teeth were collected from various dental clinics. Only teeth which had been extracted for periodontal or orthodontic reasons were used. Ethical and safety guidelines for the handling of human teeth and laboratory research were strictly followed. All selected teeth were examined and only roots with narrow canals, with no sharp curves were included in this study. Any roots that showed evidence of resorption, fractures or open apices (larger than 0.3 mm) upon visual inspection under 3.5X magnification using a Dental Operating Microscope (MC-M3101 DF Vasconcellos S.A. – Brasil, Av Indianopolis, Sao Paulo, Brazil)(Fig. 2.1) were excluded from this study.

2.2 Preparation of Root Canals

Access cavities were prepared using a Ti-Max Ti95L 1:5 friction grip handpiece (NSK, Nakanishi Inc., Kanuma, Japan), with size 023 round diamond burs (Dentsply Maillefer Instruments SA, Baillagues, Switzerland). The finishing of the access cavities was done with size 023 round steel burs (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) and a Ti-Max Ti25L 1:1 contra-angle handpiece (NSK, Nakanishi Inc., Kanuma, Japan).

All the root canals were prepared by one operator under 3,5X to 16X magnification (MC-M3101 DF Vasconcellos S.A. – Brasil, Av Indianopolis, Sao Paulo, Brazil).

Working length was determined by passing a 08 K-file (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) carefully along the canal, until the tip of the file was visible at the apical foramen. This length was recorded and 1mm subtracted to provide the operator with a working length for each root canal. Apical patency was established by using C+ Files (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) size 08 (Fig. 2.2), 10 and 15, with a reciprocating handpiece (NSK TiMax Ti35L 10:1)(Fig. 2.3) operating at 40 000 RPM using constant distilled water irrigation. A glide path was established with a 20 K file (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) to working length.

Root canal preparation was done using RaCe nickel titanium rotary files (FKG Dentaire, La Chaux-de-Fonds, Switzerland) (Fig. 2.4) mounted in a 16:1 gear reduction handpiece driven by an electric motor (Micro-Mega, Besancon, France) (Fig. 2.5), under constant irrigation with TopClear Solution (Dental Discounts CC, Paulshof, Sandton, South Africa) (Fig. 2.6), which is a mixture of 0.2 percent cetremide and 17 percent EDTA. The TopClear Solution was alternated with Chlor-XTRA (Vista Dental Products, 2200 Northwestern Avenue, Racine, WI, USA)(Fig 2.7), a 6 percent sodium hypochlorite solution (NaOCl). The files were used according to manufacturer's instructions by opening canal orifices to size 40 (10 percent taper) and the apical region of each canal was prepared to a size 30 (6 percent taper).

Finally, the dentinal smear layer was removed from all prepared root canals by leaving TopClear Solution (Dental Discounts CC, Paulshof, Sandton, South Africa) in the prepared root canals for 2 minutes before rinsing for 5 minutes with Chlor-XTRA (Vista Dental Products, 2200 Northwestern Avenue, Racine, WI, USA). The irrigation solutions were delivered in a disposable syringe with a NaviTip needle (Ultradent Products Inc, South Jordan, Utah, USA) (Fig 2.8).

The prepared teeth were randomly and equally divided into four groups (n = 40 canals). Each group contained prepared root canals of the following teeth:

- two maxillary first molars (four canals each),
- six maxillary premolars (two canals each),

- two maxillary canines (one canal each),
- two maxillary central incisors (one canal each),
- two mandibular molars (three canals each),
- six mandibular premolars (one canal each),
- two mandibular canines (one canal each), and
- two mandibular central incisors (one canal each).

In two of the groups that will be obturated with resin-based sealers, the canals were finally rinsed with TopClear Solution for 30 seconds (Dental Discounts CC, Paulshof, Sandton, South Africa), because oxygen-generating solutions, like NaOCl, can inhibit the setting process of some resin cements.

All canals were dried by using several 6 percent tapered Paper Points (Dentsply Maillefer Instruments SA, Baillagues, Switzerland)(Fig 2.9).

2.3 Obturation of Prepared Root Canals

- ***Group A:* Single Cone Technique with Gutta-percha and Hybrid Root SEAL cement (Hybrid Root SEAL technique)**

A single gutta-percha point with a taper of 6 percent (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) was used as a master cone, in conjunction with Hybrid Root SEAL root canal cement (J. Morita, Europe GmbH, Dietzenbach, Germany)(Fig. 2.10). The cement was applied to the entire length of the canals using a lentulo spiral, the master cone placed, seared off with System B (Analytic Richmond, Washington, USA)(Fig. 2.11) at the coronal orifice and compacted with a Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland).

- ***Group B:* Single Cone Technique with Gutta-percha and EndoREZ Cement (EndoREZ technique)**

A single EndoREZ gutta-percha point with a taper of 6 percent (Ultradent Products Inc., South Jordan, Utah, USA) was used as a master cone, in conjunction with EndoREZ root canal sealer/filler (Ultradent Products Inc., South Jordan, Utah, USA)(Fig. 2.12). By using the TwoSpense syringe (Ultradent Products Inc., South Jordan, Utah, USA) with the Ultra-Mixer tip (Ultradent Products Inc., South Jordan, Utah, USA) the Skini syringe (Ultradent Products Inc., South Jordan, Utah, USA) was filled with the mixed base and catalyst. A Navitip (Ultradent Products Inc., South Jordan, Utah, USA) was fitted to the Skini syringe and inserted into the canal to within 2-3 mm short of working length. The Navitip was withdrawn slowly while sealer was delivered to the canal until the canal orifice was reached. The master cone was subsequently placed and seated to working length. A size 25 accessory cone was dipped in EndoREZ Accelerator (Ultradent Products Inc., South Jordan, Utah, USA) and inserted next to the master cone into the canal as far as possible. The cones were seared off with System B (Analytic Richmond, Washington, USA) and compacted with a Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland).

- ***Group C:* Continuous Wave of Obturation with Gutta-percha and Pulp Canal Sealer (System B/Obtura technique)**

A single gutta-percha point with a taper of 6 percent (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) was used as a master cone, Pulp Canal Sealer (Kerr Co., Romulus, Michigan, USA)(Fig. 2.13) as root canal cement and System B Heat Source (Analytic Richmond, Washington, USA) (Fig. 2.14) to perform the continuous wave of condensation. Canals were back-filled with gutta-percha heated to 180°C in the Obtura II unit (Obtura Corporation, Fenton, Missouri, USA) (Fig. 2.15).

The master cone was cut back to 0.5 mm short of working length to ensure that the cone binds to the canal wall in its terminal 1 mm. The continuous wave electric heat plugger was selected with a taper matching the master cone taper. The plugger was inserted into the canal and confirmed that the binding point was within 4 mm of the working length. The stop was then adjusted to that reference point.

The master cone was buttered with Pulp Canal Sealer and slowly placed in the prepared root canal. The System B Heat Source (Analytic Richmond, Washington, USA) set on 180°C, was used to sear off the master cone at the orifice with the tip of the continuous wave plugger and the softened gutta-percha was compacted with a Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland). The cold continuous wave plugger was placed against the gutta-percha, the System B handpiece switch activated and gently pushed downwards until it was 3-4 mm shy of its binding point. With the switch released, apical pressure was maintained firmly on the plugger and after pressure was sustained for 10 seconds, the handpiece switch was activated for 1 second, the continuous wave plugger rotated and retracted to remove the coronal access of gutta-percha. The apical gutta-percha seal was compacted with a small Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) to create a flat surface that would avoid the formation of a void when backfilling. With the downpack completed, the Obtura II Gun and needle (Obtura Corporation, Fenton, Missouri, USA) were allowed to heat to 180°C. A 23 gauge needle was inserted into the canal until it touched the apical seal. A waiting period of 5 seconds was observed before pulling the trigger of the Obtura II Gun (Obtura Corporation, Fenton, Missouri, USA) to inject the heated gutta-percha into the backfill space. The gutta-percha was compacted at the canal orifices with a Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland).

- ***Group D:* Thermafil Obturators with Pulp Canal Sealer (Thermafil technique)**

The canals were verified with size 30 nickel titanium Verifier (Dentsply Maillefer Instruments SA, Baillagues, Switzerland). Pulp Canal Sealer (Kerr

Co., Romulus, Michigan, USA) (Fig. 2.13) was placed in the canals, adapting it to the walls and eliminating the excess with a paper point. Size 30 Thermafil Obturators (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) (Fig. 2.16) were heated in the ThermaPrep Plus Oven (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) (Fig. 2.17). The heated obturators were introduced into the canals, using small clockwise/counter-clockwise movements until they reached their final positions. While light pressure was kept on the obturators, the coronal soft gutta-percha was compacted with a Schilder plugger (Dentsply Maillefer Instruments SA, Baillagues, Switzerland). After 8-10 seconds the obturators were sectioned with a Thermacut bur (Dentsply Maillefer Instruments SA, Baillagues, Switzerland) using light pressure.

After root canal obturation all the access openings were cleaned with 90% alcohol and sealed with Miracle Mix (GC Corporation, 76-1 Hasunuma-Cho, Itabashi-Ku, Tokyo, Japan) (Fig. 2.18). Specimens were stored at 37°C at 100 percent humidity for 48 hours to ensure complete setting of the root canal cements.

2.4 Radiographic Evaluation and Criteria Used For Obturation Quality Assessment:

Digital radiographs were taken of each obturated tooth from buccolingual and mesiodistal directions to assess the quality of the root canal obturation using a Trophy RVG sensor (Trophy Radiologie S.A., Croissy-Beaubourg, France).

The quality of obturation was determined separately for the coronal and apical halves of each canal and was rated and scored according to the following radiographic appearances (Kersten et al., 1987):

1. Well condensed root filling material that obturated the entire prepared canal, well adapted to the root canal wall and only show

few minor areas of relative radiolucency (less than 0.25mm in diameter) -Scored 1,

2. Imperfectly condensed root filling material that show irregularities of less than 1 mm in adaptation - Scored 2,

3. Root canal filling material was inadequately condensed with irregularities of less than 2mm - Scored 3,

4. Root canal filling material was poorly condensed with irregularities of more than 2 mm - Scored 4.

2.5 Assessment of Apical Leakage and Potential to Obturate Lateral Canals

The specimens of each obturation group were randomly subdivided into two equal groups (n=20 canals). One group was used to determine apical leakage of the root canal obturation materials and the second group used to assess the ability of the root canal obturation techniques to obturate lateral canals. Each group represented canals from the following teeth (n=20 canals):

- one maxillary first molar (four canals),
- three maxillary premolars (two canals each),
- one maxillary canine (one canal),
- one maxillary central incisor (one canal),
- one mandibular molar (three canals),
- three mandibular premolars (one canal each),
- one mandibular canine (one canal),
- one mandibular central incisor (one canal).

2.5.1 **Apical Leakage**

For evaluation of apical leakage, root surfaces of each tooth were coated with three layers of nail varnish and a final layer of sticky wax leaving 4 mm around the apical foramen exposed. The specimens were then immersed in 2 percent methylene blue dye (pH 7.0) for 48 hours. After removal from the dye the specimens were rinsed in distilled water and embedded in clear acrylic resin (Fig. 4.19).

All the specimens were then processed according to the procedure prescribed by Wu et al., (2001):

- Specimens were sectioned horizontally in 1 mm increments (Fig. 2.20) with a wafering blade in an Isomet 11-1180 low speed saw (Buehler Ltd., LakeBluff, Illinois, USA)(Fig. 2.21) under permanent water irrigation. Teeth were orientated so that the sections were perpendicular to their long axes.
- Each succeeding section was advanced 1 mm so that the new section would represent the next 1 mm level.
- Specimens were sectioned to their midroot area unless dye penetration was still visible.
- The resulting sections of each specimen were mounted on microscopic slides and examined in a stereomicroscope (Leica, Microsystems, Heerbrugg, Switzerland) (Fig. 2.22) by two independent evaluators who were unaware of the material used.
- The extent of dye penetration was measured to the nearest millimeter to where the presence of dye was visible on the filling material or dentine walls.
- Apical leakage was measured at the point where gutta-percha was first observed. In teeth where the foramen exited short of the anatomical apex, the most apical segment was removed until gutta-percha was exposed.

2.5.2 **Assessment of Lateral Canals**

In order to assess the number of lateral canals that were obturated by the different techniques, all the obturated root canals were required to be subjected to a clearing technique.

Root canal treated teeth were immersed in the below mentioned demineralizing solution for 14 days according to the technique described by Venturi et al., (2003):

Teeth were immersed in the following demineralizing solution:

- 7 percent formic acid, 3 percent hydrochloric acid and 8 percent sodium citrate in aqueous solution.
- The specimens were kept under continuous agitation in a Vibromatic (Secta, Spain) (Fig 2.23) and the solution changed every 3 days.
- After 14 days the specimens were removed from the acid and rinsed in running tap water for 2 hours.
- The specimens were then immersed in 99 percent acetic acid overnight, rinsed in distilled water, dehydrated in ascending concentrations of ethanol of 30, 50, 70, 90 and 96 percent (30 min passage each), and finally cleared and stored in methyl salicylate (Schilder, 1976; Venturi et al., 2003).

Morphological analysis was performed using a stereomicroscope (Leica Microsystems, Heerbrugg, Switzerland) (Fig. 2.24) fitted with a graded lens to reveal details of any obturated lateral canals. Observations were performed by two independent observers who counted the number of visible lateral canals within the coronal, middle and apical thirds of the roots. The following scores (Schilder, 1976; Venturi et al., 2003), were used to evaluate the filling of lateral canals:

a) *No filling (Grade 0)*: Filled with cement only <10 percent of their total length.

b) *Partial filling with cement without gutta-percha (Grade 1)*: Filled with cement but not up to their full length, or not three-dimensionally, leaving empty spaces.

c) *Complete filling with cement with or without evidence of gutta-percha (Grade 2)*: Filled three-dimensionally and up to their full length by cement, without presence of gutta-percha, or with gutta-percha up to 50 percent of their total length.

d) *Complete filling with cement and partial filling with gutta-percha (Grade 3)*: Filled three-dimensionally up to their full length by cement where gutta-percha penetrated between 50 and 90 percent of their total length.

e) *Complete filling with cement and gutta-percha (Grade 4)*: Totally filled with cement and gutta-percha.

2.6 **Statistical Analysis**

All the data was collected tabulated and statistically analyzed using Mann-Whitney U test.

Figure 2.1: MC-M3101 DF Vasconcellos Dental Operating Microscope (Vasconcellos).

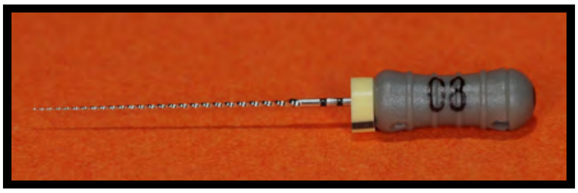


Figure 2.2: 08 C+ File (Dentsply Maillefer).

Figure 2.3: NSK TiMax Ti35L 10:1 reciprocating handpiece (NSK).

Figure 2.4: RaCe nickel titanium rotary files (FKG).

Figure 2.5: TC Electric motor with a 16:1 gear reduction handpiece (Micro Mega).

Figure 2.6: TopClear Solution (Dental Discounts).

Figure 2.7: Chlor-XTRA (Vista Dental Products).

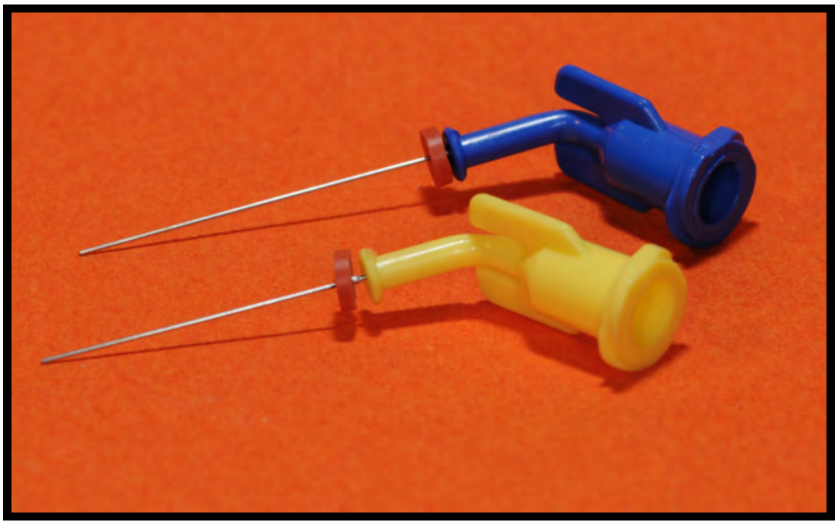


Figure 2.8: NaviTip irrigation needles, 25 mm length (blue) and 21 mm length (yellow) (Ultradent).

Figure 2.9: 6% Tapered Paper Points (Dentsply Maillefer).

Figure 2.10: 6% Tapered Gutta-Percha Points (Dentsply Maillefer).

Figure 2.11: Hybrid Root SEAL Root Canal Cement (J. Morita).

Figure 2.12: EndoREZ Resin Based Root Canal Sealer (Ultradent).

Figure 2.13: Pulp Canal Sealer (Kerr).

Figure 2.14: System B Heatsource and medium size plugger (Analytic Technology).

Figure 2.15: Obtura II unit (Obtura Corporation).

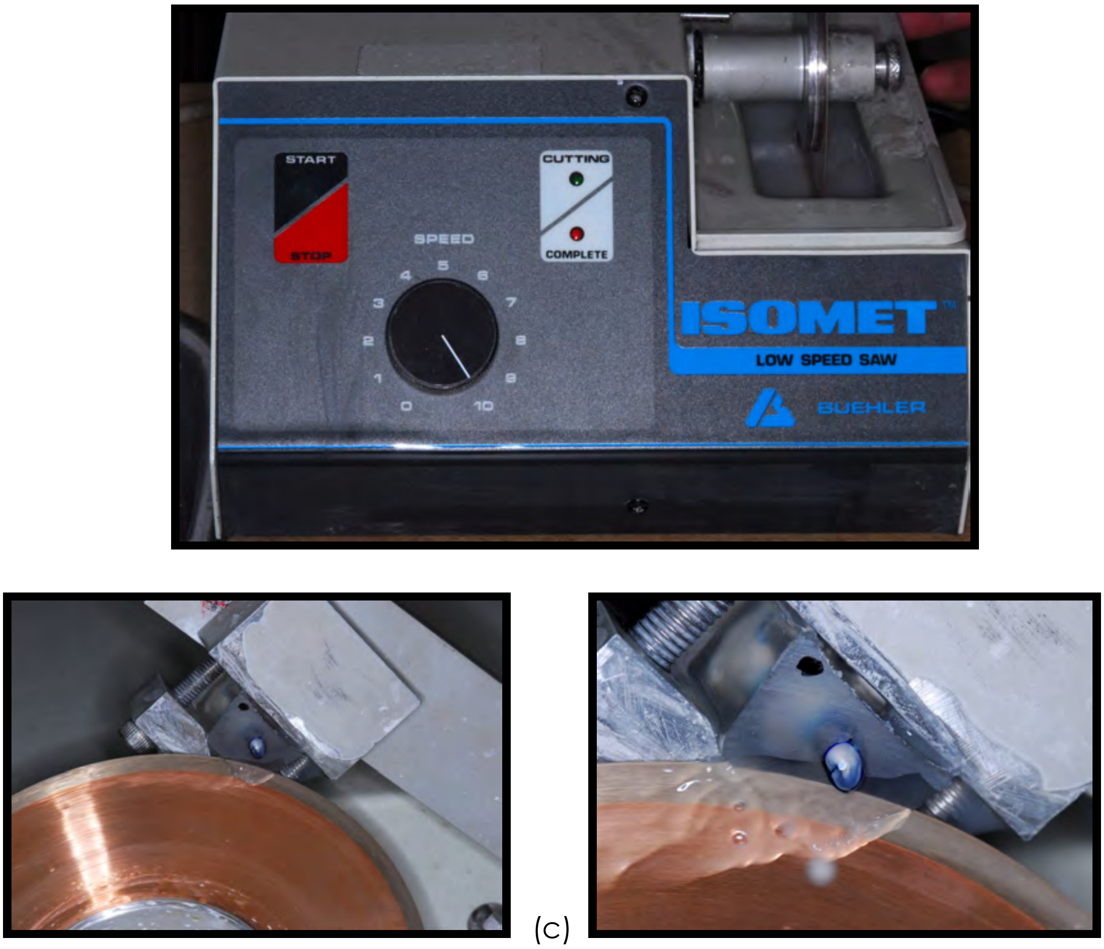
Figure 2.16: Thermafil size 30 Obturators (Dentsply Maillefer).

Figure 2.17: ThermaPrep Plus Oven (Dentsply Maillefer).

Figure 2.18: Miracle Mix Capsules (GC).

Figure 2.19: Specimen embedded in clear acrylic resin.

Figure 2.20: Sectioned specimen in 1 mm increments.



(a) (b) (c)

Figure 2.21: (a) The Isomet 11-1180 low speed saw (Buehler); (b,c) specimens sectioned horizontally with a wafering blade in 1mm increments.

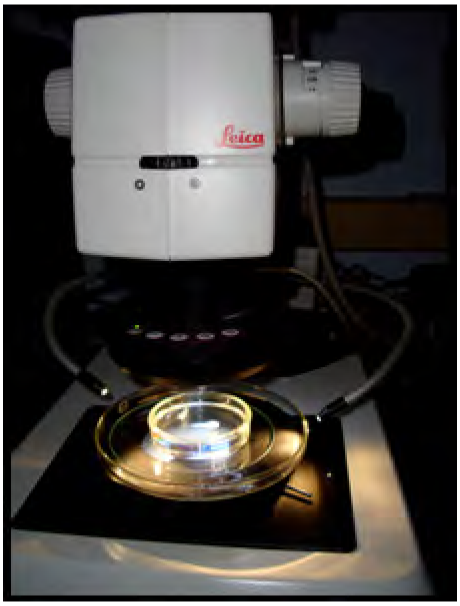


Figure 2.22: Leica M165C stereomicroscope (Leica).

Figure 2.23: Vibromatic (Selecta) was used for constant agitation of the specimens during the demineralizing process.

CHAPTER 3

RESULTS

3.1 Radiographic Evaluation

The results of the radiographic evaluation of the coronal and apical parts of the four groups tested are presented in Tables 3.1 - 3.4 and summarized in Figure 3.1. Results of the radiographic evaluation of the apical parts of the four groups tested are presented in Tables 3.7 – 3.10 and summarized in Figure 3.2.

The means, standard deviations and coefficient of variance of these results are presented in Tables 3.5, 3.6, 3.11 and 3.12.

3.1.1 Group A: Hybrid Root SEAL Technique (Tables 3.1 and 3.7)

In the coronal aspects of the root canals in this group, most of the specimens demonstrated well condensed root fillings with no areas of radiolucency (Score 1) (Fig. 3.3). Figure 3.4 illustrates the radiographic appearance of one of these specimens (lower canine).

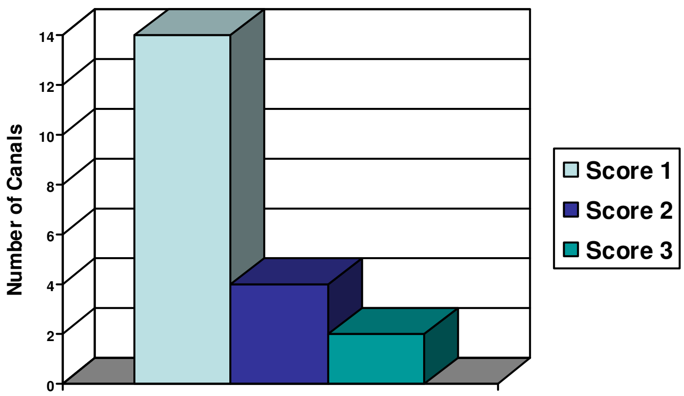


Figure 3.3 (Coronal)

Four of the twenty obturated root canals (coronal aspect) in this group showed imperfectly condensed root fillings, with irregularities of less than 1 mm in adaptation (Score 2). Two canals presented with inadequately condensed root canal fillings, with irregularities of less than 2 mm (Score 3) (Fig. 3.3).

Figure 3.4

The same specimens also demonstrated inadequately condensed root canal fillings in the apical parts of these root canals (Fig. 3.5).

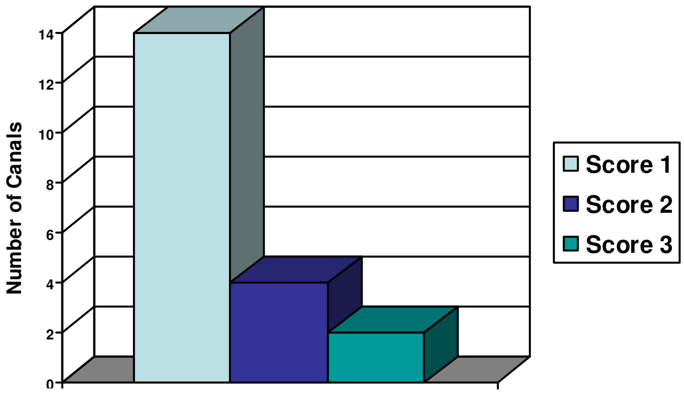


Figure 3.5 (Apical)

Figure 3.6 shows a Hybrid Root SEAL technique specimen (upper premolar) that illustrated irregularities of less than 1mm (Score 2) in the coronal aspect of the buccal canal (arrow right) and the apical aspect of the palatal canal (arrow left).

Figure 3.6

The specimens that were obturated with Hybrid Root SEAL technique demonstrated a statistically significant ($p<0.05$) higher number of radiographic obturation defects in the coronal aspect of the root canals compared with System B/Obtura and Thermafil techniques. There was no significant difference between Hybrid Root SEAL and EndoREZ techniques ($p>0.05$).

In the apical aspect, there was also a statistically significantly higher number of radiographic obturation defects between the root canal fillings of Hybrid Root SEAL technique compared with all the other techniques ($p<0.05$).

3.1.2 Group B: EndoREZ Technique (Tables 3.2 and 3.8)

Most of the canals in this group demonstrated well condensed root fillings with no areas of radiolucency (Score 1) in the coronal aspects of the canals. However, five of the canals in this group showed imperfectly condensed root fillings in the coronal aspects of the root canals (Score 2) (Fig. 3.7).

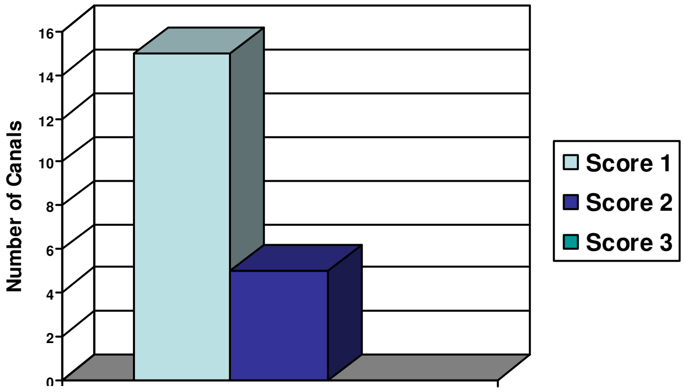


Figure 3.7 (Coronal)

Figure 3.8 depicts an EndoREZ technique specimen (upper premolar) that illustrated irregularities of less than 1 mm (Score 2) in the coronal aspects of the buccal and palatal canals (arrow).

Figure 3.8

All the root canals in apical regions demonstrated well condensed root fillings (Score 1) (Fig. 3.9).

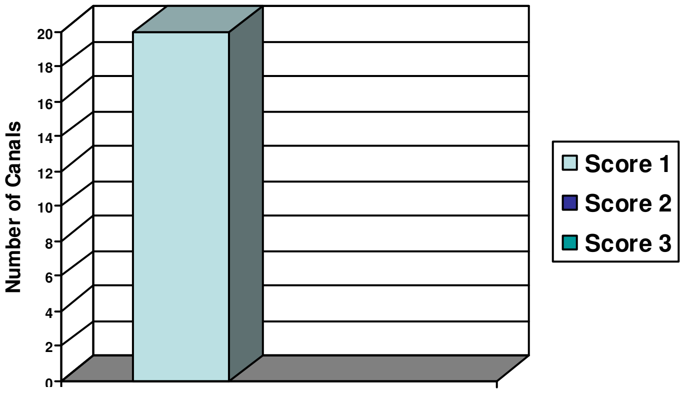


Figure 3.9 (Apical)

An example of an EndoREZ technique specimen (upper first molar) that was well condensed with no areas of radiolucency in all four root canals (Score 1), is depicted in Figure 3.10.

Figure 3.10

3.1.3 Group C: System B/Obtura Technique (Tables 3.3 and 3.9)

Most of the canals in this group demonstrated well condensed root fillings with no areas of radiolucency (Score 1) in the coronal and apical aspects of the root canals (Fig. 3.11).

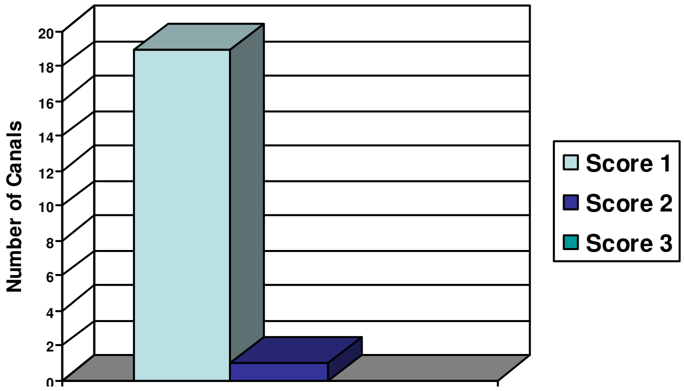


Figure 3.11 (Coronal and Apical)

The quality of obturation of one of these System B/Obtura technique specimens is depicted in Figure 3.12. All three root canals in this lower first molar were well condensed with no areas of radiolucency (Score 1).

Figure 3.12

There was evidence of only one imperfect root filling (Score 2) (Fig 3.11) in the coronal aspect of a lower canine (arrow) (Fig. 3.13) as well as in the apical aspect of a buccal canal of an upper premolar (arrow) (Fig. 3.14) of all the other root canals in this group.

Figure 3.13

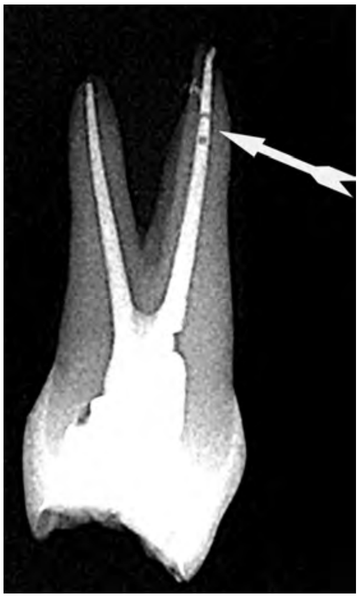


Figure 3.14

The specimens that were obturated using System B/Obtura technique demonstrated the lowest number of radiographic obturation defects in the coronal aspects of the root canals compared with all the other techniques. However, there was only a statistically significant difference between System B/Obtura and Hybrid Root SEAL techniques ($p<0.05$).

3.1.4 **Group D: Thermafil Technique (Tables 3.4 and 3.10)**

Nearly all the canals in this group demonstrated well condensed root fillings with no areas of radiolucency (Score 1) in the coronal (Fig. 3.15) and apical (Fig. 3.16) aspects of the root canals.

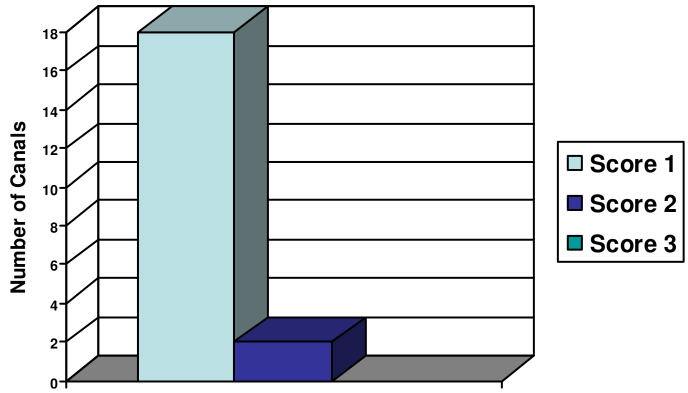


Figure 3.15 (Coronal)

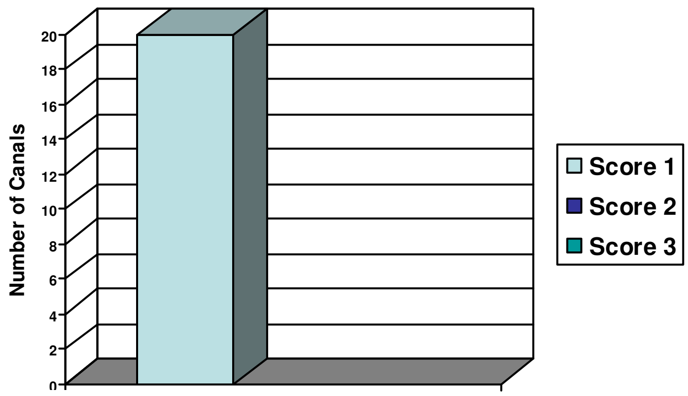


Figure 3.16 (Apical)

An example of a Thermafil technique specimen (upper first premolar) that was well condensed with no areas of radiolucency in the buccal and palatal root canals (Score 1) is depicted in Figure 3.17.

Figure 3.17

Two of all the obturated root canals in this group illustrated imperfect root fillings (Score 2) (Fig. 3.15) in the coronal aspects of the root canals. All the root canals in this group showed well condensed root fillings in the apical aspects of the obturated root canals.

Figure 3.18 shows one of the Thermafil technique specimens (upper central) that illustrated irregularities of less than 1 mm (Score 2) (arrow) in the coronal aspect of the root canal.

Figure 3.18

The specimens that were obturated with Thermafil and EndoREZ techniques demonstrated the lowest number of radiographic obturation defects in the apical aspects of the root canals compared with all the other groups. However, there was only a statistically significant difference between these two techniques and Hybrid Root SEAL technique ($p<0.05$).

3.2 Apical Leakage

The apical leakage scores of the four different obturation groups are presented in Tables 3.13 – 3.16 and summarized in Figure 3.19.

The means, standard deviations and coefficient of variance for the apical leakage are presented in Table 3.17 and the significance of differences is presented in Table 3.18.

3.2.1 Group A: Hybrid Root SEAL Technique (Table 3.13) (Figure 3.20)

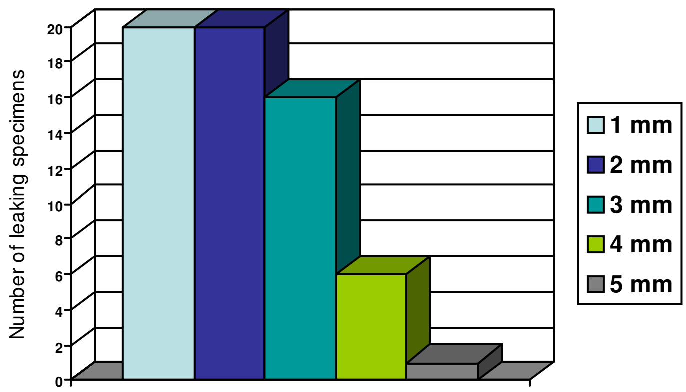


Figure 3.20

Sixteen canals (Fig. 3.20) of the specimens in the Hybrid Root SEAL technique group showed apical leakage (arrows) up to 3 mm from the apical foramina (Fig. 3.21) and six canals (Fig. 3.20) demonstrated apical leakage up to 4 mm from the apical foramina.

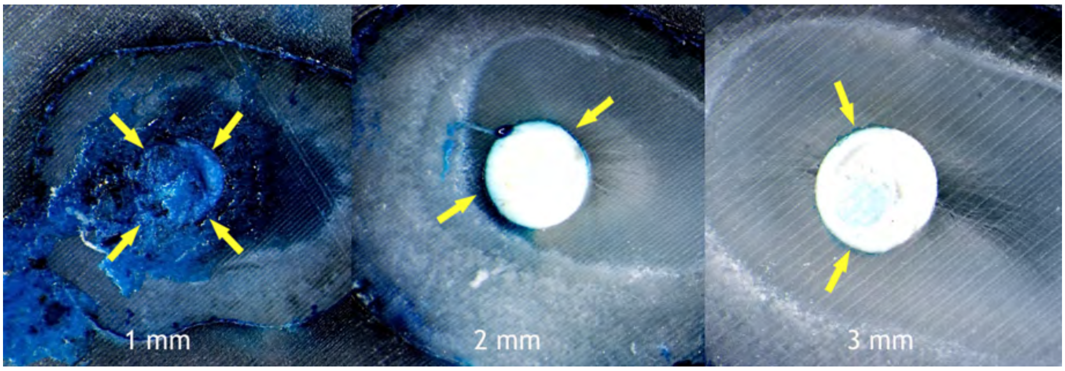


Figure 3.21 (5X magnification)

Only one root canal (Fig. 3.20) (upper canine) illustrated leakage (arrows) up to 5 mm from the apical foramina (Fig. 3.22).

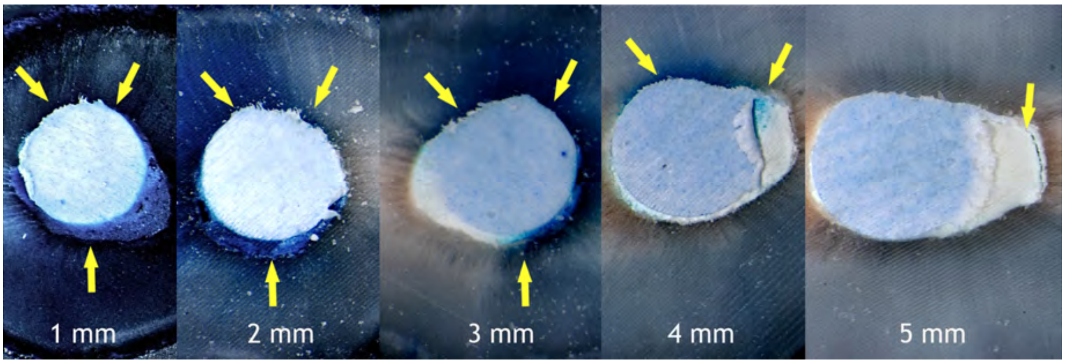


Figure 3.22 (5X magnification)

3.2.2 Group B: EndoREZ Technique (Table 3.14) (Figure 3.23)

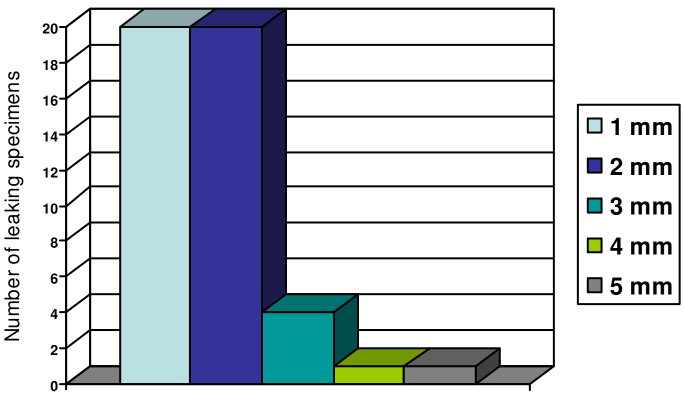


Figure 3.23

In this group, four root canals (Fig. 3.23) demonstrated apical leakage up to 3 mm from the apical foramina (arrows) (Fig. 3.24) and one root canal (upper canine) showed apical leakage up to 5 mm from the apical foramina.

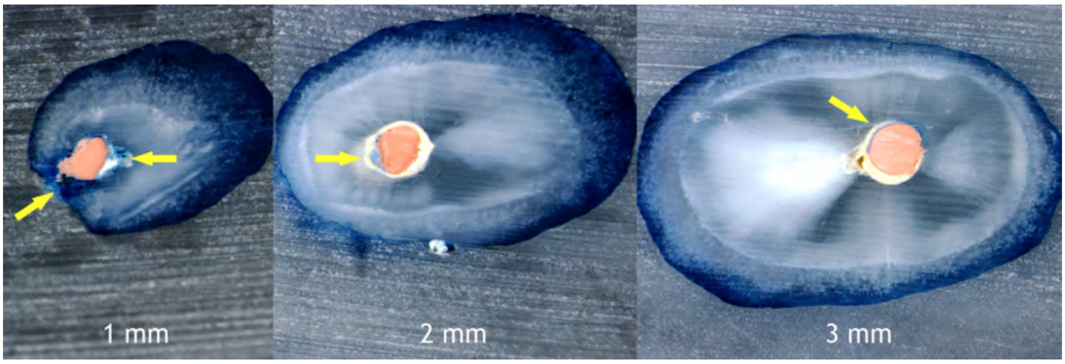


Figure 3.24 (5X magnification)

The specimens that were obturated with EndoREZ technique demonstrated the least apical leakage as compared with all the other groups. Figure 3.25 depicts an example of one of the specimens in this group that demonstrated apical leakage only up to a level of 2 mm. However, there was only a statistically significant ($p<0.05$) difference in apical leakage when EndoREZ technique was compared with Hybrid Root SEAL and System B/Obtura techniques. There was no significant difference between EndoREZ and Thermafil techniques ($p>0.05$).

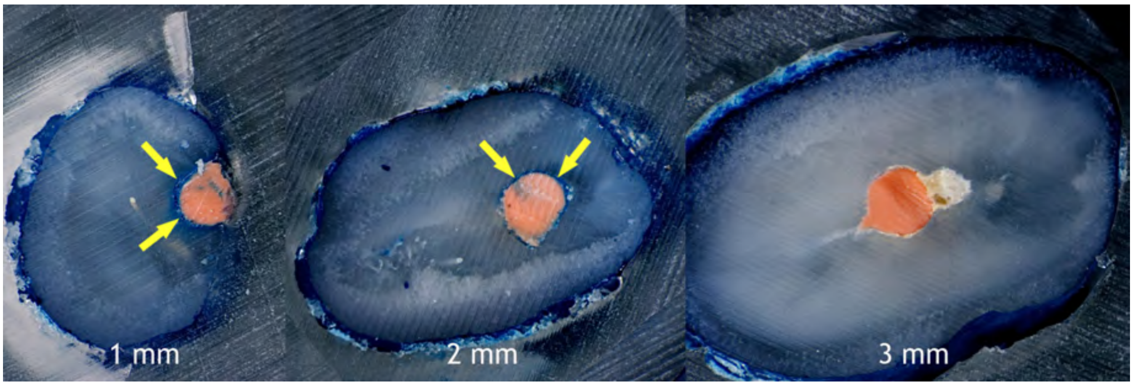


Figure 3.25 (5X magnification)

3.2.3 Group C: System B/Obtura Techniques (Table 3.15) (Figure 3.26)

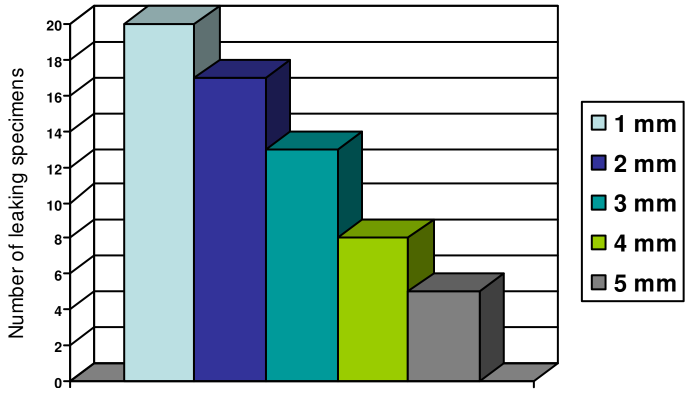


Figure 3.26

Thirteen canals of the System B/Obtura technique group illustrated apical leakage of up to 3mm from the apical foramina; eight canals demonstrated apical leakage (arrows) up to 4 mm from the apical foramina (Fig. 3.27) and five canals demonstrated apical leakage (arrows) up to 5 mm from the apical foramina (Fig. 3.28).

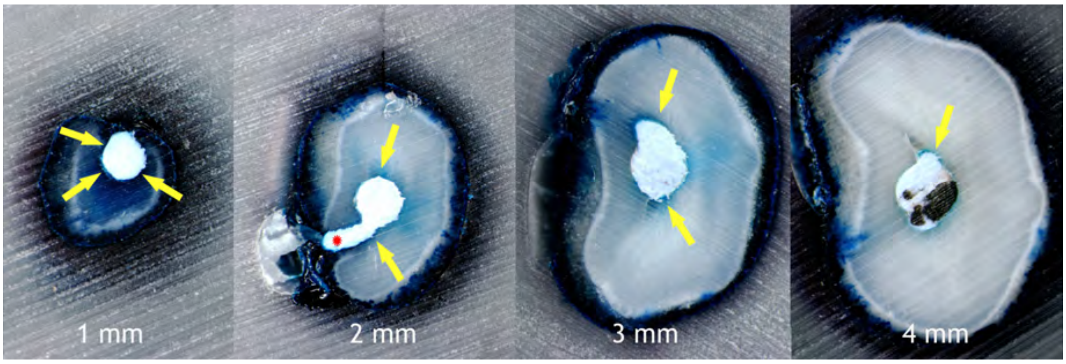


Figure 3.27 (5X magnification)

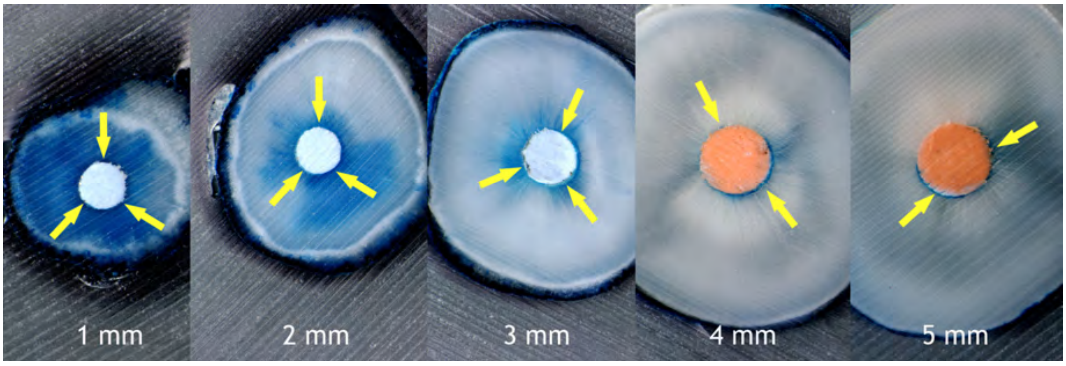


Figure 3.28 (5X magnification)

The specimens that were obturated with System B/Obtura technique demonstrated the most apical leakage as compared with all the other techniques. However, there was only a statistically significant ($p<0.05$) difference in apical leakage when System B/Obtura technique was compared to EndoREZ and Thermafil techniques. There was no significant difference between System B/Obtura and Hybrid Root SEAL techniques ($p>0.05$).

3.2.4 Group D: Thermafil Technique (Table 3.16) (Figure 3.29)

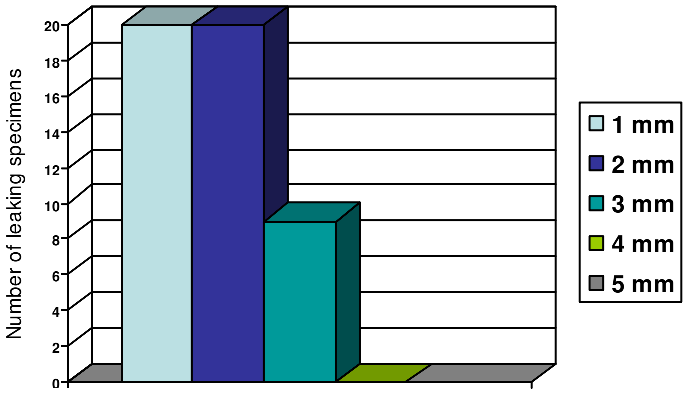


Figure 3.29

In this group, nine of the canals (Fig. 3.29) showed apical leakage up to 3 mm from the apical foramina. There was no evidence of apical leakage (arrows) past the 3 mm level in any of the specimens (Fig. 3.30).

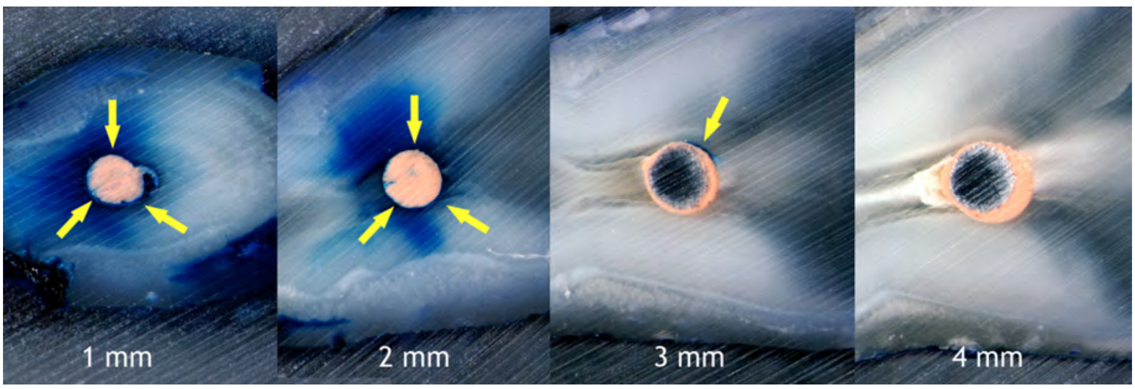


Figure 3.30 (5X magnification)

3.3 Lateral Canals

The presence of lateral canals in the coronal, midroot and apical aspects of the four groups tested are presented in Tables 3.19–3.22 and summarized in Figure 3.31.

The means, standard deviations and coefficient of variance for the presence of lateral canals in the four groups tested are presented in Table 3.23 and the significance of differences is presented in Table 3.24.

3.3.1 Group A: Hybrid Root SEAL Technique (Table 3.19) (Figure 3.32)

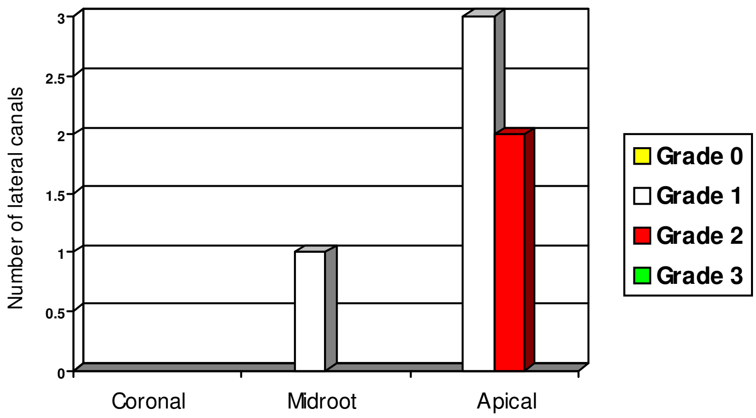


Figure 3.32

Five lateral canals were observed in the apical aspects of the obturated root canals in this group. Three of these lateral canals were partially filled with cement without the presence of gutta-percha (Grade 1) (Fig. 3.32). Figure 3.33 (2,5X magnification) demonstrates a stereomicroscopic view of a palatal root of an upper premolar that was obturated with gutta-percha and Hybrid Root SEAL technique. Note the presence of a lateral canal (white arrow) in the apical part of the root canal. Approximately 50 percent of the total length of the lateral canal is filled with Hybrid Root SEAL technique (Grade 1).

Figure 3.33 (2.5X magnification)

The other two lateral canals that were observed in the apical aspects of the obturated root canals in this group were completely filled three-dimensionally with cement without the presence of gutta-percha (Grade 2) (Fig. 3.32). Figure 3.34 (5X magnification) illustrates a stereomicroscopic view of a buccal root of an upper premolar where the Hybrid Root SEAL technique obturated the entire length of the lateral canal (Grade 2) (red arrow).

Figure 3.34 (5X magnification)

Only one lateral canal (Grade 1) (white arrow) was observed in the midroot aspect between the two root canals of an upper premolar of all the obturated root canals in this group (Figure 3.35).

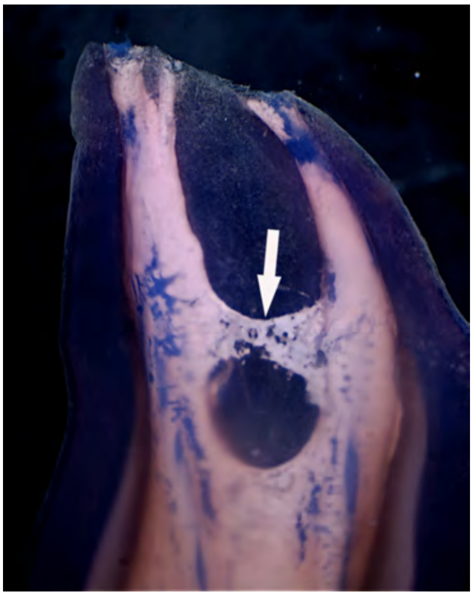


Figure 3.35 (5X magnification)

3.3.2 **Group B: EndoREZ Technique (Table 3.20) (Figure 3.36)**

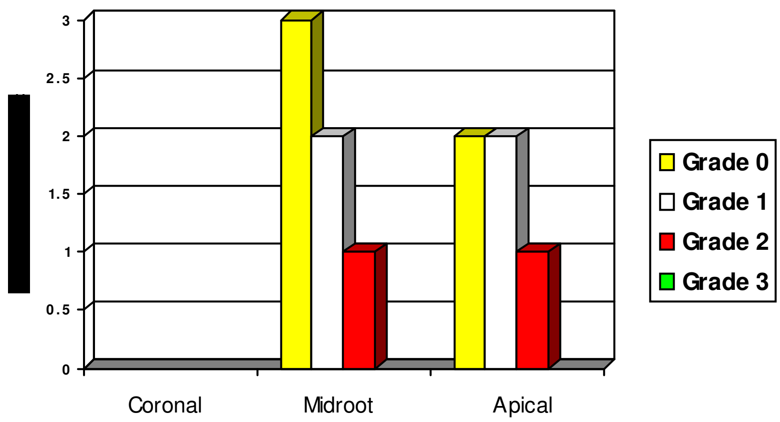


Figure 3.36

In this group, five lateral canals were observed in the apical aspects of the obturated root canals (Fig. 3.36). Two of the lateral canals were filled with cement, less than 10 percent of their total length (Grade 0). Another two of the lateral canals were partially filled with cement without the presence of gutta-percha (Grade 1) and only one of the lateral canals was completely filled three-dimensionally with cement without the presence of gutta-percha (Grade 2).

Figure 3.37 (2.5X magnification) shows a stereomicroscopic view of a palatal root of an upper premolar. The apical lateral canal (red arrow) is completely filled with EndoREZ cement (Grade 2).

Figure 3.37 (2.5x magnification)

Six lateral canals were observed in the midroot aspect of the obturated root canals in this group (Fig. 3.36). Three of the lateral canals were filled with cement, less than 10 percent of their total length (Grade 0) and two of the lateral canals were partially filled with cement without the presence of gutta-percha (Grade 1). One of the lateral canals was completely filled three-dimensionally with cement without the presence of gutta-percha (Grade 2).

Figure 3.38 (2.5X magnification) and Figure 3.39 (5X magnification) depict stereomicroscopic views of an upper canine that was obturated with gutta-percha and EndoREZ cement. Note the presence of three lateral canals, two in the midroot area (Grade 2 and Grade 0) and one in the apical area (Grade 0). At higher magnification (Fig. 3.42) it is clearly visible that there was a large lateral canal in the midroot area, completely filled with EndoREZ cement (Grade 2) (red arrow), followed by a narrower lateral canal (yellow arrow) where the cement filled less than 10 percent of the total length of the canal (Grade 0). Also visible on this magnified view is the apical lateral canal (yellow arrow), filled to less than 10 percent of its total length with cement (Grade 0).

Figure 3.38 (2.5X magnification)

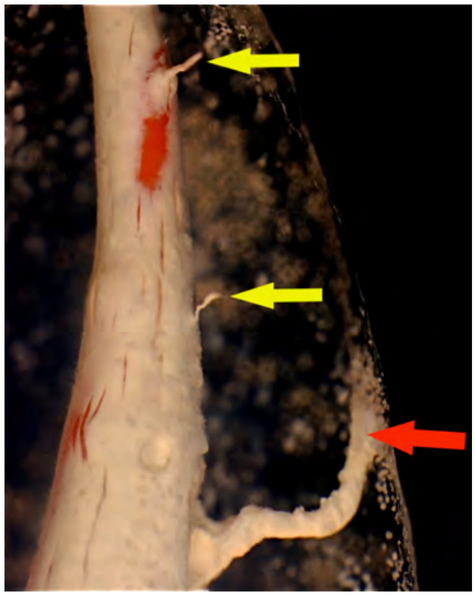


Figure 3.39 (5X magnification)

3.3.3 **Group C: System B/Obtura Technique (Table 3.21) (Figure 3.40)**

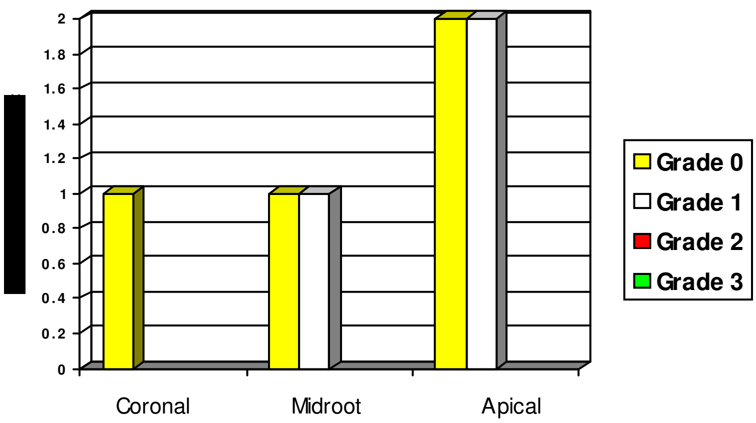


Figure 3.40

Four lateral canals were observed in the apical aspects of the obturated root canals in this group (Fig. 3.40). Two of the lateral canals were filled with cement to less than 10 percent of their total length (Grade 0) and two of the lateral canals were partially filled with cement (Grade 1) without the presence of gutta-percha.

In the midroot aspects of the obturated root canals in this group two lateral canals were observed. One of the lateral canals was filled with cement to less than 10 percent of its total length (Grade 0), while the other one was partially filled with cement without the presence of gutta-percha (Grade 1).

Figure 3.41 (2.5X magnification) demonstrates a stereomicroscopic view of the root canal of an upper canine that was obturated with the System B/Obtura technique. Note the presence of cement in a midroot lateral canal (Grade 0) (yellow arrow).

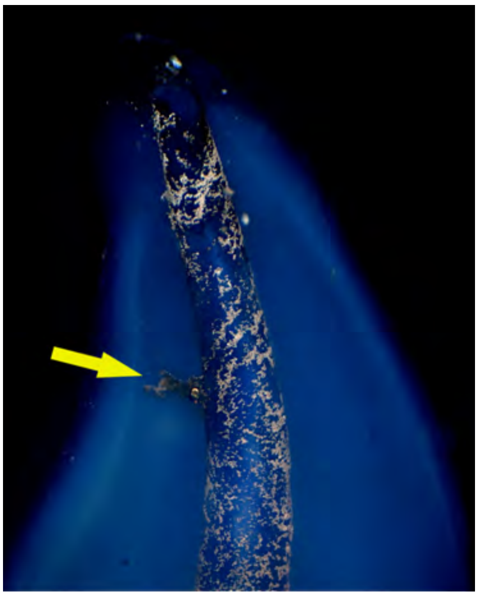


Figure 3.41 (2.5X magnification)

In this group, there was also evidence of one lateral canal in the buccal root of an upper premolar (yellow arrow), that was filled with cement to less than 10 percent of the total length (Grade 0) in the coronal aspect of the obturated root canal (Fig. 3.42).

Figure 3.42 (2.5X magnification)

3.3.4 **Group D: Thermafil Technique (Table 3.22) (Figure 3.43)**

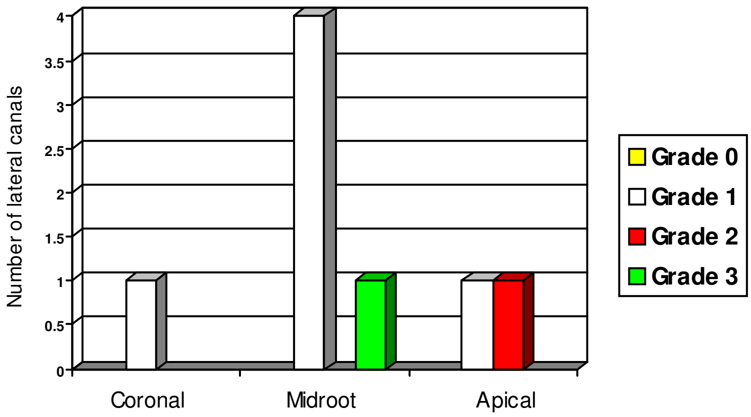


Figure 3.43

In this group, two lateral canals were observed in the apical aspect of the obturated root canals (Fig. 3.43). One of the lateral canals was filled with cement to less than 10 percent of its total length (Grade 1) while the other one was partially filled with cement (Fig. 3.44) and gutta-percha to approximately 20 percent of the canal length (Grade 2) (red arrow).

Figure 3.44 (2.5X magnification)

Five lateral canals were observed in the midroot aspects of the obturated root canals in this group. Four of the lateral canals were partially filled with cement without the presence of gutta-percha (Grade 1) and one of the lateral canals was completely filled with cement (Fig. 3.45) and partially filled with gutta-percha (Grade 1) (red arrow), to less than 50 percent of the total canal length.

Figure 3.45 (2.5X magnification)

Only one lateral canal was observed in the coronal aspects of the specimens in this group. The lateral canal was filled with cement to less than 10 percent of the total canal length (Grade 1).

The specimens that were obturated with the Thermafil technique demonstrated the greatest number of filled lateral canals. However, there was no statistically significant ($p<0.05$) difference between the Thermafil technique and all the otherobturation techniques.

Table 3.1: Radiographic evaluation of Group A (Hybrid Root SEAL Technique) in the coronal aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D		*		
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B		*		
	P			*	
Premolar Lower		*			
Premolar Lower				*	
Premolar Lower			*		
Canine Upper			*		
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.2: Radiographic evaluation of Group B (EndoREZ Technique) in the coronal aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B		*		
	P		*		
Premolar Upper	B		*		
	P		*		
Premolar Lower		*			
Premolar Lower			*		
Premolar Lower		*			
Canine Upper		*			
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.3: Radiographic evaluation of Group C (System B/Obtura Technique) in the coronal aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Lower		*			
Premolar Lower		*			
Premolar Lower		*			
Canine Upper		*			
Canine Lower			*		
Central Upper		*			
Central Lower		*			

Table 3.4: Radiographic evaluation of Group D (Thermafil Technique) in the coronal aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Lower		*			
Premolar Lower			*		
Premolar Lower		*			
Canine Upper		*			
Canine Lower		*			
Central Upper			*		
Central Lower		*			

Table 3.5: Mean, Standard Deviation and Coefficient of Variance of the radiographic evaluation of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques in the coronal aspects of the root canals.

	Hybrid Root SEAL	EndoREZ	System B	Thermafil
Mean	1.4000	1.2500	1.0500	1.1000
Standard Deviation	0.6806	0.4443	0.2236	0.3078
Coefficient of Variance	48.611	35.541	21.296	27.981

Table 3.6: Significance of difference between the mean values (Table 3.5) of the radiographic evaluation of Hybrid Root Seal, EndoREZ, System B/Obtura and Thermafil techniques in the coronal aspects of the root canals.

	Hybrid Root SEAL	EndoREZ	System B	Thermafil
Hybrid Root SEAL		p>0,05	p<0,05	p>0,05
EndoREZ			p>0,05	p>0,05
System B				p>0,05
Thermafil				

Table 3.7: Radiographic evaluation of Group A (Hybrid Root SEAL Technique) in the apical aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D		*		
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B			*	
	P		*		
Premolar Lower		*			
Premolar Lower				*	
Premolar Lower			*		
Canine Upper			*		
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.8: Radiographic evaluation of Group B (EndoREZ Technique) in the apical aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Lower		*			
Premolar Lower		*			
Premolar Lower		*			
Canine Upper		*			
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.9: Radiographic evaluation of Group C (System B/Obtura Technique) in the apical aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B		*		
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Lower		*			
Premolar Lower		*			
Premolar Lower		*			
Canine Upper		*			
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.10: Radiographic evaluation of Group D (Thermafil Technique) in the apical aspects of the root canals.

Tooth	Canal	Score 1	Score 2	Score 3	Score 4
Molar Upper	MB 1	*			
	MB 2	*			
	BD	*			
	P	*			
Molar Lower	MB	*			
	ML	*			
	D	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Upper	B	*			
	P	*			
Premolar Lower		*			
Premolar Lower		*			
Premolar Lower		*			
Canine Upper		*			
Canine Lower		*			
Central Upper		*			
Central Lower		*			

Table 3.11: Mean, Standard Deviation and Coefficient of Variance of the radiographic evaluation of Hybrid Root Seal, EndoREZ, System B/Obtura and Thermafil techniques in the apical aspects of the root canals.

	Hybrid Root SEAL	EndoREZ	System B	Thermafil
Mean	1.4500	1.0000	1.0500	1.0000
Standard Deviation	0.6863	0.0000	0.2236	0.0000
Coefficient of Variance	47.333	0.0000	21.296	0.0000

Table 3.12: Significance of difference between the mean values (Table 3.11) of the radiographic evaluation of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques in the apical aspects of the root canals.

	Hybrid Root SEAL	EndoREZ	System B	Thermafil
Hybrid Root SEAL		p<0,05	p<0,05	p<0,05
EndoREZ			p>0,05	p>0,05
System B				p>0,05
Thermafil				

Table 3.13: Apical leakage of Group A (Hybrid Root SEAL Technique).

Tooth	Canal	1 mm	2 mm	3 mm	4 mm	5 mm
Molar Upper	MB 1	*	*			
	MB 2	*	*			
	BD	*	*			
	P	*	*	*	*	
Molar Lower	MB	*	*	*		
	ML	*	*	*		
	D	*	*	*	*	
Premolar Upper	B	*	*	*	*	
	P	*	*	*	*	
Premolar Upper	B	*	*	*		
	P	*	*	*		
Premolar Upper	B	*	*	*		
	P	*	*	*	*	
Premolar Lower		*	*	*		
Premolar Lower		*	*	*		
Premolar Lower		*	*	*		
Canine Upper		*	*	*	*	*
Canine Lower		*	*	*		
Central Upper		*	*			
Central Lower		*	*	*		

Table 3.14: Apical leakage of Group B (EndoREZ Technique).

Tooth	Canal	1 mm	2 mm	3 mm	4 mm	5 mm
Molar Upper	MB 1	*	*			
	MB 2	*	*			
	BD	*	*			
	P	*	*			
Molar Lower	MB	*	*			
	ML	*	*			
	D	*	*			
Premolar Upper	B	*	*			
	P	*	*			
Premolar Upper	B	*	*			
	P	*	*			
Premolar Upper	B	*	*	*		
	P	*	*			
Premolar Lower		*	*			
Premolar Lower		*	*			
Premolar Lower		*	*	*		
Canine Upper		*	*	*		
Canine Lower		*	*	*	*	*
Central Upper		*	*			
Central Lower		*	*			

Table 3.15: Apical leakage of Group C (System B/Obtura Technique).

Tooth Canal **1 mm** **2 mm** **3 mm** **4 mm** **5 mm** Molar Upper MB
1 * * * MB
2 * * * * * BD * * * P * * Molar
Lower MB * * * * * ML * * * D * * Premolar
Upper B * * * * * P * * * * Premolar
Upper B * * * * P * * * * * Premolar
Upper B * * * P * * * * Premolar
Lower * * * * Premolar
Lower * * * Premolar
Lower * * Canine Upper * * Canine
Lower * Central
Upper * Ce

emolar
Upper B * * P * * Premolar
Upper B * * * P * * Premolar

oREZ, System B/Obtura and Thermafil techniques.

	Hybrid Root SEAL	**EndoREZ**	**System B**	**Thermafil**
Mean	3.1500	2.3000	3.4500	2.4500
Standard Deviation	0.8127	07327	1.1459	0.5104
Coefficient of **Variance**	**25.801**	**31.856**	**33.215**	**20.833**

Table 3.18: Significance of difference between the mean values (Table 3.17) of the apical leakage of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques.

	Hybrid Root SEAL	**EndoREZ**	**System B**	**Thermafil**
Hybrid Root SEAL		p<0,05	p>0,05	p<0,05
EndoREZ			p<0,05	p>0,05
System B				p<0,05
Thermafil				

Table 3.19: Lateral Canals of Group A (Hybrid Root SEAL Technique).

Tooth Canal **Coronal** **Midroot** **Apical** **Score** Molar Upper MB 1 MB 2 BD P 1 1 Molar

Lower□MB□□□□□□□□ML□□□□□□□□D□□□□□□□□□□□□□□Premolar
Upper□B□□□□□□□□P□□□□□□□□□□□□□□Premolar
Upper□B□□□2□2□□□P□□1□□1□□□□□□□□□□Premolar
Upper□B□□□1□1□□□P□□□□□□□□□□□□□□Premolar
Lower□□□□□□□□□□□□□□□□Premolar Lower□□□□2□2□□□□□□□□□□Premolar
Lower□□□□1□1□□□□□□□□□□Canine Upper□□□□□□□□□□□□□□□□Canine
Lower□□□□□□□□□□□□□□□□Central Upper□□□□□□□□□□□□□□□□Central
Lower□□□□□□□□

Table 3.20: Lateral Canals of Group B (EndoREZ Technique).

Tooth□Canal□**Coronal**□**Midroot**□**Apical**□**Score**□□□□□□□□□□Molar Upper□MB
1□□□1□1□□□MB 2□□□□□□□□BD□□□□□□□□P□□□□□□□□□□□□□□Molar
Lower□MB□□□□□□□□ML□□□□□□□□D□□1□□1□□□□□□□□□□Premolar
Upper□B□□□□□□□□P□□□□□□□□□□□□□□Premolar
Upper□B□□0□□0□□□P□□1□□1□□□□□□□□□□Premolar
Upper□B□□□□□□□□P□□□2□2□□□□□□□□□□Premolar
Lower□□□□□□□□□□□□□□□□Premolar Lower□□□□1□1□□□□□□□□□□Premolar
Lower□□□□□□□□□□□□□□□□Canine Upper□□□2,0□0□2,0,0□□□□□□□□□□Canine
Lower□□□□0□0□□□□□□□□□□Central Upper□□□0□□0□□□□□□□□□□Central
Lower□□□□□□□□

Table 3.21: Lateral Canals of Group C (System B/Obtura Technique).

Tooth□Canal□**Coronal**□**Midroot**□**Apical**□**Score**□□□□□□□□□□Molar Upper□MB
1□□1□□1□□□MB 2□□□□□□□□BD□□□□□□□□P□□□□□□□□□□□□□□Molar
Lower□MB□□□□□□□□ML□□□□□□□□D□□□1□1□□□□□□□□□□Premolar
Upper□B□0□□□0□□□P□□□□□□□□□□□□□□Premolar
Upper□B□□□1□1□□□P□□□□□□□□□□□□□□Premolar
Upper□B□□□0□0□□□P□□□□□□□□□□□□□□Premolar
Lower□□□□□□□□□□□□□□□□Premolar Lower□□□□□□□□□□□□□□□□Premolar

Lower□□□□0□0□□□□□□□□□□Canine Upper□□□0□□0□□□□□□□□□□Canine Lower□□□□□□□□□□□□□□□Central Upper□□□□□□□□□□□□□□□Central Lower□□□□□□□□

Table 3.22: Lateral Canals of Group D (Thermafil Technique).

Tooth□Canal□**Coronal**□**Midroot**□**Apical**□**Score**□□□□□□□□□□Molar Upper□MB 1□□□□□□□□MB 2□□□□□□□□BD□□□□□□□□P□□1□□1□□□□□□□□□□Molar Lower□MB□□□□□□□□ML□□□□□□□□D□□□1□1□□□□□□□□□□Premolar Upper□B□□□□□□□□P□□1□□1□□□□□□□□□□Premolar Upper□B□□2□□2□□□P□□□□□□□□□□□□□□Premolar Upper□B□□1□□1□□□P□□□□□□□□□□□□□□Premolar Lower□□□□□□□□□□□□□□□Premolar Lower□□□□□□□□□□□□□□□Premolar Lower□□□1□□1□□□□□□□□□□Canine Upper□□□□□□□□□□□□□□□Canine Lower□□□□2□2□□□□□□□□□□Central Upper□□□□□□□□□□□□□□□Central Lower□□1□□□1□□

Table 3.23: Mean, Standard Deviation and Coefficient of Variance of lateral canals filled with Hybrid Root SEAL, EndoREZ, System B/OPbtura techniques and Thermafil.

□**Hybrid Root SEAL**□**EndoREZ**□**System B**□**Thermafil**□□**Mean**□1.3333□0.7273□0.8571□1.3750□□**Standard Deviation**□0.5164□.07862□1.4639□1.0607□□**Coefficient of Variance**□38.730□108.11□170.78□77.139□□

Table 3.24: Significance of difference between the mean values (Table 3.21) of lateral canals filled with Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques.

□**Hybrid Root SEAL**□**EndoREZ**□**System B**□**Thermafil**□□Hybrid Root **SEAL**□□**p>0,05**□**p>0,05**□**p>0,05**□□EndoREZ□□□**p>0,05**□**p>0,05**□□System **B**□□□□p>0,05□□**Thermafil**□□□□□□

□

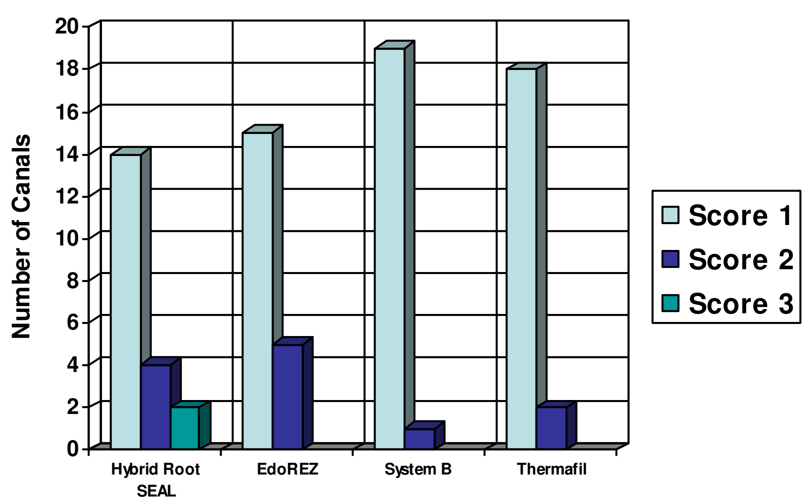


Figure 3.1: Radiographic evaluation of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques in the coronal aspects of the root canals.

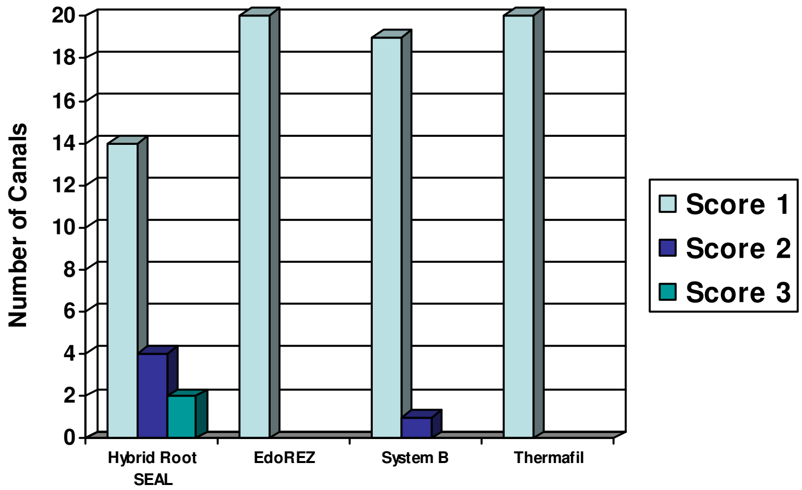


Figure 3.2: Radiographic evaluation of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques in the apical aspects of the root canals.

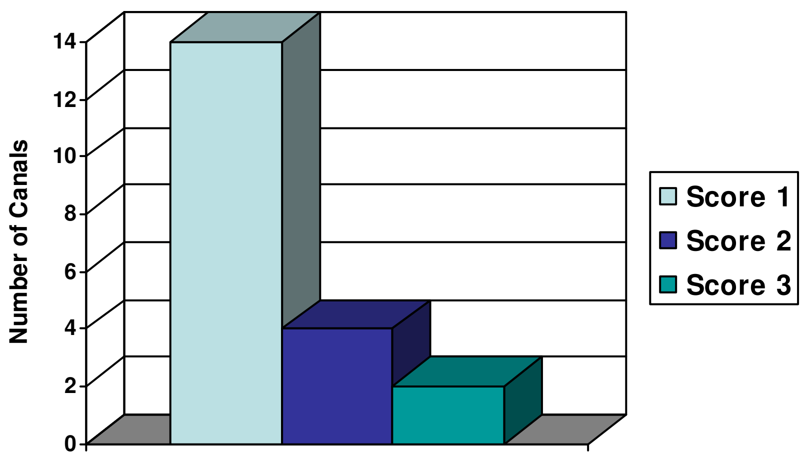


Figure 3.3: Radiographic evaluation of Hybrid Root SEAL technique specimens in the coronal aspects of the root canals.

Figure 3.4: The quality of obturation of one of the Hybrid Root SEAL technique specimens that were well condensed with no areas of radiolucency (Score 1).

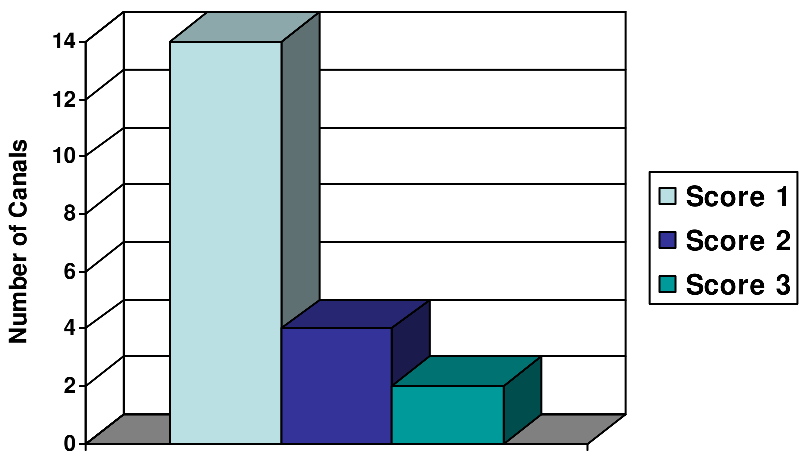


Figure 3.5: Radiographic evaluation of Hybrid Root SEAL technique specimens in the apical aspects of the root canals.

Figure 3.6: A Hybrid Root SEAL technique specimen (upper premolar) that illustrated irregularities of less than 1mm (Score 2) in the coronal aspect of the buccal canal (arrow right) and the apical aspect (arrow left) of the palatal canal.

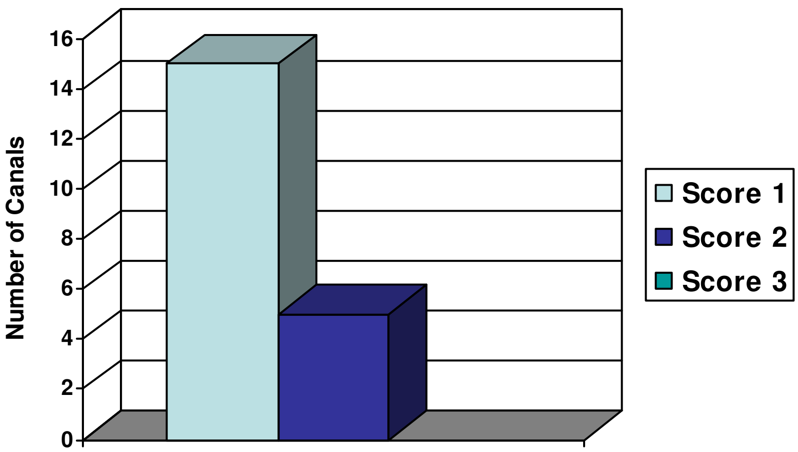


Figure 3.7: Radiographic evaluation of EndoREZ technique specimens in the coronal aspects of the root canals.

Figure 3.8: An EndoREZ technique specimen (upper premolar) that illustrates irregularities of less than 1mm (Score 2) in the coronal aspects (arrow) of the buccal and palatal canals.

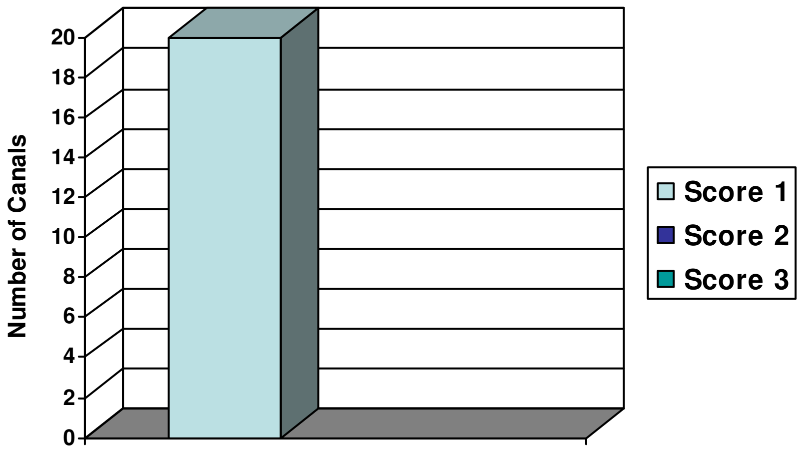


Figure 3.9: Radiographic evaluation of EndoREZ technique specimens in the apical aspects of the root canals.

Figure 3.10: An example of an EndoREZ technique specimen (upper first molar) that was well condensed with no areas of radiolucency in all four root canals (Score 1).

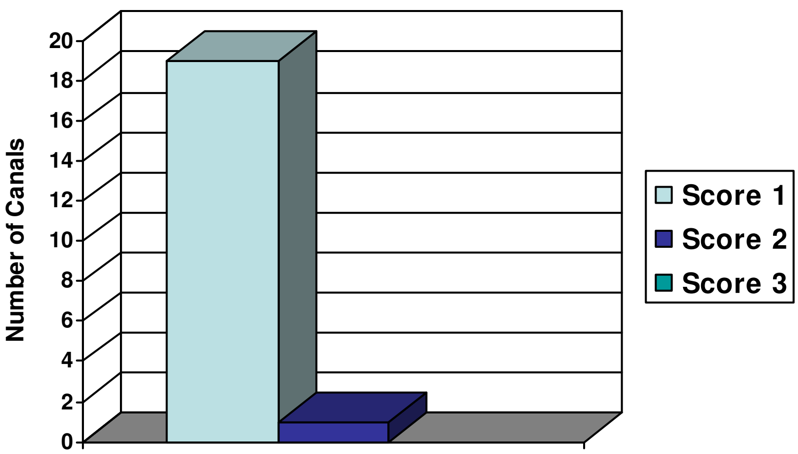


Figure 3.11: Radiographic evaluation of System B/Obtura technique specimens in the coronal and apical aspects of the root canals.

Figure 3.12: The quality of obturation of a System B/Obtura technique specimen. All three root canals in this lower first molar were well condensed with no areas of radiolucency (Score 1).

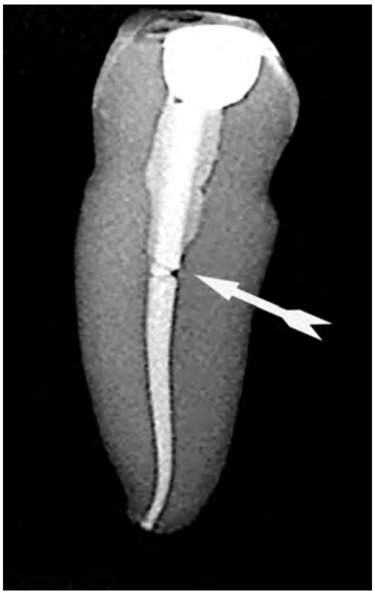


Figure 3.13: System B/Obtura technique specimen with an imperfect root filling (Score 2) in the coronal aspect (arrow) of a lower canine.

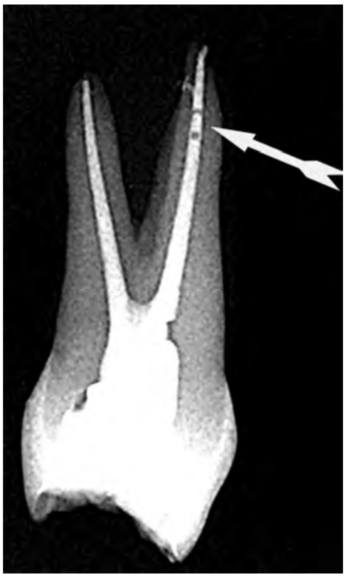


Figure 3.14: System B/Obtura technique specimen with an imperfect root filling (Score 2) in the apical aspect (arrow) of the buccal canal of a maxillary premolar.

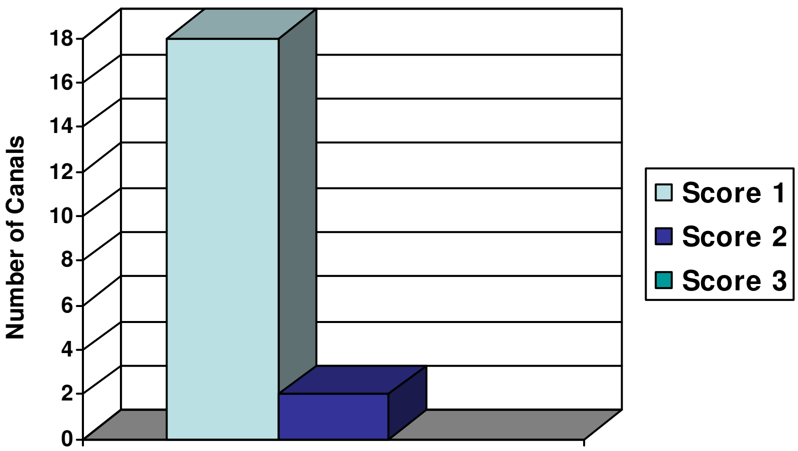


Figure 3.15: Radiographic evaluation of Thermafil technique specimens in the coronal aspects of the root canals.

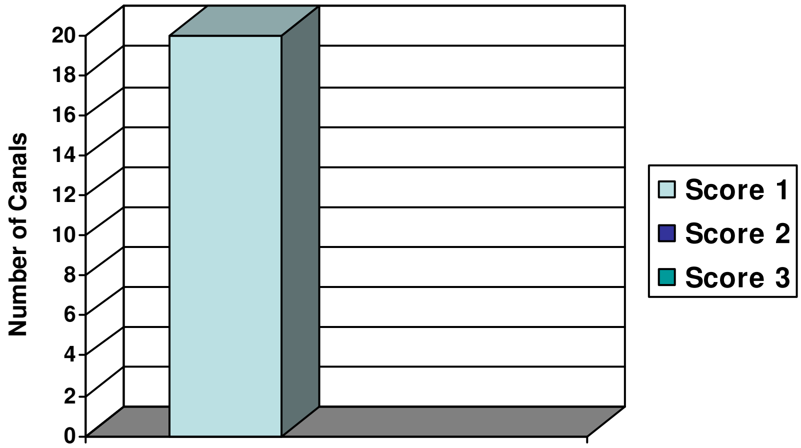


Figure 3.16: Radiographic evaluation of Thermafil technique specimens in the apical aspects of the root canals.

Figure 3.17: An example of a Thermafil technique specimen (upper first premolar) that was well condensed with no areas of radiolucency in the buccal and palatal root canals (Score 1).

Figure 3.18: A Thermafil technique specimen (upper central) that illustrates irregularities of less than 1mm (Score 2) in the coronal aspect (arrow) of the root canal. No irregularities were evident in the apical aspect of the root canal (Score 1).

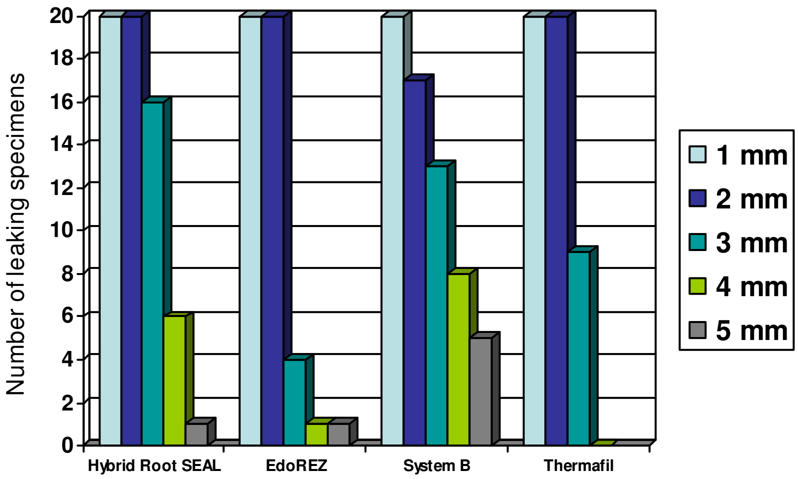


Figure 3.19: Apical leakage of Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques in the apical aspects of the root canals.

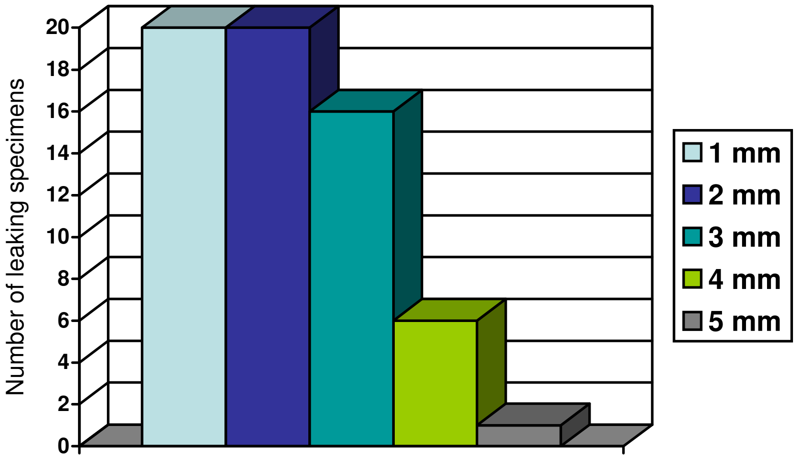


Figure 3.20: Apical leakage of Hybrid Root SEAL technique specimens in the apical aspects of the root canals.

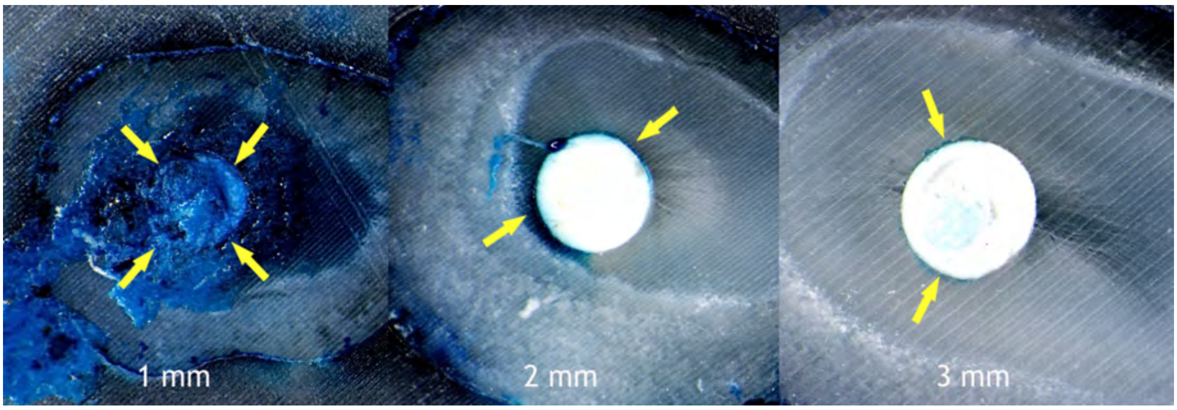


Figure 3.21: An example of a root canal (premolar) obturated with Hybrid Root SEAL technique, that showed apical leakage (arrows) up to 3 mm from the apical foramina (5X magnification).

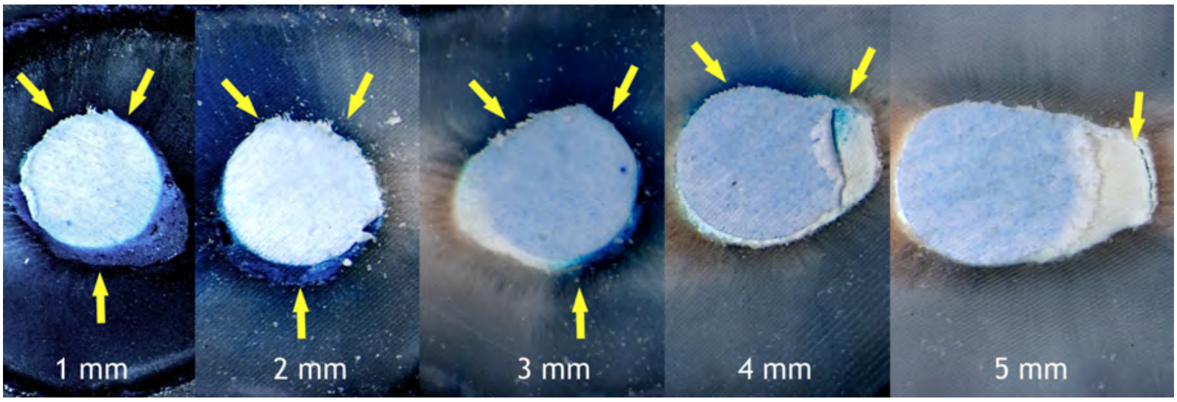


Figure 3.22: An example of one of the root canals (upper canine) obturated with Hybrid Root SEAL technique that illustrated apical leakage (arrows) up to 5 mm from the apical foramina (5X magnification).

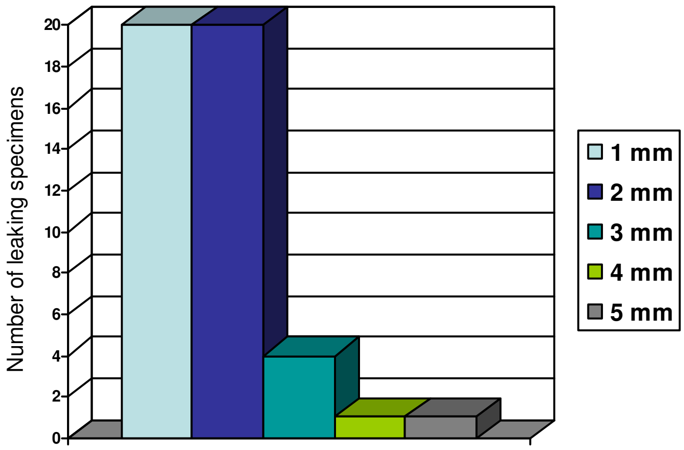


Figure 3.23: Apical leakage of EndoREZ technique specimens in the apical aspects of the root canals.

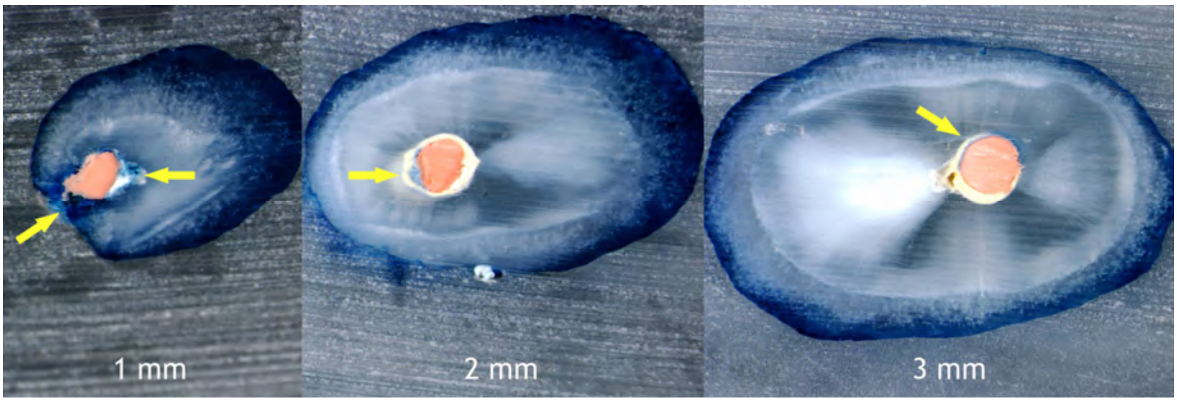


Figure 3.24: Specimen that was obturated with EndoREZ technique. Apical leakage (arrows) was evident up to 3 mm from the apical foramina (5X magnification).

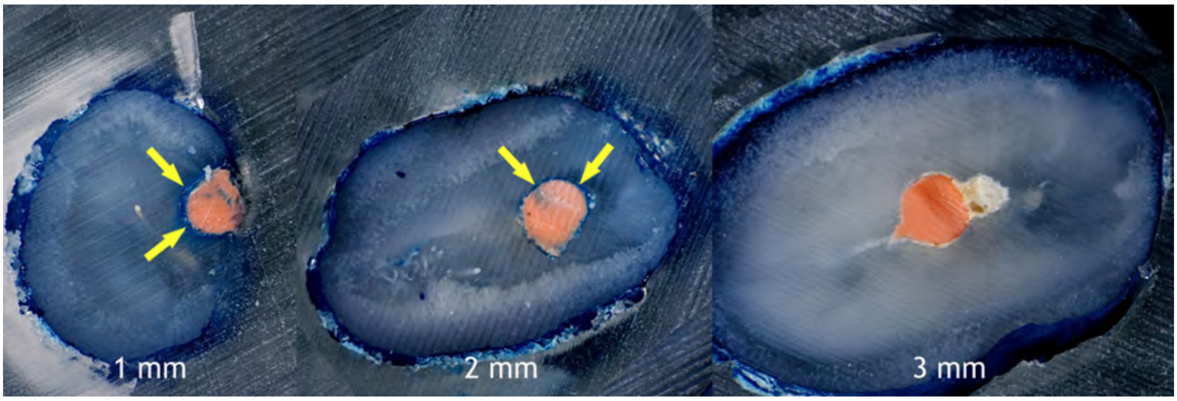


Figure 3.25: Specimen that was obturated with EndoREZ technique. Apical leakage (arrows) was only visible up to 2 mm from the apical foramina (5X magnification).

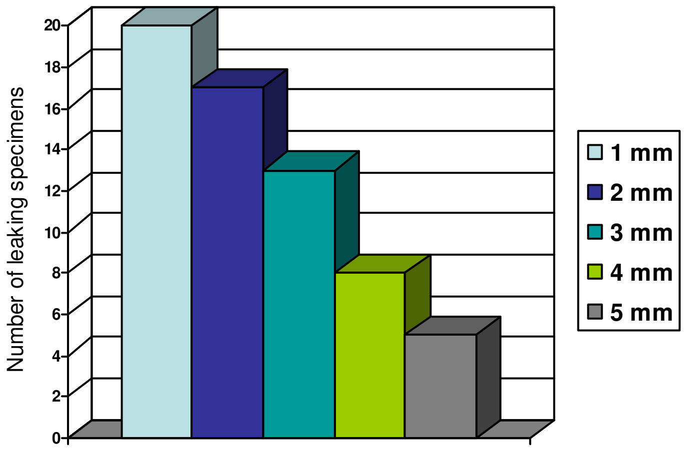


Figure 3.26: Apical leakage of System B/Obtura technique specimens in the apical aspects of the root canals.

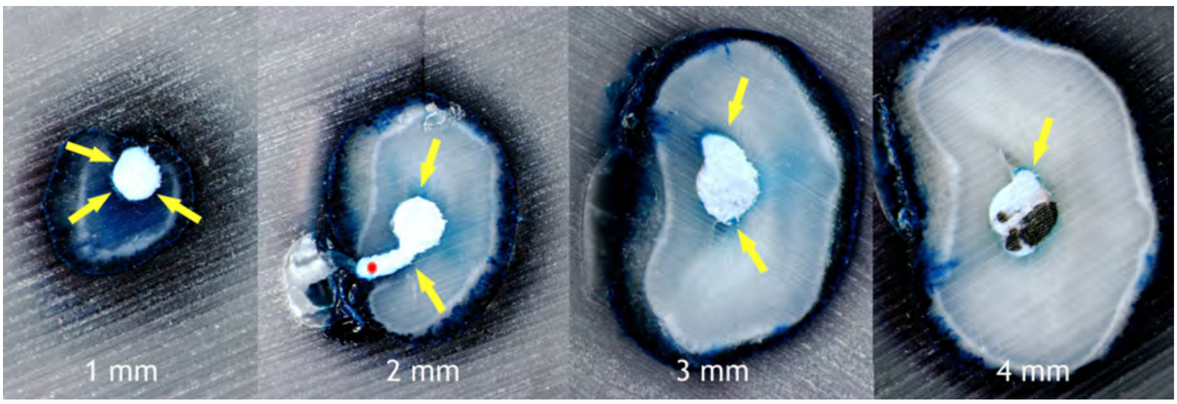


Figure 3.27: An example of a specimen obturated with System B/Obtura technique that demonstrated apical leakage (arrows) up to 4 mm from the apical foramina (5X magnification).

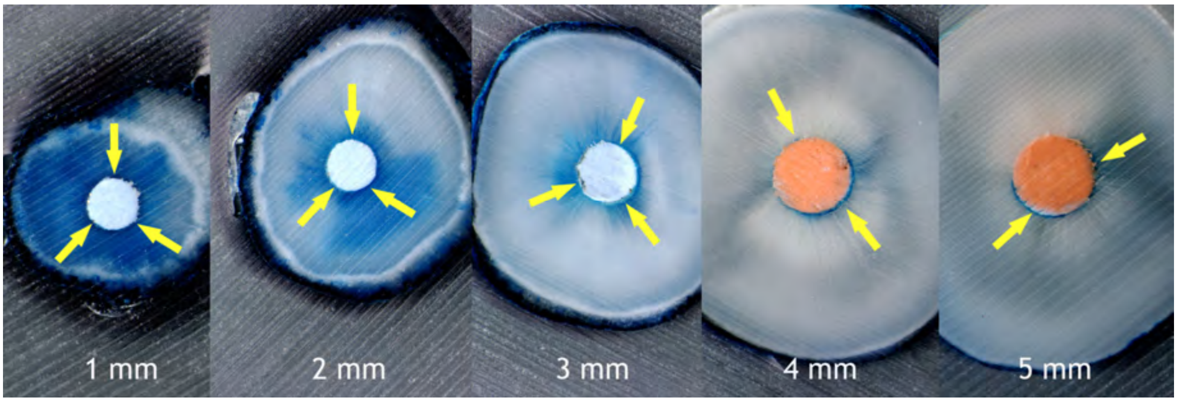


Figure 3.28: An example of a specimen obturated with System B/Obtura technique that demonstrated apical leakage (arrows) up to 5 mm from the apical foramina (5X magnification).

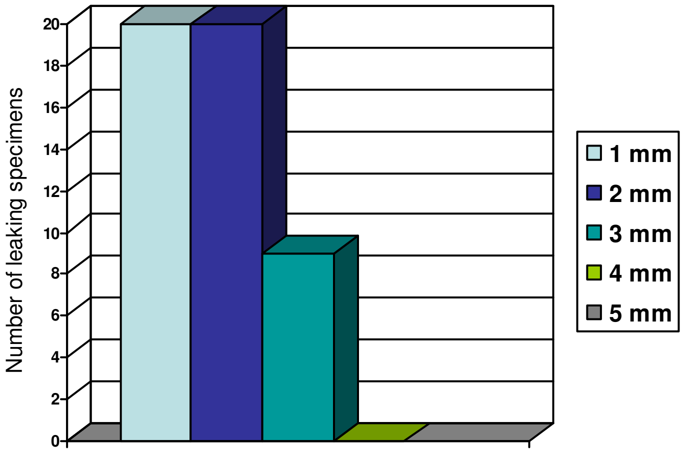


Figure 3.29: Apical leakage of Thermafil technique specimens in the apical aspects of the root canals.

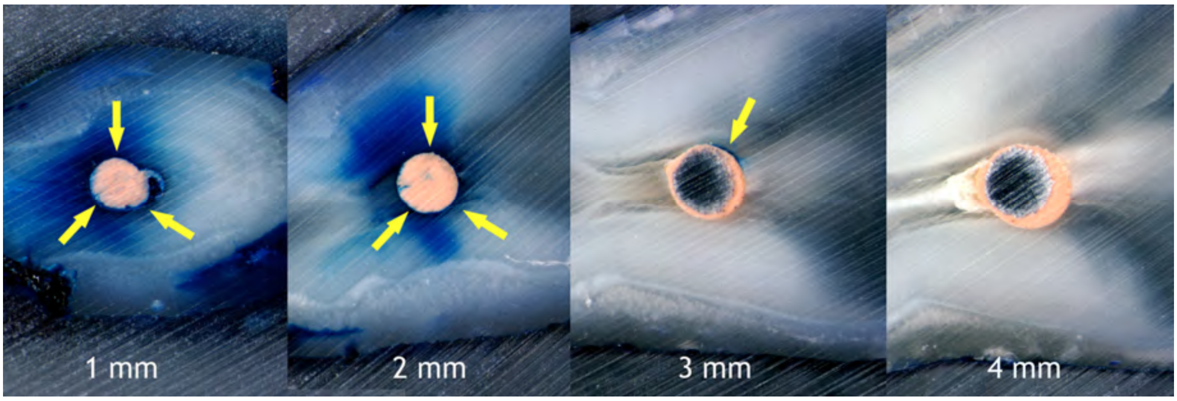


Figure 3.30: An example of a specimen obturated with Thermafil technique that showed apical leakage (arrows) up to 3 mm from the apical foramina (5X magnification).

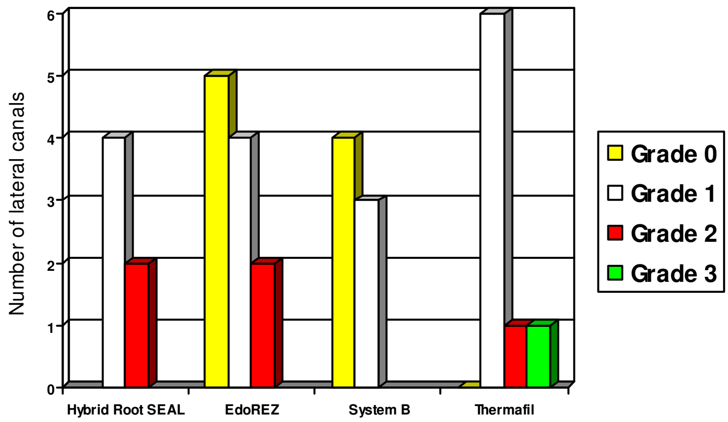


Figure 3.31: Number of lateral canals obturated with Hybrid Root SEAL, EndoREZ, System B/Obtura and Thermafil techniques.

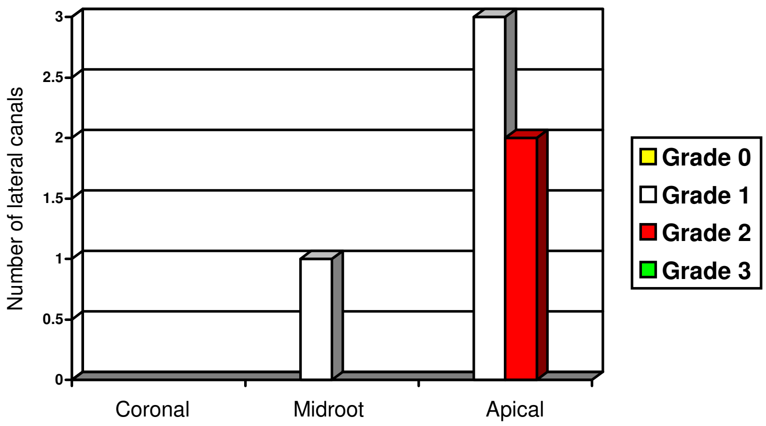


Figure 3.32: Number of lateral canals obturated with Hybrid Root SEAL technique in the coronal, midroot and apical aspects of the root canals.

Figure 3.33: A stereomicroscopic view (2.5X magnification) of a palatal root of an upper premolar that was obturated with gutta-percha and Hybrid Root SEAL cement. Note the presence of an apical lateral canal (Grade 1) (white arrow).

Figure 3.34: A stereomicroscopic view (5X magnification) of a buccal root of an upper premolar where the Hybrid Root SEAL cement obturated the entire length of the apical lateral canal (Grade 2) (red arrow).

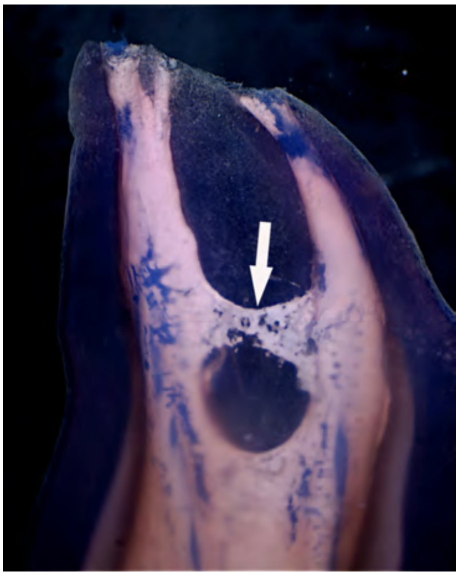


Figure 3.35: A stereomicroscopic view (5X magnification) of the root of an upper premolar where the root canals were obturated with Hybrid Root SEAL cement. A lateral canal (Grade 1) (white arrow) was observed in the midroot aspect.

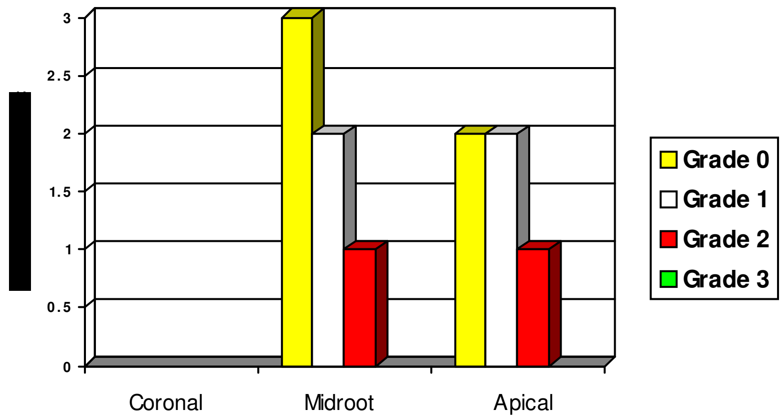


Figure 3.36: Number of lateral canals obturated with EndoREZ technique in the coronal, midroot and apical aspects of the root canals.

Figure 3.37: A stereomicroscopic view (2.5X magnification) of a palatal root of an upper premolar. Note the apical lateral canal that was completely filled with EndoREZ cement (Grade 2) (red arrow).

Figure 3.38: A stereomicroscopic view (2.5X magnification) of an upper canine that was obturated with gutta-percha and EndoREZ cement with the presence of three lateral canals.

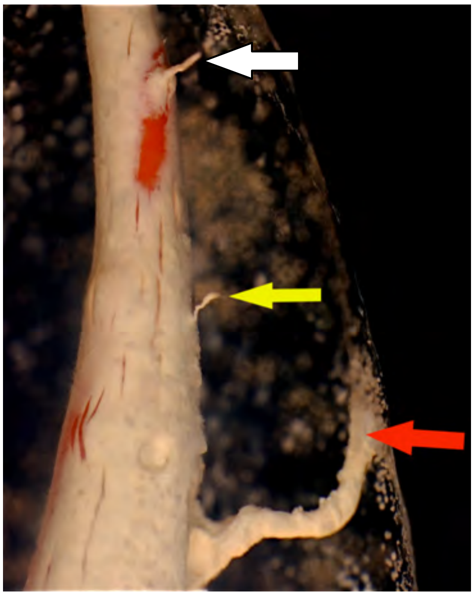


Figure 3.39: On higher magnification (5X magnification) it is clearly visible that there was a large lateral canal (Grade 2) (red arrow), followed by a narrower lateral canal (Grade 0) (yellow arrow) in the midroot area. Also visible on this magnified view is the apical lateral canal (Grade 0) (white arrow).

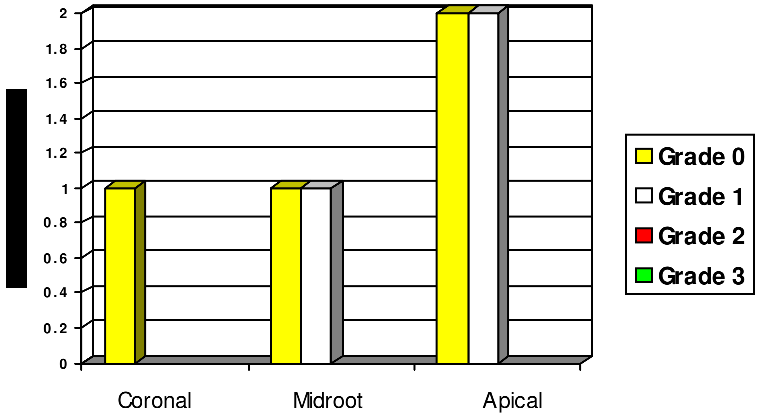


Figure 3.40: Number of lateral canals obturated with System B/Obtura technique in the coronal, midroot and apical aspects of the root canals.

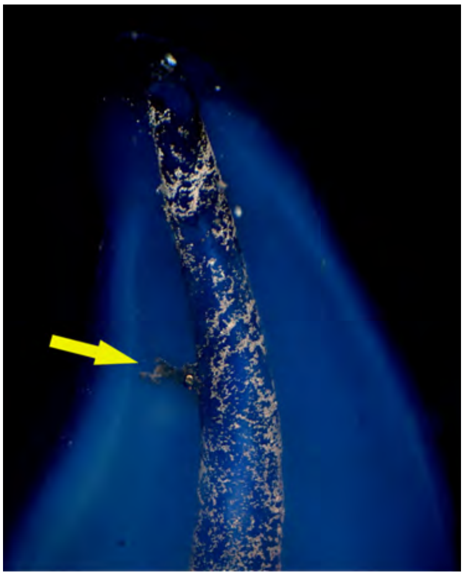


Figure 3.41: A stereomicroscopic view (2.5X magnification) of the root of an upper canine that was obturated with the System B/Obtura technique. Note the presence of a midroot lateral canal (yellow arrow).

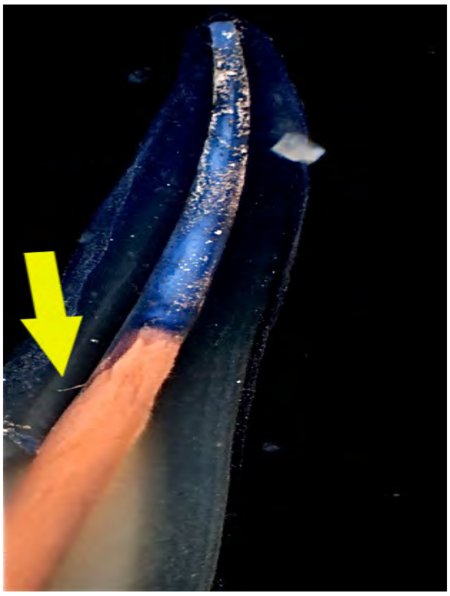


Figure 3.42: A stereomicroscopic view (2.5X magnification) of the buccal root of an upper premolar that was obturated with Thermafil technique. Note the lateral canal (Grade 0) (yellow arrow) in the coronal aspect of the root canal.

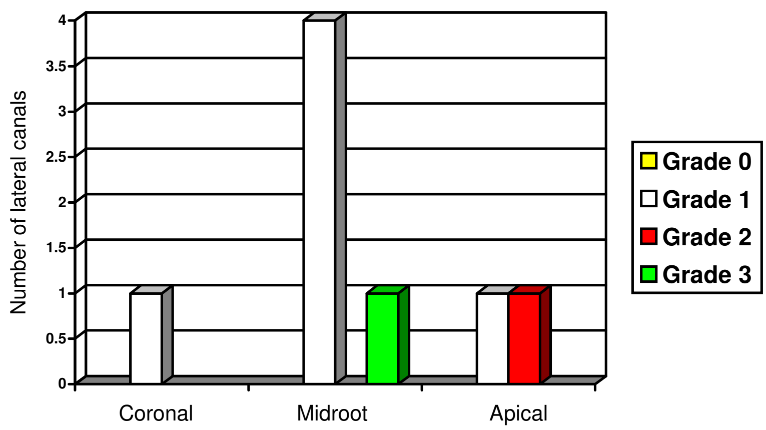


Figure 3.43: Number of lateral canals obturated with Thermafil technique in the coronal, midroot and apical aspects of the root canals.

Figure 3.44: A stereomicroscopic view (2.5X magnification) of the root canal of a lower canine. Note the presence of an apical lateral canal that was completely filled with cement and gutta-percha to less than 50 percent of the total canal length (Grade 2) (red arrow).

Figure 3.45: A stereomicroscopic view (2.5X magnification) of the buccal and palatal roots of an upper premolar that was obturated with Thermafil technique. Note the presence of a midroot lateral canal that was completely filled with cement and gutta-percha to less than 50 percent of the total canal length (Grade 2) (red arrow).

CHAPTER 4

DISCUSSION

It is well known that bacteria are the primary source of persistent periradicular inflammation and endodontic failure. Once the root canal has been adequately debrided, shaped and disinfected, the final objective of the endodontic procedure is to obtain a three-dimensional obturation of the root canal space with a fluid-tight seal of the apical foramen (Shabanang, 2005).

The objectives of this *in vitro* study were to evaluate four different root canal obturation techniques in respect of the radiographic quality of root canal obturation, apical leakage and the potential of these techniques to obturate lateral canals.

4.1. **Radiographic Evaluation**

The radiopacity of gutta-percha points used in endodontic treatment was evaluated by Katz et al., (1990) and it was verified that the average radiopacity of the points was approximately the same as 7.4 mm aluminum. The radiopacity of root canal sealers were compared by McComb and Smith (1976) and it was concluded that the radiopacity of resin-based sealers is higher than zinc oxide eugenol-based sealers.

In the radiographic evaluation of the obturation quality in the present study, Hybrid Root Seal technique resulted in the poorest obturation quality, coronally and apically. Many voids were observed in the obturations and these irregularities are directly related to the difficulty of placement of Hybrid Root Seal in the prepared canals. This is contrary to the findings made by Beli et al., (2008).

In the coronal aspects of the root canals the System B/Obtura technique gave the best results. This can be explained due to the fact that backfilling of the root canals was done with Obtura II thermoplasticized injectable technique after the initial downpack was done with System B. The gutta- percha delivered by the Obtura II unit resulted in a solid gutta-percha mass that was well adapted to canal walls. This finding is in agreement with research done by Weller et al., (1997) where they compared the ability of Thermafil obturators, Obtura II thermoplasticized injectable technique and the lateral condensation technique to obturate a standard root canal. They concluded that the Obtura II thermoplasticized injectable technique demonstrated the best adaptation to the prepared root canal, followed by Thermafil and finally by the lateral condensation technique. In the present study the Thermafil technique also produced the second best results concerning adaptation in the coronal aspects of the root canals.

The EndoREZ and Thermafil techniques resulted in the best obturation quality in the apical aspects of the root canals. In a clinical follow-up study Zmener and Pameijer (2007) showed that 92 out of 120 teeth obturated with EndoREZ were rated to be adequately filled after 5 years.

The excellent obturation quality obtained by the Thermafil technique specimens in the apical aspects of the root canals can be attributed to the fact that the plastic core of the obturator compressed the alpha–phase gutta-percha and cement into a homogeneous mass. Characteristics of alpha–phase gutta-percha also includes elevated radiopacity and excellent viscosity and flow (Johnson, 1978) that could have contributed to the results obtained in the present study.

The statistical analysis of the radiographic evaluation of the obturation quality of the coronal aspects in the present study demonstrated a statistically significant difference between System B/Obtura and Hybrid Root SEAL techniques ($p<0.05$). In the apical aspects there was a statistically significant difference ($p<0.05$) between the Hybrid Root SEAL technique and all the other obturation techniques.

4.2. **Apical Leakage**

It is not possible by means of a radiograph to fully assess the seal established during obturation, and it is important to remember that no material or technique will prevent leakage or maintain a long-term apical seal (Ainley, 1970; Gutmann and Hovland, 1997; Machtou, 2006).

Obturation can only be complete by using a sealer in conjunction with a core material such as gutta-percha (Wu et al., 2000). Clinical studies addressing the causes of endodontic failure established that incomplete obturation accounted for many of these, and an *in vitro* study indicated that incomplete obturation caused microleakage (Adenubi and Rule, 1976).

In the present study the System B/Obtura technique presented with the most apical leakage as compared with all the other groups. However, there was only a statistically significant ($p<0.05$) difference in apical leakage when System B technique was compared with EndoREZ and Thermafil techniques technique. There was no significant difference between System B/Obtura and Hybrid Root SEAL techniques ($p>0.05$).

Pommel and Camps (2001) examined the *in vitro* apical leakage of System B as compared with other filling techniques. In their study System B was found to be as effective as either vertical condensation or the Thermafil technique. Inan et al., (2007) compared the leakage of lateral condensation in System B and Thermafil techniques by using electro-chemically and dye penetration methods. In this study the lowest mean leakage values were observed with Thermafil and the highest were observed for the cold lateral condensation technique. System B obturations showed a moderate amount of apical leakage in their study.

It is important to note that in the present study a selection of different teeth was used for each obturation group. This variation may have influenced the results of this *in vitro* study. If one looks at the apical leakage results of the System B/Obtura technique (Table 3.15) it is evident that teeth with single, round canals and straight root canals demonstrated less apical leakage as compared with teeth presenting with more complex root canal systems. However, this observation was not as significant on the apical leakage results for the other groups tested in this study (Tables 3.14, 3.15 and 3.16). In a study by De-Deus et al., (2007) they demonstrated that the System B technique results in lower gutta-percha-filled areas in the apical aspects of root canals as compared with the Thermafil technique. Samples in their study with oval or flattened canals demonstrated a poor filling when System B was used and that only the Thermafil technique was efficient in filling irregular root canal forms.

The Hybrid Root SEAL technique illustrated the second most apical leakage in the present study. Results for this new dual-cure self-etching resin cement were very disappointing. Hybrid Root SEAL contains 4-META that is well known for its ability to promote monomer diffusion into the acid-conditioned and intact underlying dentine, in order to produce a hybrid layer (Nakabayashi et al., 1982). According to the author's knowledge only one other research paper has been published on the sealing ability of this root canal cement. In this study the long-term sealing ability of Hybrid Root SEAL was compared with RealSeal and AH Plus sealers (Belli et al., 2008). It was concluded that Hybrid Root SEAL showed similar sealing properties to those of RealSeal or AH Plus when used with either gutta-percha or Resilon cones after 24 weeks.

The best apical seal in the present study was obtained by the EndoREZ technique. However, there was no statistical significant difference between the mean apical leakage scores of EndoREZ and Thermafil techniques ($p>0.05$).

In a study done by Zmener and Pameijer (2005) where EndoREZ as compared with Grossman's sealer, EndoREZ also presented with the least amount of apical leakage. In a more recent study by Gernhardt et al., (2007) EndoREZ was compared with another epoxy resin-based sealer (AH Plus) using the lateral condensation, warm vertical and Thermafil techniques. The results indicated that the sealing ability of EndoREZ is not as effective as that of AH Plus. However, the authors suggested that when EndoREZ is used with the warm vertical condensation or Thermafil techniques it might decrease the risk of apical leakage.

In the present study the Thermafil technique also obtained very low apical leakage values. Despite the fact that there were no statistical significant differences between the mean apical leakage scores of Thermafil and EndoREZ techniques, it must be noted that there was only apical leakage up to the 3mm level from the apical foramina in all the specimens of this group. EndoREZ specimens demonstrated a slightly lower mean apical leakage value but some of the specimens illustrated leakage up to the 5mm level from the apical foramina.

As previously mentioned, the study by De-Deus et al., (2007) demonstrated that the Thermafil technique can produce higher gutta-percha filled areas in the apical aspects of root canals as compared with the lateral condensation or System B techniques. This phenomenon is very evident if one considers the apical cross-sections of the Thermafil specimens in the present study (Fig. 3.30). There was a more homogenous mass which included only gutta-percha or gutta-percha and plastic carrier surrounded by a very thin uniform layer of root canal cement around the perimeter of the canal. All specimens of the other obturation techniques in this study demonstrated a central mass of gutta-percha surrounded by a thicker layer of root canal cement. Restricting the sealer to a thin layer, uniformly distributed around a solid mass of gutta-percha has been the aim of recent investigations (De-Deus et al., 2007). It can be speculated that the thicker the layer of root canal cement between the gutta-percha and the canal wall, the higher the amount of apical leakage (Kontakiotes et al., 1997).

4.3. **Lateral Canals**

The potential pathogenicity of unfilled lateral canals was demonstrated in a number of studies (Venturi et al., 2005) due to the fact that healing of periradicular lesions occurred after lateral canals were successfully filled. It was also showed that there is no correlation between unfilled lateral canals and inflammation of the periodontal ligament (Barthel et al., 2004).

Many studies have compared different obturation techniques and their ability to fill lateral canals (Himmel and Cain, 1993; Schilder, 1983; Clark and El Deeb, 1993). However, to date no study could be found in literature reporting on the incidence of lateral canals filled by Hybrid Root SEAL or EndoREZ root canal cements.

The modified tooth-clearing technique as used in this study was performed by using a weak acid solution and sodium as a buffering agent. According to Venturi et al., 2003, the additional step of immersing the specimens in acetic acid improves the quality of the dentine matrix due to its capabilities of fixing organic components. A disadvantage of using a weak acid for this technique was that it took more time for specimen preparation. The advantage of using this technique was that a high level of transparency was achieved that clearly demonstrated the morphology of the root canal systems.

All four obturation techniques in this study caused filling of lateral canals with sealer, gutta-percha or a combination of both. The stereomicroscope that was used in this study allowed the examiners to visualize very small lateral canals in some of the specimens.

The specimens that were obturated with the Thermafil technique demonstrated the greatest number of filled lateral canals, followed by the

Hybrid Root SEAL, System B/Obtura and then the EndoREZ techniques. It is important to note that there was no statistical significant difference ($p<0.05$) between the number of lateral canals filled by Thermafil technique compared with all the other obturation techniques.

In the Thermafil technique most of the filled lateral canals was present in the midroot area. The majority of the lateral canals in this group were filled with cement to less than 10 percent of their total length (Grade 1). However, one of the Thermafil technique specimens also demonstrated a lateral canal that was partially filled with gutta-percha up to 20 percent of the total canal length (Grade 2). Clark and El Deeb (1993) demonstrated that the heated gutta-percha around the plastic obturator has the potential to fill lateral and accessory canals. However, Pathomovich and Edmunds (1996) in their study found that with the Thermafil technique only sealer penetrated into accessory canals without any evidence of gutta-percha.

The lateral canals that were filled with the Hybrid Root SEAL technique were either partially filled with cement without the presence of gutta-percha (Grade 1) or completely filled with cement without the presence of gutta-percha (Grade 2). In this group most of the lateral canals that were filled were present in the apical aspect of the root canals.

Specimens in the EndoREZ technique group demonstrated a high percentage of lateral canals that were filled with cement to less than 10 percent of the total canal length (Grade 0). The remaining canals were partially filled (Grade 1) or completely filled (Grade 2) with cement without the presence of gutta-percha. In this group there were more or less an equal number of lateral canals in the midroot and apical aspects of the root canals.

The results that were obtained from the Hybrid Root SEAL and EndoREZ technique groups is to be expected from these techniques since they are both single cone techniques and therefore only the root canal cement has the potential to penetrate into the lateral canals.

In the System B/Obtura technique group most of the lateral canals that were filled were present in the apical aspects of the root canals. Most of the lateral canals in this group were partially filled with cement without gutta-percha (Grade 1). Buchanan (1994) reported that the continuous wave of condensation can fill lateral and accessory canals. The results of the present study indicated that most of the lateral canals were only filled with cement and not gutta-percha.

The clinical relevance of the results of this *in vitro* study must be viewed with caution because the results cannot directly be clinically extrapolated. A selection of different teeth was used in each group of this study in order to obtain a more representative sample size. However, a major clinical variable in this study was the extent of anatomical differences that exist between the different teeth as well as the presence or absence of lateral canals. Further clinical studies are needed to determine whether these materials and obturation techniques will have an influence on the final success of endodontic therapy.

CHAPTER 5

CONCLUSIONS

5.1 Radiographic Evaluation

- The Hybrid Root SEAL technique demonstrated a statistically significant higher number of radiographic defects in the coronal aspects of the root canals when compared to the System B/Obtura and Thermafil techniques ($p<0.05$).
- There was no statistically significant difference between the radiographic defects in the coronal aspects of the root canals between the Hybrid Root SEAL and EndoREZ techniques ($p>0.05$).
- The Hybrid Root SEAL technique demonstrated a statistically significantly higher number of radiographic defects in the apical aspects of the root canals compared to all the other obturation techniques ($p<0.05$).

5.2 Apical Leakage

- The specimens that were obturated with the EndoREZ technique demonstrated the least apical leakage compared to all the other obturation techniques tested in this study. However, there was only a statistically significant difference when the EndoREZ technique was compared to the Hybrid Root SEAL and System B/Obtura techniques ($p<0.05$).
- The specimens that were obturated with the System B/Obtura technique demonstrated the most apical leakage compared to all the other obturation techniques tested in this study. However, there was only a statistically significant difference when the System B/Obtura technique was compared to the EndoREZ and Thermafil techniques ($p<0.05$).

5.3 **Lateral Canals**

- The Thermafil technique demonstrated the greatest number of filled lateral canals. However, there was no statistically significant difference between the Thermafil technique and all the other obturation techniques ($p<0.05$).

CHAPTER 6

REFERENCES

Adenubi JO and Rule DC (1976) Success rates of root fillings in young patients. *Br Dent J* **141,** 237-241

Ainley JF (1970) Fluorometric assay of the apical seal of root canal fillings. *Oral Surg Oral Med Oral Pathol* **29**, 753-762

Allan NA, Walton RC and Schaffer MA (2001) Setting times for endodontic sealers under clinical usage and *in vitro* conditions. *J Endod* **27**, 421-423

Aguirre AM el-Deeb ME and Aguirre R (1997) The effect of ultrasonics on sealer distribution and sealing of root canals. *J Endod* **23,** 759-764

Augsburger RA and Peters DD (1990) Radiographic evaluation of extruded obturation materials. *J Endod* **16,** 492-497

Ayhan H, Sultan N, Cirak M, Ruhi MZ and Bodur H (1999) Antimicrobial effects of various endodontic irrigants on selected microorganisms. *Int Endod J* **32**, 99-102

Barthel CR, Zimmer S and Trope M (2004) Relationship of radiologic and histologic signs of inflammation in human root-filled teeth. *J Endod* **30**, 75-79

Baumgartner JC and Mader CL (1987) A scanning electron microscopic evaluation of four root canal irrigation regiments. *J Endod* **13**, 147-157

Belli S, Ozcan E, Derinbay O and Eldeniz Au (2008) A comparative evaluation of sealing ability of a new, self-etching, dual-curable sealer: Hybrid Root SEAL (MetaSEAL). *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* **106**, 45-52

Blum JY, Machtou P, Micallef JP (1998a) Analysis of forces developed during obturations. Wedging effect Part I. *J Endod* **24**, 217-222

Blum JY, Machtou P, Micallef JP (1998b) Analysis of forces developed during obturations. Wedging effect Part II. *J Endod* **24,** 223-228

Bowman CJ and Baumgartner JC (2002) Gutta-percha obturation of lateral grooves and depressions. *J Endod* **28,** 220-223

Brady JM and del Rio CE (1975) Corrosion of endodontic silver cones in humans: a scanning electron microscope and X-ray microprobe study. *J Endod* **1**, 205-210

Brothman P (1981) A comparative study of the vertical and the lateral condensation of gutta-percha. *J Endod* **7**, 27-30

Brown DC, Moore BK, Brown CE, Newton CW (1995) An *in vitro* study of apical extrusion of sodium hypochlorite during endodontic canal preparation. *J Endod* **21,** 587-591

Buchanan LS (1994) The art of endodontics laboratory course manual. Dental Education Laboratories, Santa Barbara, CA

Buchanan LS (1998) Continuous wave of condensation technique. *Endod Prac)* **1**, 7-10

Cantatore G (2001) "Thermafil versus System B". *Endodontic Practice,* December 6

Cantatore G and Cochet JY (1998) "Le système Thermafil". *Endo Rev Franc Endod* **17,** 35-36

Castelli WA, Caffesse RG, Pameijer CH, Diaz-Perez R, Farquhar J (1991) Periodontaium response to a root canal condensing device (Endotec). *Oral Surge Oral Med Oral Pathol* **71**, 333-337

Castellucci A (2005a) *Endodontics Volume I*. (Eds) Il Tridente, Florence, Italy

Castellucci A (2005b) *Endodontics Volume II*. (Eds) Il Tridente, Florence, Italy

Chapman C (1969) A microscopic study of the apical region of the human anterior teeth *J Br Endod Soc* **3**, 52

Clark DS and El Deeb ME (1993) Apical sealing ability of metal versus plastic carrier Thermafil obturators. *J Endodon* **19,** 4-9

Cohen BI, Pagnillo MK, Musikant BL and Deutsch AS (1998) The evaluation of apical leakage for three endodontic fill systems. *Gen Dent* **Nov-Dec**: 46, 618-623

Cohen S and Hargreaves KM (2006) *Pathways of the Pulp*, (9th Ed) Mosby Inc, St Louis, Missouri

Collins J, Walker MP, Kulild J and Lee C (2006) A comparison of three gutta-percha obturation techniques to replicate canal irregularities. *J Endod* **32**, 762-765

Coolidge ED (1960) Past and present concepts in Endodontics. *J Am Dent Assoc* **61**, 676-688

Cruse WP and Bellizzi R (1980) A historic review of Endodontics, 1689-1963 part 2. *J Endod* **6**, 532-535

Davalou S, Gutmann JL, and Nunn MH (1999) Assessment of apical and coronal root canal seals using contemporary endodontic obturation and restorative materials and techniques. *Int Endod J* **32,** 388-396

Davis MC, Walton RE and Rivera EM (2002) Sealer distribution in coronal dentin. *J Endod* **28**, 464-466

De-Deus G, Maniolia-Ferreira CM, Gurgel-Filho ED, Paciornik S, Machado AC, and Coutinho-Filho T (2007) Comparison of the percentage of gutta-percha-filled area obtained by *Thermafil and System B Aust Endod J* **33**, 55-61

Duke WW (1918) Oral Sepsis in its relationship to systemic disease. The CV Mosby Company, St Louis

Erisen R, Yucel T, and Kucukay S (1989) Endomethasone root canal filling material in the mandibular canal : A case report. *Oral Surg Oral Med Oral Pathol* **68**, 343-345

Filho MT, Leonardo MR, Silva LAB, Anibal FF, and Faccioli LH (2002) Inflammatory response to different endodontic irrigating solutions. *Int Endod J* **35**, 735

Frank AL, Simon JHS, Abou-Rass M and Glick DH (1983) *Clinical and surgical endodontics: concepts in practice.* JB Lippincott, Philadelphia

Friedman CE, Sandrik JL, Heuer MA and Rapp GW (1977) Composition and physical properties of gutta-percha endodontic filling materials. *J Endod* **3**, 304-308

Friedman S (1998) Treatment outcome and prognosis of endodontic therapy. Essential Endodontology: Prevention and Treatment of Apical Periodontitis. *Oxford: Blackwell Science*

Friedman S (2002) Prognosis of initial endodontic therapy. *Endontic Topics* **2,** 59-88

Friedman S, Löst C, Zarrabian M and Trope M (1995) Evaluattion of success and failure after endodontic therapy using glass ionomer cement sealer. *J Endod* **21**, 384-390

Friedman S and Mor C (2004) The Success of Endodontic Therapy-Healing and Functionality. *J Calif D Assoc* **32**, 493-503

Fulton MO (1938) *History of Dentistry in Missouri*. The Ovid Press Inc

Gambarini G, Andreasi-Bassi M, Bolognini M, Testarelli L, Nocca G, Ceccarelli L, Scatena R, Lupi A and Castagnola M (2003) Cytotoxicity of a new endodontic filling material. *Aust Endod J* **29,** 17-19

Gernhardt CR, Bekes K and Schaller H (2007) Apical sealing ability of 2 epoxy resi-based sealers used with root canal obturation techniques based on warm gutta-percha compared to cold lateral condensation. *Quintess Int* **38**, 229-234

Gilhooly RM, Hayes SJ, Bryant ST and Dummer PM (2001) Comparison of lateral condensation and thermomechanical compacted warm alpha-phase gutta-percha with a single cone for obturating curved root canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* **91**, 89-94

Gimlin DR, Parr CH and Aguirre-Ramirez G (1986) A comparison of stresses produced during lateral and vertical condensation using engeneering models. *J Endod* **12**, 235-241

Glickman G, Butler J and Berry C (1992) "Microbiological evaluation of Thermafil obturators". *J Endod* **18**, 187-189

Goldberg F, Gurfinkel J and Spielberg C (1979) Microscopic study of standardized gutta-percha points. *Oral Surg Oral Med Oral Pathol* **47**, 275-276

Goldman M, Goldman LB, Cavaleri R, Bogis J and Lin PS (1982) The efficacy of several endodontic irrigating solutions: a scanning electron microscopic study: Part 2. *J Endod* **8**, 487-492

Goodman A, Schilder H and Aldrich W (1974) The thermomechanical properties of gutta-percha II. The history and molecular chemistry of gutta-percha. *Oral Surg Oral Med Oral Pathol* **37**: 954-961

Gordon MP, Love RM and Chandler NP (2005) An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals. *Int Endod J* **38**, 87-96

Grossman LI (1958) Some observations in root canal filling materials. In: Grossman LI (Eds) *Trans Of the 2nd Inter Conf of Endo*, Philadelphia

Grossman LI (1980) A personal history of dental practice: 1920-1980. *J Am Dent Assoc***102**, 360-365

Grossman LI (1988) *Endodontics* (11th Ed) Lea & Febiger, Philadelphia

Gutmann JH and Hovland EJ (1997) Problems in root canal obturations. In: Gutmann J, Dumsha T, Lovdahl P, Hovland E, (Eds) *Problem Solving in Endodontics*, (3rd Ed) St Louis, Mosby

Gutmann JL (1993) Adaptation of injected thermoplasticized gutta-percha in the absence of the dentinal smear layer. *Int Endod J* **26,** 87-92

Hardie EM (1987) Further studies on heat generation during obturation techniques involving thermally softened gutta-percha. *Int Endod J* **20**, 122-127

Hata G, Imura N, Matsuda T, Kato A, Souza FJ and Toda T (2002) Apical sealing ability of the EZ-Fill obturation technique. *J Endod* **28**, 260

Hefferman ML, Teixeira FB, Williams JM, Caplan DJ and Trope M (2005) Clinical Performance of Resilon and Gutta-percha at 3 and 6 months. *J Endod* **31,** Abstract # PO11

Heling I (1996) The antimicrobial effect within dentinal tubules of four root canal sealers. *J Endodon* **22**, 257-259

Himmel VT and Cain CW (1993) An evaluation of the number of condenser insertions needed with warm lateral condensation of gutta-percha. *J Endodon* **19**, 79-81

Holland R, De Mello W, Nery MJ, Bernabé PF and de Souza (1977) Reaction of human perirapical tissue to pulp extirpation and immediate root canal filling with calcium hydroxide. *J Endod* **3**, 63-67

Holland R, & De Souza V (1985) Ability of a new calcium hydroxide root canal filling material to induce hard tissue formation. *J Endod* **11**, 535-543

Holland R, Nery MJ, de Mello W, de Souza, Bernabé PF and Otobini Filho JA (1979) Root canal treatment with calcium hydroxide I. Effect of overfilling and refilling. *Oral Surg Oral Med Oral Pathol* **47**, 87-92

Huang TH, Lee H and Kao CT (2001) Evaluation of the genotoxicity of zinc oxide eugenol-based, calcium hydroxide-based and epoxy resin-based root canal sealers by comet assay. *J Endod* **27**, 744-748

Hulsmann M, Heckendorff M and Lennon A (2003) Chelating agents in root canal treatment: mode of action and indications for their use. *Int Endod J* **36**, 810-830

Huumonen S, Lenander-Lumikari M, Sigurdsson and A, Orstavic D (2003) Healing of apical periodontitis after endodontic treatment: a comparison between a silicone-based and a zinc oxide-eugenol-based sealer. *Int Endod J* **36,** 296-301

Inan U, Aydemir H and Taşdemir T (2007) Leakage evaluation of three different root canal obturation techniques using electromechanical evaluation and dye penetration evaluation methods. *Aust Endod J* **33**, 18-22

Ingle JL (1985) *Endodontics* (3rd Ed) Lea and Febiger, Philidelphia

Jacobson EL and BeGole EA (1992) A comparison of four root canal obturation methods employing gutta-percha: a computerized analysis of the internal structure. *Endod Dent Traumatol* **8**, 206-209

Jasper EA (1941) Adaptation and tissue tolerance of silver point canal fillings. *J Dent Res* **4**, 355-358

Johnson WB (1978) A new gutta-percha technique. *J Endod* **4**, 184-188

Johnson WT and Gutmann JL (2006) Chapter 10 In: S Cohen KM Hargreaves (Eds) *Pathways of the Pulp*, (9th Ed) St Louis, Missouri: Mosby Inc., pp 361

Jung IY, Lee SB, Kim ES, Lee CY and Lee SJ (2003) Effect of different temperatures and penetration depths of a System B plugger in the filling of artificially created oval canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* **96**, 453-457

Katz, A, Kaffe I, Littner M, Tagger M and Tamse A (1990) Densitometric measurement of radiopacity of gutta-percha cones and root dentin. *J Endod* **16**, 211-213

Kazemi R, Safavi KE and Spångberg LS (1993) Dimensional change of endodontic sealers. *Oral Surg Oral Med Oral Pathol* **76**, 766-271

Keane HC (1944) *A Century of Service to Dentistry,* Philadelphia, SS White Dental Manufacturing

Kersten HW, Fransman R and Thoden van Velzen SK (1986) Thermomechanical compaction of gutta-percha I. A comparisonof several compaction procedures. *Int Endod J* **19**, 125-133

Kersten HW, Wesselink PR and Thoden van Velzen SK (1987) The diagnostic reliability of the buccal radiograph after root canal filling. *Int Endod J* **20**, 20-24

Kleier DJ and Averbach AE (1988) Painful dysesthesia of the inferior alveolar nerve following use of a paraformaldehyde-containing root canal sealer. *Endodon Dent Traumatol*. **4**, 46-48

Koch CRE and Thorpe BLT (1909) *A History of Dental Surgery*, Vol 2 and 3. National Art Publishing Co, Fort Wayne, Indianapolis

Kontakiotis EG, Wu MK and Wesslink PR (1997) Effect of sealer thickness on long-term sealing ability: a 2-year follow-up study. *Int Endod J* **30**, 307-312

Kuttler Y (1955) Microscopic investigation of root apexes. *J Am Dent Assoc* **50**, 544-552

Kytridou V, Gutmann JL and Nunn MH (1999) Adaptation and sealability of two contemporary obturation techniques in the absence of the dentinal smear layer. *Int Endodon J* **32**, 464-474

Langeland K (1974) Root canal sealants and pastes. *Dent Clin North Am* **18**, 309-327

Lee CQ (1998) *In vitro* evaluation of the Thermafil technique with and without gutta percha coating. *Gen Dent* **46**, 378-381

Lee KW, Williams MC, Camps JJ and Pashley DH (2002) Adhesion of endodontic sealers to dentin and gutta-percha. *J Endod* **28**, 684-688

Lipski M (2004) Root surface rises *in vitro* during root canal obturation with thermoplasticized gutta-percha in a carrier or by injection. *J Endod* **30**, 441-443

Lipski M (2006) *In vitro* infrared thermographic assessment of root surface temperatures generated by high temperature thermoplasticized injectable gutta-percha obturation technique. *J Endod* **32**, 438-441

Loest C, Trope M and Friedman S (1993) Follow-up of root canals obturated with glass ionomer and epoxy resin root canal sealer. *J Endod* **19**, 201-205

Machtou P (2006) Apical seal versus coronal seal. *Endodontic Practice* p 19

Malagnino VA, Cantatore G, Lupoli G (1994) Analyse chimique quatitative . point de fusion at temps de plasticisation de differénts types de gutta-percha. *Endo-Revue Francaised'Endodontie* **13**, 39-42

Mamootil K and Messer HH (2007) Penetration of dentinal tubules by endodontic sealer cements in extracted teeth and *in vivo*. *Int Endod J* **40**, 873-881

Marlin J, Krakow AA, Desilets RP and Gron P (1981) Clinical use of injection-molded thermoplastcized gutta-percha for obturation of the root canal system: a preliminary report. *J Endod* **7**, 277-281

Martin H and Fischer E (1990) Photoelastic stress comparison of warm (Endotec) versus cold lateral condensation techniques. *Oral Surg Oral Med Oral Pathol* **70**, 325-327

Mayne JR, Shapiro S and Abramson II (1971) An evaluation of standardized gutta percha points I. Reliability and validity of standardization. *Oral Surg Oral Med Oral Pathol* **31**, 250-257

Mc Cullagh JJ, Biagioni PA, Lamey PJ and Hussey DL (1997) Thermographic assessment of root canal obturation using thermomechanical compaction. *Int Endod J* **30**, 191-193

McComb D and Smith DC (1975) A preliminary scanning electron microscopic study of root canal after endodontic procedures. *J Endod* **7**, 238-242

McComb D and Smith DC (1976) Comparison of physical properties of polycarbo-xylate-based and conventional root canal sealers. *J Endod* **6**, 228-235

McMichen FR, Pearson G, Rahbaran S and Gulabivala K (2003) A comparative study of selected physical properties of five root-canal sealers. *Int Endod J* **36**, 629-635

McSpadden JT (1993) Multiphase gutta-percha obturation technique. *Dent Econom* **9**, 95-97

Mickel AK, Nguyen TH and Chogle S (2003) Antimicrobial activity of endodontic sealers on *Enterococcus faecalis. J Endod* **29**, 257-258

Miletić I, Devcić N, Anić I, Borcić J, Karlović Z and Osmak M (2005) The cytotoxicity of RoekoSeal and AH plus compared during different setting periods. *J Endod* **31**, 307-309

Miyagak DC, de Cavalho EM, Robazza CR, Chavasco JK and Levorato GL (2006) *In vitro* evaluation of the antimicrobial activity of endodontic sealers. *Braz Oral Res* **4**, 303-306

Monica WS (1972) Outline of dental history, Hackensack, NJ, Fairleigh Dickinson University Dental School

Musikant BL (2002) Knowing the Research Makes All the Difference [www document]. URL: http://www.endomail.com/articles/blm20/knowingresearch/html.

Najar AL, Saquy PC, Vansan LP and Sousa-Neto MD (2003) Adhesion of a glass-ionomer root canal sealer to human dentine. *Aust Endod J* **29**, 20-22

Nakabayashi N, Kojima K and Masuhara E (1982) The promotion of adhesion by the infiltration of monomers into tooth substrates. *J Biomed Mat Res* **16**, 265-73

Nixon CE, Lin L and Jandinski J (1991) Evaluation of three silicone-based materials as potential retrograde fillings in endodontics. *J Endod* **17**, 479-482

Orban B (1930) Why root canals should be filled to the dentinocemental junction. *J Am Dent Assoc* **17**, 1086-1087

Orstavik D and Haapasalo M (1990) Disinfection by endodontic irrigants and dressings or experimentally infected dentinal tubules. *Endodon Dent Traumatol* **6**, 142-149

Orstavik D (2005) Materials used for root canal obturation: technical, biological and clinical testing. *Endodontic Topics* **12,** 25-38

Parsons JR, Walton RE and Ricks-Williamson L (2001) *In vitro* longitudinal assessment of coronal discoloration from endodontic sealers. *J Endod* **27**, 699-702

Pashley DH (1984) Smear layer: physiological considerations. *Oper Dent Suppl* **3**, 13-29

Pashley EL, Birdsong NL, Bowman K and Pashley DH (1985) Cytotoxic effect of NaOCl on vital tissue. *J Endod* **11**, 525-528

Pataky L, Iványi I, Grigár A and Fazekas A (2002) Antimicrobial efficancy of various root canal preparation techniques: an *in vitro* comparative study. *J Endod* **28**, 603-605

Pathomovich M and Edmunds DH (1996) The sealing ability of Thermafil obturators assessed by four different microleakage techniques. *Int Endodon J* **29**, 327-34

Perry SG (1883) Preparing and filling the roots of teeth. *Dent Cosmos* **25**, 185-187

Peters LB and Wesselink PR (2002) Periapical healing of endodontically treated teeth in one and two visits obturated in the presence or absence of detectable microorganisms. *Int Endod J* **35**, 660-667

Pommel L and Camps J (2001) *In vitro* apical leakage of system B compared with other filling techniques. *J Endod* **27**, 449-451

Prinz H (1917) Electro-sterilization of root canals. *Dent Cosmos* **59,** 373

Ray HA and Trope M (1995) Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. *Int Endod J* **28**, 12-18

Reader CM, Himel VT, Germain LP and Hoen MM (1993) Effect of three obturation techniques on the filling of lateral canals and the main canal. *J Endod* **19**, 404-408

Romero AD, Green DB and Wucherpfennig AL (2000) Heat transfer to the periodontal ligament during root obturation procedures using an *in vitro* model. *J Endod* **26**, 85-87

Saunders EM (1989) The effect of variation in thermomechanical compaction techniques upon the quality of the apical seal. *Int Endod J* **22**, 163-168

Saunders WP and Saunders EM (1997) The root filling and restoration continuum. Prevention of long-term endodontic failures. *Alpha Omega* **90**, 40-46

Saw LH and Messer HH (1995) Root strains associated with different obturation techniques. *J Endod* **21**, 314-320

Schäfer E and Zandbiglari, T (2003) Solubility of root-canal sealers in water and artificial saliva. *Int Endod J* **36**, 660-669

Schilder H (1976) Filling root canals in three dimensions. *Dent Clin North Am* **11**, 723

Schilder H (1978) Advanced course in Endodontics. Boston University School of Graduate Dentistry Boston, MA

Schilder H (1983) Vertical compaction of warm gutta-percha. In: Gerstein H (Ed) *Techniques in clinical endodontics.* WB Saunders Company, Philadelphia, pp 76-98

Schilder H, Goodman A and Aldrich W (1985) The thermomechanical properties of gutta-percha. Part V. Volume changes in bulk gutta-percha as a function of temperature and its relationship to molecular phase transformation. *Oral Surg Oral Med Oral Pathol* **59**, 285-296

Seltzer S, Green DB, Weiner N and DeRenzis F (1972) A scanning electron microscope examination of silver cones removed from endodontically treated teeth. *Oral Surg Oral Med Oral Pathol* **33**, 589-605

Seltzer S (1988) *Biologic Considerations in Endodontic Procedures*. (2nd Ed) Lea and Febiger, Philadelphia

Serper A, Ucer O, Onur R and Etikan I (1998) Comparative neurotoxic effects of root canal filling materials on rat sciatic nerve. *J Endod* **24**, 592-594

Shabahang S (2005) State of the art and science of endodontics. *J Am Dentistry Assoc* **136**, 41-52

Shipper G, Orstavik D, Teixeira FB and Trope M (2004) An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon). *J Endod* **30**, 342-347

Siqueira JF Jr, da Silva CH, Cerqueira Melas D, Lopes HP and de Uzeda M (1998) Effectiveness of four chemical solutions in eliminating Basillus subtilis spores on gutta-percha cones. *Endodon Dent Traumatol* **14**, 124-126

Sjøgren U, Hagglund B, Sundqvist G and Wing K (1990) Factors affecting the long-term results of endodontic treatment. *J Endod* **16**, 498-504

Skillen WG (1930) Why root canals should be filled to the dentinocemental junction. *J Am Dent Assoc* **17**, 2082-2084

Spångberg LS, Barbosa SV and Lavigne GD (1993) AH 26 releases formaldehyde. *J Endod* **19**, 596-598

Swartz DB, Skidmore AE and Griffin JA (1983) Twenty years of endodontic success and failure. *J Endod* **9**, 198-202

Sweatman TL, Baumgartner JC and Sakaguchi RL (2001) Radicular temperatures associated with thermoplasticized gutta-percha. *J Endod* **27**, 512-515

Tagger M (1967) Endodontics: a review of the past and its present status. *Alpha Omegan* **60**, 107-118

Tay FR, Loushine RJ, Monticelli F, Weller RN, Breschi L, Ferrari M and Pashley DH (2005) Effectiveness of resin-coated gutta-percha cones and a dual-cured hydrophilic methacrylate resin-based sealer in obturating root canals. *J Endod* **31**, 659-664

Torabinejad M, Cho Y, Khademi AA, Bakland LK and Shabahang S (2003) The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. *J Endod* **29**, 233-239

Trope M, Moshonov J, Nissan R, Buxt P and Yesilsoy C (1995) Short vs long-term calcium hydroxide treatment of established inflammatory root resorption in replanted dog teeth. *Endodon Dent Traumatol* **11**, 124-128

Trope MB and Bergenholtz G (2002) Microbial basis for endodontic treatment: can a maximal outcome be achieved in one visit? *Endod Topics* **1**, 40-46

Venturi M, Di Lenarda R, Prati C and Breschi L (2005) An In Vitro Model to Investigate Filling of Lateral Canals. *J Endod* **3**, 877-881

Venturi M, Prati C, Capelli G, Falconi M and Breschi L (2003) A preliminary analysis of the morphology of lateral canals after root canal filling using a tooth-clearing technique. *Int Endod J* **36**, 54-63

Von der Fehr F and Nygaard-Østby B (1963) Effect of EDTAC and sulfuric acid on root canal dentine. *Oral Surg Oral Med Oral Pathol* **16**, 199-203

Weiger R, Rosendahl R and Löst C (2000) Influence of calcium hydroxide intracanal dressings on the prognosis of teeth with endodontically induced periapical lesions. *Int Endodon J* **33,** 219-226

Weinberger BW (1948) *An Introduction to the History of Dentistry,* St Louis, Mosby

Weine FS (1982) *Endodontic Therapy.* (3rd Ed) The CV Mosby Company, St Louis, London

Weller RN, Kimbrough WF and Anderson RW (1997) A comparison of thermoplastic obturation techniques: adaptation to the canal walls. *J Endod* **23**, 703-706

West JD (1975) *The relationship between the three-dimensional Tendodontic seal and endodontic failures.* Thesis, Boston University

Wolcott J, Himel VT, Powell W and Penney J (1997) Effect of two obturation techniques on the filling of lateral canals and the main canal. *J Endod* **23**, 632-635

Wu MK, Fan B and Wesselink PR (2000) Diminished leakage along root canals filled with gutta-percha without sealer: A laboratory test. *Int Endod J* **33**,121-125

Wu MK, Kastákova A and Wesselink PR (2001) Quality of cold and warm gutta-percha fillings in oval canals in mandibular premolars. *Int Endod J* **34**, 485-491

Wu MK, van der Sluis LW and Wesselink PR (2002) A preliminary study of the percentage gutta-percha-filled area in the apical canal filled with vertically compacted warm gutta-percha. *Int Endod J* **35**, 527-535

Wu MK, Wesselink PR and Walton RE (2000) Apical terminus location of root canal treatment procedures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* **89**, 99-103

Yee FS, Marlin J, Krakow AA and Gron P (1977) Three-dimensional obturation of the root canal using injection-molded, thermoplasticized dental gutta-percha. *J Endod* **3**, 168-174

Zidan O, al-Khatib Z and Gomez-Marin O (1987) Obturation of root canals using the single cone gutta-percha technique and dentinal bonding agents. *Int Endod J* **20**, 128-132

Zmener O and Pameijer CH (2004) Clinical and radiographic evaluation of a resin-based root canal sealer. *Am J Dent* **17**, 19-22

Zmener O and Pameijer CH (2005) Evaluation of the Apical Seal in Root Canals Prepared with a New Rotary System and Obturated with a Methacrylate Based Endodontic Sealer: An In Vitro Study. *J Endod* **31**, 392-395

Zmener O and Pameijer CH (2007) Clinical and Radiographical Evaluation of a Resin-based Root Canal Sealer: A 5-year follow-up. *J Endod* **33**, 676-679