IN VITRO COMPARISON OF RETRIEVAL EFFICIENCY AND CAPACITY FOR THREE ENDODONTIC OBTURATION MATERIALS

by

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Abstract

GuttaCore® is advertised as rendering high-quality carrier-based obturation and being retreatable with unprecedented ease. This study's aim was to evaluate time required for ProTaper®Retreatment files to remove three obturation materials in mesio-buccal (MB) canals and distal (D) canals of lower molars, and quantify residual material left on canal walls following retreatment.

MB and D canals of first and second lower molars were standardized according to type, length, curvature and quadrant, and divided into three obturation groups ($N_{MB}=15$; $N_D=12$). MB canals were instrumented to 25/.08 (ProTaper®Universal F2) and D to 30/.09 (ProTaper®Universal F3). Canals were obturated with vertically compacted gutta-percha cones (GP), Thermafil®Plus (T) or GuttaCore® (GC). Teeth were stored for two weeks allowing sealer setting. Retreatment time to reach working length with ProTaper®Universal Retreatment files (D1, D2, D3) and with last ProTaper®Universal file used during original instrumentation was recorded in seconds. Roots were then sectioned longitudinally, visualized using 8.0x magnification, and residual gutta-percha along canals was quantified using a five-point grading system.

A statistical significant difference in retreatment time between GC group and T group in MB canals was found (P = 0.026). No statistical significant difference in retreatment time was detected amongst the materials ($P > 0.05$). No statistical significant difference was found in residual obturation material between groups both in MB and D canals.

GC group is more efficient to remove than T group in MB canals. No difference was found in the obturation removal amongst the three groups in the wider D canals. All groups exhibited

residual gutta-percha along canal walls; further instrumentation is needed for thorough material removal.

Preface

The research question of this project was identified and designed by Dr. Marina Braniste (M.B) under the guidance of Dr. Jeffrey Coil. All of the samples and preparations were performed by Dr. Marina Braniste. The collected data was analyzed by Dr. Marina Braniste and the supervising committee. The relative contribution of the collaborators in this project was: Dr. Marina Braniste 60%, Dr. Jeffrey Coil 30% and Dr. Ya Shen 10%. University of British Columbia Clinical Research Ethics Board approval was obtained (Certificate Number: **H12-00310**).

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List of Abbreviations

D…..…......Distal

DOM……………………………………………………….…Dental Operating Microscope

EDTA…………………………………………………….....Ethylenediaminetetraacetic acid

GC………………………………….…………………….………………………...GuttaCore®

P…………………………………………...…...Warm vertically condensed gutta-percha

ISO……………………………………….……International Organization for Standardization

MB……………………………………………………………………………..Mesio-buccal

M……………………………………………………………….……………..………..Mesial

NaOCl……………………………………………………...………Sodium Hypochlorite

NiTi………………………………………………………………………...Nickel-Titanium

N_{MB}…………………......Number of samples in the mesio-buccal canals per root filling group

N_D………………………………Number of samples in the distal canals per root filling group

PDL……………………………………………………………...…Periodontal Ligament

RPM……………………………………………...………………..Rotation per minute

T……………………………………………………..……………..……..Thermafil®Plus

SD………………………………………………………………………Standard Deviation

Sec……………………………………………………………………………..Seconds

SEM……………………………………………………….…Scanning electron microscope

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Dedication

I dedicate this to my amazing family, parents and grandparents, and my loving fiancé who have been supporting me throughout my education. I will forever be indebted for your endless care, support and love. I firmly believe that I could not have done it without you.

Chapter 1: Literature Review

1.1 Root Filling Materials – An Introduction

Root canal treatment success has been considered to rely on the control of pulp space infection. Infliction on pulp and subsequent periradicular infection results from the presence of microorganisms, microbial toxins and metabolites, and the products of pulp tissue degradation (Whithworth, 2005). Eliminating these etiologic factors and preventing further irritation from persistent contamination of the root canal are the foundation of nonsurgical and surgical root canal therapy success.

While cleaning, shaping and irrigating of the canal system are essential components of the equation of root canal success, three-dimensional obturation cannot be underestimated. It has the difficult task of attempting a complete seal, so as to prevent and eliminate the avenues of leakage from the oral cavity, as well as rendering an environment where bacteria cannot strive. Root filling obturation is essential to long-term root canal success. Dr. Schilder described the objective of root canal therapy as being “the total obturation of the root canal space” and “the sealing of the complex root canal system from the periodontal bone that ensures the health of the attachment apparatus against breakdown of endodontic origin” (Schilder, 1967). The canal system should be sealed apically, laterally and coronally and various methods and materials are advocated for obturation. Recent root filling materials involve a combination of sealer and core material. The core, not only obturates the major part of the canal, but acts as a piston on the sealers, hopefully spreading in isthmuses, lateral canals and areas untouched by instrumentation. The insertion of the core along with the sealer allows therefore the filling of voids and can closely approach the dentinal walls (Ørstavik, 2005).

The primary functions of obturation materials have been discussed as being a seal against ingrowth of bacteria, capable of entombing remaining microorganisms and completely obturating a canal system at a microscopic level to prevent coronal leakage which could further allow penetration of fluid serving as nutrients for persistent bacteria.

With this aim in mind, an elaborated list of desired properties of the root filling materials, consisting of ten requirements, has been identified by Grossman in 1978 (Grossman, 1978).

1. Easily introduced into canal
2. Seal the canal
3. Not shrink after insertion
4. Impervious to moisture
5. Bacteriostatic
6. Radiopaque
7. Not stain tooth structure
8. Not irritate periapical tissue
9. Sterile, or sterilizable
10. Easily removed from canal

Figure 1.1 List of requirements for an ideal root filling material (Grossman, 1978)

1.2 Core Materials

Through the years, multiple core materials have been used for root filling obturation, mainly silver points, resin-based core filling materials and gutta-percha.

Silver points were introduced by Jasper in 1941 and were considered to have the same success rate as gutta-percha (Jasper, 1941). Even though quite flexible, it is their stiffness compared to conventional gutta-percha that allowed for easy insertion to desired working length. They were usually cemented with sealer and gutta-percha laterally condensed. Their great disadvantage was the lack of adaptation to the canal anatomy which permitted leakage and also resulted in eventual formation of corrosion byproducts along the points (Seltzer et al., 1972). This corrosion was found to be cytotoxic and could initiate or support inflammatory reactions, impeding on the periapical healing and even promote apical pathosis (Brady and del Rio, 1975; Chana et al., 1998; Seltzer et al., 1972). Nowadays, the use of silver points is considered to be below the level of standard of care in contemporary endodontic practice and the American Association of Endodontics has even released a position statement which disadvises the continued use of silver points.

Synthetic resins have also been discussed in the past and been tested as endodontic core materials for many years (Grossman, 1978). When synthetic resin-based cones, more commonly known under the name of Resilon™ (SybronEndo, Orange, CA) appeared, their clinical use gained popularity. This core material is polyester-based and consists of dysfunctional methacrylate resin, bioactive glass, bismuth and barium salts as fillers (Shipper et al., 2004). Physical and handling characteristics, as well as obturation methods, are similar to the ones of gutta-percha. The main advantage named, but debated in literature, is the capacity of products, such as Resilon™(SybronEndo), to result in a monoblock obturation, where the sealer and the core material form a unit attaching to the etched canal wall's surface (De Bruyne and De Moor, 2009; Tay and Pashley, 2007). It is believed by some that due to this uniform obturation, the root strength can be increased and root vertical fractures can be reduced. However, other studies question the foundation of the Resilon™ concept, as this technique depends on the capacity of the practitioner to etch and bond the totality of the canal prior to the insertion of the core material and this notion is disputable (Ribeiro et al., 2008). Even though, a great variety of core materials exist, gutta-percha, since the middle of the 19^{th} century, has marked endodontics. Gutta-percha's plasticity, and physical capacity to adapt to root canals and their complexities, has made this material the most frequently used obturation core in endodontics.

Gutta-percha is derived from dried juices from Palaquium trees of the family of *Sapotaceae* (Goodman et al., 1974). It is a trans-isomer of poly isoprene, whose molecular structure is similar to natural rubber, caoutchouc. However this material is more brittle and less elastic, and behaves more like crystalline polymers. It exists in three forms, namely: alpha phase, beta phase and gamma phase. The alpha form is considered runny, tacky, sticky and having a low viscosity. The beta form is solid, compactible and has a higher viscosity. The gamma form is similar to alpha form; however, it is amorphous in nature and less stable. The various phases are achieved through manufacturing at various temperatures. The alpha- and beta-phases are often used commercially, as they are stable phases of gutta-percha.

Commonly, gutta-percha is found in the beta-phase and is accessible as gutta-percha cones which may be compacted and compressed in a solid mass. When heated, the material can change to the alpha-phase and become pliable and tacky. Even though, this is a property that can be considered as an advantage, it also carries a drawback; the material shrinks to setting.

Schilder revealed the beta to alpha transformation usually occurred between 42 °C and 49 °C. Alpha to amorphous change occurred usually between 53 °C and 59 °C depending of the compound structure. Gutta-percha expands of approximately 1-3% and contracts to a capacity of 3-5% when heated (Schilder et al., 1974).

Most gutta-percha cones consist of approximately 20% gutta-percha, 65% zinc oxide, 10% radiopacifiers and 5% plasticizers. Moreover, gutta-percha can become more flowable and more adaptable to the canal irregularities when it is heated or used along with solvents such as chloroform.

Finally, gutta-percha can be delivered in other forms as well, such as cartridges and capsules filled with an alpha-phase gutta-percha (Cohen, 2006).

1.3 Obturation Techniques

Obturation and compaction techniques of core material such as gutta-percha continue to be at the center of clinical endodontics. As the perpetual search for an ideal root filling continues, clinicians are compelled to optimize the density and the flow of the core into the irregularities and morphologic configuration of a root canal, as well as reduce the sealer volume. It is still uncertain whether success rates are influenced by the various compaction methods, however dentists have strived to achieved a uniform and homogenous root filling obturation in the hopes of achieving long-term clinical success. Most common techniques used are lateral compaction, warm vertical compaction, and carrier-based obturation. Derivatives and alterations to the techniques exist, such as warm lateral compaction, continuous wave techniques and hybrid techniques for carrier-based obturation.

1.3.1 Lateral compaction

Lateral Compaction is the most taught method in dental schools world-wide (Qualtrough et al., 1999). Following canal preparation, lateral condensation consists of choosing standardized cones dependable on the largest file used in the canal at the working length. Once, the main cone is chosen then it is adapted to the canal by cutting small increments of the tip until resistance to displacement is achieved, so called the “tug back” effect. The aim of these adjustments is to achieve a cone that is adapted as closely as possible to the canal shape and walls. If the “tug back” is not strong, further increments can be reduced from the cones or the cones can even be modified or softened with chloroform so as to take a better impression of the canal shape and diameter (van Zyl et al., 2005). This chloroform adaptation technique can be particularly useful in flat or oval canals, where the standard round gutta-percha cones might not be able to adapt to the canal walls (Metzger et al., 1988).

Once the master cone has been chosen and adapted, its apical extension is checked and confirmed with a radiograph. If the cone placement is satisfactory, then sealer can be placed and an appropriate spreader is selected, which matches the taper of the canal. The spreader should fit 1 to 2 mm of the prepared length and when introduced into the canal with master cones in place, it should be visualized 2mm from the working length (Allison et al., 1981). The space vacated by the spreader is then filled with an accessory cone and the extension of the accessory cone into the canal is then radiographically checked, as there appears to be a correlation between the seal and spreader penetration. This process is repeated until the spreader can only fit in the coronal third. The excess gutta-percha is then seared off with a heated instrument and compacted into the canal with pluggers. Care must be taken with the forces used not only with the spreaders but also with the pluggers. In endodontic literature, apical forces, as small as 1.5 kg of pressure, have been mentioned to result in root fractures (Holcomb et al., 1987; Pitts et al., 1983; Wilcox et al., 1997). Lateral condensation is considered safe, cost-efficient and easy to use. It can be applied to a variety of clinical situations and provides a good length control during compaction (Gilhooly et al., 2001). Some of the disadvantages are incapacity to consistently reproduce the canal irregularities (Wong et al., 1981; Wu and Wesselink, 2001), as well as a lack of homogeneity of the fill due to the fact that the accessory and the master cones are laminated and remain separate through the process. The voids, thereafter created, are hopefully filled with sealer (Lea et al., 2005). Through the years, many articles have been demonstrating the technique’s clinical success including recent reports showing its ability to exclude the oral flora after long-term exposure (Bystrom et al., 1987; Kerekes and Tronstad, 1979; Sjogren et al., 1990). It is also important to remember that for many years, most of the epidemiological studies evaluating the predictability of root canal treatment have used as controls canal filling by cold lateral condensation.

1.3.2 Vertical compaction

Dr. Schilder introduced warm vertical compaction in 1967 as a method of filling the root canal space in “three-dimensions” and he attempted to fill the voids that other condensation techniques could not (Schilder, 1967). He states: “It would seem desirable to fill root canals with a homogeneous, inert, dimensionally stable, physiologically acceptable material which could be manipulated with sufficient plasticity to form a permanent cast of the internal configuration of the root canal system.” Contemporary practitioners of this method advocate that there are four main criteria to achieve success with this particular technique:

1. Continuously tapered preparation;
2. Original anatomy maintained;
3. Position of the apical foramen maintained;
4. Foramen diameter as small as practicable.

By warming gutta-percha in a tapered canal, the warm vertical technique would allow sealing of the apical third with greater density and provides a greater frequency in filling of accessory canals and foramina (Reader et al., 1993).

To apply the warm vertical technique, the root canal must be prepared and shaped with a continuous taper, in the shape of a funnel, and maintain the apical foramen as small as possible. The funnel shape of the canal allows the introduction of a graded series of pluggers, now often referred to as Schilder pluggers, with which the gutta-percha can be compacted apically. A master gutta-percha cone is then selected and adjusted to the apical end of the canal. The cone must be wider than the apical end of the root canal and preferably its taper must be more gradual than the taper of the root canal. As for the lateral condensation technique, a “tug back” is necessary, and if not achieved, the cones must be adjusted accordingly by removing small increments with a pair of sharp scissors. In any root canal treatment procedure, there is need for an apical control zone to allow resistance to overfilling. Once the cone is adapted, a small amount of cement is introduced into the root canal with a lentulo spiral. Care must be taken, so that the cement is spread throughout the canal’s walls so that with the insertion of the core, the cement can spread in areas otherwise not accessed. The cones are then dipped in cement and introduced into the canal and the warm vertical condensation can be started (Whithworth, 2005).

The coronal end of the gutta-percha is seared off with red-hot heated heat carrier. The same heated carrier is then inserted 3-4mm into the canal, in order, to soften the material and allow vertical condensation to be applied with the pluggers. In the same time, as the heat carrier is inserted into the canal, gutta-percha can be also removed, to allow condensation of the core material further apically into the canal. This will allow for a fill integrating the irregularities of the canal. This sequential vertical condensation is continued until the pluggers, which should be measured to reach about 3-5mm away from the apex of the tooth (Bowman and Baumgartner, 2002; Schilder, 1967). They come in various sizes including numbers 8, 9, $9^{1/2}$, 10, 10 ½, 11, 11 ½ and 12. A plugger that cannot fit within a few millimeters of the end of the canal is useless to this particular technique. Furthermore, forcing the pluggers down the canal will only create lateral pressure to the walls of the canal and almost no vertical pressure against the gutta-percha, so this motion should be avoided. A radiograph should be taken at this point, a "down-pack" radiograph. At this point, the canal is approximately two-thirds empty, as only about 4-5mm of gutta-percha is left in the apical portion. The "back-fill" consists of filling the rest of the canal with either warmed segments of 2, 3 or 4mm in length of gutta-percha, selected to adapt to the root canal, or with new incoming technology using thermoplasticized injection techniques, such as Calamus® (©DENTSPLY Tulsa Dental, Tulsa, OK), Obtura (Spartan Endodontics, Algonquin, IL) and Element (SybronEndo, Orange, CA). These products can deliver heated gutta-percha, up to 200 °C into the canal, allowing uniform filling of the rest of the canal. Injectable gutta-percha is commonly deposited in a 3-5mm increments, with intermittent compaction (Whithworth, 2005), although there are studies showing that the deposition of increments up to 10 mm is possible (Johnson and Bond, 1999). Condensing the "back-fill" material gradually creates a well-adapted filling to the canal walls, and therefore an increase of the overall core material filling, as well as reduction in sealer.

Compaction techniques of any type require the instruments used to be relatively sized to the dimensions of the canal. In the past, classical warm vertical technique has been critiqued for the excessive removal of dentine to obtain the funnel shaped canals; to adapt to the pluggers required for this technique. In recent years, with the arrival of contemporary instruments, efficient heat carrier, nickel-titanium pluggers, as well as smaller diameter needles for the back-filling cartridges, some of the complaints have been addressed. The potential damaging forces in non-physiological directions as well as the thermal damage to the periodontal ligament during thermal compaction have also been discussed (Sweatman et al., 2001). However, there is little evidence to prove clinical implications.

Furthermore, multiples studies have discussed the adaptability of the warm vertical compacted gutta-percha to canal walls and the capacity to reduce sealer-pools following heating and compaction to different depths. The consensus is that the most successful down-pack compaction is one in the closest proximity to the apex, more specifically 2-3 mm away from the canal terminus (Bowman and Baumgartner, 2002; Sweatman et al., 2001), therefore, this implies that it is not necessary a simple technique to apply, as it can be quite challenging to bring the heat carrier and plugger in proximity to the canal terminus. The challenge is even more pronounced in cases where the roots are narrow and where the taper given to the canal is limited due to pronounced curvatures.

Another consideration to be discussed with warm vertical condensation is the prevalence of sealer extrusion and the consequential risk of tissue injury and eventually delay in healing (Hoskinson et al., 2002).

1.3.3 Carrier-based obturation

Carrier systems were invented by Dr. Ben Johnson and first described in an article published in the Journal of Endodontics in 1978 (Johnson, 1978). It was presented as another practical mean to deliver gutta-percha to the canal in a thermally softened form, allowing therefore the fill of canal's complexities. Initially, the technique consisted of a notched and prepared for coating stainless steel file, which was then uniformly coated with gutta-percha. The file covered with gutta-percha was softened with a bunsen burner and inserted gently into the instrumented, cleaned and already covered with sealer canal to the desired working length. The obturator was then twisted off or bent until the file would break. The shank of the file was then discarded and the residual gutta-percha was then condensed vertically around the file with a small plugger. Gutta-percha was then added if need to fill the rest of the canal. Since the procedure was first introduced, the technique has been commercialized in the early 1990's. Various products with different carrier design exist, but the most common example of gutta-percha based carrier device is Thermafil® (©DENTSPLY Tulsa Dental, Tulsa, OK). The brand has evolved in time and was significantly modified, now forming an integral part of a complete and sophisticated root canal obturation system. Through time, various studies have shown its clinically successful results.

Thermafil® obturators (©DENTSPLY) consist of two major parts, the carrier and the alpha phase gutta-percha. Through time, the carrier has changed from a stainless steel file, to a stainless steel pre-made carrier to a plastic carrier. Presently, the plastic carrier surrounded by alpha-phase gutta-percha is known under the name of ThermaFil®Plus (©DENTSPLY) (Figure 1.2)

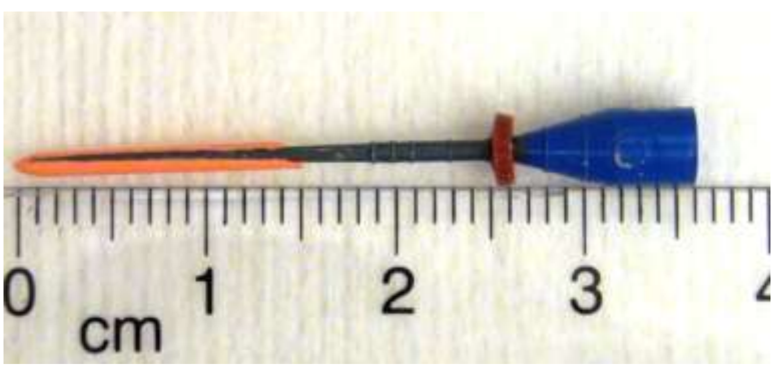


Figure 1.2 ThermaFil®Plus size 30 obturator with the carrier partially exposed

The plastic core is made out a special radio-opaque derivative of polysulfone, which is inert and biocompatible. It also has an ISO classification colored grip reflecting the size of the obturator. The newer generation of plastic carrier-based obturation has a groove along the carrier's length which is visible when the obturator is voided of its gutta-percha. This groove has two main functions:

1. To increase its flexibility and reduce its mass;
2. To facilitate, if needed, the retreatment of the canal by creating a space between the carrier and canal walls.

The shaft is marked with reliefs that represent 18, 19, 20, 22 and 24 mm extensions from the tip. These can be used as a reference for the penetration of the obturators and should be matched with the one found on the verifiers.

Obturators are available in different diameters and tapers so as to match the instrumentation system used during the cleaning and shaping of the canals. The list below is enumerating the most common members of the Thermafil® family.

1. Thermafil®Plus (©DENTSPLY);
2. GT® Obturators (©DENTSPLY);
3. GT Series X® (©DENTSPLY);
4. ProFile® Vortex® (©DENTSPLY);
5. ProTaper NEXT™ (©DENTSPLY);
6. ProTaper® Universal (©DENTSPLY);
7. WaveOne® (©DENTSPLY);
8. GuttaCore® (©DENTSPLY).

The last addition of the Thermafil® family was GuttaCore® (©DENTSPLY). GuttaCore® (©DENTSPLY) is unique in its kind, since it is the first cross-linked gutta-percha core obturator. Still keeping its flexible strength and retaining its shape when heated, one of its main advantages advertised by the company is that the handle can be removed with ease by bending it on either side of the canal without affecting the seal. Moreover, it is also publicized that post space and retreatment are facilitated as the material can be removed with post-space drills or rotary retreatment files with effortlessly.

Carrier-based obturations are different from conventional condensation techniques, not only in their fabrication, but also in their clinical manipulations. Their manipulation requires the use of two products unique to this type of obturation, namely the verifier and the obturator oven. Following proper cleaning and shaping, the verifier, which is a nickel-titanium file pertaining to this system, is used to check and confirm the final working length. The verifier must fit to the desired length passively. An obturator is then chosen in function of the verifier used and tested. The adequate obturator has to be selected in accordance to the verifier and its stopper is set to the desired working length according to the reliefs on the handle. Following these measurements, the obturator is inserted in the Thermafil®/ GuttaCore® oven (©DENTSPLY). The oven will heat the alpha phase gutta-percha surrounding the carrier and prepare the obturator for insertion into the canal (Figure 1.3).

Figure 1.3 GuttaCore® and ThermaPrep®Plus Ovens (©DENTSPLY)

ThermaPrep®Plus/GuttaCore® (©DENTSPLY) ovens should be used with the heating setting specific to the size of the obturator according to the manufacturing indications. Once heated, the obturator is slowly inserted into the instrumented and sealer coated canal. Manufacturers recommend a resin based sealer such as ThermaSeal® PlusRibbon™ (©DENTSPLY). The carrier-based obturator is inserted with gentle and gradual pressure until the working length is reached. Depending of the type of obturator, the handle can be bended off or removed with a slow-hand piece round bur. For GuttaCore® (©DENTSPLY), the carrier is easily bent and removed only by winding the obturator on each side of the access cavity. Interestingly, there are very few differences between the two used ovens, as the GuttaCore® oven (©DENTSPLY) is an updated version of the ThermaPrep®Plus Oven (©DENTSPLY). Amongst the differences, it is advertised that the newer GuttaCore® oven (©DENTSPLY) renders a more uniform heating process, slower release of the obturator holder, has indicator lights and audible alerts, as well as a cleaning mode.

1.4 Evaluation of Root Filling Obturation Techniques

Obturation techniques are multiple and they are chosen at the discretion of the practitioner. Techniques such as lateral condensation, warm vertical condensation and carrier-based obturation have been proven to result in successful healing of periapical tissues. Lateral condensation has been regarded for a long-time as being safe, cost effective and easy to manipulate. Its applications are wide and have been proven to be efficacious over time (Chu et al., 2005; Dammaschke et al., 2003; Friedman et al., 2003; Oliet, 1983; Orstavik et al., 1987; Sjogren et al., 1997; Sjogren et al., 1990; Trope et al., 1999). Technique's limitations have been mentioned when it comes to canals with abrupt diameter changes, or wide apical opening, or even extreme variations in anatomy due to possible internal resorption. Adaptation of the gutta-percha to such variations can be a challenge, resulting in a poor filling density (Kersten et al., 1987). Another drawback reported by Chu et al. (2005) when comparing the time of manipulation amongst the various techniques was that lateral condensation was more time consuming compared to other thermoplasticized techniques (Chu et al., 2005).

Clinical studies of warm vertical condensation have shown similar satisfaction in periapical healing to lateral condensation methods (Friedman et al., 2003; Hoskinson et al., 2002; Peters and Wesselink, 2002). Part of the success of this technique is due to the compaction of heated gutta-percha in areas that might only be reached by sealer. Furthermore, this results in a reduction of sealer/gutta-percha ratio. However, this obturation technique relies greatly on the apical compaction, more specifically the depth of heating and condensation of gutta-percha inside the canal. Laboratory studies have shown that compaction must be within 2-3mm of the apex to allow further material adaptation (Bowman and Baumgartner, 2002; Wu et al., 2002). Other challenges lie in the balance between dentine removal and the accommodation of condensing instruments in narrow and curved canal, so as to allow the compaction of the obturation material within 2-3mm from the desired apical extension. Apical extrusion or overfilling and periodontal ligament over-heating during condensation have also been discussed but have shown no clinical implication over-time (Augsburger and Peters, 1990; Glennon et al., 2004). While both lateral and warm vertical condensations have had strengths, they also maintain some limitations, therefore allowing the continuation of the quest for the perfect obturation material.

Carrier-based obturation such as Thermafil® Plus (©DENTSPLY) and now GuttaCore® (©DENTSPLY), have been attempting to fill the voids of previous condensation techniques. Carrier-based obturations are often useful in long-curved canals, where neither heat carriers, nor pluggers, nor spreaders can reach. This type of obturation permits little dentine removal and allows a quick but dense filling obturation. Laboratory evidence suggests that it is a low-pressure technique, capable of a rapid and efficient obturation. It can seal various canal ramifications and isthmuses, therefore resulting in a dense fill, where the sealer/core ratio is small (Gencoglu et al., 2002). Clinical trials have been showing clinical success similar to the more traditional techniques (Chu et al., 2005; Gagliani et al., 2004). One of the flaws of carrier-based obturation constantly mentioned is the possible overfilling hazard. Overfilling or extrusion of root filling material has been discussed in the past. Attempting to prevent it, authors have proposed the use of hybrid techniques, which sometimes involved a main gutta-percha cone adequately fitted to the canal, followed by the sequential insertion of a carrier-based obturation along its side, so as to benefit of the apical control provided by the cone and the fluidity of the carrier-based obturation to fill the complexity of the canal (Da Silva et al., 2002).

As no system encompasses all the requirements of an ideal root filling, it can be concluded that no matter the obturation condensation technique used, the practitioner must realize the benefits, limitations and comfort level for each technique and choose specifically to the clinical situation encountered.

1.4.1 Obturation overfill

During routine obturation of root canals, it is not unusual that sealer and/or gutta-percha can extrude beyond the apex or through accessory or lateral canals (Orstavik and Mjor, 1988). Usually, sealers are recognized as more serious irritants to periradicular tissues than gutta-percha (Orstavik et al., 1987; Schilder, 2006). However, studies argue that the body is able to manage apical extrusion of sealer and gutta-percha over time through the healing process. It is debated that the extruded material could be removed by the body through the lymphatic system (Augsburger and Peters, 1990; Langeland et al., 1971).

The Toronto Studies (Friedman et al., 2003), on the other hand, have shown that extrusion of filling materials beyond the root end usually results in poorer prognosis and should be avoided if possible (Orstavik and Horsted-Bindslev, 1993; Sjogren et al., 1990). It is discussed that material extrusion can be well tolerated but the impaired prognosis most probably results from the inadequate instrumentation and the periapical displacement or extrusion of infected debris (Friedman, 2002; Yusuf, 1982).

The result of healing in cases of material extrusion could be explained by a concept clarified by Dr. Schilder in 1967. He defined the concepts of overextension and overfilling. In a root canal, overextension or underextension is described as having only a vertical dimension component of extrusion, meaning a root filling beyond or short of the root apex (Schilder, 1967). Overfilling and underfilling, conversely, imply the canal has been adequately sealed and filled three-dimensionally, but the obturation material was extended to short or beyond the root apex. Overextension, underextension and underfill are all complications which might render a root filling obturation failing to seal the circumference of the apical foramen in more than one dimension. This, therefore, leaves space for stagnation of fluids, persistent infection and recontamination (Gluskin, 2009).

The overfill, on the other hand, was believed by Dr. Schilder to render a periapical environment who's healing will be unaffected by the extrusion of the material in the periapical tissues, no matter the compatibility of the material, as it has the capacity to seal off the root canal system.

Even though, overfilling has been more easily accepted, it still can indicate a faulty technique and ideally should be avoided. Studies have shown that depending on the size of the instrumentation, as well as the condensation techniques used, the extension of the material can vary (Mann and McWalter, 1987; Ritchie et al., 1988). For instance, Mann & McWalter showed that when the sealing ability of laterally condensed gutta-percha was compared with injection-molded thermoplasticized gutta-percha in straight and curved canals, thermoplasticized gutta-percha solely produced overextension of material. Clinical case reports, involving overfills with heat-softened gutta-percha, are frequent in the literature. The emphasis on maintaining apical patency, along with the use of thermoplastic gutta-percha filling techniques, has increased the likelihood of overfilling (Blanas et al., 2002; Fanibunda et al., 1998). These variations in overfilling with warm obturation techniques, as well as considerable differences in flowability between gutta-percha brands (Tagger and Gold, 1988), have influenced the emergence of hybrid techniques involving cold condensation of gutta-percha or a custom-chloroform-dipped master cone apically, followed by warm obturation in the coronal two-thirds (Da Silva et al., 2002; van Zyl et al., 2005).

Regarding carrier-based obturation, this technique requires a canal preparation that allows enough space for the heated obturation material to flow into the isthmuses and irregularities of the soon-to-be obturated canal. Carrier-based obturation guidelines caution against the use of excess cement because of the true risk and limitation of this technique to overfill (Robinson et al., 2004). This is most probably due to the piston-like effect of the obturator during its insertion (Gluskin, 2009). Authors and manufacturers advised against a few of the most common errors produced with thermoplasticized carrier-based obturation: incorrect canal preparation including overinstrumentation and impingement on the apical terminus, excessive cement or gutta-percha, excessive force and velocity during insertion and improper obturator selection (highlighting the importance of choosing the matching obturator to the adequate verifier) (Cantatore, 2006; Gluskin, 2009).

1.5 Root Filling Removal in Root Canal Retreatments

A major difference between initial root canal treatment and root canal retreatment is the need to remove the previous filling material. Only when the access to the canal system is achieved and the canal can be negotiated can the deficiencies of the previous root canal obturation be improved upon (Duncan and Chong, 2011). This explains why the last property on Grossman's list of ideal materials includes the capacity of the obturation material to be easily removed from the canal, if needed.

Depending on the obturation material initially used in the primary root canal, various techniques can be applied for its removal. As gutta-percha is still the most widely used obturation material, most removal suggestions and techniques aim for its removal.

1.5.1 Root filling removal techniques

Techniques suggested to retrieve materials from the canals include the use of hand files, rotary files, heat, solvents, ultrasound and lasers.

Depending on the quality of the previous root filling material, the removal of the material can have various ranges of difficulty. When a canal is obturated with well condensed gutta-percha, most clinicians will feel the need to use a product that will be able to soften the gutta-percha first. This can most probably be achieved with the use of heat and solvents.

Heat can be applied by using heat carriers along with a Bunsen burner flame, or alternatively with electric heated spreaders or pluggers, such as Touch 'n Heat (SybronEndo), System B Heat Source (SybronEndo) (Gilbert and Rice, 1987). The heat transfers through the material, softening the gutta-percha, which can later be removed with mechanical instrumentation, either with hand-files or with rotary instrumentation. Care must also be taken with the use of mechanical instrumentation products so as to avoid breakage of the instrument in the canal. Indirect heat can be applied with the use of instruments such as Gates-Glidden drills and long-neck burs such as Mueller or Munce burs. As with all techniques, challenges are discussed in literature. Caution is required to avoid overheating of the PDL when manipulating the heat carrier intermittently. It is therefore important not wedge the heat source on the canal walls (Lee et al., 1998).

Solvents are also very useful in softening and easing the removal of gutta-percha, as well as removing portions of the material that could not be accessed by mechanical instrumentation only (Friedman et al., 1990). Chloroform has been shown to be the most effective and popular solvent despite its classification as a carcinogenic agent with a potential risk to the dental environment (Tamse et al., 1986; Wennberg and Orstavik, 1989). Other less toxic alternatives have been suggested such as Eucalyptol, Xylene/Xylol (Wennberg and Orstavik, 1989), Methyl Chloroform (Wennberg and Orstavik, 1989), Halothane, Rectified Turpentine (Wennberg and Orstavik, 1989) and Orange Solvent (Barbosa et al., 1994), but their efficiency has been proven to be reduced.

The use of the solvents, such as chloroform, within the root canal has no detrimental effect on tooth structure and as long as the substance is confined in the canal, there is minimal risk associated (Kaufman et al., 1997; McDonald and Vire, 1992). The safer way to apply chloroform is to reduce the gutta-percha in the coronal third of the canal first with mechanical removal, and along with a small syringe ideally made of glass or polypropylene, inject small incremental amount into the canals. The softened gutta-percha can then gradually be removed with rotary or hand instrumentation further and further into the canal (Gu et al., 2008; Imura et al., 2000).

The use of piezo-electric ultrasonics in retreatment is usually confined to retreatment of pastes, cements and silver points, but it can be used without irrigation to create frictional heat to plasticize gutta-percha and therefore facilitate its removal (Joiner et al., 1989). However, with this particular technique, gutta-percha can be pushed against the canal's walls increasing the difficulty of its removal, especially if a slurry is created. Nevertheless, ultrasonics appear to be efficient in removing the bulk of the gutta-percha in the straighter part of the canal (Ladley et al., 1991).

1.5.2 Rotary versus hand instrumentation

In the past, Lexicon® Gates Glidden drills, along with the use of hand files, were exclusively used for the retrieval of the root filling materials, however with the appearance nickel-titanium (NiTi) files having a reputation of increased effectiveness and improved speed of removal of gutta-percha, the focus seems to have shifted (Sae-Lim et al., 2000; Valois et al., 2001). Various rotary files have been evaluated for their retreatment capacity (ex: ProFile® (©DENTSPLY)(Ferreira et al., 2001), System GT® (©DENTSPLY) (Hulsmann and Bluhm, 2004), HERO Shaper®(MicroMega®, Besancon, France)(de Carvalho Maciel and Zaccaro Scelza, 2006), K3®(SybronEndo) (Saad et al., 2007), ProTaper®Universal (©DENTSPLY) (Marques da Silva et al., 2012) , MTwo® (VDW®, Munich, Germany) (Tasdemir et al., 2008) and EndoSequence® (Brasseler USA®, Savannah, GA)(Ring et al., 2009)) and some NiTi files have even been designed specifically for this purpose (ex: ProTaper®Universal Retreatment files (©DENTSPLY) and R-Endo®(MicroMega®)) (Kumar et al., 2012; Unal et al., 2009). Studies are divided on which technique is more efficient in retrieval of gutta-percha from the canal walls. Valois et al. (2001) discussed that rotary nickel-titanium system such as ProFile® (©DENTSPLY) were faster than hand instruments in removing root filling materials. Yet, other studies have found opposing results (Betti and Bramante, 2001; Zmener et al., 2006). Both of these last studies seemed to suggest that even though rotary files may be faster in retrieving most of the root filling, they were less efficient overall compared to hand files in rendering cleaner calls. Hulsmann & Bluhm (2004), however, discussed that the effectiveness and efficiency of rotary files systems in removing root filling material depended on the characteristics of the cross-sectional design of the instruments (Hulsmann and Bluhm, 2004). Files such as ProTaper®Universal Retreatment files (©DENTSPLY) can remove great amounts of gutta-percha in their flutes, whereas U-type cross-section designs might not be capable of cutting the filling materials in the first place and have trouble in penetrating the root filling apically. The increased suggested speed of rotation of certain retreatment files system might also allow the gutta-percha to soften, further promoting the penetration of the file into the material and allowing its removal (Gu et al., 2008; Ma et al., 2012; Valois et al., 2001).

1.5.3 Rotary systems and operating speeds

Root canal treatment using rotary instruments is usually carried out, according to the various systems' manufacture's recommendations, at around 300 to 700 RPM, the vast majority being at 300 RPM (Barrieshi-Nusair, 2002; Ferreira et al., 2001; Sae-Lim et al., 2000; Schirrmeister et al., 2006b; Unal et al., 2009). However, some authors and products protocols have been recommending higher speeds such as to increase the efficiency of retreatment by plasticizing gutta-percha. These speeds can even go as high as 1500 RPM (Bramante and Betti, 2000; Royzenblat and Goodell, 2007), but case selection according to the canal's curvature must be done to avoid procedural errors, such as file breakage (Betti and Bramante, 2001). Royzenblat & Goodell (2007) found that there was a trend towards increased file fracture with higher speeds, but it was not significant. Some manufacture's such as ProTaper® Universal Retreatment files (©DENTSPLY) recommend 500-700 RPM. Recent studies have tested this 500 RPM, as a higher speed and have noticed no further procedural errors compared to 300 RPM (Gu et al., 2008; Huang et al., 2007; So et al., 2008; Zmener et al., 2006)

1.5.4 Removal of gutta-percha carrier devices

Carrier-based obturation system, most commonly known under manufacturing name Thermafil®Plus(©DENTSPLY), allow easy and quick placement of the obturator into the cleaned and shaped canal, but presents a few challenges when it comes to removal of the obturation and more specifically the carrier. Often, the removal of carrier-based obturation can be problematic especially when inadequate cleaning and instrumentation and improper choosing of the obturator has been opted for. As a result, the obturator is often not well adapted to the canal and when inserted to the canal, the gutta-percha can be stripped from the carrier. The result is not only an apical obturation void of gutta-percha but also a carrier that is wedged into the canal and therefore hard to remove if necessary. This situation can be challenging to the clinician since inserting a hand file or even a rotary file around the carrier is quite difficult.

Several studies have addressed retreatment of carrier-based obturation and compared it to both lateral (Abarca et al., 2001; Chu et al., 2005; Clark and ElDeeb, 1993; Dalat and Spangberg, 1994; Frajlich et al., 1998b; Gulabivala et al., 1998; Gutmann et al., 1993;

Pathomvanich and Edmunds, 1996; Wilcox and Juhlin, 1994)and warm vertical condensed gutta-percha (Beasley et al., 2013; Dalat and Spangberg, 1994; De-Deus et al., 2007; De Deus et al., 2004; De Moor and Hommez, 2002; Gencoglu et al., 2002; Gopikrishna and Parameswaren, 2006). Retrieval of the carriers were traditionally attempted with the use of Hedstrom, K-files, forceps and solvents and then later with the appearance of plastic core obturators, such as Thermafil®Plus (©DENTSPLY), and gutta-percha-based obturators, such as GuttaCore® (©DENTSPLY) with Gates Gliddens (©DENTSPLY) and even rotary files with or without solvents.

As the carrier was initially metal, a combination of stainless steel and titanium, studies focused on the retrieval of these types of carrier-based obturation systems. The removal of gutta-percha metal carrier devices was concluded to be challenging and time-consuming (Wilcox, 1993; Wilcox and Juhlin, 1994). Wilcox et al. (1993/1994) found that metal carrier were particularly difficult to remove in curved canals compared to straight canals, resulting in difficulty in removing up to 50% of the carriers . Zuolo et al. (1994) found that retreatment of Thermafil® (DENTSPLY)with a metal carrier was more time-consuming and in six cases could not be removed at all (Zuolo et al., 1994). Other studies supported the same beliefs (Frajlich et al., 1998a) and as a result of these studies and general practitioner’s concern, the production of gutta-percha devices with metal carrier was discontinued.

The principal difference in the technique in removal of the plastic carrier lies on the deformation of the carrier to heat and more recently on the new design of the carrier. Heat application, either with a heat carrier (Wolcott et al., 1999) or through the high rotational speed of Gates Gliddens (©DENTSPLY) (Imura et al., 2000) or rotary files to the coronal aspect of the carrier, could allow further penetration of the files into the canal. Gates Glidden

(©DENTSPLY) should only be used in the straight part of canal, most probably the coronal third, to avoid ledging, stripping or even worse, perforation. Their use has therefore clear limitations. However, rotary NiTi can be more diverse in their use, reaching the other two third of the canals. Most studies discuss using these rotary files without solvents (Baratto Filho et al., 2002). To facilitate the penetration of those rotary files into/along the carrier, some manufacturers as well as some authors (Royzenblat and Goodell, 2007) have suggested to increase the speed of use, so as to promote heat production and propagation into the carrier. This technique seemed to even be efficient in moderately curved teeth, allowing faster removal and no further risk of perforations. However, a trend in file fractured was noticed but is not statistically significant. To further facilitate the removal of the plastic carrier-based obturation, especially in situations where the carrier is inserted and wedged into the canal without prior proper cleaning and shaping, manufacturers have attempted to mend this problem by creating a notch running along one of the side of the carrier of Thermafil®Plus (©DENTSPLY) to provide space in order to allow insertion of a file and ease of removal (Duncan and Chong, 2011). With these new modifications and techniques presented in ex-vivo studies, comparing removal of plastic carrier obturation with conventional condensation techniques, Thermafil®-like obturation can be removed successfully and efficiently.

Nevertheless, clinicians still tend to complain of the troubles in removing plastic-carrier based obturators, consequently Tulsa Dental (©DENTSPLY) has recently introduced GuttaCore® (©DENTSPLY), the first cross-linked gutta-percha core, which implies that the whole obturator is formulated of gutta-percha. It is important to highlight that the core behaves unlike gutta-percha and it does not melt in the oven, does not dissolve in solvents but has the advantage of rendering a carrier-based obturation that is easier to retreat compared to plastic carrier and easier to create a post space, according to the manufacturers. To date, only one study has evaluated the root filling removal of this new product. This study concluded that GuttaCore® (©DENTSPLY) was removed in less time from moderately curved canals with ProTaper®Universal Retreatment files (©DENTSPLY) than either thermoplasticized gutta-percha or Thermafil®Plus (©DENTSPLY) materials (Beasley et al., 2013).

1.5.5 Residual material following root filling removal

When endodontic failure occurs and nonsurgical retreatment is considered, the main goal of is to gain access to the apical foramen and attempt the complete removal of the previous root canal filling material, thus facilitating adequate cleaning and shaping of the contaminated system (Stabholz and Friedman, 1988). The previous root filling material can be removed by rotary instruments, heat carrier instruments and solvents. Even with all these available approaches, clean root canal walls are not usually obtainable (Marfisi et al., 2010) and various obturation materials are left behind as residual materials. Generally, studies state that regardless the removal techniques, whether hand or rotary filling, with or without solvents, no techniques are effective in providing complete removal of filling material from the root canal (Dall'Agnol et al., 2008; Kfir et al., 2012; Pirani et al., 2009). When comparing retreatment of carrier-based obturation techniques, beliefs are divided. While most studies report no difference in residual materials (Imura et al., 2000; Wolcott et al., 1999; Zuolo et al., 1994), some studies have shown differences amongst the carrier-based obturation and the traditional condensation. Frajilich et al. (1998) compared the residual material left behind when obturation was done using Thermafil® (©DENTSPLY) with a metal carrier, Thermafil®Plus (©DENTSPLY) with a plastic carrier and lateral condensation. The results of this study showed more residual material when Thermafil® (©DENTSPLY) with metal carrier was used. Additionally, it was noted that when the plastic carrier was retrieved, plastic fragments of the carrier were left behind (Frajlich et al., 1998b). These remnants could impede on adequate cleaning and shaping of canals.

1.5.6 Complications

Main risks and complications of root canal retreatments discussed in the literature have included ledging, perforations, blockages, loss of working length, file unwinding and finally fracture of the instrument used during the procedure (Duncan and Chong, 2011). Rotary files are prone to unwinding and even worse, separation; however, the incidence may be reduced with a thorough understanding of the canal morphology in the hands of experienced clinician that exercises the removal of the previously placed material with care. Most retreatment studies have evaluated filling removal in straight canals, and papers focusing on retreatment of curved canals are limited (Royzenblat and Goodell, 2007; Unal et al., 2009). Perforations are also a complication that must be avoided. Systems such as ProTaper®Universal Retreatment files (©DENTSPLY) have to be used with care, especially with the first files, D1, as this file has an active tip. The active tip is useful in the initial penetration of gutta-percha, however if used incorrectly it can be reason for some of the procedural errors discussed. Same applies to files such as MTwo® (VDW), which also have active tips. D2, D3 rotary retreatment files from ProTaper®Universal Retreatment (©DENTSPLY) system can reduce the incidence of perforations, stripping and ledging and therefore can be used more freely in the further apical parts of the canal (Duncan and Chong, 2011; Giuliani et al., 2008).

Hulsmann & Bluhm (2004) and supplementary studies have discussed and iterated that no procedural errors such as perforations, blockages and loss of working length or ledging have been encountered with rotary files used for retreatment purposes (Barrieshi-Nusair, 2002; Gu et al., 2008; Hulsmann and Bluhm, 2004; Imura et al., 2000). Other studies, however, report the contrary (Gergi and Sabbagh, 2007; Schirrmeister et al., 2006b; Unal et al., 2009).

Chapter 2: Rational and Hypothesis

Thermafil®Plus (©DENTSPLY) is a gamma phase gutta-percha based endodontic obturation device a plastic core. Early on, the easy to use material had gained popularity due to the practitioner's belief that it rendered a more uniform and complete obturation. However, this material, and especially its solid core, has been perceived as being difficult to retrieve. The solid plastic carrier is not soluble in solvents such as chloroform and poses a challenge to clinicians trying to retrieve it from the canal.

Recently, the solid core in Thermafil®Plus (©DENTSPLY) has been changed to cross-linked gutta-percha and the new product is named GuttaCore® (©DENTSPLY). This new carrier system can retain its shape when heated and can be centrally condensed in three dimensions. Furthermore, the manufacturers claim that GuttaCore® (©DENTSPLY) can be removed from root canals with unprecedented ease.

Despite these new modifications brought to the Thermafil® family the hypothesis is null (H=0): No difference amongst the three groups - namely vertically compacted gutta-percha cones (GP), Thermafil®Plus (T) or GuttaCore® (GC) - in terms of retrieval time, as well as no difference amongst the three groups in terms of canal cleanliness is expected.

Chapter 3: Materials and Methods

3.1 Teeth Selection

Forty-five extracted mesio-buccal canals (MB) and thirty-six distal canals (D) of first and second mandibular molars with no previous endodontic treatment, fractures, resorptive defects, posts and open apices were selected for the purposes of this study. The study was approved by the University of British Columbia Ethics Board (**H12-00310).** Extracted teeth were accumulated by the generous donation of various clinics such as Department of Dentistry at the Jewish General Hospital (Montreal, QC), Undergraduate Dental Clinic of University of British Columbia (Vancouver, BC), Dental Clinic of Reach Community Health Center (Vancouver, BC) and Dentistry Clinic Vancouver General Hospital (Vancouver, BC). Teeth were stored in 0.01 % NaOCl at room temperature. Samples were preliminarily selected according to length (below 25 mm) and curvatures (below 30°) of mesial and distal roots with ruler and protractor. Once the preliminary collection was done, teeth were radiographed mesio-distally and bucco-lingually with size #2 Scan X Phosphor storage imaging plates (Air Techniques™, Melville, NY). This step allowed accurate measurement of the length of the canals, curvatures of the canals and also the variation in canal anatomy with ROMEXIS (Planmeca, Helsinki, Finland) measuring program. The length range of the MB canals had to be between 18 and 22 mm, whereas the canal curvature had to range between 15 and 30°. The inclusion criteria for the D canals implied a length range of 18-21mm and a curvature range between 3 and 20° (Figure 3.1). Canal curvatures were measured according to Schneider method (Schneider, 1971). A small field of view, Cone Beam Computed Tomography Scan (Carestream Kodak 9000 3D, Atlanta, GA) was also taken for these teeth. It also allowed discrimination between mesio-buccal canals joining with mesio-lingual canal prior to 1mm of the apical foramen.

Once, these radiographic evaluations were assessed, teeth selected were set aside for further evaluation. They were accessed using a high-speed tungsten carbide #557 cross-cut carbide bur (©DENTSPLY), an Access Endo Z burr (©DENTSPLY) and slow speed round burs (#2, 4) (©DENTSPLY). After the preparation of the access cavity, the canals were negotiated in the MB canals to a size 10 stainless steel K-file (©DENTSPLY) and in the D canals to a size 15 K-file (©DENTSPLY). Files needed to fit tightly in the canal, as this could allow a better approximation of the initial canal diameter. Teeth in which these respective files fitted loose in the canal were discarded. Working lengths were clinically and radiographically taken with the corresponding files to 1mm short of the file's emergence from the apical foramen (Hayakawa et al., 2010). Following this preliminary selection process, all teeth were recorded and an information sheet was established for each possible sample. Canals were standardized according to quadrant, whether pertaining to quadrant 3 or 4, length (mm), curvature (°) and initial diameter (0.1mm or 0.15mm). The lengths of the canals were determined according to the established working length of the canal, whereas canal curvature was measured according to a Schneider method (Gunday et al., 2005; Schneider, 1971). Teeth were given random numbers that were engraved on the crown, mostly on the mesio-buccal cusp, with #557 cross cut carbide bur (©DENTSPLY). For better visual acuity, numbers were highlighted with a Sharpie® black marker (Sanford Manufacturing Co., Oak Brook, IL). Teeth selected were equally distributed according to quadrant, length, curvature and canal in the three obturation groups, namely thermoplastic obturation technique of gutta-percha (GP), Thermafil®Plus (T) (©DENTSPLY) and GuttaCore® (GC) (©DENTSPLY).

In summary, for the forty-five MB canals (N=15 in each group), the lengths ranged between 18-22mm, whereas the curvature of the canal varied between 15-30°. As for the thirty-six D canals (N=12 in each group), the lengths ranged between 17-21mm, whereas the curvature of the canal varied between 3-20° (Figure 3.1). The specific information for the teeth sampled was collected on a specialized data sheet (0).

INCLUSION CRITERIA

MB Canals

- 1st and 2nd Mandibular Canal with standard morphology
- No previous endodontic treatment
- No previous fractures
- No previous resorptive defects
- No posts
- No open apices
- Length: 18-22mm
- Curvature: 15-30°
- MB canal separate from ML canals or at least only joining in the last apical 1mm
- First file fitting tightly into the canal and reaching working length: **10 K-file**

D canals

- 1st and 2nd Mandibular Canal with standard morphology
- No previous endodontic treatment
- No previous fractures
- No previous resorptive defects
- No posts
- No open apices
- Length: 17-21mm
- Curvature: 3-20°
- One single distal canal
- First file fitting tightly into the canal and reaching working length: **15 K-file**

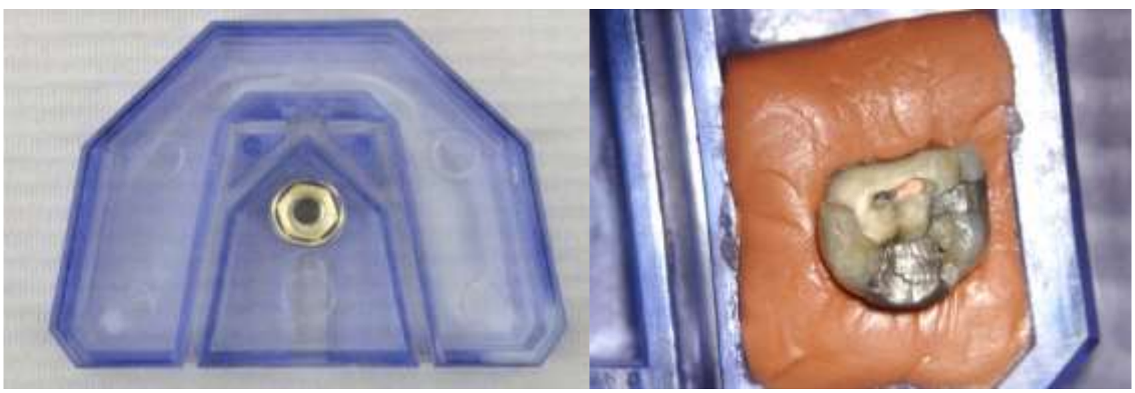
Figure 3.1 Inclusion Criteria for both MB and D canals

3.2 Teeth Mounting

Teeth were mounted using a #4 cotton pellet (©Richmond Dental, Charlotte, NC) around the apex and then surrounded by wax (Figure 3.1). This particular step was done to mimic a periapical pathosis (Nattress et al., 1997). Teeth were then inserted in Aquasil Putty (©DENTSPLY) and placed in a plastic tray constructed for clinical dental simulation on a dental phantom head (Nissin, Huddersfield, UK) (Figure 3.2). This set-up allowed the practice of all steps of the root canal obturation and material removal in a clinical situation. Using Aquasil Putty (©DENTSPLY) allowed removal of teeth from their mount with unprecedented ease, so that stages, such as material overfilling, could be evaluated and samples could be preserved.

A. **B.**

Figure 3.2 Mounting of the samples: **A.** Cotton pellet positioned around the apical portion of the root **B.** Once the cotton pellet is placed, wax surrounds the apical and middle third of the root.



A. **B.**

Figure 3.3 Using a plastic mounting tray adapted for a mannequin head **(A.)**, teeth were inserted in Aquasil Putty **(B.)**

3.3 Canal Instrumentation

For clinical procedures, all samples were prepared by a single practitioner, Dr. Marina Braniste (M.B). Glide path was created with the 10 K-file (©DENTSPLY) in the MB canals and with a 15 K-file (©DENTSPLY) in the D canals. Coronal flaring, providing access to restricted areas of the coronal aspect of the canal, was performed with Sx, ProTaper® Universal file (©DENTSPLY) at 300 RPM, as per manufacturer's instruction. Root canal instrumentation was done in crown-down fashion using the S1, S2, F1, F2, F3 ProTaper® Universal files (©DENTSPLY) with the rotary system motor, Contra-Angle 16:1 and Endo DTC Electronic Endodontic System (©DENTSPLY) at 300 RPM. The canals were instrumented up to an F2 (25/.08) for MB canals and to an F3 (30/.09) for D canals. Sodium hypochlorite (1 ml), NaOCl 6%, was used in between each instrument insertion with a side-vented, 30 gauge, ProRinse® closed-ended needle (©DENTSPLY) and a 10 ml syringe. Cleaning and shaping of the canal was judged adequate for obturation when canal walls were perceived as being smooth and uniform under X8 magnification with an dental operating microscope (DOM) (Global Surgical™ Corporation, St-Louis, MO). Prior to obturation, canals were irrigated for a final rinse with NaOCl 6% (10 ml) and then EDTA 17% (10 ml).

3.4 Canal Obturation

MB and D canals were obturated with one of the following three techniques according to previously determined sample allocation:

A. Thermoplastic obturation technique of gutta-percha with non-standardized gutta-percha points (GP);

B. Thermafil®Plus with plastic core obturation (T);

C. GuttaCore® obturation (GC).

Furthermore, three resin blocks with simulated canal of 30° curvature and 16 mm of length (Zipper, Munich, Germany) were also instrumented and obturated with these three techniques, with the purpose to be retreated in between teeth samples, so as to avoid an adaptation phenomenon.

Figure 3.4 Resin block being obturated according to the GP technique

3.4.1 Thermoplastic obturation technique of gutta-percha (GP)

In GP group (N_{MB}= 15 and N_D=12), master gutta-percha cone size F2 for MB canals and F3 for D canals from ProTaper®Universal (©DENTSPLY) were adapted to the appropriate canals until adequate tug-back was seated. Following drying with matching paper points (©DENTSPLY Tulsa Dental, Tulsa, OK), canals were coated with sealer, Thermaseal® Plus Ribbon™ (©DENTSPLY) , and the excess sealer was removed with one size-smaller paper point, meaning size F1 paper point for the MB canals and size F2 paper point for the D canals. Chosen cones were covered with a thin and uniform coat of sealer and gently inserted in the canal. Gutta-percha was then down-packed with a heat carrier system (Touch'n Heat 5004, SybronEndo) and Schilder pluggers sizes 8, 8 ½, 10 and 11(©DENTSPLY Tulsa Dental, Tulsa, OK). The canal was then re-coated with sealer and then back-filled using the Calamus® 3-D Obturation Unit (®DENTSPLY) with a gradual addition of gutta-percha, which implied further compaction in between each addition of 1-2mm of gutta-percha addition. Once the canal filled, obturation material excess was removed at orifice following compaction using a sharp spoon excavator. Final compaction was then applied with Schilder pluggers (©DENTSPLY).

3.4.2 Thermafil®Plus (T)

In T group (N_{MB}= 15 and N_D=12), Thermafil®Plus obturator (©DENTSPLY), having a plastic carrier, was used. All the manipulations were done according manufacturer's recommendations. The obturator was chosen in consistency with the canal shape, size and sequentially the appropriate size verifier. For MB canals, a size 25 verifier was used and for the D canals a size 30. The suitable obturator was then chosen and inserted in the

Thermafil®Plus oven (®DENTSPLY) to be soften and then inserted gently into the canal, over a period of 5 seconds. Once the carrier inserted, it was resected with a slow speed #2 carbide round bur (®DENTSPLY) and the excess material was compacted with #11 size Schilder plugger slightly below the pulp chamber floor of the tooth.

3.4.3 GuttaCore® obturation (GC)

In GC group, (N_{MB}= 15 and N_D=12), GuttaCore® (©DENTSPLY), having a cross-linked gutta-percha carrier, was used. The apical diameter of the canal to be obturated was assessed with the size verifier. All the manipulations were done according to manufacturer's recommendations. Similarly to the T group, a 25 size for the MB canals and a 30 size verifier for the D canals were used, as it was suggested by the manufacturing company. GuttaCore® obturator (©DENTSPLY) recommended for the MB canal was of a size 25 and for the D canals of a size 30. The obturators were then inserted in the GuttaCore® oven (®DENTSPLY) in a gentle manner, over a 5 seconds period, until the desired length was achieved. Once the obturator inserted, the carrier handle was twisted off and the excess material was compacted with #11 size Schilder plugger slightly below the pulp chamber floor of the tooth.

3.5 Obturation Overfill Evaluation

After obturation, samples were sealed with size #4 cotton pellet and Cavit^{TM}-3M (Henry Schein, New York, NY), and stored for fourteen days at 100% humidity, at 37°C to allow setting of the sealer. Teeth were then radiographed from a bucco-lingual dimension to evaluate obturation quality and the amount of extrusion. Obturation overfill was initially analyzed radiographically for each sample. The nature of the extruded material could not be determined by radiographic analysis only, and therefore, the samples were dislodged from the Aquasil Putty mount and directly visualized. The material extruded beyond the pre-determined apical foramen was recorded as:

A. Sealer only;

B. Sealer with gutta-percha;

C. No material extrusion.

However, statistical analysis was pursued to evaluate the extrusion of sealer with gutta-percha exclusively. Sealer-only extrusion was disregarded from the positive extrusion group, as it was considered to have a minimal effect on the clinical outcome of the root canal.

3.6 Root Filling Removal

This section of the experiment was started once the sealer was left to set for fourteen days at 100% humidity, at 37°C. Cavit^{TM}-3M (Henry Schein, New York, NY) was removed from the access cavity and the access was cleaned with ethanol and cotton pellets. Teeth were then reposition in the plastic tray constructed for clinical dental simulation on a Dental Phantom Head and the procedures were started under X8 magnification with the DOM.

3.6.1 Root filling removal technique

All three obturation materials could be removed with rotary system and therefore a rotary system that had been approved not only by the manufacturing company but also previous studies was used (Baratto Filho et al., 2002; Hayakawa et al., 2010; Royzenblat and Goodell, 2007). Considering the challenges that can be encountered during part of retreatment procedures, a standardized approach or a protocol had to be consistently applied.

3.6.2 Rotary system and operating speeds

The root fillings of all specimens were removed using ProTaper® Universal Rotary Retreatment files (©DENTSPLY) (D1, D2, D3) at 700 RPM in a crown-down manner up to the previously established working length. D1 was used down the canal up to 10mm, D2 up to 15mm and D3 up to the established working length. The files were used in a continuous motion. Upon withdrawal, files were cleaned and wiped with wet NaOCl 6% gauze before being reintroduced in the canal. Throughout the procedure, and before each reinsertion of file, the canal was irrigated with NaOCl 6% (1 ml).

Once the working length was reached, the patency of the canal was checked with a 10 K-file. Finally, the last rotary file used during the initial instrumentation of the canals was employed once again in canals undergoing retreatment procedures. Namely, F2 was used as a final rotary instrument in the MB canals and F3 in the D canals.

One series of ProTaper® Universal Retreatment files (D1, D2, D3) (©DENTSPLY) was used for each sample. Time was measured in seconds (sec) for each sample from the start of the retrieval of the obturation material to the reach of working length. The total time, from the beginning of the retrieval procedure to the last file used, as well as the time spent with each rotary file individually was recorded. After instrumentation, the canals were irrigated with 10ml of NaOCl 6%.

3.6.3 Adjunctive techniques

In the T group, the manufacturer recommended using ProTaper® Universal Retreatment files (D1, D2, D3) (©DENTSPLY) by placing the files in between the carrier and canal wall and lean into the carrier until resistance is encountered. If the Thermafil®Plus obturators (©DENTSPLY) were not removed during these steps, a size 25 Hedstrom file (Sybron-Endo) was wedged against the carrier and pulled coronally. If this was unsuccessful to dislodge the carrier, then two Hedstrom files of the same size were used on either side of the carrier and a braiding technique was applied.

If there was difficulty to reach working length after the use of the rotary retreatment files for any of the three groups, then a 10 K-file (©DENTSPLY) was manipulated along with increments of 0.1 ml of chloroform until working length was achieved.

3.7 File Deformation Evaluation

For each sample, ProTaper® Universal Retreatment files (©DENTSPLY) were kept and for analysis. Files were later visualized under X8 and X12.8 magnification with a DOM (Global Surgical™ Corporation). File unwinding was recorded, as well as the location of the unwinding along the flutes of the files, whether apical, middle or coronal third.

3.8 Residual Material Evaluation

For the residual material evaluation along the canal walls, the samples were prepared for splitting. Adequate size paper points were inserted into the canals, namely F2 paper points in the MB canals and F3 paper points in the D canals. The accesses were protected with Cavit. Teeth were decoronated using a 0.60mm diamond disk (Brasseler, Savannah, GA) with an IsoMet 5000 Linear Precision Saw (Buehler, Lake Bluff, IL) at the cementalenamel junction. Once decoronated, the roots were split, separating the MB root from the D root. Roots were then sectioned longitudinally using initially a #149L cross cut carbide bur to create a shallow grove along the axis of the tooth and then the roots were split along this groove using an industrial blade (Red Devil® Single Edge Razor Blade, Decatur, AL) gently tapped with a small hammer. The side of the root with the highest residual debris score was regarded for further statistical analysis. Residual debris along the canal walls were visualized using aid from a DOM at 8X magnification and pictures were taken with a Sony camera (HDR-XR520V, Tokyo, Japan) (**Error! Not a valid bookmark self-reference.**).

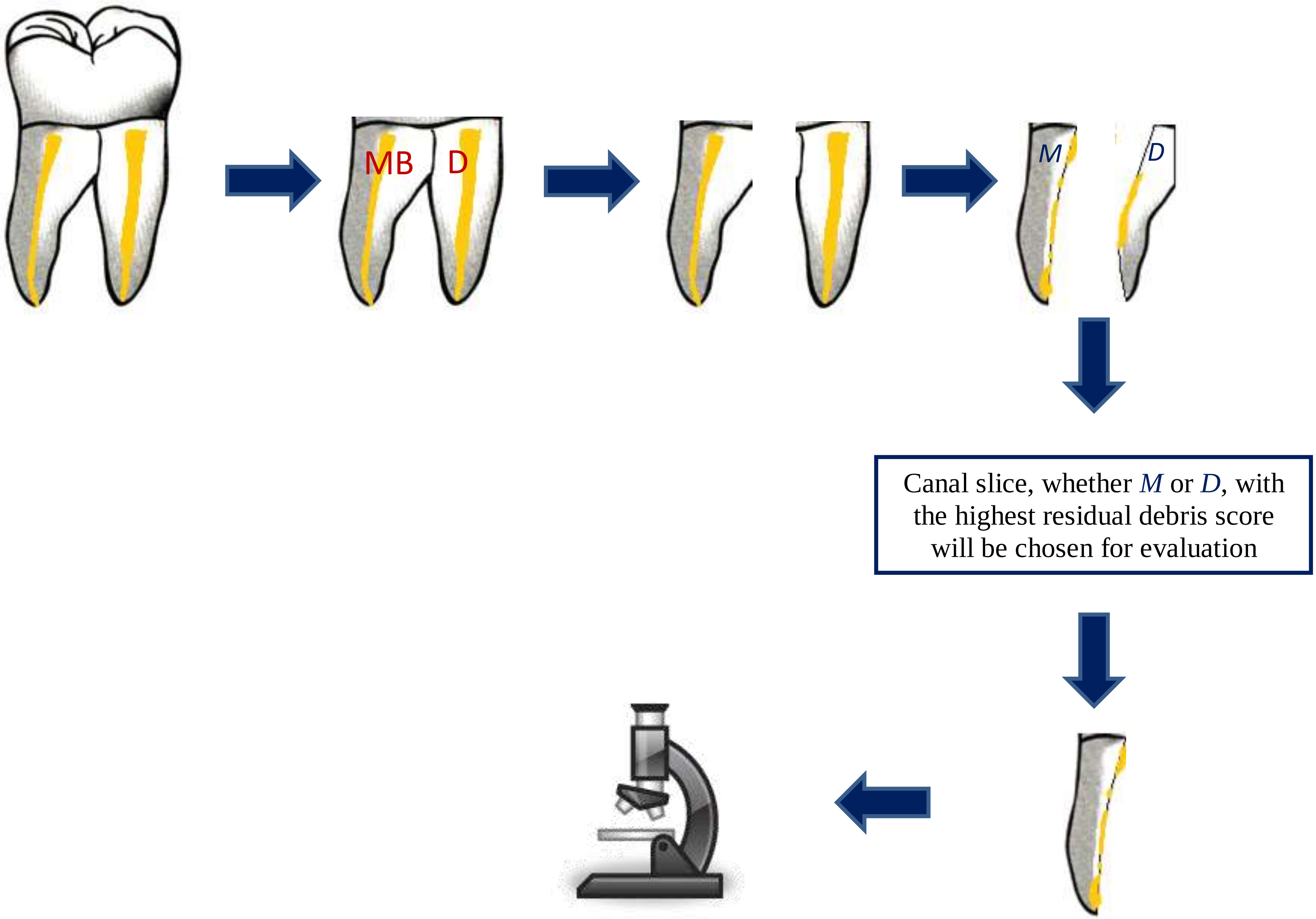


Figure 3.5 Schematic diagram of the residual material evaluation

A five-point grading system was used with respect to residual obturation material and debris at the coronal, middle, and apical third of each canal were evaluated. The highest score found on either *M* or *D* aspect of the resection was recorded.

The following scores were attributed to the residual obturation debris (Tay et al., 2010) (Figure 3.6)

Score 0: No debris noticed;

Score 1: Clean canal wall and only very few Gutta-Percha particles;

Score 2: Few small conglomerations of Gutta-Percha;

Score 3: Many conglomerations, **<50%** of the canal wall covered;

Score 4: >50% of the canal wall covered with conglomerations.

The evaluation was done blindly in regards to which samples pertained to which groups and the results were recorded by one single observer (M.B). Blinded analysis was done three times at various moments to confirm soundness of the results. Variation in the scoring occurred rarely and when discrepancy was observed an average of the scores was considered and rounded.

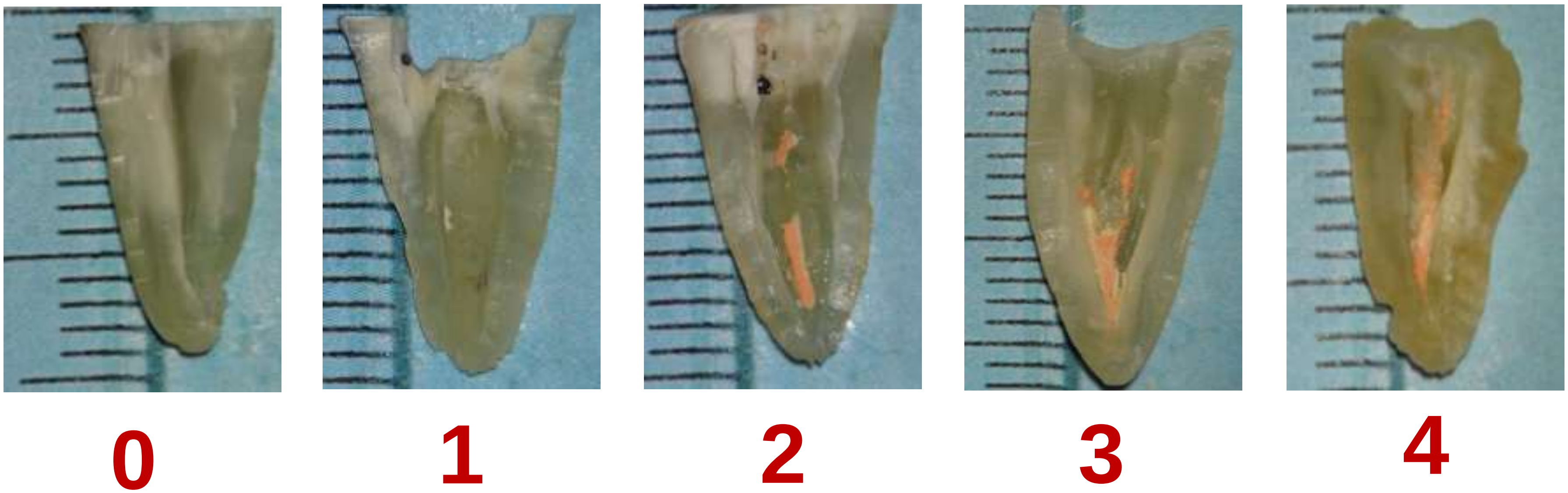


Figure 3.6 Explanatory pictures revealing the scores according to the five-point grading system allocated for to the apical third of five samples

3.9 Complications

During the retrieval of the obturation, if one of the instruments used was to separate, the canal involved would be discarded from the study. However, the group in which the separation occurred, the canal, and file type would be recorded. The level of the file separation would also be recorded. Similarly, if the patency could not be achieved following partial removal of the obturation, detailed information would be documented, so as to better understand the challenges during carrier-based obturation retrieval.

Moreover, challenges could be encountered during the longitudinal splitting of the teeth and some samples might be lost. If this was the case, those teeth were not considered for statistical analysis.

Chapter 4: Results

This study had two specific aims: to record the retrieval time of three root obturation materials, namely GP, T and GC, and evaluate the residual debris left on the canal walls following retreatment using ProTaper® Universal Retreatment files. This research also examined the occurrence of gutta-percha overfill of the three root filling materials, as well as file unwinding of the ProTaper® Universal Retreatment files. All results were gathered chronologically according to the experiment protocol by one single blinded practitioner (M.B). In sequential order of data accumulation, the results were captured in regards to material overfill, time of retrieval, file deformation and finally residual material left on the canal walls.

All MB and D canals were strategically divided amongst the three groups according to length, curvature and quadrants, so as to equilibrate group samples. Canal curvatures for the MB canals ranged from 15-30° and varied in length between 18-22 mm. Canal curvatures for the D canals ranged from 3-20° and varied in length between 17-21mm. There were no differences in the repartition of the samples according to curvature, length and quadrants between the obturation groups formed (Table 4.1, **Error! Reference source not found.**, Table 4.3).

Tooth #	Curvature (°)	Length(mm)	Quadrant (Q3/4)
GP (N=15)			
1	16	20.5	3
2	30	20	3
3	27	19	3
6	17	21	4
10	27	20.5	3
11	25	20	3
14	25	20	4
20	17	18	3
25	23	18.5	3
33	18	20.5	4
36	24	19.5	4
39	27	20	4
43	20	20	4
44	27.5	21	4
46	15.5	20	4
SD	4.89	0.85	
Median	24.00	20.00	
T (N=15)			
5	27	20	3
12	15	19	3
15	25	19.5	3
22	16	19.5	3
23	29	19	3
26	30	18.5	3
29	24	21	4
31	16	20	4
35	19	18	4
48	27	19	3
49	21	19	4
50	23	19	4
51	15	21	4
54	27	20.5	3
58	19	18	3
SD	5.28	0.95	
Median	23.00	19.00	
GC (N=15)			
9	26	20.5	3
16	17	21	3
21	27	20.5	3
24	23	19	3
27	30	22	3
30	23.5	21	4
34	17	19.5	4
38	19	20	4
45	17	19.5	4
52	15	20	4
53	17	20.5	4
55	30	20.5	3
56	26.5	20.5	3
57	24	18	3
59	18	18	3
SD	5.14	1.09	
Median	23.00	20.50	

Table 4.1 Information on MB canals according to curvature, length and quadrant

Tooth #	Curvature (°)	Length (mm)	Quadrant (Q3/4)
GP (N=12)			
1	8	20	3
3	4	19	3
4	3	19	3
5	19	20	3
10	9.5	20.5	3
11	8	18	3
18	7	21	3
25	6	18	3
28	12	18	4
39	6	19	4
41	9	19	4
46	6	19	4
SD	4.20	0.99	
Median	7.50	19.00	
T (N=12)			
2	12	18	3
8	5	18	3
12	9	18	3
15	17	20	3
22	4	18	3
29	9	20	4
31	13	18.5	4
40	8	19	4
48	20	19	3
51	7	18	4
55	3	20	3
58	7	18	3
SD	5.16	0.86	
Median	8.50	18.25	
GC (N=12)			
9	8	20	3
16	4	20	3
17	16	18	3
27	3	20	3
34	3	20	4
38	6	19	4
45	17	19	4
50	9	18	4
52	9	18.5	4
53	7	20	4
54	12	20	3
59	14	18	3
SD	4.84	0.89	
Median	8.50	19.50	

Table 4.2 Information on D canals according to curvature, length and quadrant

		CURVATURE (°)		LENGTH (mm)	
		Average	SD	Average	SD
MB	GP	22.6	4.89	19.9	0.85
	T	22.2	5.28	19.4	0.95
	GC	22.2	5.14	20	1.09
D	GP	8.1	4.2	19.2	0.99
	T	9.5	5.16	18.6	0.86
	GC	9	4.84	19.2	0.89

Table 4.3 Table displaying the average and standard deviation (SD) of length and curvature of both MB and D canals for the three obturation groups

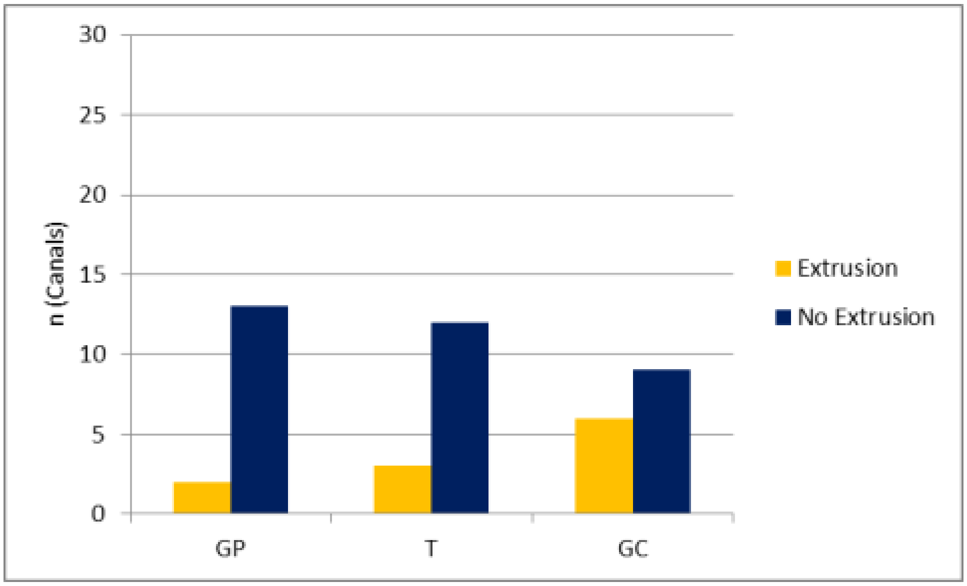
4.1 Obturation Overfill Results

All twenty-seven samples, fifteen in MB canals and twelve in D canals were radiographically interpreted to have acceptable obturation quality and were used for analysis. Overfilling was initially verified radiographically. However, it was difficult to differentiate between sealer extrusion and combined extrusion of gutta-percha and sealer and therefore, our results reflect samples with gutta-percha and sealer overfilling. Samples were clinically checked by removing the extracted tooth from the Aquasil Putty mount and by examining the simulated periapical area. The differentiation between sealer and gutta-percha was simple, as there is a distinguishable difference in color; gutta-percha being orange whereas the sealer is pale beige. Our records reported only the presence or the absence of gutta-percha beyond the apical foramen and no quantitative evaluation was done. Extrusion of gutta-percha was examined according to type of canals individually (MB versus D) and for both types of canals combined (MB with D).

According, to *Kruskal-Wallis test*, there was no statistical significant difference for gutta-percha/sealer overfill in the three obturation groups, (GP, GC and T) for the MB canals ($P = 0.580$) (Table 4.4, Figure 4.1) or the D canals ($P = 0. 051$) (Table 4.5, Figure 4.2). As the P value was approaching the significance limit in the D canals, a *Mann-Whitney-U-test with Bonferroni Correction* was run. *Bonferroni correction* overcomes alpha error accumulation and its local significance level was adapted to this investigation ($\alpha' < 0.017$). The local significances were the following: GP versus T ($\alpha' = 0.089$); GP versus GC ($\alpha' = 0.319$); T versus GC ($\alpha' = 0.514$). Even though a difference was not expected, data was analyzed.

	GP	T	GC
Extrusion	2	3	6
No Extrusion	13	12	9

Table 4.4 Table of gutta-percha extrusion beyond the apical foramen in the MB canals for the three obturation groups (N=15)

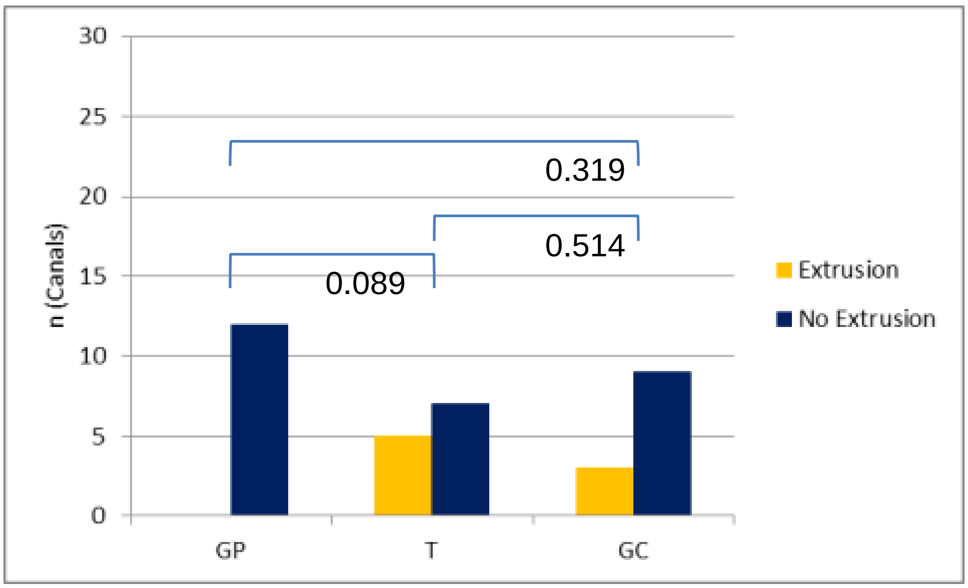


• Kruskal-*Wallis test: P= 0.580*

Figure 4.1 Column chart of gutta-percha extrusion beyond the apical foramen in the MB canals for the three obturation groups

	GP	T	GC
Extrusion	0	5	3
No Extrusion	12	7	9

Table 4.5 Table of gutta-percha extrusion in the D canals for the three obturation groups (N=12)



• Kruskal-*Wallis test: P= 0. 051 with Mann-Whitney-U-test with Bonferroni Correction*

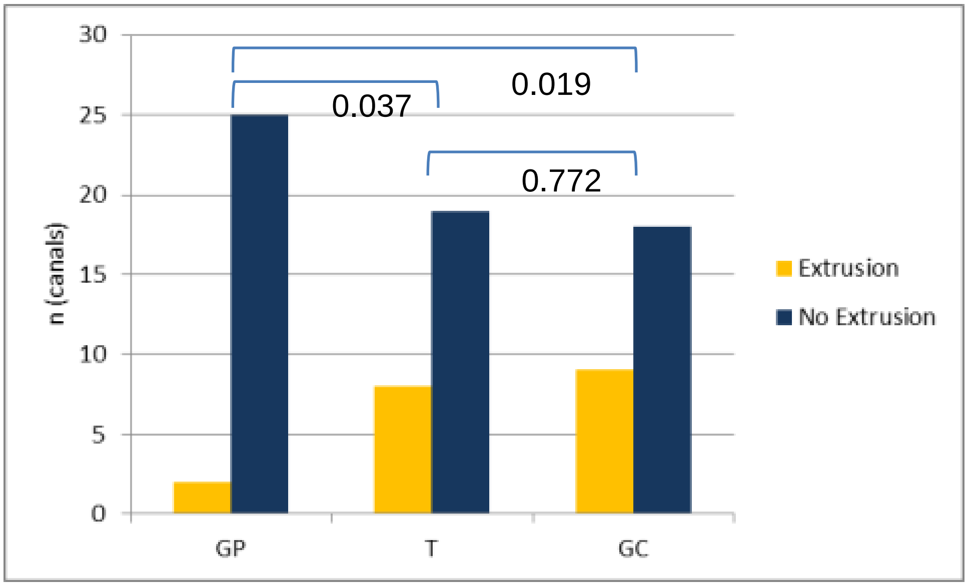
*(*N.B: The number shown on the connectors are the α' values)

Figure 4.2 Column chart for gutta-percha extrusion beyond the apical foramen in the D canals for the three obturation groups

In regards to overfilling the canals according to the three obturation material (GP, T, GC), when combining both MB and D canals, results show no statistical significance within the obturation groups with *Kruskal-Wallis test* ($P = 0.054$). However, the *P* value is neighboring statistical significance, and therefore a pair-wise comparison with a *Mann-Whitney-U- test* with *Bonferroni* correction was applied. As previously mentioned, *Bonferroni* correction overcomes the alpha error accumulation and its local significance level was adapted to this investigation ($\alpha' < 0.017$ if statistically significant). The local significances were the following: GP versus T ($\alpha' = 0.037$); GP versus GC ($\alpha' = 0.019$); T versus GC ($\alpha' = 0.772$). Results showed that samples in the GP groups compared to T groups, and especially GP groups compared to GC groups are close to being statistically significant in difference; meaning that the carrier-based obturation could render further gutta-percha extrusion. Analysis of T and GC groups results in similar and closely related values (Table 4.6, Figure 4.3).

	GP	T	GC
Extrusion	2	8	9
No Extrusion	25	19	18

Table 4.6 Extrusion of gutta-percha beyond the apical foramen combining MB and D canals in the three obturation groups (N=27)



• Kruskal-*Wallis test: P= 0.054* with *Mann-Whitney-U-test* with *Bonferroni Correction*

(N.B: The number shown on the connectors are the α' values)

Figure 4.3 Column Chart for gutta-percha extrusion beyond the apical foramen combining MB and D canals in the three obturation groups

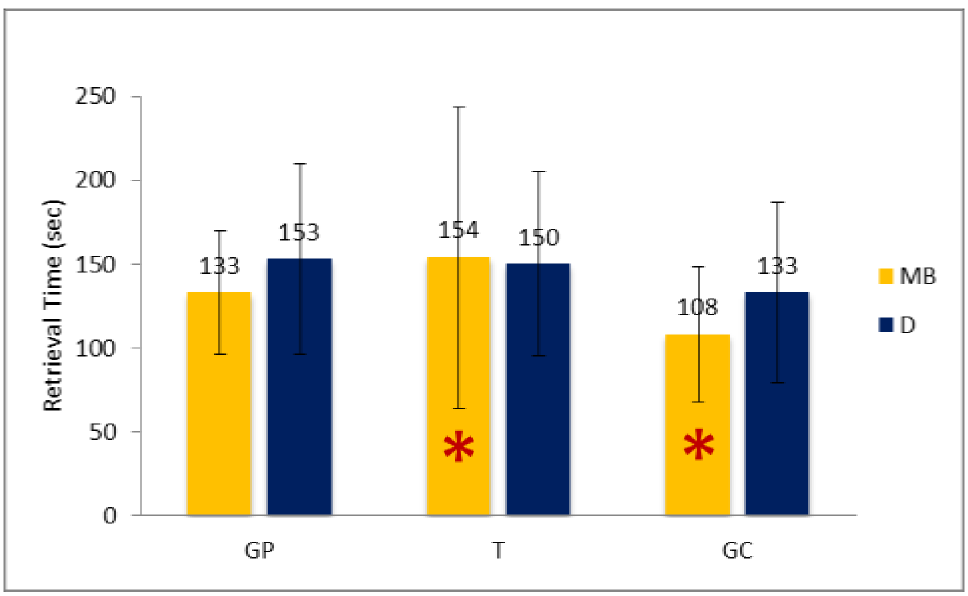
4.2 Root Filling Removal Time Results

Two samples were lost during retreatment procedure because of file separation that occurred during canal instrumentation. An F2 ProTaper® Universal file in a MB canal of the T group and a D2 ProTaper® Universal Retreatment file in D canal of GC separated. The groups were, therefore, adjusted to maintain uniformity in regards to length and curvatures of canals. The number of samples per group was reduced to N=12 in the MB canals and N= 9 in the D canals. This resulted into a total number of twenty-one samples. Times for retrieval of the root filling material were recorded for each file used and also as a total time (sec), following the use of D1, D2, D3 ProTaper® Universal Retreatment files and the last file used in the previous initial instrumentation, meaning F2 ProTaper® Universal file for the MB canal and F3 ProTaper® Universal file for the D canals. The most clinically relevant result was considered to be the total time recorded for retrieval of the previous root filling material. *ANOVA and Post-Hoc Test* was applied and a statistical significant difference was found between GC and T groups in MB canals ($P = 0.026$) (Table 4.7, Figure 4.4). Canals obturated with GC were faster to retrieve than the ones obturated with T (108 sec (GC) versus 154 sec (T)). No other significant difference in retreatment time was detected amongst the materials tested ($P > 0.05$).

	Time (sec)	
	MB canals	D canals
GP	133 ± 37	153 ± 57
T	154 ± 90*	150 ± 55
GC	108 ± 40*	133 ± 54

* *ANOVA and Post-Hoc Test: Statistical* significant difference between GC and T groups on MB canals (*P = 0.026*)

Table 4.7 Mean retrieval time (sec) of root filling removal combining MB and D canals



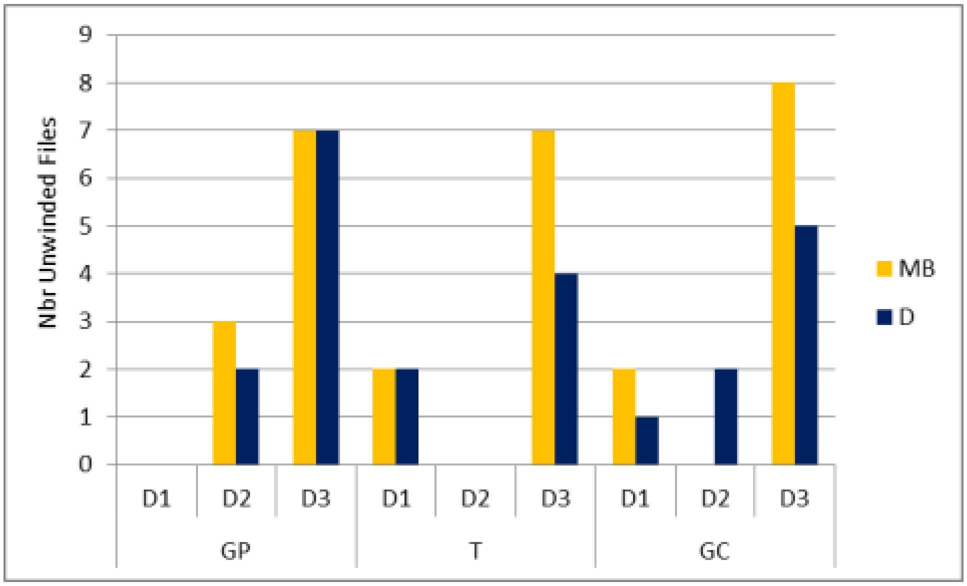
* *ANOVA and Post-Hoc Test: Statistical* significant difference between GC and T groups on MB canals (*P = 0.026*)

Figure 4.4 Column chart for the mean retrieval time (sec) of root filling removal combining MB and D canals

4.3 File Deformation Results

As previously stated, two samples were lost during retreatment due to file separation which could not be retrieved or bypassed. There was also a D2 ProTaper® Universal Retreatment file separated in a MB canal in a T group, however this was retrieved with ease, not affecting the overall results.

To compare the amount of deformation of the files, we applied *two-way ANOVA* with *Tuckey' Multiple Comparison Test.* We observed no statistically significant difference between the amount of file deformation and the two types of canals retreated (MB and D) *(P = 0.81)*. No statistically significant difference was noticed for the type of obturation materials (GP, T or GC) *(P= 0.72)* and no statistically significant difference when comparing materials within the two types of canals *(P=0.92).* All files unwound 3mm away from the instrument tip. D3, ProTaper® Universal Retreatment file, was the file that deformed the most and D1, ProTaper® Universal Retreatment file, the least. D1, ProTaper® Universal Retreatment file was unwound only in T and GC groups (Figure 4.5).



• *Two-way ANOVA* with *Tuckey's Multiple Comparison Test*

Figure 4.5 Clustered column chart representing file deformation according to the type of canal (MB vs D) and type of obturation material retrieved (GP, T, GC).

4.4 Residual Material Results

Prior to starting investigation of residual material found on canal walls, confirmation of a standardized and reproducible scoring technique found. As the scores were reproduced three times at various moments, it was estimated that the scoring method had approximately 95% of consistency, namely a 5% error of variance (Midtgard et al., 1974). Furthermore, *Friedman Test ($P = 0.266$)* were applied to confirm that no significant differences amongst scoring at the various times was encountered. Analysis of the residual debris on the canal walls was quite complex, as there are a multitude of variables that had to be considered. This could result in an extensive, and clinically inconclusive, statistical analysis. For better understanding of the results' clinical implications, the statistical analysis was initially focused on the type of canal (MB versus D canals), localization of the residual score (coronal, middle and apical third) and finally, on the type of material (GP, T or GC).

When comparing the overall residual debris in the two types of canals, MB versus D, using *Pearson Chi-square test with Cochran-Mantel-Haenszel (CMH)*, no statistically significant difference was found ($P = 0.253$) (Figure 4.6, Figure 4.7).

Statistical analysis, with the same test, when comparing debris scores in coronal, middle and apical thirds of the canals revealed that there was a statistical significant difference ($P < 0.001$) (Figure 4.8, Figure 4.9). The apical third, followed by the middle third were observed to have the most residual debris subsequent to obturation retrieval.

Furthermore, no statistical significant difference was found in debris scores amongst the three obturation types, GP, T and GC ($P = 0.148$) (Figure 4.10, Figure 4.11), nor when analyzing specifically the obturation type in the coronal (Figure 4.12, Figure 4.13), middle (Figure 4.14, Figure 4.15) and apical third ($P = 0.060$) (Figure 4.16, Figure 4.17, Figure

4.18). When exploring even further the results and comparing specifically the GP sample results with the T sample results (*P* = 0.445) and T sample results with GC sample results (*P* = 0.344) in the apical third, no statistically significant difference was found. However, when comparing the GP sample results and the GC sample results in the apical thirds of the canals, a statistical significant difference was found (*P* = 0.010). GC group resulted in more residual debris than GP group following removal of the root filling.

Interestingly, carrier residues were noticed in the groups of carrier-based obturation, namely T and GC. Carrier debris were found in the apical third in four samples from the T group: three from MB canals, one from a D canal. One sample only had noticeable carrier debris for GC group in a MB canal. These debris were easily visualized as they appeared as thin concave sheets of grey matter, usually closely adapted to the canal wall.

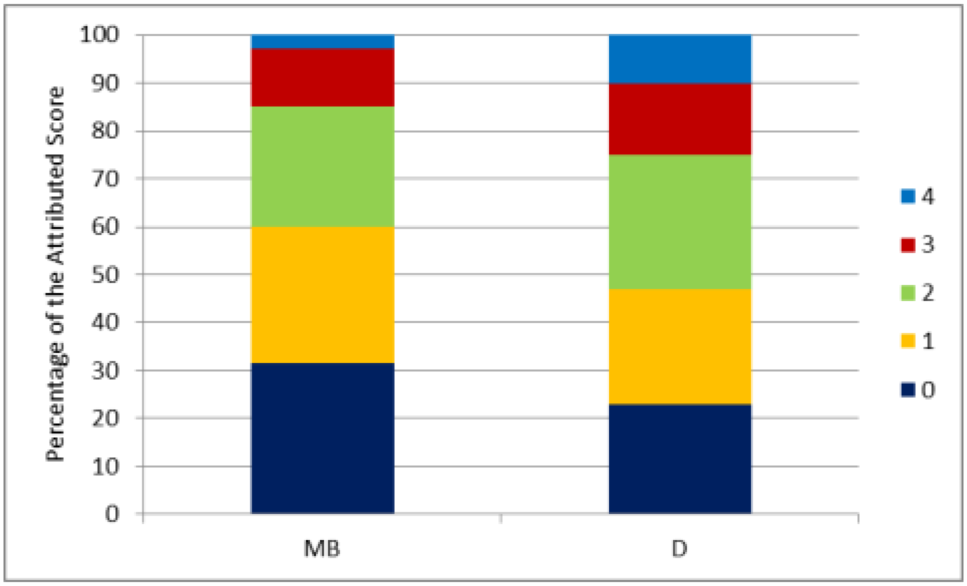
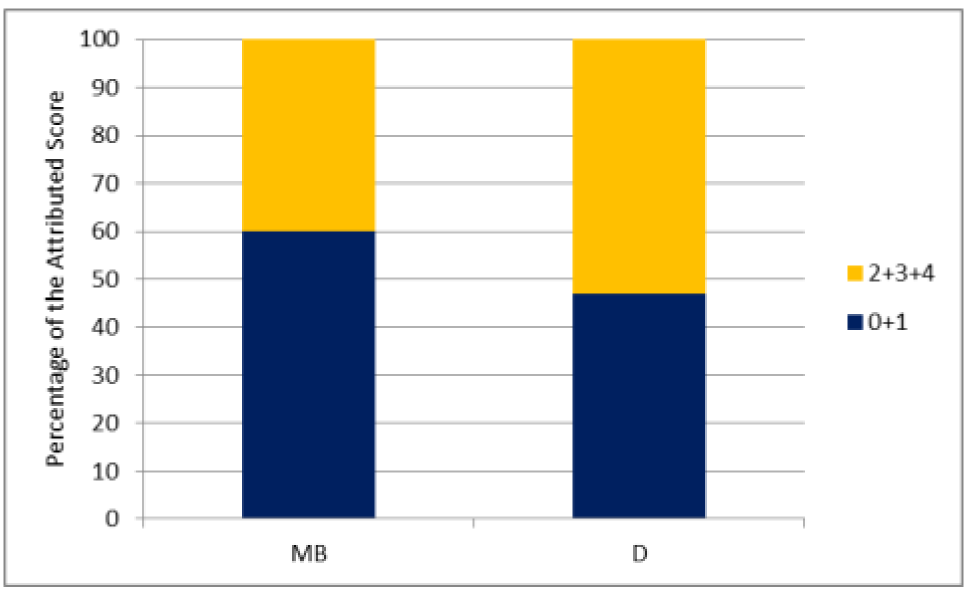


Figure 4.6 Stacked column chart presenting the percentage of residual material scores in the coronal, middle and apical thirds in the MB and D canals combined



• *Pearson Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistically significant difference (P = 0.253)*

Figure 4.7 Stacked column chart presenting the percentage of strategically regrouped residual material scores in the coronal, middle and apical thirds in the MB and D canals combined

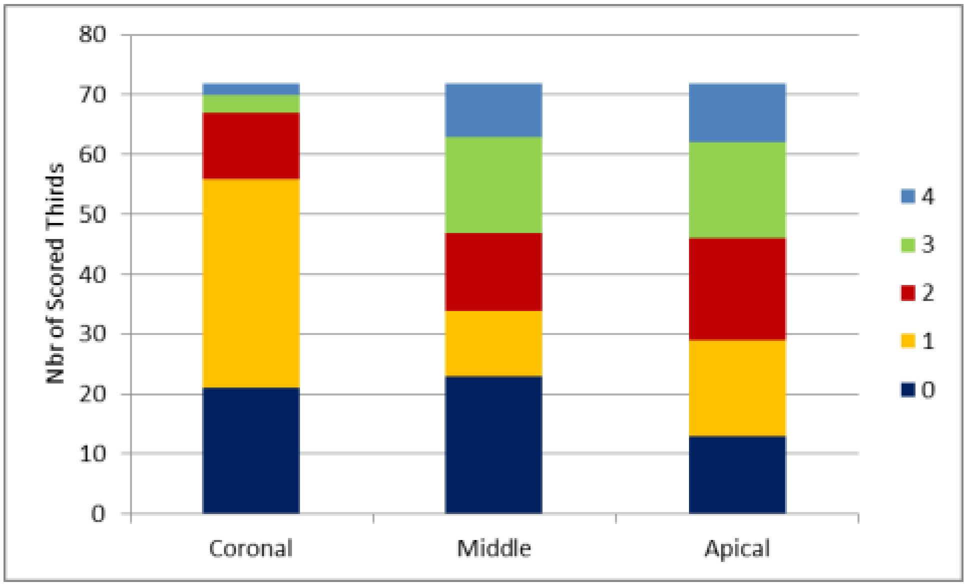
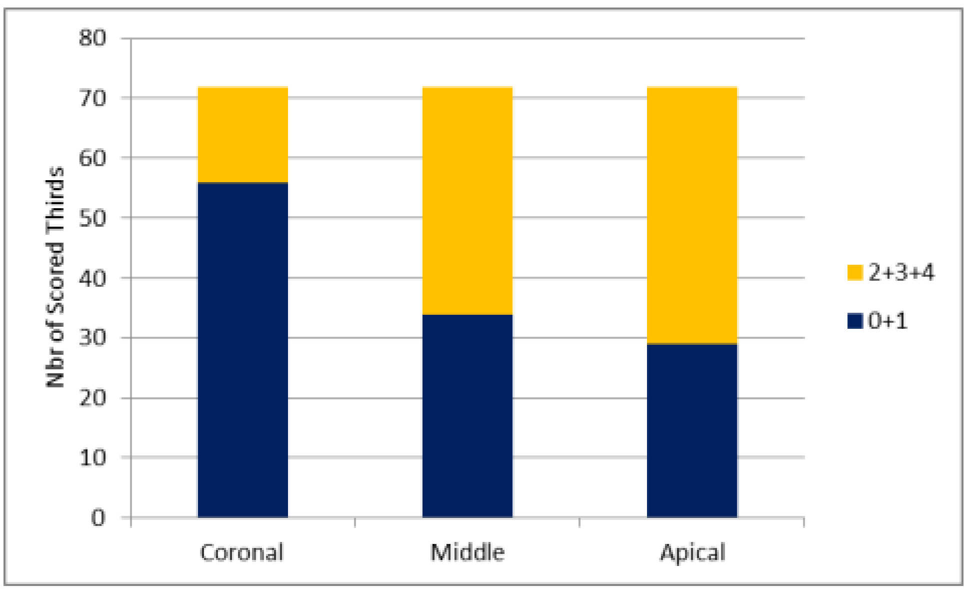


Figure 4.8 Stacked column chart presenting number of residual material score in each of coronal, middle and apical thirds in the MB and D canals combined



• *Pearson Chi-Square test with Cochran-Mantel-Haenszel (CMH) - Statistically significant difference (P = 0.001)*

Figure 4.9 Stacked column chart presenting number of strategically regrouped residual material scores in each of coronal, middle and apical thirds in the MB and D canals combined

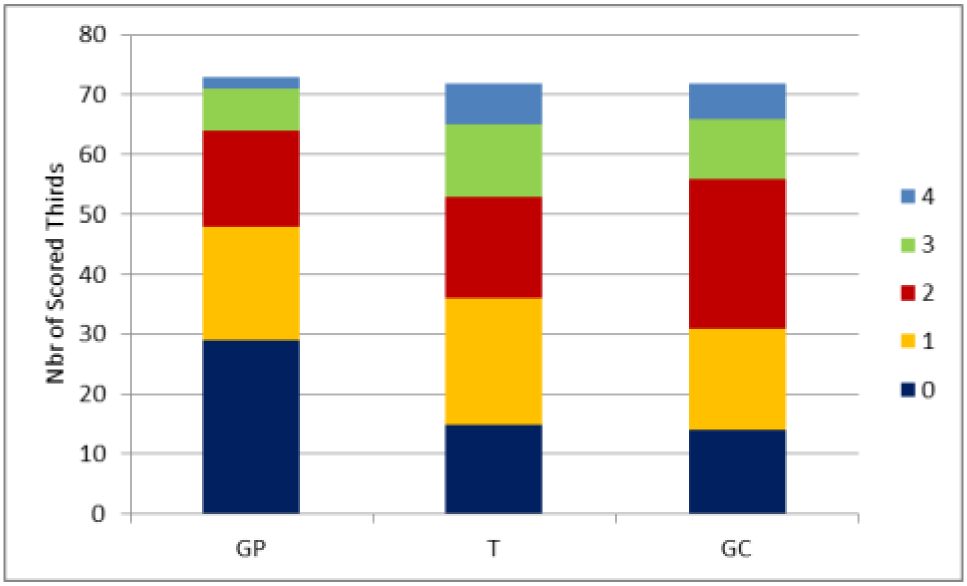
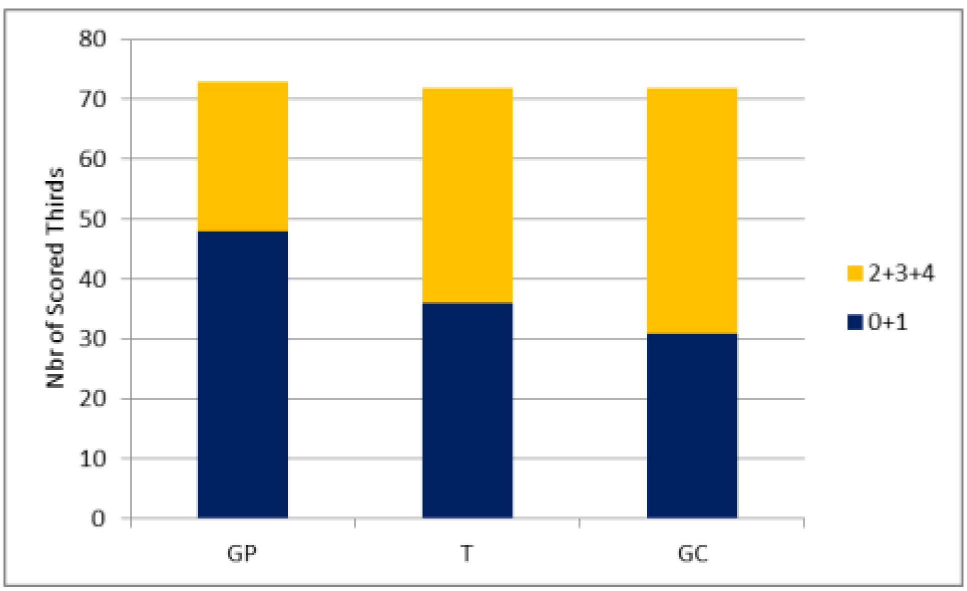


Figure 4.10 Stacked column chart presenting number of residual material score in each of GP, T, GC groups for both MB and D canals combined



• *Pearson Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistical significant difference (P = 0.148)*

Figure 4.11 Stacked column chart presenting number of strategically residual material scores in each of GP, T, GC groups for both MB and D canals combined

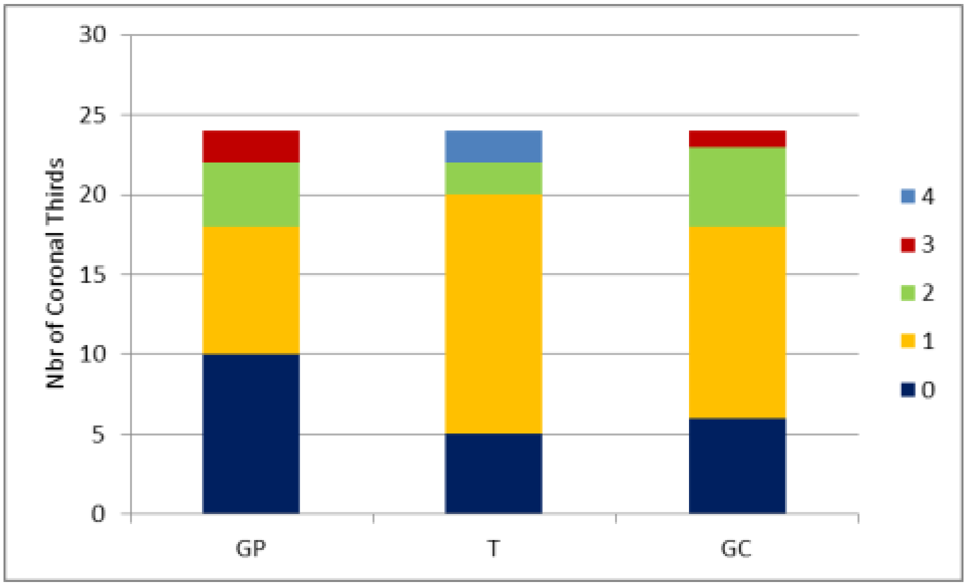
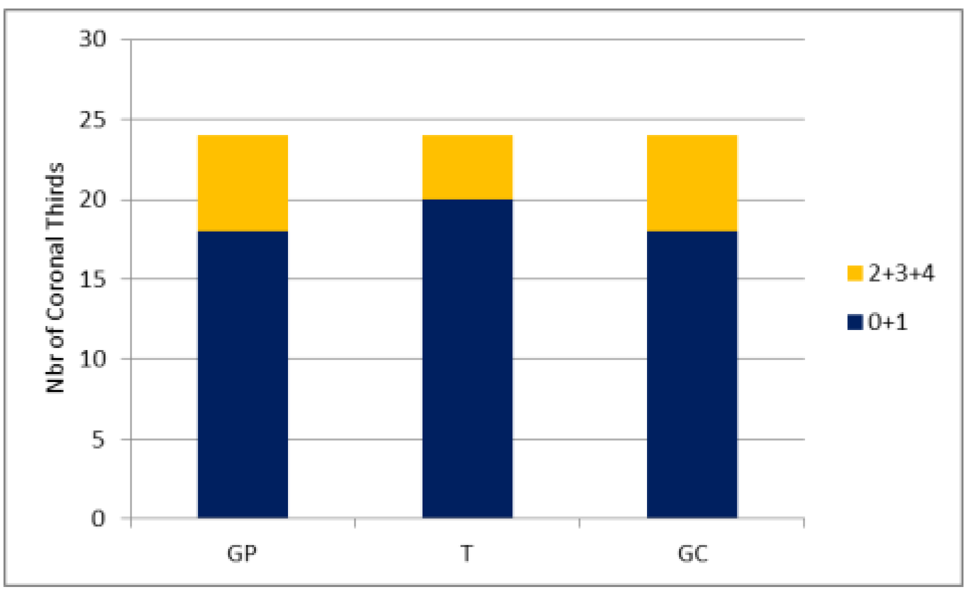


Figure 4.12 Stacked column chart presenting residual material score in the coronal third of both the MB and D canals combined according to the retreated materials



• Pearson *Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistical significant difference (P = 0.583)*

Figure 4.13 Stacked column chart representing strategically regrouped residual material scores in coronal third of both MB and D canals combined

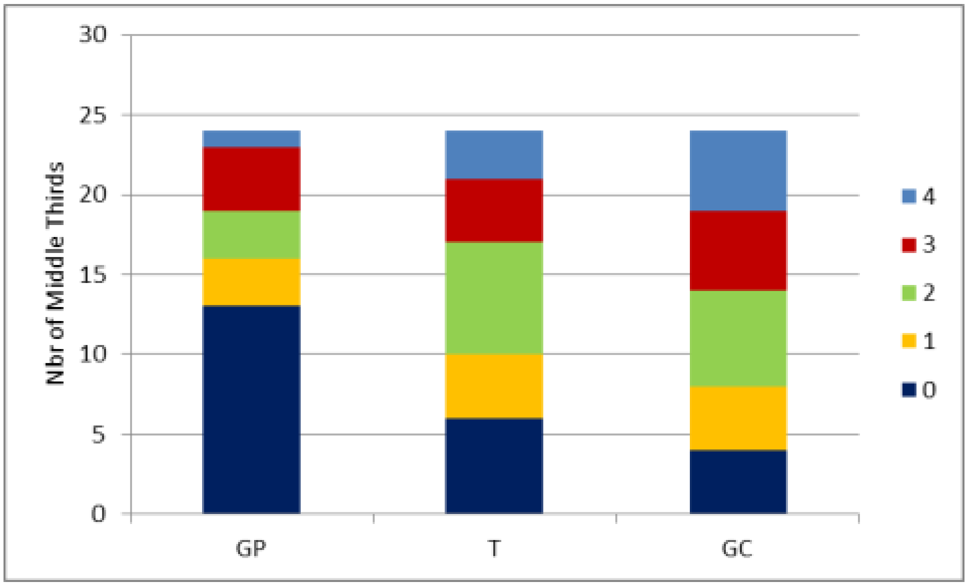
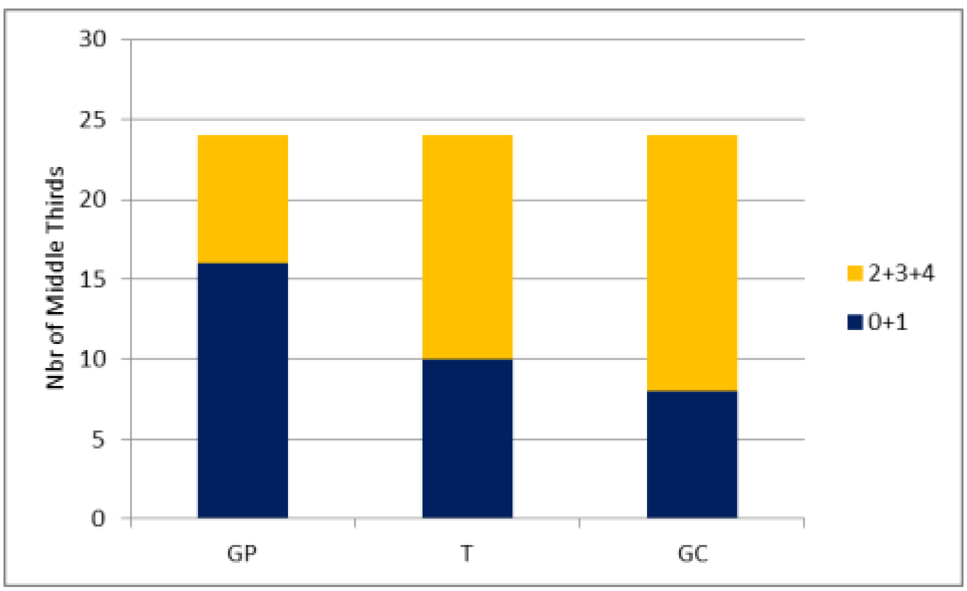
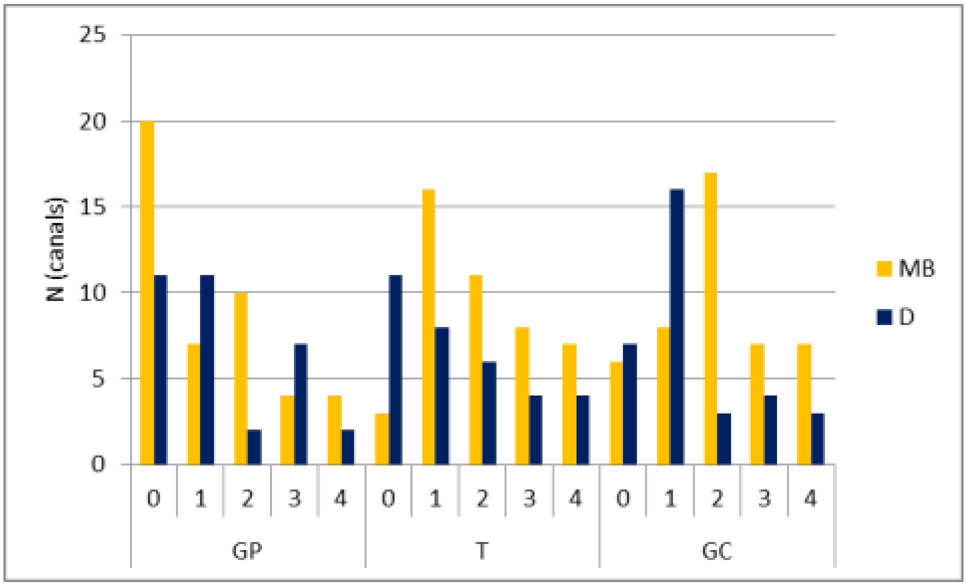


Figure 4.14 Stacked column chart representing residual material scores in middle third of both MB and D canals combined



• Pearson *Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistical significant difference (P = 0.055)*

Figure 4.15 Stacked column chart representing strategically regrouped residual material scores in middle third of both MB and D canals combined



• *Pearson Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistically significant difference (P = 0.344)*

Figure 4.16 Clustered column chart representing residual material score in apical third of both MB and D canals combined

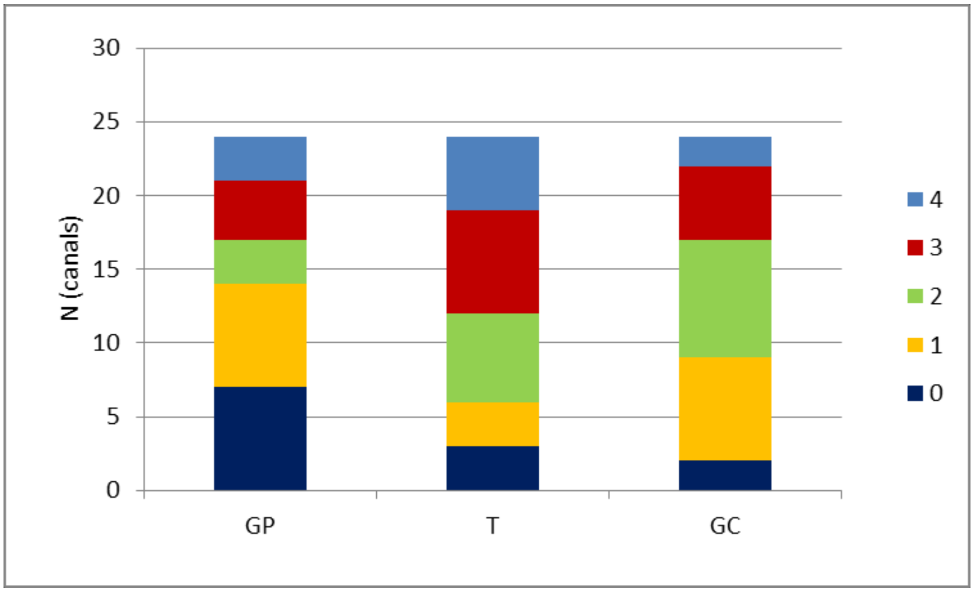
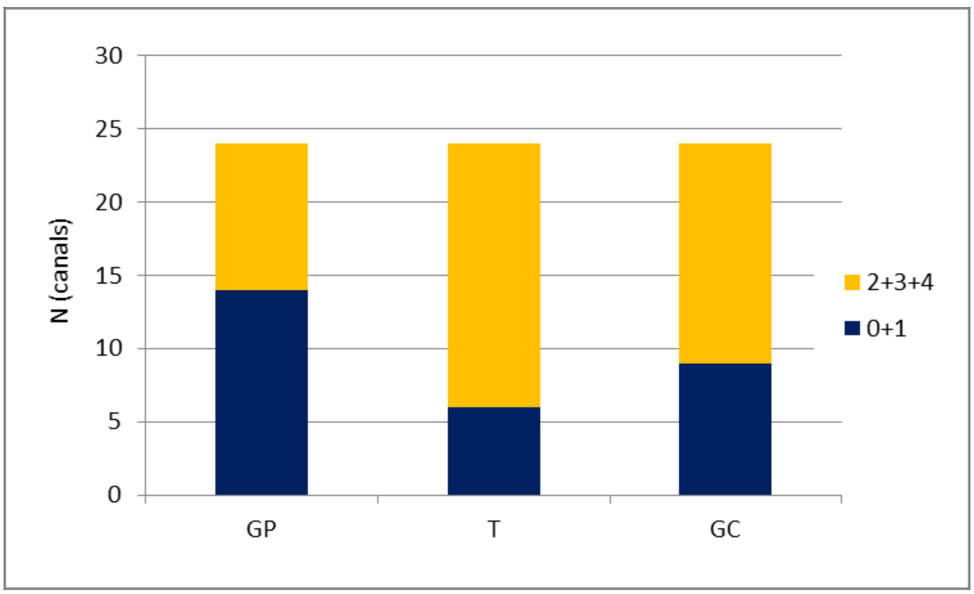


Figure 4.17 Column chart representing residual material scores in apical third of both MB and D canals combined



• *Pearson Chi-Square test with Cochran-Mantel-Haenszel (CMH) - No statistically significant difference (P = 0.059)*

Figure 4.18 Column chart representing strategically regrouped residual material scores in apical third of both MB and D canals combined

Chapter 5: Discussion

Endodontics has greatly evolved in recent years, yet the quest for the perfect root filling obturation has never ceased. Numerous root filling obturation materials and techniques are currently available. Two of the increasingly performed obturation techniques are the warm condensation technique and the carrier-based obturations, such as Thermafil®Plus and GuttaCore® (Whithworth, 2005). Over time, Thermafil® family root fillings have demonstrated to render high quality obturations reaching the caliber of traditional obturation techniques (Chu et al., 2005). Even though, multiple studies exist comparing traditional obturation techniques, such as lateral condensation and vertical condensation, with Thermafil®Plus, the new generation of Tulsa Dental's carrier-based obturation, GuttaCore®, has not yet been well studied. While manufacturer advertises that the quality between these sibling obturation products is unchanged, the retreatment of GuttaCore® is believed to be more efficient. As no root filling is impervious to coronal leakage and bacterial contamination over time, it was essential to validate that this new carrier-based obturation was retrievable, let alone more efficiently retrieved. To our knowledge, only one published study to date discusses the retreatment of this previously mentioned material (Beasley et al., 2013) indicating that research is presently lacking on GuttaCore®. Our study aimed to evaluate specific features of GuttaCore®, mean time of retrieval and residual material following core retrieval. Additionally, materials overfill and file unwinding and were also evaluated.

Summation of conclusions throughout various papers show no significant difference in success rate of main obturation techniques, namely lateral condensation, vertical

condensation and carrier-based obturation (Fleming et al., 2010; Hale et al., 2012). One prominent point consistently brought up is the overfilling of the obturated canals with carrier-based obturation (Gluskin, 2009). This is a particularly important point as extrusion of the material, or material overfill, could not only cause periapical irritation and trauma but also have an impact on the outcome of the endodontic treatment (Friedman et al., 2003).
While, the main aim of the study was to determine retrieval time of three obturation materials, observations on the rate of material overfill amongst the three materials was also examined. Material overfill was only a side investigation of the project; the sample size was therefore not powered to this purpose. Material overfill was assessed radiographically with one buccal-lingual radiograph and direct visualization. Radiographic evaluation could have been improved by adding a second angled radiograph (Kersten et al., 1987). Nevertheless, as the second radiograph would not have given us all the desired information, this was compensated by the implementation of direct visualization of the extruded gutta-percha material. Overall the study showed no statistical significant differences of gutta-percha extrusion beyond the established working length amongst the three obturation groups. However, a pattern of extrusion was more prominent in the T and GC groups in both MB and D canals. This pattern echoes similar findings with various authors (Gluskin, 2009; Pettiette et al., 2001). When considering carrier-based obturation systems such as Thermafil®Plus and GuttaCore®, the flow characteristics of the materials, the heat energy used, the amount of sealer initially introduced and the rate of insertion of the obturators, are all factors that influence the amount of material extrusion. Therefore, the practitioner must diligently use these products. It is important to note that the speed of insertion during this project was tested on plastic blocks prior to starting work on sampled teeth. This was done purposefully, so as

the single user (M.B) could get used to the correct manipulation of the materials and avoid causing further extrusion than ideally expected. Discussion with the manufacturers were initiated and it was determined that for both carrier-based obturation groups, it would be preferable to insert the obturators in a slow constant motion perpetuating over a span of 5 seconds. However, this careful motion did not seem to limit the pattern of extrusion noticed with carrier-based obturation products, T and GC. These tendencies should therefore be considered when manipulating these products on patients, especially if extrusion or material overfilling is more prone to happen such as in situations of open apex apical, root resorption or large periapical lesions.

While we have briefly discussed some of the findings on obturation overfill, we will look at our primary aim: mean time of retrieval of the three materials tested. The goal of retreatment is the removal of the previous obturation material, residual tissue, microorganisms and microbial byproducts from the root canal system. Gaining access to the canals is essential for disinfection purposes and improvement of the previous root filling obturation. GuttaCore® has seldom been tested for its retrieval capacity. To quantify retrieval ability of this new carrier-based obturation, time was recorded. While individual times for each file used in this study were also chronicled, the total time required for the removal of the previous root filling material was judged to be of greater clinical relevance.

Overall, all three materials were retrievable in a reasonable time (average time estimated to 2-3minutes) and working length was obtained in the grand majority of canals treated. Results echo previous studies testing the retrievability of carrier-based obturations (Bertrand et al., 1997; Ibarrola et al., 1993). Formerly, various root filling removal techniques had been suggested which included mechanical (Imura et al., 2000; Wilcox, 1993), chemical (Bertrand et al., 1997; Ibarrola et al., 1993) and thermal approaches (Wolcott et al., 1999). Rotary instrumentation has been reported to be more efficient in removing root filling material than manual instrumentations, such as K-files and Hedstroms (Betti and Bramante, 2001; Ferreira et al., 2001). While no ideal removal system exists, ProTaper®Universal Retreatment files was chosen in this project as a rotary NiTi removal system. Effectiveness of ProTaper®Universal Retreatment files has been supported by various studies (Giuliani et al., 2008; Gu et al., 2008; Hayakawa et al., 2010). These retreatment files can retrieve large amounts of gutta-percha in the flutes of the files due to their negative cutting angles and the absence of radial lands. Other files aimed for retreatment, such as ProFile®, have a U-type cross-section which removes gutta-percha in small increments. Their cutting efficiency is diminished and they have more a planning action on the material than a cutting effect. One study debated the efficacy of ProTaper® Retreatment files in removing filling materials and concluded that manual files or ProFiles® were more efficient methods to remove root filling materials from curved canals (Unal et al., 2009). When examining the study closely, it was noticed that their initial canals were instrumented up to 30/0.06 while the retreatment instrumentation was arrested at a size of D3 from ProTaper® Universal Retreatment files, namely 20/0.07. In the present study, even though the ProTaper® Universal Retreatment System was used, the mean time was recorded following canal re-instrumentation with the last file used in the initial instrumentation, more explicitly ProTaper® Universal files F2 (25/.08) in the MB canals and F3 (30/.09) in the D canals. This allowed us to evaluate the removal of the material in the previously shaped canal, without instrumenting the canals to a wider size. Using ProTaper® Universal Retreatment files permitted removal for all three materials tested, GP, T, GC and regaining patency was possible in the majority of cases in a reasonable amount of time, between 2 to 4 minutes. This finding answered our initial research question and suggested that GC is retrievable and should not cause problems for patients necessitating a root canal retreatment.

In the past, authors had suggested that the success in retrieving the obturator's carrier was depended on the ability of the practitioner to remove the carrier first and then the surrounding gutta-percha (Wilcox and Juhlin, 1994). As GuttaCore® has a brittle core, the retrieval method was aimed at the obturation material as a whole and the focus was mostly on regaining working length. Results appeared to be similar in mean time but GC was slightly faster to retrieve than the two other materials. Shorter retrieval time for GC compared to T could be explained by the shredding of the carrier of GuttaCore® obturation compared to the ThermaFil®Plus GuttaCore®'s cross-linked gutta-percha core has different mechanical properties than Thermafil®Plus plastic carriers. GuttaCore®'s carrier has a low modulus of elasticity and can be easily fractured under torsional loading. Thermafil®Plus has a carrier which is advertised as being stiffer. These publicized differences have not yet been proven to have a direct effect on the efficiency of retreatment and reduction in procedural errors; however, our results seem to reinforce these beliefs and join those of Hayakawa 2010 (Hayakawa et al., 2010). Interestingly, contrary to ThermaFil®Plus, which sometimes permits the retrieval of the carrier in one piece, this concept does not apply to GuttaCore®. Hedstrom bradding technique or wedging between carrier and canal wall is not efficient with GuttaCore®. In canals, with excessive curvature, GuttaCore®'s core brittleness, insolubility to solvents, heat resistance and finally incapacity of removing its core in one piece could be a disadvantage for its retrieval. In our study however, we used moderately curved canals and this parameter was not examined.

Remarkably, many retreatment studies use straight canals (Baratto et al., 2002; Barrieshi-Nusair, 2002; Sae-Lim et al., 2000; Schirrmeister et al., 2006b). Yet, our results pertain to moderately curved canals of first and second lower mandibular molars, truthful to a clinical environment (Skidmore and Bjorndal, 1971). Due to the complexities of these canals, thorough standardization according to quadrant, length, canals and curvature amongst the three root filling groups was necessary. Strict exclusion criteria, such as demand for the MB canals to be independent of ML canals, or joining only 1mm from the apical foramen, as well as the demand for one single canal in the distal root reduced even further the teeth available for the study. While teeth accumulated were limited, collection of both MB and D canals allowed interesting comparisons between two types of canals varying in diameter and taper. This strengthened the study, since it introduced clinically relevant anatomical variations during obturation retrieval.

The fastest and statistically significant retrieval pattern occurred in the MB canals for GC, which positively reflects on the deduction of another study that concluded that "ProTaper Retreatment files were effective in removing Thermafil Plus plastic carriers and that canals with a larger diameter and or taper required more time for removal" (Hayakawa et al., 2010). In our research, MB canals were shaped to a size 25/08 and the D canals to a size of 30/09, concurring with previous results. Our results showed that carrier-based obturation removal was less time consuming in smaller diameter and tapered canals. Our results replicate the findings of the previously mentioned study. Blades of NiTi rotary files could come in contact with the carrier and the canal walls more promptly in narrow canals and therefore promote further shredding for GuttaCore® and further pulling of the plastic carrier for Thermafil®Plus. The narrower space resulting from canal instrumented to a smaller taper and diameter could increase the effectiveness of extracting forces on the carriers, therefore allowing higher speed of retrieval, exposing even further the differences amongst the two carrier-based obturations.

Most of the samples we used were voided of the initial obturation material inserted with the help of NiTi rotary files. Variation in core consistency between GC and T promoted an interest in the investigation of file unwinding following the use ProTaper® Universal files during retrieval of the three obturation material. No statistical difference was seen amongst the three groups tested. However, our study was not powered to this particular purpose so the results could only be considered for observations. D3 was the file with the most significant deformation in all three obturation groups. This result was predictable as this was the only retreatment file used to the extent of the working length. It was also the smallest file used: 20/0.07. Another interesting observation was that greater file deformation was noticed in the MB canals compared to the D canals specifically for carrier based obturation. This could be related to the same concept presented in the discussion for time of retrieval. In narrower canals, with smaller diameter and taper, retreatment files might be in greater contact with not only the canal walls but also the carrier, increasing resistance and promoting further file deformation (Hayakawa et al., 2010).

Many factors may influence file deformation including tooth type, morphology and operator dexterity. The operator’s skill is an important factor in file deformation and file failure. It is in the hands of the practitioner to reduce applied apical forces or to arrest the brushing motion when binding or even “locking” of the file occurs within the canal. The experience of the operator with the rotary system is crucial for smooth root filling removal and canal instrumentation (Parashos and Messer, 2006; Yared et al., 2002). This was recognized early in our study, as, in between each sample retreated, three plastic blocks previously obturated with the root filling groups were also retreated. This step included in our methodology familiarized the operator (M.B) to the system and materials but also prevented an adaptation phenomenon.

File deformation can also be due to file design. An increase in instrument's diameter and hence its cross-sectional area, could influence the torsional resistance of the file. ProTaper®Universal files have been previously recorded to have a low defect rate (Ankrum et al., 2004). On the basis of the results, manufacturers of carrier-based obturation system such as Thermafil®Plus and GuttaCore® recommend using higher speeds with ProTaper®Universal Retreatment rotary files. This can allow the shredding of the carrier and also the heating of the gutta-percha around the carrier, which can permit the rotary instrument to advance into the root filling and perpetuate further insertion along the canal walls. ProTaper®Universal Retreatment files have recommended speeds between 500-700 RPM for gutta-percha and carrier-based obturators. Other studies using various rotary files such as ProTaper®Universal and ProFile® systems have used speeds ranging from 300 to 1500 RPM (Duncan and Chong, 2011; Royzenblat and Goodell, 2007). Higher speeds resulted in more time efficient retreatment. However, it was found that higher speeds can be faster with no significant increase in instrument fracture, although a higher incidence of instrument unwinding was noticed (Royzenblat and Goodell, 2007). Roysenblat & Goodell in 2007 investigated the use ProFiles® 0.04 taper at 300 and 1500 RPM, and found faster retreatments with higher speeds and no significant increase in fractures were observed. Nevertheless, more file deformation was noticed in the 1500 RPM group (Royzenblat and Goodell, 2007). Yared et al. in 2002 contradicts this statement since they encountered further file separation with higher rotational speeds (Yared et al., 2002). Recently, a study similar to the one in this project was conducted, where ProTaper® Universal Retreatment files were used at 500RPM (Beasley et al., 2013). As in our project, in that particular project, where the same root filling groups were tested, D3 ProTaper® Universal Retreatment file exhibited the most file deformation. This file weakening was distributed amongst the three groups with no statistical significance. In our research, retreatment was performed at 700 RPM, and we noticed an increasing pattern, from D1 to D2, to D3, of file deformation. Beasley et al. 2013, while using a slower speed, 500 RPM, experienced three files separated in the Thermafil®Plus group, while in ours, where the higher manufacture's recommendation was used, 700 RPM, only two file separations occurred, on in the T and one in the GC groups. An interesting observation in our study was that D1 ProTaper® Universal Retreatment file deformation ensued only in the carrier-based obturation groups, specifically, T and GC. This could be explained by the difference in resistance encountered with the carrier compared to plain gutta-percha.

Multiple studies have conducted examinations and evaluations of deformation of NiTi instrument with use of SEM and stereo microscopy (Parashos and Messer, 2006; Shen et al., 2009a; Shen et al., 2009b; Yared et al., 2002). This method allowed thorough evaluation of file deformation, file crack initiation and even file crack propagation in case of separation. As file deformation was not the primary aim of the study, we considered to evaluate the data with a DOM. This type of assessment could be reproduced in a clinical environment by the practioner and influence clinical decisions. Since there is no agreement in the literature with respect to the number of uses of the NiTi files, their discard is determined by the operator. Often NiTi failure is influenced more by file manipulation in specific clinical situations than the number of uses of the file. Therefore, we considered important to analyze the deformation of the files once used for retreatment as per clinical situation. In fact, a practitioner can, at the end of the procedure, quickly evaluate file deformation with the use of the DOM. File visualization, following its use, assists the operator in judging if files could be re-used once re-sterilized or if it should be discarded so as to avoid future breakage. In our study, while deformation and file separation were not statistically significant amongst groups, the pattern of deformation was more prominent in the T and GC groups. Therefore, clinically, it would be vigilant to replace files following the removal of carrier-based obturation such as Thermafil®Plus and GuttaCore®.

While time of material retrieval was a critical part of our study, and proved the success in retrieving GuttaCore®, residual material evaluation is also of interest as it could have a direct implication on the outcome of retreatment. As previously mentioned, the complete removal of previous root filling material would provide a biologic environment, free of contaminated debris and conductive of healing, as well as the development of a canal shape receptive to healing. Most studies agree that it is impossible to remove all the traces of gutta-percha and sealer from the root canal walls, no matter the technique or instruments used (Ma et al., 2012; Marfisi et al., 2010; Schirrmeister et al., 2006a). Our study concurs with this statement, as none of the canals observed were voided of residual debris. Multiple statistical comparisons were done and analysis resulted in a few clinically relevant statements. Neither size of canals, nor type of materials seemed to influence the overall canal cleanliness. However, when residual debris scores were analyzed according to the level within the root, the apical third had the greatest concentration of debris. This is similar to previous studies analyzing residual debris following retreatment (Somma et al., 2008). Further refining of the canals beyond the initial size of instrumentation would be recommended since it may result in a better cleaning of the canals (Huang et al., 2007; Kunert et al., 2010). It was also noticed in the apical third that there was a significant difference between GP and GC. This could be due to the flow of carrier-based obturation in the anatomical variation especially when it comes to the apical third. While GC experienced more residual material, no significant difference was found between T and GC groups and this could be due to the fact that the carrier in the T groups could be dislodged during retreatment and a great part of the filling can be removed as once. Whereas, GC has a brittle core that will gradually shred as the rotary files are introduced and therefore no extraction forces can be counted one for root filling retrieval.

Various techniques have been used to analyze residual material along the canal walls. They vary from transparency technique (Gu et al., 2008; Schirrmeister et al., 2006c), to optical stereomicroscopy, to scanning electron microscopy (SEM) (Somma et al., 2008). Often when these methodologies are applied, roots are sectioned perpendicular to the long access of the root. This would not allow the overall quantification of the residual material left behind. Our study focused on evaluation of the canal longitudinally and examined each third of the root as well as the entire canal length. When using SEM, the total area of the canal minus the area covered with residual debris can be quantified with computer software, like Image Pro (MediaCybernetics, Bethesda, MD). This would give a complete evaluation of the residual materials. Our study used a simpler evaluation of the residual debris founded on a five-point grading system (Dai et al., 2011; Ezzie et al., 2006) determined by a single observer (M.B) under DOM (Imura et al., 2000). This had been previously observed in another study published in 2012 (Chauhan et al., 2012). DOM under high magnification allowed good visibility and enabled overall visualization of the whole canal. The root thirds were then analyzed independently and debris scores were assigned. The single observer (M.B) was blinded and the scores were redone at three different times to confirm consistency. However, it is undeniable that the SEM evaluation in conjunction with computer software would have rendered a more precise evaluation of residual debris. Another weakness in the methodology was that samples were resected longitudinally in a buccal-lingual plane at the cemental-enamel junction (CEJ) and this could have influenced the evaluation of the coronal third, as the canals would start below the CEJ (Krasner and Rankow, 2004). In this case, it is possible that the coronal thirds could have been under-evaluated compared to the middle and apical thirds. However, we still consider that the middle and apical third cleanliness are the most impactful on the clinical outcome of root canal retreatment and our evaluations have not been affected in those two areas.

When considering thorough cleaning and shaping of canals, even when using rotary NiTi systems such as ProFile® and ProTaper® Universal System, canals perfectly voided of residual debris have not been encountered (Hulsmann and Bluhm, 2004; Schirrmeister et al., 2006b; Tasdemir et al., 2008; Wilcox et al., 1987). The anatomic complexities of the root canal systems give rise to this problem (Caliskan et al., 1995; Gulabivala et al., 2001). Isthmuses, anastomosis, fins and irregularities harbor residual debris and microbes following re-instrumentation (Paque et al., 2009; Peters et al., 2000). In spite of adequate retreatment techniques, mechanical instrumentation cannot adequately clean all the periphery of the canal system. This is particularly significant in the apical third, where the concentrations of canal variations are even more prominent (Hsu and Kim, 1997). Masiero & Barletta 2005 remarked that most of the residual filling material following instrumentation in retreatment cases remained in the apical third of the canals (Masiero and Barletta, 2005). This was also noticed in our study and can be explained by the anatomical variations that are more pronounced in the apical third (Figure 4.9) (de Pablo et al., 2010). Wilcox 1993 even stated that the amount of residual debris left behind in the apical third after re-instrumentation is proportional with the difficulty in carrier-based obturation retrieval (Wilcox, 1993). This, however, was not perceived in our study, as we did not encounter much difficulty in the retrieval of the carrier-based obturation groups.

Finally, it is of interest to note that during the residual debris evaluation, the T groups experienced carrier shredding during retreatment as particles of carrier were left behind in the canal. This confirms other findings that have expressed the same concerns (Frajlich et al., 1998b). This causes concern when it comes not only to the disinfection of the canals but also for sealability of the new root filling material. This occurrence of material shredding could be diminished for materials such as GuttaCore® where even the carrier is gutta-percha-based and therefore the material might not interfere with the overall seal of the new root filling material, if particles are left behind. Nevertheless, no matter the previous root filling material used, it is crucial for the dental practioner to carefully examine the canal walls, ideally with a DOM, and attempt to render canals voided of residual debris and as clean as possible.

Chapter 6: Conclusions

All three materials used for initial obturation, namely vertically condensed gutta-percha, Thermafil®Plus and GuttaCore®, exhibited material extrusion beyond the apical foramen. GuttaCore® group exhibited an insignificant trend for more extrusion than the traditional warm vertical obturation. Therefore, consideration should be given to the type of obturation material used in cases where apical control is a challenge.

For all three root filling materials, reaching working length was possible following root filling retrieval. GuttaCore® was removed quicker than warm vertically condensed gutta-percha and Thermafil®Plus. However, the results were statistically significant only when comparing the retrieval of GuttaCore® with Thermafil®Plus in the smaller diameter and tapered MB canals (108sec; 154 sec). Nevertheless, none of the obturation materials posed a challenge for retrieval.

During mechanical retrieval of the root filling materials, two files separated in the carrier-based obturation groups, Thermafil®Plus and GuttaCore®, although, file unwinding was not significantly different in any of the groups tested. While statistically insignificant, retrieval of carrier-based obturation groups rendered more files unwinding for the initial D1 ProTaper® Universal Retreatment File. Single use for the retreatment files should be considered in cases of carrier-based obturation.

A trend for more residual debris during obturation removal was noticed in the carrier-based obturation groups but this was not statistically significant. Carrier-based obturation material left behind included particles of the carrier, which could have an effect on the disinfection and the seal of the new root filling during root canal retreatment. It is our conclusion that further caution should be taken when cleaning the canals of carrier-based previously obturated canals.

Ultimately, our study responded to several clinical concerns regarding GuttaCore®, a new carrier-based root filling material. Dental practioner can be comforted in knowing that if recontamination occurs, GuttaCore® can be retrieved from canals rather safely and efficiently using ProTaper® Universal Retreatment file system. Naturally, as with any new material, there is an interest for future studies to expand on clinically relevant unanswered questions. Research avenues are needed in evaluating the influence of the final apical preparation size on the overextension/overfilling of GuttaCore®, the relationship between the canal's degree of curvature and the difficulty of its removal from the canal, as well as the effect of the canal's degree of curvature on the file deformation. Moreover, as GuttaCore® becomes further employed, retrospective studies would be needed to evaluate its long-term clinical success.

References

Abarca A.M., Bustos A., Navia M. (2001) A comparison of apical sealing and extrusion between Thermafil and lateral condensation techniques. J Endod 27:670-2.

Allison D.A., Michelich R.J., Walton R.E. (1981) The influence of master cone adaptation on the quality of the apical seal. J Endod 7:61-5.

Ankrum M.T., Hartwell G.R., Truitt J.E. (2004) K3 Endo, ProTaper, and ProFile systems: breakage and distortion in severely curved roots of molars. J Endod 30:234-7.

Augsburger R.A., Peters D.D. (1990) Radiographic evaluation of extruded obturation materials. J Endod 16:492-7.

Baratto F., Ferreira E.L., Fariniuk L.F. (2002) Efficiency of the 0.04 taper ProFile during the re-treatment of gutta-percha-filled root canals. Int Endod J 35:651-654.

Baratto Filho F., Ferreira E.L., Fariniuk L.F. (2002) Efficiency of the 0.04 taper ProFile during the re-treatment of gutta-percha-filled root canals. Int Endod J 35:651-4.

Barbosa S.V., Burkard D.H., Spangberg L.S. (1994) Cytotoxic effects of gutta-percha solvents. J Endod 20:6-8.

Barrieshi-Nusair K.M. (2002) Gutta-percha retreatment: effectiveness of nickel-titanium rotary instruments versus stainless steel hand files. J Endod 28:454-6.

Beasley R.T., Williamson A.E., Justman B.C., Qian F. (2013) Time required to remove guttacore, thermafil plus, and thermoplasticized gutta-percha from moderately curved root canals with protaper files. J Endod 39:125-8.

Bertrand M.F., Pellegrino J.C., Rocca J.P., Klinghofer A., Bolla M. (1997) Removal of Thermafil root canal filling material. J Endod 23:54-57.

Betti L.V., Bramante C.M. (2001) Quantec SC rotary instruments versus hand files for gutta-percha removal in root canal retreatment. Int Endod J 34:514-9.

Blanas N., Kienle F., Sandor G.K. (2002) Injury to the inferior alveolar nerve due to thermoplastic gutta percha. J Oral Maxillofac Surg 60:574-6.

Bowman C.J., Baumgartner J.C. (2002) Gutta-percha obturation of lateral grooves and depressions. J Endod 28:220-3.

Brady J.M., del Rio C.E. (1975) Corrosion of endodontic silver cones in humans: a scanning electron microscope and X-ray microprobe study. J Endod 1:205-10.

Bramante C.M., Betti L.V. (2000) Efficacy of Quantec rotary instruments for gutta-percha removal. Int Endod J 33:463-7.

Bystrom A., Happonen R.P., Sjogren U., Sundqvist G. (1987) Healing of periapical lesions of pulpless teeth after endodontic treatment with controlled asepsis. Endod Dent Traumatol 3:58-63.

Caliskan M.K., Pehlivan Y., Sepetcioglu F., Turkun M., Tuncer S.S. (1995) Root canal morphology of human permanent teeth in a Turkish population. J Endod 21:200-4.

Cantatore G. (2006) Root canal obturation and root integrity. Endod Pract 9:9-19.

Chana H., Briggs P., Moss R. (1998) Degradation of a silver point in association with endodontic infection. Int Endod J 31:141-6.

Chauhan R., Tikku A., Chandra A. (2012) Detection of residual obturation material after root canal retreatment with three different techniques using a dental operating microscope and a stereomicroscope: An in vitro comparative evaluation. J Conserv Dent 15:218-22.

Chu C.H., Lo E.C., Cheung G.S. (2005) Outcome of root canal treatment using Thermafil and cold lateral condensation filling techniques. Int Endod J 38:179-85.

Clark D.S., ElDeeb M.E. (1993) Apical sealing ability of metal versus plastic carrier Thermafil obturators. J Endod 19:4-9.

Cohen S., Hargreaves, KM. (2006) Pathways of the Pulp. 9th edn. ed. Elsevier Mosby, St. Louis, Mo.

Da Silva D., Endal U., Reynaud A., Portenier I., Orstavik D., Haapasalo M. (2002) A comparative study of lateral condensation, heat-softened gutta-percha, and a modified master cone heat-softened backfilling technique. Int Endod J 35:1005-11.

Dai L., Khechen K., Khan S., Gillen B., Loushine B.A., Wimmer C.E., Gutmann J.L., Pashley D., Tay F.R. (2011) The effect of QMix, an experimental antibacterial root canal irrigant, on removal of canal wall smear layer and debris. J Endod 37:80-4.

Dalat D.M., Spangberg L.S. (1994) Comparison of apical leakage in root canals obturated with various gutta percha techniques using a dye vacuum tracing method. J Endod 20:315-9.

Dall'Agnol C., Hartmann M.S., Barletta F.B. (2008) Computed tomography assessment of the efficiency of different techniques for removal of root canal filling material. Braz Dent J 19:306-12.

Dammaschke T., Steven D., Kaup M., Ott K.H. (2003) Long-term survival of root-canal-treated teeth: a retrospective study over 10 years. J Endod 29:638-43.

De-Deus G., Maniglia-Ferreira C.M., Gurgel-Filho E.D., Paciornik S., Machado A.C., 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.

De Bruyne M.A., De Moor R.J. (2009) Long-term sealing ability of Resilon apical root-end fillings. Int Endod J 42:884-92.

de Carvalho Maciel A.C., Zaccaro Scelza M.F. (2006) Efficacy of automated versus hand instrumentation during root canal retreatment: an ex vivo study. Int Endod J 39:779-84.

De Deus G.A., Gurgel-Filho E.D., Maniglia-Ferreira C., T. C.-F. (2004) The influence of filling technique on depth of tubule penetration by root canal sealer: a study using light microscopy and digital image processing. Aust Dent J 30:23-28.

De Moor R.J., Hommez G.M. (2002) The long-term sealing ability of an epoxy resin root canal sealer used with five gutta percha obturation techniques. Int Endod J 35:275-82.

de Pablo O.V., Estevez R., Peix Sanchez M., Heilborn C., Cohenca N. (2010) Root anatomy and canal configuration of the permanent mandibular first molar: a systematic review. J Endod 36:1919-31.

Duncan H.F., Chong B.S. (2011) Removal of root filling materials. Endodontic Topics:33-57.

Ezzie E., Fleury A., Solomon E., Spears R., He J. (2006) Efficacy of retreatment techniques for a resin-based root canal obturation material. J Endod 32:341-4.

Fanibunda K., Whitworth J., Steele J. (1998) The management of thermomechanically compacted gutta percha extrusion in the inferior dental canal. Br Dent J 184:330-2.

Ferreira J.J., Rhodes J.S., Ford T.R.P. (2001) The efficacy of gutta-percha removal using ProFiles. Int Endod J 34:267-274.

Fleming C.H., Litaker M.S., Alley L.W., Eleazer P.D. (2010) Comparison of classic endodontic techniques versus contemporary techniques on endodontic treatment success. J Endod 36:414-8.

Frajlich S.R., Goldberg F., Massone E.J., Cantarini C., Artaza L.P. (1998a) Comparative study of retreatment of Thermafil and lateral condensation endodontic fillings. Int Endod J 31:354-7.

Frajlich S.R., Goldberg F., Massone E.J., Cantarini C., Artaza L.P. (1998b) Comparative study of retreatment of Thermafil and lateral condensation endodontic fillings. Int Endod J 31:354-357.

Friedman S. (2002) Prognosis of initial endodontic therapy. Endodontic Topics 2:59-88.

Friedman S., Abitbol S., Lawrence H.P. (2003) Treatment outcome in endodontics: the Toronto Study. Phase 1: initial treatment. J Endod 29:787-93.

Friedman S., Stabholz A., Tamse A. (1990) Endodontic retreatment--case selection and technique. 3. Retreatment techniques. J Endod 16:543-9.

Gagliani M.A., Cerutti A., Bondesan A., Colombo M., Godio E., Giacomelli G. (2004) A 24-month survey on root canal treatment performed by NiTi engine driven files and warm gutta-percha filling associated system. Minerva Stomatol 53:543-54.

Gencoglu N., Garip Y., Bas M., Samani S. (2002) Comparison of different gutta-percha root filling techniques: Thermafil, Quick-fill, System B, and lateral condensation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 93:333-6.

Gergi R., Sabbagh C. (2007) Effectiveness of two nickel-titanium rotary instruments and a hand file for removing gutta-percha in severely curved root canals during retreatment: an ex vivo study. Int Endod J 40:532-7.

Gilbert B.O., Jr., Rice R.T. (1987) Re-treatment in endodontics. Oral Surg Oral Med Oral Pathol 64:333-8.

Gilhooly R.M., Hayes S.J., Bryant S.T., Dummer P.M. (2001) Comparison of lateral condensation and thermomechanically 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.

Giuliani V., Cocchetti R., Pagavino G. (2008) Efficacy of ProTaper universal retreatment files in removing filling materials during root canal retreatment. J Endod 34:1381-4.

Glennon J.P., Ng Y.L., Setchell D.J., Gulabivala K. (2004) Prevalence of and factors affecting postpreparation pain in patients undergoing two-visit root canal treatment. Int Endod J 37:29-37.

Gluskin A.H. (2009) Anatomy of an overfill: a reflection on the process. Endodontic Topics 16:64-81.

Goodman A., Schilder H., Aldrich W. (1974) The thermomechanical properties of gutta-percha. II. The history and molecular chemistry of gutta-percha. Oral Surg Oral Med Oral Pathol 37:954-61.

Gopikrishna V., Parameswaren A. (2006) Coronal sealing ability of three sectional obturation techniques--SimpliFill, Thermafil and warm vertical compaction--compared with cold lateral condensation and post space preparation. Aust Endod J 32:95-100.

Grossman L. (1978) Endodontic Practice Lea & Febiger, Philadelphia.

Gu L.S., Ling J.Q., Wei X., Huang X.Y. (2008) Efficacy of ProTaper Universal rotary retreatment system for gutta-percha removal from root canals. Int Endod J 41:288-95.

Gulabivala K., Aung T.H., Alavi A., Ng Y.L. (2001) Root and canal morphology of Burmese mandibular molars. Int Endod J 34:359-70.

Gulabivala K., Holt R., Long B. (1998) An in vitro comparison of thermoplasticised gutta-percha obturation techniques with cold lateral condensation. Endod Dent Traumatol 14:262-9.

Gunday M., Sazak H., Garip Y. (2005) A comparative study of three different root canal curvature measurement techniques and measuring the canal access angle in curved canals. J Endod 31:796-8.

Gutmann J.L., Saunders W.P., Saunders E.M., Nguyen L. (1993) An assessment of the plastic Thermafil obturation technique. Part 2. Material adaptation and sealability. Int Endod J 26:179-83.

Hale R., Gatti R., Glickman G.N., Opperman L.A. (2012) Comparative analysis of carrier-based obturation and lateral compaction: a retrospective clinical outcomes study. Int J Dent 2012:954675.

Hayakawa T., Tomita F., Okiji T. (2010) Influence of the Diameter and Taper of Root Canals on the Removal Efficiency of Thermafil Plus Plastic Carriers Using ProTaper Retreatment Files. J Endod 36:1676-1678.

Holcomb J.Q., Pitts D.L., Nicholls J.I. (1987) Further investigation of spreader loads required to cause vertical root fracture during lateral condensation. J Endod 13:277-84.

Hoskinson S.E., Ng Y.L., Hoskinson A.E., Moles D.R., Gulabivala K. (2002) A retrospective comparison of outcome of root canal treatment using two different protocols. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 93:705-15.

Hsu Y.Y., Kim S. (1997) The resected root surface. The issue of canal isthmuses. Dent Clin North Am 41:529-40.

Huang X., Ling J., Wei X., Gu L. (2007) Quantitative evaluation of debris extruded apically by using ProTaper Universal Tulsa rotary system in endodontic retreatment. J Endod 33:1102-5.

Hulsmann M., Bluhm V. (2004) Efficacy, cleaning ability and safety of different rotary NiTi instruments in root canal retreatment. Int Endod J 37:468-476.

Ibarrola J.L., Knowles K.I., Ludlow M.O. (1993) Retrievability of Thermafil Plastic Cores Using Organic-Solvents. Journal of Endodontics 19:417-418.

Imura N., Kato A.S., Hata G.I., Uemura M., Toda T., Weine F. (2000) A comparison of the relative efficacies of four hand and rotary instrumentation techniques during endodontic retreatment. Int Endod J 33:361-6.

Jasper E. (1941) Adaptation and tolerance of silver point canal filling. *J Dent Res.* 4:355.

Johnson B.T., Bond M.S. (1999) Leakage associated with single or multiple increment backfill with the Obtura II gutta-percha system. J Endod 25:613-4.

Johnson W.B. (1978) A new gutta-percha technique. J Endod 4:184-8.

Joiner H.L., Canales M.L., del Rio C.E. (1989) Temperature changes in thermoplasticized gutta-percha: a comparison of two ultrasonic units. Oral Surg Oral Med Oral Pathol 68:764-9.

Kaufman D., Mor C., Stabholz A., Rotstein I. (1997) Effect of gutta-percha solvents on calcium and phosphorus levels of cut human dentin. J Endod 23:614-5.

Kerekes K., Tronstad L. (1979) Long-term results of endodontic treatment performed with a standardized technique. J Endod 5:83-90.

Kersten H.W., Wesselink P.R., Thoden van Velzen S.K. (1987) The diagnostic reliability of the buccal radiograph after root canal filling. Int Endod J 20:20-4.

Kfir A., Tsesis I., Yakirevich E., Matalon S., Abramovitz I. (2012) The efficacy of five techniques for removing root filling material: microscopic versus radiographic evaluation. Int Endod J 45:35-41.

Krasner P., Rankow H.J. (2004) Anatomy of the pulp-chamber floor. J Endod 30:5-16.

Kumar M.S., Sajjan G.S., Satish K., Varma K.M. (2012) A comparative evaluation of efficacy of protaper universal rotary retreatment system for gutta-percha removal with or without a solvent. Contemp Clin Dent 3:S160-3.

Kunert G.G., Camargo Fontanella V.R., de Moura A.A., Barletta F.B. (2010) Analysis of apical root transportation associated with ProTaper Universal F3 and F4 instruments by using digital subtraction radiography. J Endod 36:1052-5.

Ladley R.W., Campbell A.D., Hicks M.L., Li S.H. (1991) Effectiveness of Halothane Used with Ultrasonic or Hand Instrumentation to Remove Gutta-Percha from the Root-Canal. J Endod 17:221-224.

Langeland K., Dowden W.E., Tronstad L., Langeland L.K. (1971) Human pulp changes of iatrogenic origin. Oral Surg Oral Med Oral Pathol 32:943-80.

Lea C.S., Apicella M.J., Mines P., Yancich P.P., Parker M.H. (2005) Comparison of the obturation density of cold lateral compaction versus warm vertical compaction using the continuous wave of condensation technique. J Endod 31:37-9.

Lee F.S., Van Cura J.E., BeGole E. (1998) A comparison of root surface temperatures using different obturation heat sources. J Endod 24:617-20.

Ma J., Al-Ashaw A.J., Shen Y., Gao Y., Yang Y., Zhang C., Haapasalo M. (2012) Efficacy of ProTaper Universal Rotary Retreatment system for gutta-percha removal from oval root canals: a micro-computed tomography study. J Endod 38:1516-20.

Mann S.R., McWalter G.M. (1987) Evaluation of apical seal and placement control in straight and curved canals obturated by laterally condensed and thermoplasticized gutta-percha. J Endod 13:10-7.

Marfisi K., Mercade M., Plotino G., Duran-Sindreu F., Bueno R., Roig M. (2010) Efficacy of three different rotary files to remove gutta-percha and Resilon from root canals. Int Endod J 43:1022-8.

Marques da Silva B., Baratto-Filho F., Leonardi D.P., Henrique Borges A., Volpato L., Branco Barletta F. (2012) Effectiveness of ProTaper, D-RaCe, and Mtwo retreatment files with and without supplementary instruments in the removal of root canal filling material. Int Endod J 45:927-32.

Masiero A.V., Barletta F.B. (2005) Effectiveness of different techniques for removing gutta-percha during retreatment. Int Endod J 38:2-7.

McDonald M.N., Vire D.E. (1992) Chloroform in the endodontic operatory. J Endod 18:301-3.

Metzger Z., Nissan R., Tagger M., Tamse A. (1988) Apical seal by customized versus standardized master cones: a comparative study in flat and round canals. J Endod 14:381-4.

Midtgard J., Bjork G., Linder-Aronson S. (1974) Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances. Angle Orthod 44:56-61.

Nattress B.R., Manogue M., Carmichael F. (1997) A model for the teaching of clinical techniques in root canal treatment. Int Endod J 30:343-6.

Oliet S. (1983) Single-visit endodontics: a clinical study. J Endod 9:147-52.

Ørstavik D. (2005) Materials used for root canal obturation: technical, biological and clinical testing. Endodontic Topics:25–38.

Orstavik D., Horsted-Bindslev P. (1993) A comparison of endodontic treatment results at two dental schools. Int Endod J 26:348-54.

Orstavik D., Kerekes K., Eriksen H.M. (1987) Clinical performance of three endodontic sealers. Endod Dent Traumatol 3:178-86.

Orstavik D., Mjor I.A. (1988) Histopathology and x-ray microanalysis of the subcutaneous tissue response to endodontic sealers. J Endod 14:13-23.

Paque F., Laib A., Gautschi H., Zehnder M. (2009) Hard-tissue debris accumulation analysis by high-resolution computed tomography scans. J Endod 35:1044-7.

Parashos P., Messer H.H. (2006) Rotary NiTi instrument fracture and its consequences. J Endod 32:1031-43.

Pathomvanich S., Edmunds D.H. (1996) The sealing ability of Thermafil obturators assessed by four different microleakage techniques. Int Endod J 29:327-34.

Peters L.B., Wesselink P.R. (2002) Periapical healing of endodontically treated teeth in one and two visits obturated in the presence or absence of detectable microorganisms. Int Endod J 35:660-7.

Peters O.A., Laib A., Ruegsegger P., Barbakow F. (2000) Three-dimensional analysis of root canal geometry by high-resolution computed tomography. J Dent Res 79:1405-9.

Pettiette M.T., Delano E.O., Trope M. (2001) Evaluation of success rate of endodontic treatment performed by students with stainless-steel K-files and nickel-titanium hand files. J Endod 27:124-7.

Pirani C., Pelliccioni G.A., Marchionni S., Montebugnoli L., Piana G., Prati C. (2009) Effectiveness of three different retreatment techniques in canals filled with compacted gutta-percha or Thermafil: a scanning electron microscope study. J Endod 35:1433-40.

Pitts D.L., Matheny H.E., Nicholls J.I. (1983) An in vitro study of spreader loads required to cause vertical root fracture during lateral condensation. J Endod 9:544-50.

Qualtrough A.J., Whitworth J.M., Dummer P.M. (1999) Preclinical endodontology: an international comparison. Int Endod J 32:406-14.

Reader C.M., Himel V.T., Germain L.P., Hoen M.M. (1993) Effect of three obturation techniques on the filling of lateral canals and the main canal. J Endod 19:404-8.

Ribeiro F.C., Souza-Gabriel A.E., Marchesan M.A., Alfredo E., Silva-Sousa Y.T., Sousa-Neto M.D. (2008) Influence of different endodontic filling materials on root fracture susceptibility. J Dent 36:69-73.

Ring J., Murray P.E., Namerow K.N., Moldauer B.I., Garcia-Godoy F. (2009) Removing root canal obturation materials: a comparison of rotary file systems and re-treatment agents. J Am Dent Assoc 140:680-8.

Ritchie G.M., Anderson D.M., Sakumura J.S. (1988) Apical extrusion of thermoplasticized Gutta-percha used as a root canal filling. J Endod 14:128-32.

Robinson M.J., McDonald N.J., Mullally P.J. (2004) Apical extrusion of thermoplasticized obturating material in canals instrumented with Profile 0.06 or Profile GT. J Endod 30:418-21.

Royzenblat A., Goodell G.G. (2007) Comparison of removal times of Thermafil plastic obturators using ProFile rotary instruments at different rotational speeds in moderately curved canals. Journal of Endodontics 33:256-258.

Saad A.Y., Al-Hadlaq S.M., Al-Katheeri N.H. (2007) Efficacy of two rotary NiTi instruments in the removal of Gutta-Percha during root canal retreatment. J Endod 33:38-41.

Sae-Lim V., Rajamanickam I.D., Lim B.K., Lee H.L. (2000) Effectiveness of ProFile .04 Taper rotary instruments in endodontic retreatment. Journal of Endodontics 26:100-104.

Schilder H. (1967) Filling root canals in three dimensions. Dent Clin North Am:723-44.

Schilder H. (2006) Filling root canals in three dimensions. 1967. Journal of Endodontics 32:281-90.

Schilder H., Goodman A., Aldrich W. (1974) The thermomechanical properties of gutta-percha. 3. Determination of phase transition temperatures for gutta-percha. Oral Surg Oral Med Oral Pathol 38:109-14.

Schirrmeister J.F., Wrbas K.T., Meyr K.M., Altenburger M.J., Hellwig E. (2006a) Efficacy of different rotary instruments for gutta-percha removal in root canal retreatment. Journal of Endodontics 32:469-472.

Schirrmeister J.F., Wrbas K.T., Schneider F.H., Altenburger M.J., Hellwig E. (2006b) Effectiveness of a hand file and three nickel-titanium rotary instruments for removing gutta-percha in curved root canals during retreatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101:542-7.

Schirrmeister J.F., Wrbas K.T., Schneider F.H., Altenburger M.J., Hellwig E. (2006c) Effectiveness of a hand file and three nickel-titanium rotary instruments for removing gutta-percha in curved root canals during retreatment. Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics 101:542-547.

Schneider S.W. (1971) A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 32:271-5.

Seltzer S., Green D.B., Weiner N., 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.

Shen Y., Coil J.M., Haapasalo M. (2009a) Defects in nickel-titanium instruments after clinical use. Part 3: a 4-year retrospective study from an undergraduate clinic. J Endod 35:193-6.

Shen Y., Haapasalo M., Cheung G.S., Peng B. (2009b) Defects in nickel-titanium instruments after clinical use. Part 1: Relationship between observed imperfections and factors leading to such defects in a cohort study. J Endod 35:129-32.

Shipper G., Orstavik D., Teixeira F.B., Trope M. (2004) An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon). J Endod 30:342-7.

Sjogren U., Figdor D., Persson S., Sundqvist G. (1997) Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J 30:297-306.

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

Skidmore A.E., Bjorndal A.M. (1971) Root canal morphology of the human mandibular first molar. Oral Surg Oral Med Oral Pathol 32:778-84.

So M.V., Saran C., Magro M.L., Vier-Pelisser F.V., Munhoz M. (2008) Efficacy of ProTaper retreatment system in root canals filled with gutta-percha and two endodontic sealers. J Endod 34:1223-5.

Somma F., Cammarota G., Plotino G., Grande N.M., Pameijer C.H. (2008) The effectiveness of manual and mechanical instrumentation for the retreatment of three different root canal filling materials. J Endod 34:466-9.

Stabholz A., Friedman S. (1988) Endodontic retreatment--case selection and technique. Part 2: Treatment planning for retreatment. J Endod 14:607-14.

Sweatman T.L., Baumgartner J.C., Sakaguchi R.L. (2001) Radicular temperatures associated with thermoplasticized gutta-percha. J Endod 27:512-5.

Tagger M., Gold A. (1988) Flow of various brands of Gutta-percha cones under in vitro thermomechanical compaction. J Endod 14:115-20.

Tamse A., Unger U., Metzger Z., Rosenberg M. (1986) Gutta-percha solvents--a comparative study. J Endod 12:337-9.

Tasdemir T., Er K., Yildirim T., Celik D. (2008) Efficacy of three rotary NiTi instruments in removing gutta-percha from root canals. Int Endod J 41:191-6.

Tay F.R., Gu L.S., Schoeffel G.J., Wimmer C., Susin L., Zhang K., Arun S.N., Kim J., Looney S.W., Pashley D.H. (2010) Effect of vapor lock on root canal debridement by using a side-vented needle for positive-pressure irrigant delivery. J Endod 36:745-50.

Tay F.R., Pashley D.H. (2007) Monoblocks in root canals: a hypothetical or a tangible goal. J Endod 33:391-8.

Trope M., Delano E.O., Orstavik D. (1999) Endodontic treatment of teeth with apical periodontitis: single vs. multivisit treatment. J Endod 25:345-50.

Unal G.C., Kaya B.U., Tac A.G., Kececi A.D. (2009) A comparison of the efficacy of conventional and new retreatment instruments to remove gutta-percha in curved root canals: an ex vivo study. Int Endod J 42:344-50.

Valois C.R., Navarro M., Ramos A.A., de Castro A.J., Gahyva S.M. (2001) Effectiveness of the ProFile.04 Taper Series 29 files in removal of gutta-percha root fillings during curved root canal retreatment. Braz Dent J 12:95-9.

van Zyl S.P., Gulabivala K., Ng Y.L. (2005) Effect of customization of master gutta-percha cone on apical control of root filling using different techniques: an ex vivo study. Int Endod J 38:658-66.

Wennberg A., Orstavik D. (1989) Evaluation of alternatives to chloroform in endodontic practice. Endod Dent Traumatol 5:234-7.

Whithworth J. (2005) Methods of filling root canals: principles and practices. Endodontic Topics:2–24.

Wilcox L.R. (1993) Thermafil retreatment with and without chloroform solvent. J Endod 19:563-6.

Wilcox L.R., Juhlin J.J. (1994) Endodontic Retreatment of Thermafil Versus Laterally Condensed Gutta-Percha. Journal of Endodontics 20:115-117.

Wilcox L.R., Krell K.V., Madison S., Rittman B. (1987) Endodontic Retreatment - Evaluation of Gutta-Percha and Sealer Removal and Canal Reinstrumentation. Journal of Endodontics 13:453-457.

Wilcox L.R., Roskelley C., Sutton T. (1997) The relationship of root canal enlargement to finger-spreader induced vertical root fracture. J Endod 23:533-4.

Wolcott J.F., Himel V.T., Hicks M.L. (1999) Thermafil retreatment using a new "System B" technique or a solvent. J Endod 25:761-4.

Wong M., Peters D.D., Lorton L. (1981) Comparison of gutta-percha filling techniques, compaction (mechanical), vertical (warm), and lateral condensation techniques, Part 1. J Endod 7:551-8.

Wu M., van der Sluis L.W., Wesselink P.R. (2002) A preliminary study of the percentage of gutta-percha-filled area in the apical canal filled with vertically compacted warm gutta-percha. Int Endod J 35:527-35.

Wu M.K., Wesselink P.R. (2001) A primary observation on the preparation and obturation of oval canals. Int Endod J 34:137-41.

Yared G.M., Dagher F.E., Machtou P., Kulkarni G.K. (2002) Influence of rotational speed, torque and operator proficiency on failure of Greater Taper files. Int Endod J 35:7-12.

Yusuf H. (1982) The significance of the presence of foreign material periapically as a cause of failure of root treatment. Oral Surg Oral Med Oral Pathol 54:566-74.

Zmener O., Pameijer C.H., Banegas G. (2006) Retreatment efficacy of hand versus automated instrumentation in oval-shaped root canals: an ex vivo study. Int Endod J 39:521-6.

Zuolo M.L., Imura N., Ferreira M.O. (1994) Endodontic retreatment of thermafil or lateral condensation obturations in post space prepared teeth. J Endod 20:9-12.

Appendix

Marina Braniste - Research 2012

Tooth #:

Quadrant: Q3: ☐ Q4: ☐

Roots: MB: ☐ D: ☐

Length: MB: __________ D: ____________

Curvature: MB: __________ D: ____________

Radiograph: (Insert radiographic image below)