COMPARISON OF THE EFFECT OF FIXED AND VARIABLE TAPER ON THE QUALITY OF OBTURATION

A O A Hassan

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

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Supervisors: Dr. I. Munshi & Dr. S.Tootla

School of Oral Health Sciences, Faculty of Health Sciences, University of the Witwatersrand,

South Africa

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DECLARATION

I, Almeqdad Osman Ali Hassan, declare that this study "**Comparison of the Effect of Fixed and Variable Taper on the Quality of Obturation**" is my own work. It has been submitted in partial fulfillment of the degree of Master in Dentistry in the branch of Endodontics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at this or any other university.

A O A HASSAN **Date: 24/4/2018**

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DEDICATION

To my parents and extended family for their support and encouragement.

ABSTRACT

Purpose

It has long been accepted that the quality of obturation is determined by the final shape of the root canal. This study uses µCT to examine the effect of two canal preparation geometries, fixed and variable taper, on the quality of obturation. The study also compares the effect of shape geometry on the volume of extruded GP.

Methodology

Sixty-four extracted teeth were randomly divided into two groups and prepared using two different file systems: Wave One Gold and One Shape files. The obturation was standardized for both groups using GuttaCore obturator and then each tooth was scanned with µCT. The following parameters were measured: POV, 3-D difference, 2-D area of voids (at 2, 6 and 9mm) and volume of extrusion (E).

Results

The WO group had a significantly higher POV ($P = 0.045$) and a lower D% ($p = 0.0034$) than the OS group but the correlation between canal taper and quality of obturation was small (r=0.38). The 2-D analysis showed no significant differences between the OS and WO group. The OS group had a significantly ($P = 0.0013$) greater value of extruded GP than the WO group but the correlation was low (r=042).

Conclusion

Within the limitation of this study, this study shows that when the apical taper is large enough, 6 - 8%, the geometrical shapes of fixed and variable tapers have a small impact on the quality of the obturation. The variable tapered preparation had a slightly less GP extrusion than the fixed tapered preparation.

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ABBREVIATIONS AND SYMBOLS

NaOCL: Sodium Hypochlorite

EDTA: Ethylenediaminetetraacetic Acid

NiTi: Nickel Titanium

M-W: Memory-Wire

CM: Controlled Memory

CW: Clockwise

CCW: Counter Clockwise

GP: Gutta-Percha

3-D: 3- Dimensional

2-D: 2- Dimensional

µCT: Micro-Computed Tomography

CT: Computed Tomography

µm: Micrometer

μm^2: Square Micrometer

μm^3: Cube Micrometer

OS: One Shape Group

WO: Wave One Gold Group

RPM: Round Per Minute

N.cm: Newton Centimetre

POV: Percentage of Obturated Volume

VC: Volume of Canal

VO: Volume of Obturation

D: Difference of Volume of Canal and Volume of Obturation

S-2: 2-Dimensional Slice at 2mm

S-6: 2-Dimensional Slice at 6mm

S-9: 2-Dimensional Slice at 9mm

E: Extrusion of the Gutta-Percha

G*power: Tool to Compute Statistical Power Analysis

IQR: Interquartile Range

SD: Standard Deviation

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Three-dimensional cleaning and shaping of the root canal system have clear objectives: cleaning relates to debridement and shaping facilitates obturation (Stewart,1955; Schilder, 1974; Ritchard, 1992). It has been shown that an adequate root canal procedure affects the health of the periapical tissue thereby maintaining the functionality of the tooth in question (De Moor *et al*, 2000). Providing a fluid tight seal from the apical foramen to the orifice level (obturation) is affected by adequate shaping and proper cleaning (Schilder, 1974). Hence, cleaning and shaping of the root canal system are critical steps in the endodontic procedure in order to reduce irritants and create adequate space for irrigation solutions to reach areas that are inaccessible to instrumentation (Ritchard, 1992; Khademi *et al*, 2006).

1.1 Root Canal Preparation

In 1955, Stewart highlighted the significance of proper shaping and cleaning of the root canal system (Stewart, 1955), which was further confirmed by Ritchard in 1992. In the mid-1970s Schilder emphasized that the biomechanical objectives of endodontics were that the root canal should be adequately prepared to facilitate both cleaning and obturation (Schilder, 1974). Furthermore, the inadequate shaping of the root canal system resulted in an uninstrumented area being unsealed by the obturating material (Wu and Wesselink, 2001). This in turn affects the outcome of endodontic treatment.

However, complexities of the root canal system such as the presence of lateral canals, deltas, bifurcations and the presence of stones, invariably jeopardize the success of endodontic treatments (Vertucci, 2005). This is a limitation of endodontic files that interfere with the natural configuration of the root canal system. The cross sectional geometry of endodontic files creates a round path in most cases. This leaves a substantial area of the root canal system untouched (Wu *et al*, 2000) which necessitates the use of efficient irrigation solutions to clean these areas. Adequate cleaning has a significant impact on the subsequent obturation (Wu and Wessenlink, 2001).

Many irrigation solutions are available but the two most commonly used are full strength 5% to 6% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA). The wide antimicrobial and tissue dissolving properties of NaOCl that are considered to be significantly higher than other irrigation solutions and the efficacy of EDTA to remove inorganic constituent of the smear layer, mean that NaOCl and EDTA are widely accepted as gold standards in irrigation solutions (Zehnder, 2006; Giardino *et al,* 2007; Lui *et al*, 2007; Stojicic *et al*, 2010). Irrigation and shaping of the root canal system are interconnected and for irrigation to reach the apical third of the root canal system the canal must be prepared and enlarged to at least a size 30 endodontic file (Khademi *et al*, 2006).

1.2 Tapered Root Canal Preparation

The biomechanical objective for cleaning and shaping and the need to take the type of obturating material used into account has been emphasized previously (Schilder, 1974; Ritchard, 1992). While maintaining the natural path of the root canal system, the root canal should be prepared in a continuous tapered form that narrows apically and widens coronally. Failure to do so affects obturation and jeopardizes success. Successful cleaning and shaping create an apical resistance form (apical seat) which reduces extrusion of the filling material beyond the apical foramen and creates a wider coronal third to facilitate movement of irrigation solutions (Schilder, 1974).

Schilder's method of creating a tapered funnel shaped canal was difficult to achieve with non-tapered stainless steel endodontic files that were stiff, with the stiffness increasing with increasing file size. In addition, many instruments and steps were required and it was time consuming. These difficulties were also the reasons for preparation complications like ledges, canal transportation and perforations. It was difficult to create a predictable tapered shape of the root canal system (Buchanan, 2000).

Shaping the root canal system can follow three different configurations:

1- The standardized root canal preparation (not accepted any longer) was described by Ingle and Beveridge to prepare the root canal to the full working length using the same size file. Each file had to reach the full working length (Allison *et al*, 1979). This type of preparation is highly affected by the canal configuration. It becomes dangerous in small canals and in the presence of curvatures (Ingle, 1961 cited in Richard, 1992). A canal prepared using this method often resulted in an inadequate mid-root preparation and over preparation of the apical third subsequently resulted in premature contact of the obturating material with the middle of the root canal as well as a high incidence of procedural errors (Esposito and Cunningham, 1995; Buchanan, 2000).
2- The flaring (fixed tapered preparation) technique (Figure 1.1A) was advocated by (Schilder, 1974) to better shape the root canal system. This preparation improved the predictability of treatment outcomes. In this technique, the preparation degree angle remains constant from the apical third to the coronal third of the root canal. Using different techniques, a tapered root canal preparation can be achieved. These techniques include: step back, step down or a combination of the two. The degree of taper angle is

sometimes determined by the size of the condensing instrument such as, the plugger or spreader that is used with obturation. This is similar to the lateral condensation technique of obturation where the canal must be enlarged to a size so that the spreader reaches to within 1mm of the working length (Ritchard, 1992). However, with the introduction of many obturation techniques where the condensing instrument (spreader or plugger) is not required, the angle degree of taper is not entirely dependent on the condensing instrument but rather on the quality of obturation as will be explained subsequently.

3- In 2000, Buchanan introduced the concept of variable tapered root canal preparation (Figure 1.1B). The angle of the root canal increases progressively towards the coronal third. A study showed that a variable tapered preparation creates a smaller apical diameter that reduces extrusion of the obturation material (Whitten and Levitan, 2015) and a wider coronal third that facilitates movement of irrigation solutions throughout the canal when compared to the constant taper (Buchanan, 2000).

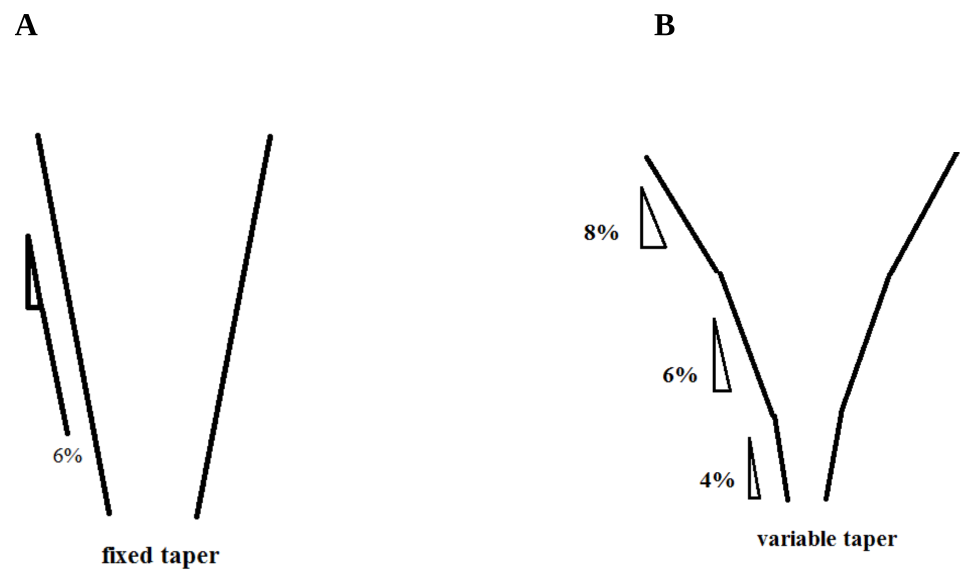

Figure 1.1: Schematic representation of two types of root canal geometrical angle

(A) Fixed tapered preparation of the root canal system where the taper angle increases constantly and **(B)** variable tapered preparation where the taper angle increases progressively toward the coronal third.

1.3 Endodontic Instruments

Endodontic instruments went through several stages of development to facilitate shaping of the root canal system. These instruments are Gates-Glidden, reamers and files. The endodontic instruments are either hand or rotary generated instruments. They are manufactured by grinding, twisting and more recently heat treatment to enhance their metallurgical properties (Ritchard, 1992).

Carbon manufactured endodontic instruments were replaced with stainless steel because of the lack of flexibility and tendency to fracture. The introduction of tapered stainless steel instruments and the development of preparation techniques facilitated a more accurate preparation of the root canal. The subsequent development of engine driven stainless steel instruments increased file performance and reduced chair time but also resulted in a higher procedural error rate (Ritchard, 1992). The Nickel Titanium (NiTi) instrument was then introduced and shown to have significantly better metallurgical properties.

1.3.1 Nickel Titanium (NiTi) Endodontic Instrument

The development of the Nickel Titanium endodontic file was a significant advancement in endodontics. The metallurgical properties and performance of the files were improved significantly (Pettiette *et al*, 1999; Haapasalo and Shen, 2013). NiTi endodontic files were first used by Walia *et al* (1988) where they used orthodontic wire to fabricate size 15 endodontic files.

NiTi endodontic files are manufactured from an alloy called nitinol (ni: nickel, ti: titanium, nol: Noval Ordnance Laboratory) (Thompson, 2000). They are largely flexible and resistant to cyclic fatigue when compared to stainless steel endodontic files (Walia *et al*, 1988; Haikel *et al*, 1998; Pettiette *et al*, 1999; Haapasalo and Shen, 2013).

The development of rotary systems such as NiTi files has improved the rates of successful outcomes of endodontic treatment and resulted in a significant reduction in procedural errors when compared to hand operated stainless steel files (Cheung and Liu, 2009). Since the introduction of NiTi rotary endodontic files, preparation of the root canal system has become more predictable and fewer instruments are required to completely shape the root canal system. This is shown where curved canals can now be mechanically prepared with NiTi endodontic files, unlike stainless steel files that have to be pre-curved (Esposito and Cunningham, 1995).

1.3.2 Evolution of NiTi Rotary Instruments

NiTi rotary instruments have been through several decades of development. The first generation was introduced in 1992 by McSpadden who developed the 2% tapered file. Due to the tendency of breakage of 2% tapered files, the 4% and 6% tapered files were introduced in 1994 by Ben Johnson (Haapasalo and Shen, 2013). In the next generation, the file cutting performance was improved as in the Endosequence and Protaper file systems so that the file could actively cut the dentine, unlike the first generation files where the file cut dentine passively. Dentsply Tulsa Dental Specialities introduced the Protaper system in 2001, which was the first system that had a variable taper in the same file.

The third generation was characterized by an enhancement in file metallurgy. The introduction of Memory-Wire (M-W) (SportsWire, Langley, OK) technology in 2007 brought more flexibility and resistance to file fatigue. M-W NiTi files are produced through cycles of thermal treatment. Examples of this generation are Profile Vortex and Vortex Blue. In this generation

Controlled Memory (CM) was also introduced in 2010. CM is manufactured by thermo-mechanical treatment of NiTi wire. CM file is extremely flexible but it does not have a shape memory (product brochure: HTTP: //www.hyflexcm.com/DevDownloads/ 30464AHYFLEX-CM_bro.pd). This was followed by the introduction of an unequal clockwise (CW) and counter clockwise (CCW) (reciprocation) motion in endodontic files by Yared (2008). The reciprocating motion of the endodontic file, lead to the invention of a single file concept where the canal can be shaped using only one file instead of a number of files. However, not all single files use the reciprocating motion such as One Shape file system which uses a continuous rotation. The last generation is characterized by an offset file design that reduces contact between file and dentine intends to reduce file fatigue and subsequent fracture, according to the manufacturer. An example of this last generation instrument is Protaper Next (Buchanan, 2000; Haapasalo and Shen, 2013).

1.3.3 Reciprocating Versus Rotating Endodontic Files

The reciprocating motion was initially applied with stainless steel files in 1958 and then used later in NiTi rotary files (Haapasalo and Shen, 2013). It is characterized by CW and CCW rotations. In the CW direction the file engages dentine and in the CCW direction, the file disengages dentine (Yared, 2008). Results have been contradictory when comparing rotating to reciprocating files on both the amount of extrusion of irritants (debris) and file performance on shaping the canals. When the F2 protaper endodontic file was driven by a reciprocating motion, the amount of extruded debris was similar to the same file when driven by continuous rotation (De-Deus *et al*, 2010). However, this study compared a single file, designated to be a rotary file, used in a reciprocating motion to multi-rotating files. On the other hand, reciprocating files produced more extrusion of debris than a full sequence of rotating files (Burklein and Schafer, 2012; Burklein *et al*, 2014).

In vitro studies have shown that a single reciprocating file system was more conservative in shaping the root canal system than a rotating file system (Franco *et al*, 2011; Berutti *et al*, 2012). In contrast, another study showed that there was no difference between reciprocating and rotating files in preserving the natural path of curved canals (You *et al*, 2011).

These variations in results from rotating versus reciprocating file systems can be related to certain factors such as the differences in cross sections between file systems, differences in cutting blade design and angle, flexibility and number of files (Caviedes-Bucheli *et al*, 2010).

In 2008, Dr. Ghassan Yared advocated the precise use of unequal CW and CCW on a single file to completely finish the root canal preparation, using the F2 Protaper system even though the F2 file is not designed to be used in a reciprocating motion (Yared, 2008). Interestingly, when the F2 Protaper was used in a reciprocating motion, the cyclic fatigue of the F2 Protaper file was reduced significantly compared to that of continuous rotation (De-Deus *et al*, 2010). This finding is supported by Pedullà *et al* (2013). This led to the invention of single file systems. In 2011 the first two reciprocating single file systems were launched. They were Wave One (Dentsply Tulsa Dental Specialities) and Reciproc (VDW). Since then a number of single file systems have been marketed such as One shape (Micro Mega) and Self Adjusting file (ReDentNova). However, the One Shape file system uses a continuous rotation while SAF uses slow continuous rotation combined with vibrations.

1.3.4 Variable versus Fixed Tapered File

NiTi rotary files have either fixed or variable tapering. Fixed tapered files have a fixed tapered angle that has a constant angle along the active portion of the file, while variable tapered files have different tapers of increasing and decreasing angles along the active portion of the file. Buchanan in 2000 described the concept of variable tapered preparation where the angle increases progressively from the apical foramen towards the coronal third. This enhances both cleaning and obturation (Buchanan, 2000). In his study series, he advocated using a set of files of constant taper to create variable tapered preparation. However, files with variable tapered angle are now available.

While many studies show the effect of rotation on canal preparation, there are very few that show the effect of fixed and variable taper on the canal or equal removal of dentine from the root (canal transportation). Variable tapered files resulted in greater straightening and transporting of the outer aspect of the apical curvature when compared to the fixed tapered file. On the mid root curvature, the variable tapered file was better in preserving tooth structure than fixed tapered endodontic files (Bergmans *et al*, 2003; Yang *et al*, 2006; Yang *et al*, 2007).

An example of a variable tapered single file is Wave One Gold (Dentsply Tulsa Dental Specialties, Switzerland). Wave One Gold was launched in 2016 as an advancement of the Wave One file system. According to the manufacturer the resistance to cyclic fatigue was enhanced by 50%. Wave One Gold is characterized by variable tapered angles of increasing and decreasing taper along the active portion. The cross sectional geometry of Wave One Gold is a parallelogram which is constant along the active part.

An example of a fixed tapered single file is OneShape (Micro Mega, France). It has a tip diameter of size 0.25mm. The taper is constant towards the coronal part at 6%. The file is generated in a continuous rotation. It is characterized by variable pitch angles in which the file has three different zones of the cross section. The first (apical part) and third (coronal part) zones are designed to have two cutting edges. The second zone represents a progressive transition from two to three cutting edges. The manufacturer claims that the different cross sections reduce instrument screwing into the canal.

1.4 Obturation

Root canal obturation refers to completely filling the root canal system with non-irritating material from the apical foramen to the orifice level. The aim of the endodontic procedure is to prevent apical, lateral and coronal microleakage that affects the long-term success of endodontic treatment (Sjogren *et al*, 1990a). This requires the use of filling materials and techniques that adequately seal the entire root canal, forming a fluid tight seal from the apical foramen to the orifice level. It has been shown that both the quality of the obturating material and quality of coronal restoration relate significantly to the status of the periodontium, determining root canal success or failure (Ray and Trope, 1995). In a study by Schilder it was emphasized that inadequate obturation of the root canal system is central to root canal failure (Schilder, 2006). A follow-up study has established that long-term success of root canal treatment is correlated to the quality of the obturation (Kerekes and Tronstad, 1979).

While many types of obturation materials have been introduced, GuttaPercha (GP) is the most widely used. It exists in alpha and beta forms. Beta and alpha GP are produced through cycles of heating and cooling. The beta form is solid when it is cold and once it is heated to approximately 56°C it converts to an amorphous form which is soft and tacky, the alpha GP (Schilder *et al*, 1974).

Pitfalls in obturation techniques led to the development of a number of techniques to facilitate GP placement and improve the quality of obturation. Cold lateral condensation of GP was established in 1914 and modified thereafter and became the standardized technique for obturation. However, it has been shown that the lateral condensation technique does not provide an adequate seal of the root canal system (Schäfer and Olthoff, 2002). Vertical condensation was developed in the early 1950s and was followed by many other types of obturation techniques such as injectable and carrier based GP (Glickman and Gutmann, 1992).

Mechanical properties of obturation materials render them difficult to condense and pack throughout the root canal. In addition, due to the lack of adhesion of the filling material to the canal wall (Gerald and James, 1992), the use of sealer has become essential. However, the introduction of softened GP has to some extent overcome the problem. Softened GP, chemically or heated, shows the ability to flow into the canal which results in better adaptation to the canal wall compared to cold GP (Gutmann *et al*, 1993, Saunders *et al*, 1993). Thus softened GP has become popular.

In 1978 Ben Johnson invented Carrier based GP, where a stainless steel file was first used as a carrier to carry the GP to the full working length of the canal (Johnson, 1978). Thereafter the alpha phase GP was mounted onto a plastic carrier (Polysulfone) (Zogheib *et al*, 2017). This type of GP is commercially known as Thermafil (Dentsply Tulsa Dental Specialities). The Thermafil obturator has better adaptation to the canal wall, fewer voids and less sealer thickness compared to cold lateral condensation and continuous wave obturation (Gutmann *et al*, 1993; Da Silva *et al*, 2002; Boussetta *et al*, 2003; Weis *et al*, 2004). Thermafil also resulted in a significantly higher area of obturation compared to cold lateral condensation and worm vertical condensation (De-Deus *et al*, 2006).

Shedding of the GP from the plastic core (carrier) of the Thermafil obturator and the binding of the core to the improperly shaped canal during obturation was investigated by Rapisarda *et al* (1999). In addition, it is difficult to remove Thermafil in retreatment and there is a potential for procedural errors during post space preparation (Zuolo *et al*, 1994). This brought about the invention of a new generation of carrier based systems in which the core is manufactured of cross-linked GP. This is known as GuttaCore obturator (Dentsply Tulsa Dental Specialities, Tulsa, OK). In 2013, Beasley *et al* showed that retreatment of GuttaCore obturator required less time to remove when compared to Thermafil and continuous wave obturation (Beasley *et al*, 2013). The GuttaCore obturator is coated with alpha phase GP. GuttaCore showed superiority to cold GP and it has been suggested as an alternative to warm vertical compaction in an oval canal (Li *et al*, 2014). Another study used a computerised fluid transport system for evaluating the apical seal of three different obturation techniques. The results showed that there was no difference between GuttaCore and continuous wave obturation but they were significantly better than cold lateral condensation (Silva-Herzog *et al*, 2017).

It is accepted that the outcome of endodontic treatment is associated with the quality of obturation (Ng *et al*, 2008). The quality of obturation is determined by many factors mainly the presence of voids and the length of obturation materials within the canal (Sjogren *et al*, 1990a). Studies have shown that voids are frequently associated with various obturating systems (Gandolfi *et al*, 2013). The significance of the presence of voids is that they become colonized by bacteria and are associated with microleakage. Microleakage occurs through voids, especially where voids have connections to the dentinal tubules, unlike blind voids (Wu *et al*, 2003). It is becoming clear that preventing leakage either from root canal to periradicular tissue or the opposite is the main aim of endodontic treatment (Love and Jenkinson, 2002).

Another factor that determines the quality of obturation is the length of the filling material (Sjogren *et al*, 1990b). The exact termination of the obturation has been controversial. Some authors emphasize that obturation must end 0.5 to 1mm short of the radiographic apex (Ricucci, 1998). Others suggested that obturation at 2mm short of the radiographic apex is accepted (Kojima *et al*, 2004; Schaeffer *et al*, 2005). Histologically, minor apical constriction determines the apical limit of the root canal. Ingle (1973) stated that the minor apical diameter is at the cementodentinal junction (CDJ) and is located 0.5mm from the external surface (cited in Ricucci, 1998). Thus both instrumentation and obturation should be limited to this area. Frank *et al* (1988) mentioned that the apical end was 0.5 to 1mm short of the radiographic apex (cited in Ricucci, 1998).

Softened GP has significant higher toxicity compared to cold GP which has a relatively low toxicity (Elizeu, 1990). Extrusion of the filling material is associated with failed endodontics (Siqueira *et al*, 2014) and a reduction in healing rate (Ricucci and Langeland, 1998). Thus avoiding extrusion of GP beyond the apical foramen is a determinant of endodontic success.

Flowable GP (chemical or heat softened GP) was shown to have a better quality of obturation compared to cold obturation (Boussetta *et al*, 2003; Weis *et al*, 2004). However, studies showed that extrusion of the obturation material beyond the apical foramen is a common finding in endodontics (Abarca *et al*, 2001). Warm GP was associated with more extrusion than cold GP (Peng *et al*, 2007), and occurs commonly with Thermafil obturation (Gutaman *et al*, 1993; Clark and ElDeeb, 1993). The incidence of thermoplastisized GP extrusion was 50% compared to 20% for cold lateral obturation (Mann and McWalter, 1987). Three dimensional (3-D) filling of the Thermoplastic GP varies with the insertion rate which also affects the overfill and underfill of the obturation. The insertion rate of Thermafil GP that produces an ideal obturation also produces undesirable extrusion of Thermafil obturation (Levitan *et al*, 2003).

1.5 Three-Dimensional (3-D) Computed Tomography

The pioneering and establishment of 3-D X-rays especially Micro-CT (μCT) has produced a great advancement in the technology of diagnosis and detection of tooth anatomy as well as the detection of all kinds of defects of root canal filling materials (Roggendorf *et al*, 2010; Moeller *et al*, 2013; Celikten *et al*, 2015).

When 3-D computed tomography (CT) was first introduced in the early 1970s, it allowed for examination of the inner aspect of the objects in 3-D by collating many images, unlike the conventional 2-dimensional (2-D) X-ray that has a limited function. However, this traditional CT radiography lacks resolution and was inadequate for scanning small objects in detail, such as teeth (Tachibana and Matsumoto, 1990). In the early 1980s, the μCT was developed. It produces significantly higher resolution images compared to standard CT. The µCT resolution has improved from 81µm (Rhodes *et al*, 1999) to significantly higher resolution of 34µm (Peters *et al*, 2000) to 15µm (Verna *et al*, 2002). Recently a resolution of 5µm is possible. The µCT system uses a microfocal spot X-ray source and a high resolution detector. The sample can be rotated at 360º producing 3-D reconstructed images of the object (Swain and Xue, 2009).

µCT has become an important research tool in endodontics, especially where an accurate investigation of the root canal system needs to be obtained. µCT is a non-destructive and rapid method to obtain reproducible information of the sample. It is a valuable and accurate tool in scanning teeth in great detail and aids in the detection of root canal anatomy (Oi *et al*, 2004; Jung *et al*, 2005; Verma and Love, 2011). One of the advantages of µCT is that the original data is available (Nielsen *et al*, 1995) which is valuable when comparing previous methods of evaluation. These previous methods were destructive as they involved sectioning of the teeth (Allison *et al*, 1979) which was inaccurate in measuring the defects in obturation such as voids and gaps that could exist between the obturation material and canal walls. They used dye and bacterial tracers with visual or digital estimation. The depth of tracer penetration was used hypothetically to determine the volume of the voids which does not represent an accurate measurement (Wu and Wesselink, 1993).

Nielsen *et al* were the first to use µCT for the evaluation of root canal obturation (Nielsen *et al*, 1995). They also evaluated the application of µCT for the detection of tooth morphology and the effect of instrumentation on the root canal system. They concluded that µCT is a reproducible technology for experimental studies. Jung *et al* established a strong correlation between µCT and histological studies. They showed the non-destructive accuracy of µCT in scanning teeth and investigating root canal filling materials (Jung *et al*, 2005).

μCT has been used in investigating the effect of instrumentation on root canal geometry (Peters *et al*, 2001), root canal anatomy (Verma and Love, 2011), quality of root canal filling material and the effect of different preparation techniques on the quality of obturation (Zogheib *et al*, 2012). As in any other methods for diagnosis, μCT has a few limitations. Li *et al* (2014) reported that a cross section from a μCT scan has a lower resolution when compared to scanning electron microscopy. Also, the appearance of the object is highly affected by the choice of an appropriate threshold (Peters *et al*, 2000).

1.6 Relation Between Canal Preparation and Obturation

As mentioned previously, Schilder's objectives for root canal preparation emphasized the requirement of achieving a funnel tapered form of the root canal to facilitate cleaning and enhance obturation (Schilder, 1974). Allison *et al* (1979) established the relationship between the taper of the prepared canal and the quality of obturation. They compared the effect of standardised taper (less taper) versus flared taper on the quality of obturation. A tracer isotope (Ca) was used to determine the penetration by autoradiography of different cross sectional slices of the teeth. The results showed that the flared preparation significantly reduced the penetration of the tracer compared to the standardised preparation which resulted in significant leakage. This was an important finding, despite the fact that the canals were prepared with stainless steel instruments and the obturation was performed with lateral condensation. The final geometry of the canal preparation has a significant influence on the quality of obturation (Allison *et al*, 1976).

Another study investigated the effect of different apical taper preparations on the quality of thermoplactisized carrier based obturation assessed by μCT (Zogheib *et al*, 2012). The canals were prepared with three different fixed taper files. The results showed that canals prepared with 8% and 6% tapered files had fewer voids than canals prepared with a 4% taper. It suggests that the larger the taper the better the obturation at the apical 5mm of the root canal. This study opened new questions indicating that the taper angle of the preparation can have an impact on the quality of obturation.

Fewer studies have been done to show the effect of variable tapered preparations on the quality of obturation. This takes us to Schilder (1974) and Buchanan (2000) where the canal taper improves the quality of obturation. Schilder’s statement on the effect of canal taper has been proved to be critically important. He only emphasized that fixed tapered preparation improved the quality of obturation versus standard preparation (Schilder, 1974). However, Buchanan discussed a new concept in 2000 which was variable tapered preparation (Buchanan, 2000). He emphasized the importance of preparing the root canal with variably tapered files for the quality of obturation in that it reduces extrusion of the filling material. A more recent study confirmed this finding when canals prepared with variable tapered files had less apical extrusion of thermoplastic carrier based GP than canals prepared with the fixed taper (Whitten and Levitan, 2015). However, files of fixed taper were used to obtain variable tapered preparation and the apical 2mm of the root canal was hand instrumented.

On the other hand, Heeren and Levitan showed that extrusion is not only related to the preparation type but can also relate to the type of filling material (Heeren and Levitan, 2012). In their study, fixed tapered preparation and variable tapered preparation were compared using two obturation materials: Thermafil plus and RealSeal. The results showed that Thermafil plus was affected by the preparation taper and resulted in significantly higher extrusion associated with the fixed tapered preparation, while Realseal was not affected by the preparation taper.

In conclusion, the quality of obturation is highly dependent on the preparation of the root canal. Furthermore, it is technique sensitive. In the lateral condensation technique of obturation, a sufficient taper is required to facilitate placement of a spreader to approximately 1mm from the working length (Ritchard, 1992). A larger taper of 8% has a better seal of obturation at apical 5mm when a carrier based obturation is chosen (Zogheib *et al*, 2012). However, to our knowledge, no studies have been published to evaluate the effect of variable versus fixed tapered canal preparation on the quality of obturation.

CHAPTER 2

AIM AND OBJECTIVES

2.1 Purpose of the Study

Previous studies have shown the effect of file taper on the preparation of the root canal system (Bergmans *et al*, 2003; Yang *et al*, 2006; Yang *et al*, 2007) and the effect of taper on the extrusion of obturating materials beyond the apical foramen (Whitten and Levitan, 2015). No studies were done to show the effect of geometry of the taper (fixed versus variable) on the quality of obturation in terms of the presence of voids or the amount of extrusion of GP.

The purpose of this study was to evaluate the effect of fixed taper and variable taper files on the quality of obturation of the root canal system regarding the presence of voids as well as to compare the extrusion of GP.

2.2 Aim and Objectives

To evaluate and compare the quality of canal obturation, as measured by µCT imaging software, in canals prepared with fixed and variable tapers.

The objectives were:

1- To measure and compare, in 3 dimensions, the percentage of obturated volume (POV) and volume of voids in canals prepared with fixed and variable taper systems.
2- To measure and compare the volume of voids of the obturation in two-dimensional slices at the coronal, middle and apical thirds of the canal.
3- To measure the volume of GP extruded beyond the apical foramen.

CHAPTER 3

METHODS AND MATERIALS

3.1 Study Design

This experimental study involved preparation of extracted teeth with different canal taper geometries followed by obturation with Guttacore and then analysis for voids and extruded GP with µCT.

The study was performed at the University of the Witwatersrand Johannesburg.

The study was approved by the Human Research Ethics Committee at the University of the Witwatersrand (W-CJ-160615-1) (Appendix 1).

3.2 Sample size Selection and Specimen Preparation

3.2.1 Sample Size Determination

The sample size was determined by the key research question, namely the comparison of the mean volume of voids between the two experimental groups. This required the application of an independent sample t-test. Based on data from a previous similar study, a mean volume percentage between-group difference (22.3738µm and 0.8103 µm) of 6% and 8% taper and their standard deviations of 24.73499µm and 1.22µm respectively, corresponds to an effect size of d=0.72, 80% power and a 5% significance level (Zogheib *et al*, 2012), indicating that a sample size of 32 teeth per group was required. Sample size calculation was carried out in G*Power (Faul *et al*, 2007).

3.2.2 Sampling Methods

All the selected 64 extracted teeth were collected from the Witwatersrand Oral Health Centre and randomly divided between the two groups, OS and WO group.

3.2.3 Inclusion Criteria

1- Only permanent single-rooted anterior and premolar teeth
2- Root with a curvature less than 25°
3- Sound root with mature fully formed apices

3.2.4 Exclusion Criteria

1- Fractured root
2- Caries extending to the root structure
3- Root resorption
4- Tooth with developmental anomalies e.g. dilacerations
5- Previous endodontically treated teeth.
6- Pulp calcification
7- C-shaped canal
8- Oval shaped canals
9- Any tooth with a canal diameter that is greater than size 25 GuttaCore size verifier.

3.2.5 Tooth Preparation

All 64 extracted single root canal teeth were collected from the Witwatersrand Oral Health Centre and immediately stored in formalin (pH 7.25) prior to use. The 64 teeth were randomly divided into two groups: OS group: 32 teeth were prepared with a fixed taper (One Shape file) and WO group: 32 teeth were prepared with a variable taper (Wave One Gold primary file).

The inclusion and exclusion criteria were assessed using conventional radiography; both buccolingual and mesiodistal views were taken; and a dental operating microscope (Carl Zeiss Surgical GmbH, Germany) was used for visual assessment (5.1 Zeiss microscope magnification). The curvature was measured as described by Schneider (1971) as is shown in figure 3.

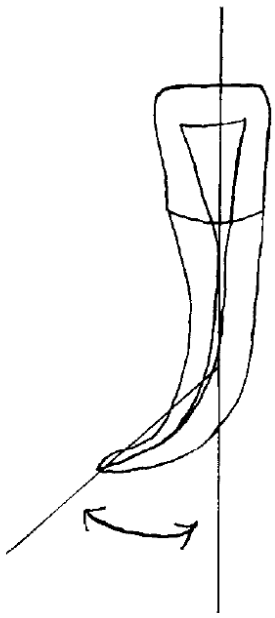

Figure 3.1: Schneider's method for measuring tooth curvature (Source: Schneider, 1971)

A parallel line is drawn along the long axis of the tooth. The second line is drawn from the apical foramen to the point on the first line where the canal deviates from the long axis of the tooth

After selection, each tooth was cleaned from any attached bone or tissue using a number 15 scalpel and high speed handpiece with a long diamond bur (Mani, Inc, Japan). Thereafter all the teeth were stored in Formalin (pH 7.25) at room temperature until preparation (storage of about two months). Before preparation, each tooth was mounted in an acrylic resin block (Sure Acrylic, packaged for Confi-Dent Agencies, SA) size 3×2×3cm to facilitate handling. The teeth were coated with Vaseline and inserted into the acrylic before the acrylic set to facilitate removal of the tooth from the acrylic when it set. A size 2 surgical length carbide round bur (Dentsply, Maillefer) was used to enlarge the apical area of the inner aspect of the acrylic. The tooth was reinserted into the pre-maintained space in the acrylic and fixed with a modeling wax (Toughened No.4 Dental Modelling Wax, UK) (Figure 3.2).

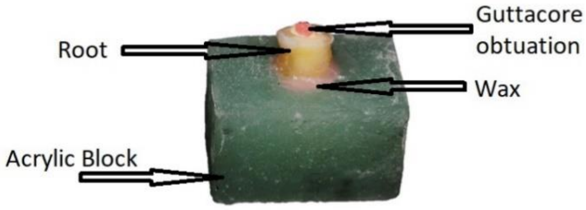

Figure 3.2: Moulded tooth in acrylic resin block

The length of each tooth was standardized by grinding the occlusal table using a long diamond bur (Mani bur) establishing a length of 15mm for all teeth.

All the procedures (preparation and obturation) were performed by a single operator at room temperature using a dental operating microscope (Carl Zeiss Surgical GmbH, Germany) and 0.6 Zeiss microscope magnification.

3.2.6 Glide Path and Working Length Determination

Patency was established and glide path was prepared for each tooth using a size 8 and 10 K file (MicroMega, France) as required. One G (MicroMega, France) and Proglider (Dentsply, Maillefer, Switzerland) files were used for rotary glide path preparation for OS and WO groups respectively. One G file and Proglider were rotated at a speed of 300rpm (continuous rotation) and torque of 2N.cm. A viscous chelating agent (RC Prep, Premier Dental Products Company, USA) was used as required during canal patency and glide path preparation.

The working length was established once a size 10 K file (MicroMega, France) appeared through the apical foramen. It was withdrawn by 0.5mm to establish the working length.

The canals were then prepared using One Shape file (MicroMega, France) for the OS group and Wave One gold primary file (Dentsply Tulsa Dental Specialities, Switzerland) for the WO group. The mechanical preparations were performed as per manufacturers' instructions, including single file use. All teeth prepared with Wave One gold file were completed with the primary file only.

A X Smart plus motor (Dentsply, Maillefer, Switzerland) was used in both rotary glide path preparation and mechanical preparation for Wave One gold and One Shape file systems.

3.2.7 Canal Preparation

3.2.7.1 OS group

After the canal was patent, glide path was secured and working length was established. An Endoflare (MicroMega, France) file was used to flare the orifice. A new One Shape file for each canal was used following the manufacturers' instruction. A One Shape (25/06) file was used in a picking motion until it reached the established working length under copious irrigation of 6%NaOCl and recapitulation with a size 15K file to the full working length. The

X Smart motor was set in a programme setting of speed 400rpm and torque of 2.5N.cm. Shaping procedure was considered to be completed once the OneShape file reached the full working length and the file brushed the apical third 3 to 4 times.

3.2.7.2 WO group

After the canal was patent, glide path was secured and working length was determined a primary Wave One gold primary file (25/07) was driven into the canal filled with 6% NaOCl. The file was manipulated using a 3 to 4mm short gentle inward stroke into the canal followed by gentle outward brushing as the file was withdrawn. This procedure was repeated until the file reached the full working length. Recapitulation was done with a size 15K file to the full working length after each stroke with copious irrigation of 6% NaOCl. The canal was considered to be shaped once the file reached the full working length and the file brushed the apical third three times. Wave One gold was used with X Smart motor (Dentsply, Maillefer, Switzerland) with the standardized reciprocating setting.

3.2.8 Irrigation Solutions and Irrigation Protocol

The irrigation solutions were standardized for both systems as follows: 6% NaOCl and 17% EDTA. Irrigation during instrumentation was done with 5ml of 6% NaOCl with a 29 gauge/17mm NaviTip needle (Ultradent, South Jordan, USA). A disposable syringe (4ml) was used.

The final rinse protocol was done using 2ml of 6% NaOCl solution for three minutes followed by 1ml 17% EDTA solution for one minute. The NaOCl was agitated using the manual dynamic activation with a master apical cone single GP. The apical 0.5mm of the GP was cut using a number 15 scalpel. The master cone single GP was activated back and forth for about 50 to 60 times while the 6%NaOCl filled the canal (60 seconds). The canal was then gently flushed with the rest of the 5ml 6% NaOCl for about two minutes. Finally, the canal was rinsed with 1ml of 17% EDTA for about one minute.

3.2.9 Root Canal Obturation

Since there is no apparent difference between the carrier based obturators of both MicroMega and Dentsply companies, it was decided to standardize the obturation by using GuttaCore obturator (Dentsply, Maillfere, Switzerland) for both the test groups.

Before obturation, each canal was thoroughly dried using paper points (Dentsply, Maillfere, Switzerland) of the same apical diameter as the master cone GP. The GuttaCore obturator system was used according to the manufacturers' instructions. A GuttaCore size 25 verifier (which is equal to ISO size 25 K file) was used to confirm the apical foramen diameter until it fitted passively to the established working length. AH Plus sealer (Dentsply, Germany) was used. A size 25 paper point was used to wipe the sealer on the canal wall to the full working length. Sealer excess was removed with a smaller paper point.

The GuttaCore obturator was heated in a Thermaprep 2 oven (Dentsply, Maillfere, Switzerland) set in the first setting mode (20 to 25 seconds). The heated GuttaCore obturator was slowly inserted in a gentle continuous motion (duration of 6 to 7 seconds) to the determined working length. Two minutes after obturation the handle of the GuttaCore obturator was removed by bending the handle to the side.

After obturation, the teeth were stored in a plastic container and then in a digital incubator (IncoTherm, Labotec, South Africa) at 37°C and 100% humidity for five days to facilitate complete setting of the sealer prior to µCT scanning.

3.3 Micro-CT (µCT) Analysis

µCT (Nikon Metrology XTH 225/320 LC Micro-CT scanner, Germany) was used to scan each tooth. The µCT tube was operated at 80Kv and 95µ. The samples were scanned at a rotational angle of 360̊ and a rotational step of 0.4̊ and 2000 projection was applied for each tooth. This resulted in an isotope voxel of approximately 14.8µm. The software package used to detect the dentine, filling material and voids for the measurements was Avizo 7.0, VGStudio MAX 3.0.

Before scanning, a flat field was established. The tooth was perpendicular to the long axis of the µCT holder and parallel to the X-ray source. After scanning any further adjustment of the long axis of the tooth was modified in µCT software by the use of the Simple Registration tool. This tool provides manual adjustment of the long axis of the tooth (Figure 3.3).

The images were processed by thresholding the images, changing the values of the pixels to divide the sample into intervals independent of each other and the background. This separated the tooth structure from the obturation and voids to obtain an image consisting of black and white pixels. The opacity curve in the rendering tool was adjusted to a particular range to obtain an adequate opacity from grey values for each interval.

To specify the regions of interest, depending on their grey values, a region growing mode was selected. Depending on the data, a reasonable value for the tolerance and the mode to include the area of interest into the region of interest was selected from the region growing option. Therefore, creating different regions of interest (Voids, obturation material or inner canal wall) was possible.

A surface determination tool was applied to the tooth image to demarcate the inner surface of the canal wall while the outer surface of the obturation is demarcated by using the region growing tool (Figure 3.4).

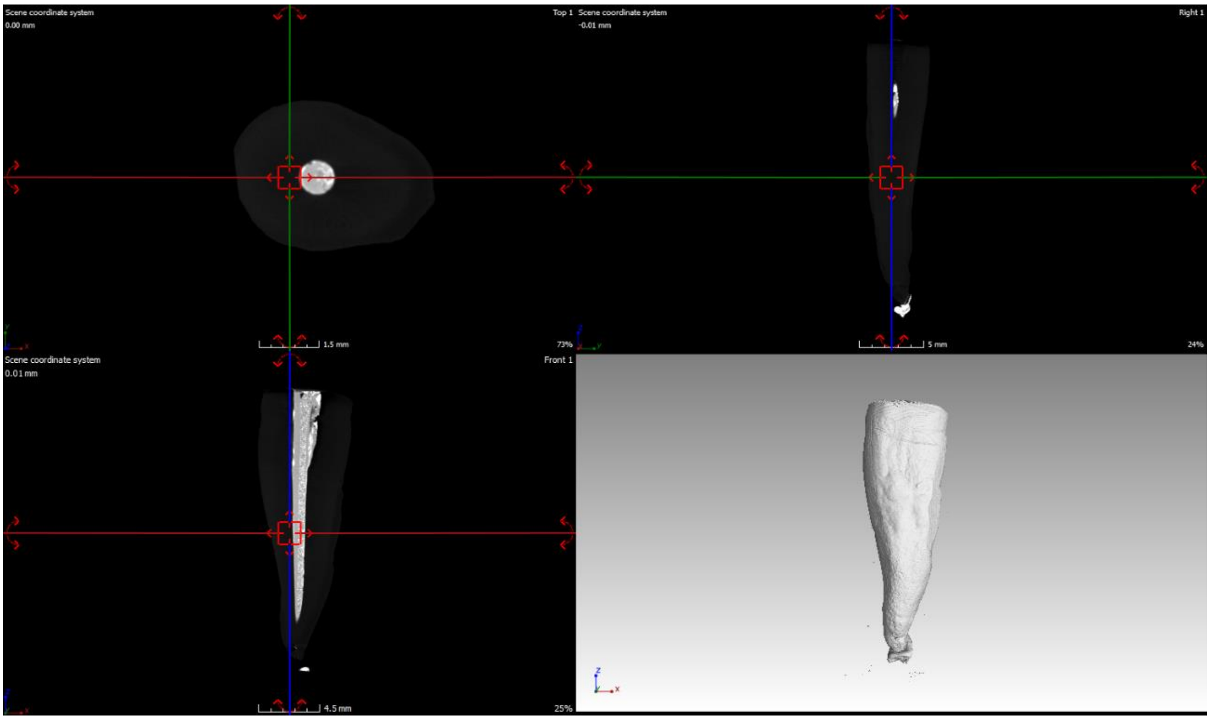

Figure 3.3: Simple registration tool for manual adjustment of the long axis of the tooth

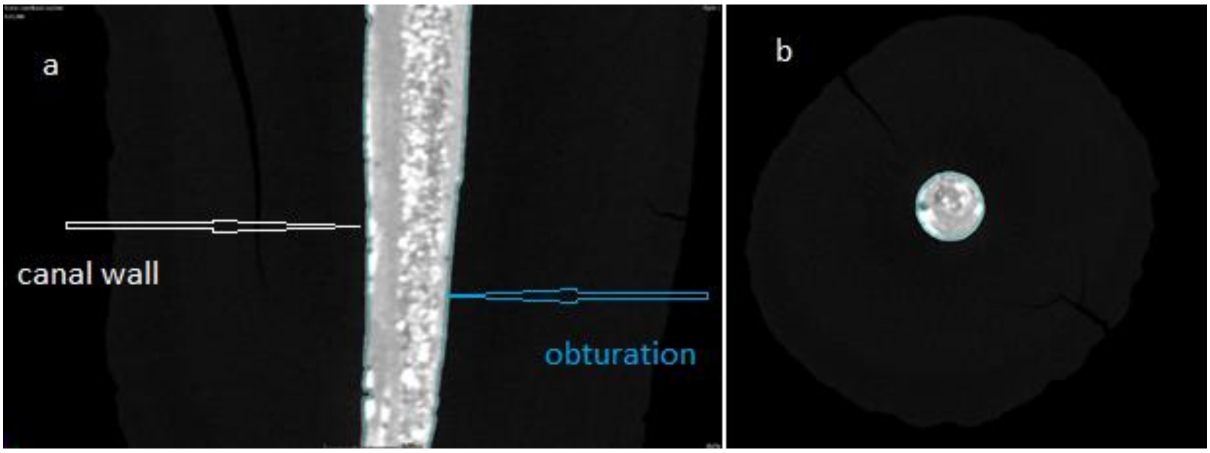

Figure 3.4: A 2-D view of measuring the canal volume and volume of obturation.

[**(a)** Sagittal section and **(b)** cross section. The inner canal wall is demarcated by the surface determination tool (white line and arrow) and the obturation is selected by the region growing tool (blue line and arrow)].

Only the apical 12 mm of each tooth was included for analysis, while the rest of the coronal part of the tooth image was removed using a Region Growing Tool. It was done after establishing a straight vertical axis of the tooth by using the simple registration tool.

3.3.1 Measurement of 3-D Canal Volume, Volume of Obturation and the Calculation of POV and 3-D Voids

After thresholding, the scanned tooth was divided into different intervals based on the level of grey values. The inner canal walls and outer obturation surfaces were demarcated by the surface determination tool and region growing tool respectively (Figure 3.4 above). The area of interest (obturation and canal volume) was selected by the region growing tool. A new region of interest was created from the selected volume. To establish a clear distinction between the root canal and the obturation material, a new region was created that included all tooth structures except the obturation by the use of the Region growing tool. This region was given a red color (Figure 3.5). Another region from the obturation material was created and was given a green color. All empty space (background and voids) remained black (see figure 3.5 below). Using this method, the 3-D volume of the canal (VC) and volume of obturation (VO) were measured in μm^3 and then the 3-D difference was calculated using the following formula: VC–VO=3-D μm^3 difference.

The percentage of obturated volume (POV) was calculated using the following equation: VC – VO / VC * 100=POV.

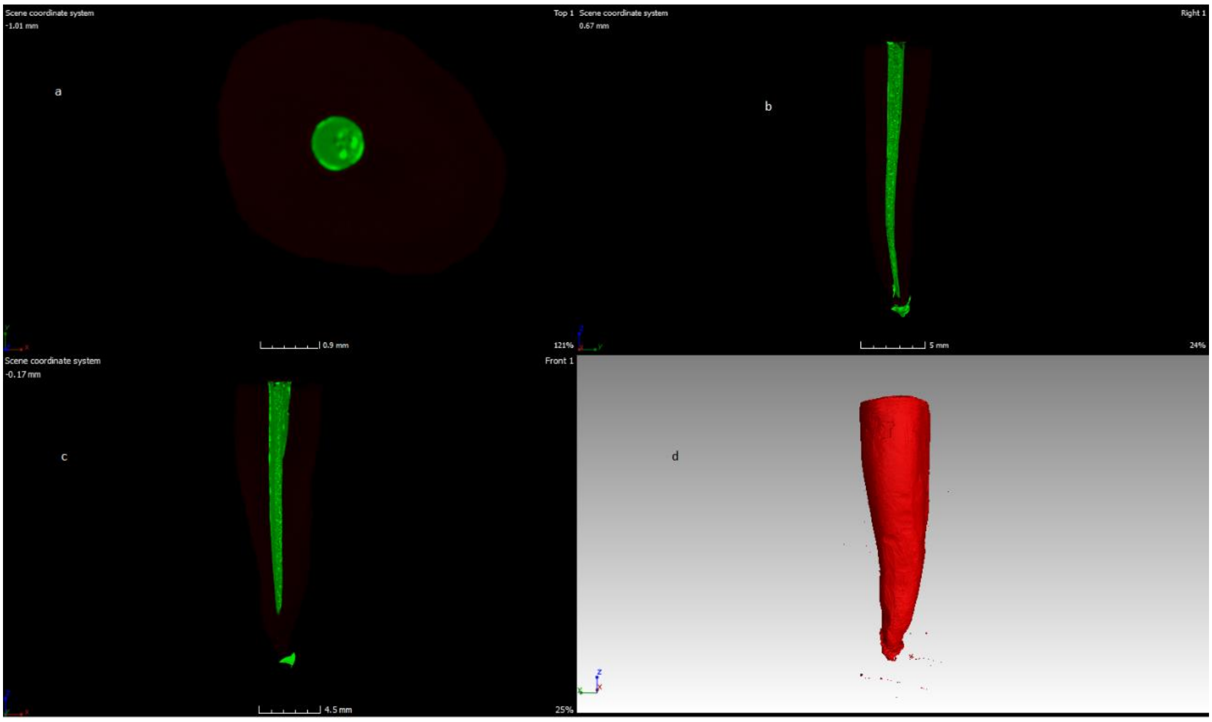

Figure 3.5: 2-D view from the µCT scan.

[**(a)** Cross section, **(b)** axial section, **(c)** sagittal section and **(d)** 3-D view. The green area represents the obturation material and the red area represents root structure].

3.3.2 Measurement of Voids at 2-D Slices

On the axial sectional 2-D view of the tooth from the µCT scan, the tooth was scrolled to the apex which was given a variance zero height. 2-D slices were obtained by scrolling the tooth coronally at 2mm, 6mm and 9mm from the apex as illustrated in Figure 3.6.

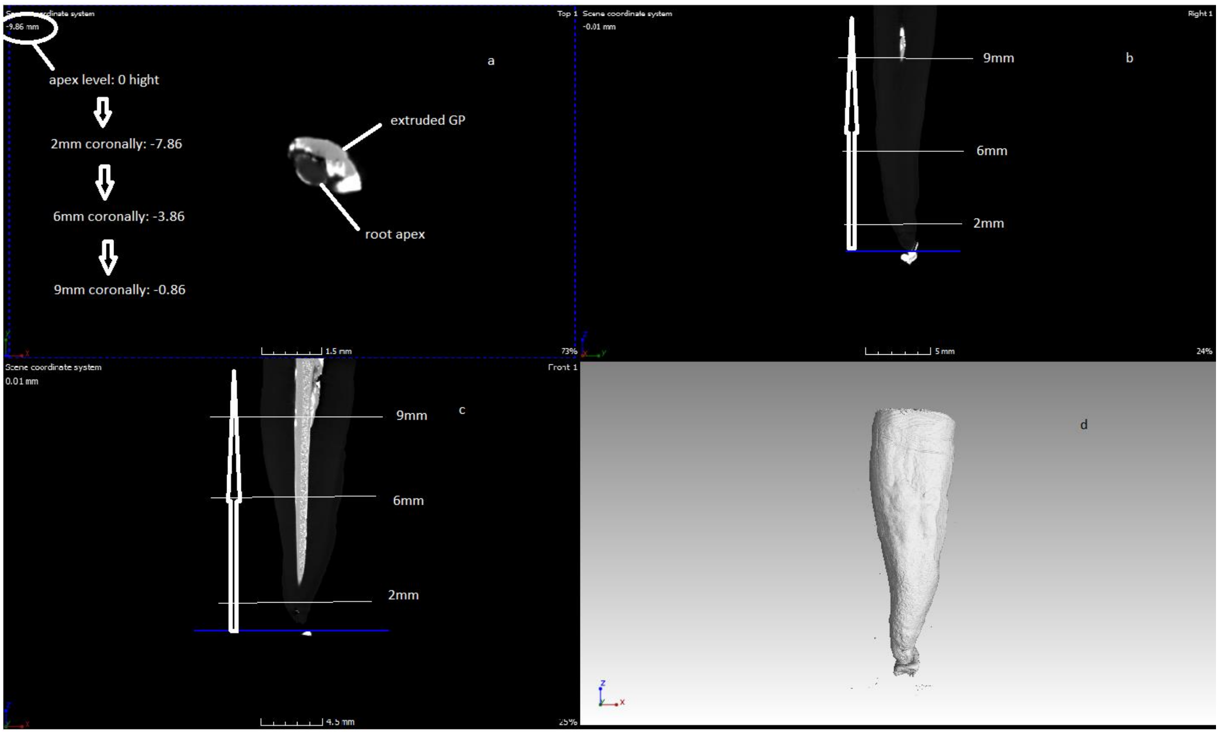

Figure 3.6: Determination of the three 2-D slices from the µCT software.

[**(a)** Cross sectional view of the tooth shows the root apex. From this point, 2-D slices were obtained by scrolling the tooth in the axial view coronally. **(b)** and **(c)** axial and sagittal section that show the level of the three 2-D slices (2mm, 6mm and 9mm). **(d)** 3-D view of the root].

The area of the obturation (AO) at each 2-D slice was selected by the region growing tool and measured in μm^2. Then the area of the canal (AC) at the 2-D slice was measured. The percentage difference between the area of voids (D) and the canal area was calculated using the following formula: AC – AO / AC * 100 = 2-D difference.

The long axis of the tooth was divided into three intervals. Only one 2-D slice was taken from each interval as follows (Figure 3.6):

1- The first interval (representing the apical third) was 2mm coronal (S-2) to the apex of the tooth.

2- The second interval (middle third) was 6mm coronal (S-6) to the apex of the tooth.

3- The third interval (coronal third) was 9mm coronal (S-9) to the apex of the tooth.

3.3.3 Measurement of 3-D Volume of Extruded GP (E)

The volume of extruded GP only, without sealer beyond the apical foramen, was measured in volume (μm^3) using the Region growing tool. A new region of interest (only extrusion) was created (Figure 3.7). The threshold and opacity curve for extruded GP (new region of interest) was adjusted to separate the GP from the sealer.

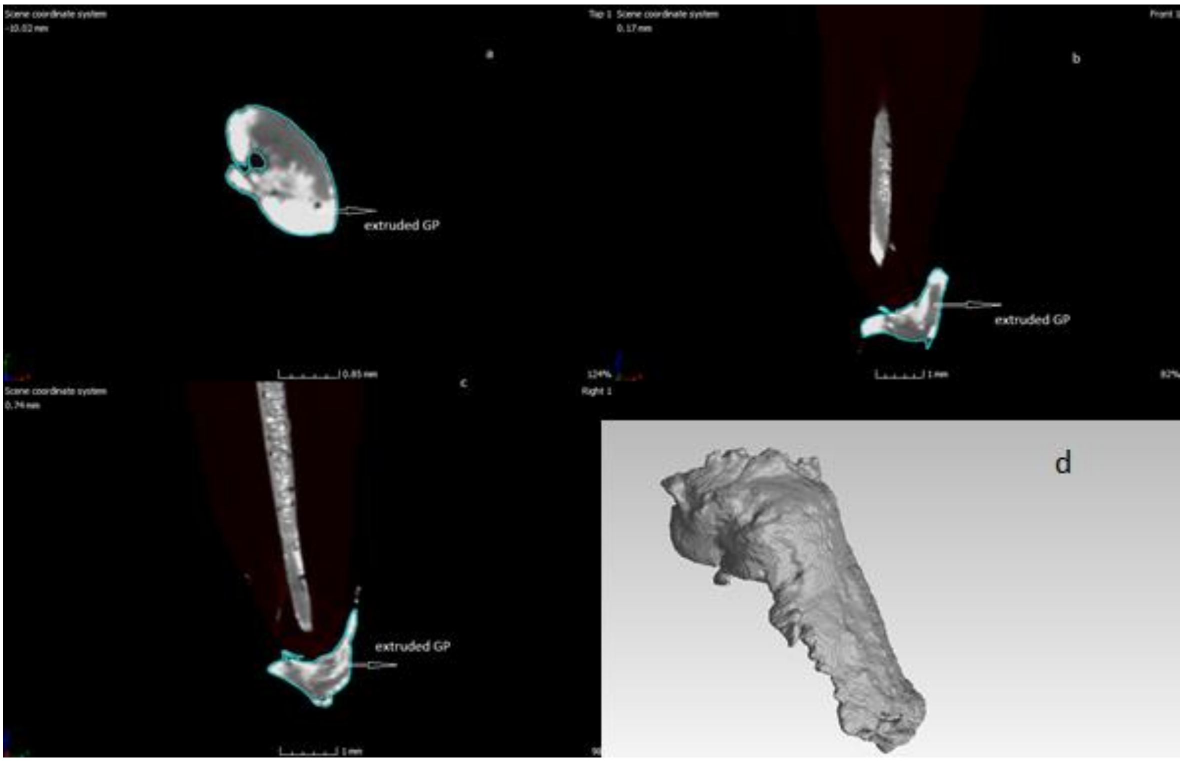

Figure 3.7: Extruded GP from µCT software.

[**(a)** cross, **(b)** axial and **(c)** sagittal 2-D views of the extruded GP, **(d)** 3-D view of the extruded GP].

3.4 Statistical Analysis

Data analysis was performed using SAS 9.4 for Windows (SAS Institute Inc; Cary, North Carolina, United States of America). Descriptive statistics for the data were calculated.

We used a Wilcoxon rank sum test (since the data did not meet the assumptions of the independent sample t-tests) to compare the OS and WO groups and to determine if there were differences in the following parameters, the percentage of obturated volume (POV), percentage difference (D%), 2-D slices at 2 mm (S-2), 6 mm (S-6) and 9 mm (S-9) and volume of extrusion (E). The comparison of the levels of S-2, S-6 and S-9 within each group was done using the Friedman test (since the data did not meet the assumptions for repeated-measures analysis of Variance (ANOVA). A 5% significance level was used. Data were tested for normality and homogeneity before being analysed. Since the data were abnormally distributed, the relationship between the two experimental groups was assessed by non-parametric methods. The median and interquartile ranges (IQR) were reported.

The strength of the associations of canal taper angle and quality of obturation was measured by r. The following scale of interpretation was used:

0.80 and above	large effect
0.50 to 0.79	moderate effect
0.20 to 0.49	small effect
below 0.20	near zero effect

CHAPTER 4

RESULTS

The current study was an examination of the effect of canal preparation geometry on the quality of GuttaCore obturation. A fixed tapered angle rotary file (One Shape) and variable tapered angle reciprocating file (Wave One Gold) were used to attain fixed and variable tapered canal preparation respectively. A total of 64 extracted single root teeth were divided equally between the two groups. The results of the study involved analysis of the following measurements:

1- POV: Percentage of the 3-D volume of obturation in relation to the total volume of the prepared canal.
2- D%: 3-D Percentage difference between canal volume and volume of obturation.
3- 2-D voids at three levels: the percentage area of the difference between area of canal and area of obturation at 2mm, 6mm and 9mm coronally from the root apex.
4- E: 3-D Volume (μm^3) of Extruded GP.

Since the data did not meet the assumptions of the independent samples t-test, median and interquartile range (IQR) were reported. Mean and standard deviation (SD) for all the variables are reported in Table 4.1.

Table 4.1: Mean and Standard Deviation (SD) of all the variables

Group	Sample size (n)	Variables	Mean	SD
OS	32	POV	89.34	2.15
		D%	10.6	2.2
		S-2	0.17	0.43
		S-6	0.15	0.35
		S-9	0.06	0.17
		E	1.94	0.97
WO	32	POV	90.85	3.61
		D%	9.2	3.6
		S-2	0.13	0.40
		S-6	0.05	0.14
		S-9	0.28	1.14
		E	1.16	0.68

Raw data and histograms representing group data are presented in Appendix 3 and 4.

4.1 3-D Analysis

4.1.1 Percentage of Obturated Volume (POV)

The results show that no obturated canals obtained 100% seal. Since the data were not normally distributed, the median and interquartile range (IQR) were reported (Table 4.2). The WO group resulted in a greater volume of obturated GP (higher POV) (P = 0.045) which is statistically significantly different to the OS group.

Table 4.2: The median (IQR) of Percentage of Obturated Volume (POV) for OS and WO groups.

Group	Sample size (n)	Volume of canal(μm^3)	Volume of obturation (μm^3)	POV % (median)	POV % (IQR)
OS	32	230.057	183.1	89.39	87.56 - 90.53
WO	32	187.1	174.91	91.54	89.27 - 93.62

4.1.2 Percentage Difference (D%) of canal volume and volume of obturation

The 3-D results show that all obturated canals had voids and no canals had 100% seal. There was a significant statistical difference (*P = 0.0034*) between the OS and WO groups in the 3D volume difference of the root canal volume and volume of obturation, with the OS group having higher percentage values. The median percentage (Figure 4.1) volume of the difference of the OS group was 10.6% (IQR: 9.5-12.4%), which was significantly higher than the WO group which had a median of 8.5% (IQR: 6.4-10.7%).

When the strength of association between the type of canal taper angle of the prepared root canal and the quality of obturation was tested, the result showed that the correlation was small (r=0.38).

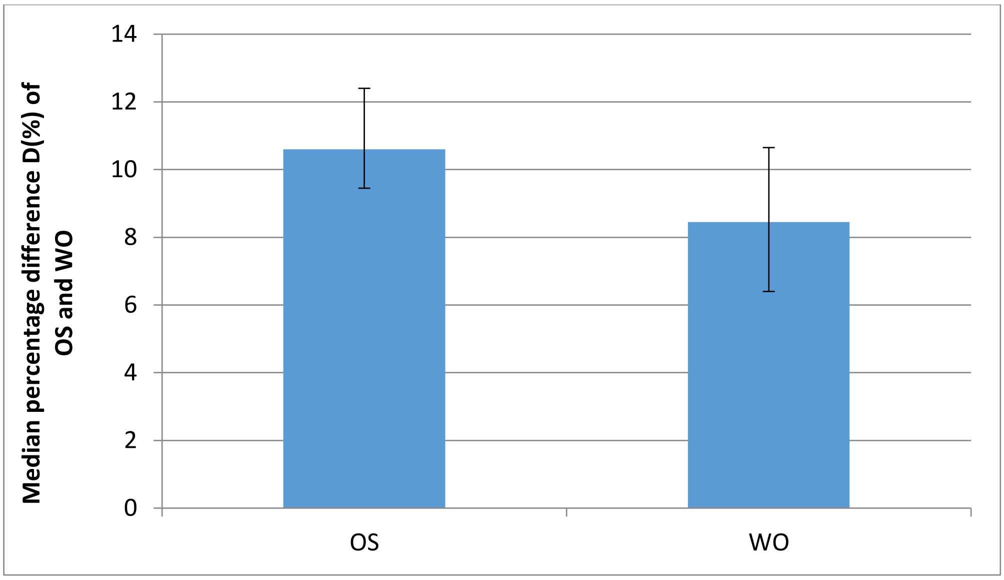

Figure 4.1: The median percentage difference (D%) for voids of OS and WO groups.

4.2 2-D analysis

There were no significant statistical differences in voids between the OS and WO groups in the 2-D slices at the three levels of 2 mm slice ($P = 0.75$), 6 mm slice ($P = 0.45$) and 9 mm slice ($P = 0.68$). Also, the median percentage of voids did not differ significantly between the three levels (S-2, S-6 and S-9 mm) within the OS group (P =0.55) or within the WO group (P =0.72).

Table 4.3: The median and IQR of percentage difference of area of voids (S-2, S-6 and S-9)

Group	n	Intervals	Median	Interquartile Range (IQR)		Minimum	Maximum
OS	32	S-2	0.00	0.00	0.00	0.00	1.90
		S-6	0.00	0.00	0.00	0.00	1.42
		S-9	0.00	0.00	0.00	0.00	0.79
WO	32	S-2	0.00	0.00	0.00	0.00	1.51
		S-6	0.00	0.00	0.00	0.00	0.59
		S-9	0.00	0.00	0.00	0.00	6.42

4.3 Extrusion

There were significant statistical differences (*P = 0.0013*) between the OS and WO groups in the volume of extrusion of the GuttaCore with the OS group having a greater volume of extrusion than in the WO group. The OS group had a median of 1.92μm^3 (IQR: 1.16-2.36μm^3) which was significantly higher than the WO group whose median was 1.16 μm^3 (IQR: 0.66-1.51 μm^3).

The strength of association between the tapered angle of the root canal and the volume of extruded GP was tested. The analysis of the result showed that the correlation was small (r= 0.42).

Table 4.4: The median and IQR of the volume of the extruded GP (μm^3)

group	N	median	**Interquartile range (**IQR)		minimum	maximum
OS	32	1.92	1.16	2.36	0.42	4.02
WO	32	1.16	0.66	1.51	0.00	2.99

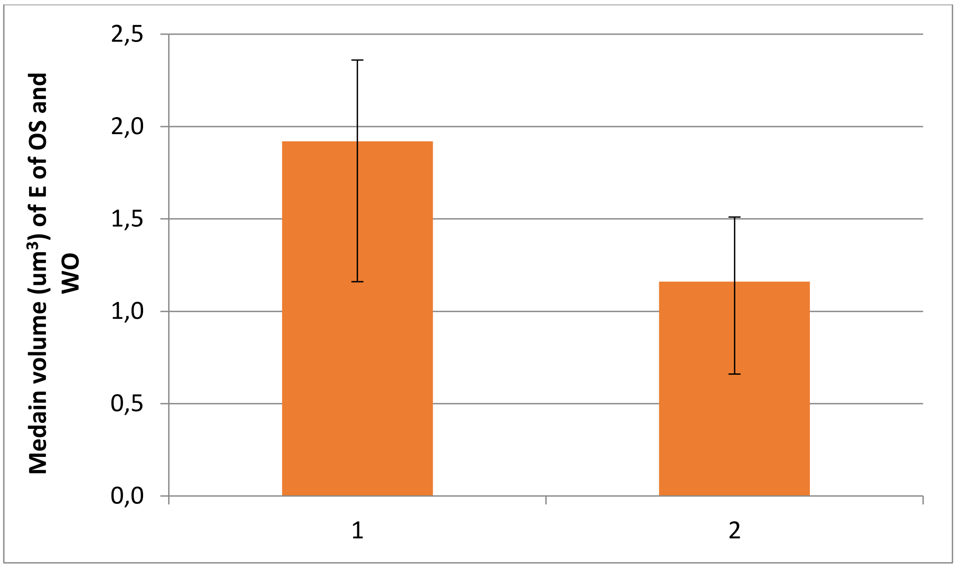

Figure 4.2: The median volume of extruded obturation (E) of OS and WO groups

CHAPTER 5

DISCUSSION

Successful endodontic treatment is underpinned by the ability to clean and shape the root canals, the ability to adequately seal the prepared canals and finally to create an effective coronal seal (Schilder, 1974; Ray and Trope, 1995; Khademi *et al*, 2006). It is accepted that the quality of the obturation is dependent on the final shape of the prepared root canal (Allison *et al* 1979). By quality of obturation, we mean a hermetic 3-D seal of the entire canal (Kerezoudis *et al*, 1999). Theoretically, a 100% seal should be attained, so that there are no voids to allow for bacterial colonization (Sjögren *et al*, 1990a). Voids are considered to be critically important. They provide spaces for bacterial colonization that lead to failure of root canal treatment (Wu *et al*, 2003). Therefore, reducing voids in obturation is critical for long term success.

5.1 3-D Analyses

Although this study analyses obturation of root canals, it is effectively a study of canal preparation with two different canal preparation geometries. The study attempted to compare fixed taper and variable tapered preparations by measuring and comparing the voids produced after obturation.

After preparing 32 canals each with OS and WO, the canals were obturated with Guttacore obturation system and AH plus sealant. The 3-D analyses of the results measured the canal volume in μm^3 and the volume of obturation in μm^3 for both groups and then calculated the

Percentage of Obturated Volume (POV), which is the area filled by the GuttaCore and AH plus sealant, and the percentage difference (D%) of voids for the two systems.

The overall results show that all the canals had voids within the obturation and there were no canals that had a 100% seal. The canals prepared with WO had a higher POV with a median of 91.54% (IQR: 89.27-93.62%) than OS group with a median of 89.39% (IQR: 87.57-90.53%). The OS had a higher D% of voids with a median of 10.6% (IQR: 9.5-12.4%) than the WO group with a median of 8.5% (IQR: 6.4-10.7%).

Although the statistical analyses showed significant differences between the two systems for POV (P = 0.045) and D% (P = *0.0034*), the correlation between canal taper angle and the quality of GuttaCore obturation was small (r=0.38). The correlation analyses indicates that the performance of the two systems was acceptable and that there is a very little difference between them.

Very few previous studies showed the POV of GuttaCore obturation. Instead, they compared quality of obturation by taking 2-D slices in cross sections to the root length and measured the area of the voids revealed in the 2D slices at different levels

The POV values in this study were comparable to those in other studies, even when other obturation techniques were compared. A study by Anbu *et al* (2010) prepared root canals by hand instrumentation with K files, and compared them using four different obturation techniques. The POV was greater with Thermafil and System B (both thermoplastisized obturation) (93.3±2.4 and 93.7±3.6 respectively) compared to Lateral condensation and Obtura II (80.4±1.6 and 84.8±6 respectively). They used spiral computed tomography for analysis which was different to our study.

The POV results of this study were also comparable to those produced by Keles *et al* (2014), who also used µCT for analysis. They measured and compared the quality of lateral condensation and wave vertical condensation techniques, and their POV results were 82.33+3.14% and 91.73+4.48% respectively.

In another study, thermoplastic obturation (e.g., GuttaCore and GuttaFusion) obtained significantly higher POV values than other obturation techniques such as lateral condensation and single cone obturation techniques (Schäfer *et al*, 2016). Their study had a smaller sample size and used a digital stereomicroscope for analysis, rather than the µCT used in this study. This technique is regarded as destructive to the tooth because it involved sectioning of the root which can lead to loss of data. The POV obtained in their study was 96.88%, which was higher than the results of this study.

In contrast, the findings of this study were lower than a study by Celikten *et al* (2015). They used µCT for analysing the quality of obturation. Single cone obturation, lateral condensation, and Thermafil obturation were compared. The POV were 97.8±1.2%, 98.1±1.3% and 98.3±1.3% respectively. These differences compared to this study can be attributed to a different µCT method for measuring the volume of the root canal and the volume of obturation.

An earlier study by Allison et al (1979) showed a strong correlation between canal taper and the quality of obturation. A flared (tapered) preparation had a better obturation than a standardized preparation (Allison *et al*, 1979). In their study, the canal shape geometry had an extensive effect on canal obturation. This study found that the difference between the two canal tapers was significant but the correlation of canal taper on the quality of obturation was small. However, in their study relatively two different canal preparation techniques were compared and also the obturation technique was entirely different to this study. In their study cold lateral condensation technique of obturation was used. In this study, flowable obturation technique was used which is not related to any condensing instrument. Also, the preparation techniques for the two groups in this study were flared (tapered) even though one was with a fixed taper and the other had a variable taper.

Zogheib *et al's* study found that the taper angle of the prepared root canal affects the quality of obturation. They compared three different tapered preparations (4%, 6% and 8%) on the quality of Real Seal 1 (thermoplastic obturation). They found that the larger the taper the better the obturation. There was no significant difference between 6% taper and 8% taper but both were significantly better than the 4% taper (Zogheib *et al*, 2012). Zogheib *et al's* findings can explain the small correlation of canal taper on the quality of obturation in this study whereby if the taper angle is sufficient the impact becomes small.

Although the One Shape file and Wave One Gold both have the same tip diameter which is 0.25mm, the apical 4mm of Wave One Gold has an increasing taper of 7% at each 1mm from the apical tip. The rest of the file has variable angles of decreasing taper (Figure 5.1). On the other hand, the One Shape file has a constant taper of 6% from the file tip to the handle of the instrument. However, the µCT obturation images show that with Wave One Gold primary file prepared tapered canals with a progressively increasing taper towards the coronal part (Figure 5.2).

In considering the findings of the study by Zogheib *et al*, the results of this study are not all that surprising. While their study showed improvements in obturation with increasing the taper, the current study kept the taper relatively constant, but varied the shape geometry.

This study shows that when the apical taper is large enough, greater than 6%, the geometrical shapes of fixed and variable tapers have a small impact on the quality of the obturation.

Figure 5.1: Wave One Gold Primary file (Source: Invention: WaveOne GOLD - Advanced Endodontics)

Figure 5.2: View from µCT showing the increase of taper of the root canal obturation

A possible explanation for the statistical significant difference between the OS and WO groups in this study can be related to the volume of the canals created by each file systems. Shaping canals with One Shape file in the OS group resulted in a larger volume of the prepared root canal (230.057μm^3) when compared to WO group in which the total volume of the prepared canals was 187.1 μm^3.

5.2 2-D Analyses

In addition to the total volume analysis, a two-dimensional analysis was carried out at selected intervals of the root canal. 2-D slices were obtained from each specimen at 2mm (representing the apical third), 6mm (representing the middle of the canal) and 9mm (representing the coronal third) from the canal apex. All the measurements obtained for the 2-D slices were compared across the two groups. A comparison between the three levels (2mm, 6mm and 9mm) within the group was also carried out. The results showed that there is no statistical significant difference in the percentage difference between the root canals prepared, using different systems with different tapered angles. There was also no statistical difference between the three 2-D slices within each group. There appears to be an inconsistency between the 3-D and the 2-D results. While the 3-D results show an obturation void rate of approximately 10.6±2.2 and 9.2±3.6 for the OS and WO group respectively, which is statistically significantly different, the 2-D analysis obtained values ranging from 0.05%-0.28% along the three intervals which were not significantly different.

There are several possible explanations for the inconsistency:

1- Too few 2-D slices were processed to be able to reveal a significant pattern of voids.
2- There is a need for several adjacent slices at regular intervals to identify the voids.
3- The possibility of inaccuracy in the determination of the canal outline between the 2-D and the 3-D analysis from μCT software.
4- Li *et al* reported that the detection of voids in cross sections of the obturated canals using μCT is less accurate than scanning electron microscopy (Li *et al*, 2014). This could be a possible explanation for the lack of voids in the 2-D slices in this study.

5.3 Extrusion Analysis

Studies have shown that extrusion of GP beyond the apical foramen is a common finding in endodontics (Abarca *et al*, 2001). Although flowable GP (chemical or heated GP) is shown to have a better quality of obturation compared to cold obturation (Boussetta *et al*, 2003; Weis *et al*, 2004), a meta-analysis indicates that it was associated with more extrusion than cold GP (Peng *et al*, 2007). The incidence of extrusion of thermoplastisized GP was 50% compared to 20% for cold lateral obturation (Mann and McWalter, 1987). The Thermafil obturation had more extruded GP than other obturation techniques (Gutman *et al*, 1993; Clark and ElDeeb, 1993).

In the current study, the OS (fixed taper) resulted in a higher volume of extruded GP (extruded GP only without sealer was measured) than in the WO (variable taper) ($p= 0.0013$) even though the correlation between canal taper and the extruded GP was small ($r= 0.42$). Extrusion of GP was detected in all the specimens except one. The findings in this study support the statement by Buchanan (2000) that variably tapered preparation resulted in a smaller apical diameter thus reducing the extruded GP beyond the apical foramen (Buchanan, 2000). It also confirms the findings by Whitten and Levitan (2015) despite the fact that the apical 2mm in the variable tapered group was hand instrumented in the latter study.

On the other hand, Heeren and Levitan (2012) showed that extrusion is not only related to the preparation type but can also relate to the filling material. In their study, fixed tapered preparation and variable tapered preparation were compared using two obturation materials, Thermafil plus and RealSeal. The results showed that Thermafil plus was affected by preparation taper and resulted in significantly higher extrusion associated with the fixed tapered preparation, while Realseal was not affected by the preparation taper.

It has been shown that the quality of the thermoplastic GP varied with the insertion rate into the canal during obturation. The insertion rate also affects the overfill or underfill of the obturation. The insertion rate of thermoplastic GP that produces an ideal obturation (fewer voids) produces undesirable extrusion of thermoplastic carrier-based obturation (Levitan *et al*, 2003). In the current study, only the GuttaCore obturation system was used. What this may suggest is that the extrusion witnessed in this study may be due to the rate of insertion or the extent of apical enlargement despite the fact that we followed the manufacturer's instruction for the insertion rate.

Clinically, voids in root fillings are difficult to detect because the use of conventional x-rays gives a limited 2-dimensional view of the tooth (Nair and Nair 2007). Root canal obturation from a conventional radiograph is regarded as acceptable when the density is uniform along the canal from the orifice level to the terminus and compatible with the canal walls (Lupi-Pegurier *et al*., 2003). *In vitro*, many methods (dye penetration, fluid transport, etc.) have been used to investigate the sealing ability of root filling techniques and materials (Tagger *et al*., 1984; Jarret *et al*., 2004). However, all had the limitation of measuring voids by analysis of sectioned roots and digital imaging software. They may not be accurate enough because some filling material might be lost in the process (Jarret *et al*., 2004). However, because of the inaccuracy and lack of standardization of the previous methods, researchers have moved to a non-destructive, reproducible and more accurate method of evaluating the quality of root filling materials using µCT. The value of the use of µCT has been demonstrated in previous studies (Oi *et al*, 2004; Verma and Love, 2011). It is non-destructive, non-invasive and a rapid method to evaluate the volume of voids within the root filling and interfacial voids between the filling material and the canal walls (Jung *et al*, 2005). It gives a 3-D visualization of the defect and continuity of the defect in the root filling material. µCT has become widely used in the research field and was used in our study to analyse and evaluate the three objectives.

The GuttaCore obturator has a significantly higher quality of obturation compared to cold obturation techniques and is similar in quality to the continuous wave obturation technique as illustrated by previous studies (Silva-Herzog *et al*, 2017). Shaping the root canal with a different rotary system can result in a different quality of obturation even with GuttaCore obturation.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Both systems used in this study, Wave One Gold and One Shape files, have the ability to prepare root canals adequately for obturation.

This study shows that when the apical taper is large enough, 6 - 8%, the geometrical shapes of fixed and variable tapers have a small impact on the quality of the obturation.

The variable tapered preparation had a slightly less GP extrusion than the fixed tapered preparation.

The value of µCT as an accurate research tool in Endodontics has been re-emphasized.

6.2 Recommendations

1- Additional research is required to assess the presence of blind and interface voids of the obturation.

2- Several adjacent 2-D slices are required to determine a reproducible correlation between the 2-D and the 3-D analysis and to identify the relation of voids to root canal intervals (apical, middle and coronal intervals).

3- Research should be done with the anatomic crown present to provide a more clinical result and to avoid excessive extrusion of the GP beyond the apical foramen.

4- Research is required to evaluate the effect of the insertion rate on the quality of GuttaCore obturation.

LIMITATIONS OF THIS STUDY

The 2-D analysis only examined one slice in each level of the canal. To achieve a more reliable result, considerably more adjacent 2-D slices should be examined at each level.

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APPENDIX 1

Ethics Clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Ref: W-CJ-160615-1 15/12/2017

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: Dr A O A Hassan (student no. 124955).

Project title: Comparison of the Effect of Fixed and Variable Taper on the Quality of Obturation.

Reason: This study will be done using information in the public domain. There are no human participants.

UNIVERSITY OF THE WITWATERSRAND
OFFICE OF THE DEPUTY VICE CHANCELLOR RESEARCH
15 DEC 2017
RESEARCH OFFICE HREC (Medical)
JOHANNESBURG

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

Copy – HREC (Medical) Secretariat: Zanele Ndlovu, Rhulani Mkansi, Lebo Moeng.

Research Office Secretariat: Faculty of Health Sciences, Phillip Tobias Building, 3rd Floor, Office 302, Corner York Road and 29 Princess of Wales Terrace, Parktown, 2193 Private Bag 3, Wits 2050 I T+27 (0)11-717-1234/2656/2700/1252 E: Lebo.Moeng@wits.ac.za I Office E HREC-Medical.ResearchOffice@wits.ac.za I Website: www.wits.ac.za/research/about-our-research/ethics-and-research-integrity/

APPENDIX 2

Raw Data for the Individual Teeth of OS Group

TN	G	VC (μm^3)	VO (μm^3)	D (μm^3)	**POV (%)**	**D (%)**	S-2 (μm^3)	**S-2 %**	S-6 (μm^3)	**S-6 %**	S-9 (μm^3)	**S-9 %**	E (μm^3)
O1	One Shape	5.16	4.45	0.71	**86.24**	**13.75**	0.0		0.03	**1.09**	0.0		1.98
O2		4.63	4.06	0.57	**87.68**	**12.31**	0.0		0.02	**0.7**	0.0		1.66
O3		6.56	6.17	0.39	**94.05**	**5.94**	0.0		0.04	**0.8**	0.01	**0.078**	1.18
O4		8.28	7.16	1.12	**86.47**	**13.52**	0.0		0.0		0.0		1.09
O5		5.74	5.09	0.65	**88.67**	**11.32**	0.0		0.0		0.0		0.52
O6		7	6.08	0.92	**86.85**	**13.14**	0.0		0.0		0.0		0.92
O7		5.08	4.6	0.48	**90.55**	**9.44**	0.0		0.0		0.0		1.78
O8		5.53	4.77	0.76	**86.25**	**13.74**	0.0		0.0		0.0		1.14
O9		8.05	7.24	0.81	**89.93**	**10.06**	0.0		0.0		0.0		0.64
O10		5.17	4.65	0.52	**89.94**	**10.05**	0.0		0.0		0.0		0.8
O11		5.96	5.48	0.48	**91.94**	**8.05**	0.0		0.0		0.0		1.1
O12		6.02	5.38	0.64	**89.36**	**10.63**	0.0		0.0		0.0		2.27
O13		5.63	5.18	0.45	**92**	**7.99**	0.0		0.0		0.0		2.09
O14		7.42	6.75	0.67	**90.97**	**9.02**	0.02	**1.08**	0.0		0.0		2.23
O15		5.22	4.75	0.47	**90.99**	**9**	0.0		0.0		0.0		1.88
O16		4.86	4.25	0.61	**87.44**	**12.55**	0.02	**0.97**	0.0		0.0		2.22
O17		6.29	5.53	0.76	**87.91**	**12.08**	0.0		0.0		0.03	**0.29**	1.99
O18		5.32	4.6	0.72	**86.46**	**13.53**	0.0		0.0		0.0		2.55
O19		5.83	5.32	0.51	**91.25**	**8.74**	0.0		0.13	**1.42**	0.02	**0.18**	3.61
O20		5.39	4.82	0.57	**89.42**	**10.57**	0.0		0.01	**0.25**	0.0		1.57
O21		5.06	4.8	0.26	**94.86**	**5.13**	0.0		0.02	**0.29**	0.0		1.39
O22		7.45	6.62	0.83	**88.85**	**11.14**	0.0		0.01	**0.209**	0.0		1.47
O23		5.09	4.49	0.6	**88.21**	**11.78**	0.0		0.0		0.0		3.03
O24		5.28	4.77	0.51	**90.34**	**9.65**	0.0		0.0		0.0		1.57
O25		6.24	5.57	0.67	**89.26**	**10.73**	0.0		0.0		0.0		3.99
O26		5.7	4.99	0.71	**87.54**	**12.45**	0.0		0.0		0.0		0.42

O27	4.91	4.29	0.62	**87.37**	**12.62**	0.0		0.0		0.0		2.45
O28	6.41	5.8	0.61	**90.48**	**9.51**	0.04	**1.9**	0.0		0.0		2.10
O29	10.07	9.04	1.03	**89.77**	**10.22**	0.03	**0.74**	0.0		0.0		3.60
O30	12.62	11.34	1.28	**89.85**	**10.14**	0.05	**0.68**	0.0		0.15	**0.79**	1.96
O31	9.25	8.34	0.91	**90.16**	**9.83**	0.0		0.0		0.0		2.83
O32	7.65	6.72	0.93	**87.84**	**12.15**	0.0		0.0		0.04	**0.489**	4.02

(TN: Tooth Number, G: Group, VC: Volume of Canal, VO: Volume of Obturation, D: difference of volume, POV: percentage of obturated volume, S-2: 2-D Slices at 2mm coronal, S-6: 2-Dimensional Slices at 6mm coronal, S-9: 2-D Slices at 9mm coronal and E: Extrusion)

APPENDIX 3

Raw Data for the Individual Teeth of WO Group

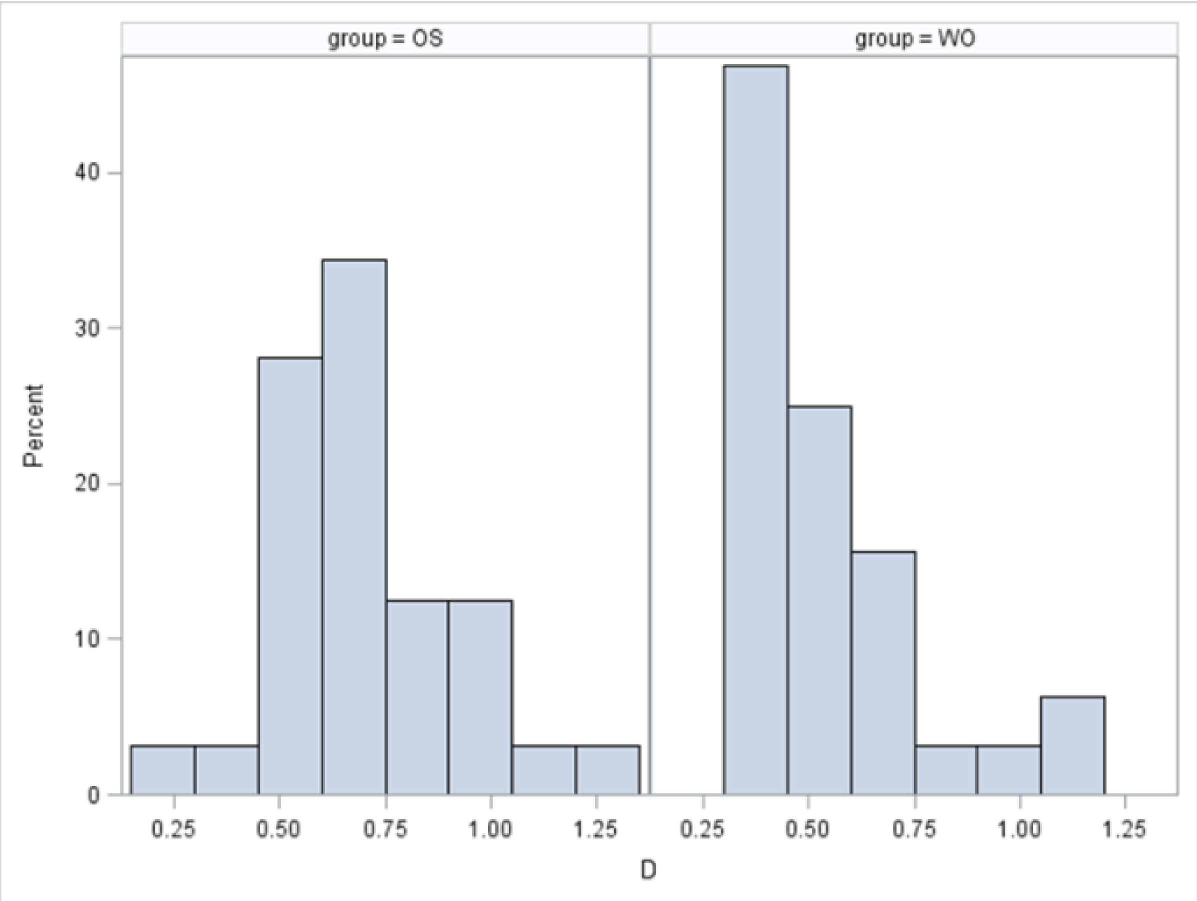
TN	G	VC (μm^3)	VO (μm^3)	D (μm^3)	**POV (%)**	**D (%)**	S-2 (μm^3)	**S-2 %**	S-6 (μm^3)	**S-6 %**	S-9 (μm^3)	**S-9 %**	E (μm^3)
W1	wave one gold	7.24	6.64	0.6	**91.71**	**8.28**	0.0		0.02	**0.22**	0.91	**6.42**	0.0
W2		7.33	6.26	1.07	**85.4**	**14.59**	0.0		0.0		0.07	**0.49**	0.62
W3		5.65	5.04	0.61	**89.2**	**10.79**	0.0		0.0		0.0		1.87
W4		4.87	4.46	0.41	**91.58**	**8.41**	0.0		0.01	**0.29**	0.0		1.05
W5		4.52	3.95	0.57	**87.38**	**12.61**	0.0		0.0		0.0		0.39
W6		5.03	4.71	0.32	**93.63**	**6.36**	0.0		0.0		0.0		0.18
W7		4.66	4.1	0.56	**87.98**	**12.01**	0.0		0.0		0.0		0.91
W8		5.01	4.69	0.32	**93.61**	**6.38**	0.0		0.0		0.0		0.65
W9		4.23	3.83	0.4	**90.54**	**9.45**	0.02	**1.51**	0.0		0.0		0.09
W10		4.63	4.2	0.43	**90.71**	**9.28**	0.0		0.0		0.0		0.97
W11		6.05	5.69	0.36	**94.04**	**5.95**	0.0		0.0		0.0		0.06
W12		4.27	3.84	0.43	**89.92**	**10.07**	0.0		0.0		0.0		1.12
W13		5.44	5.1	0.34	**93.75**	**6.25**	0.0		0.0		0.0		1.06
W14		5.87	5.45	0.42	**92.84**	**7.15**	0.0		0.0		0.0		1.28
W15		5.03	4.71	0.32	**93.63**	**6.36**	0.0		0.0		0.01	**0.13**	1.23
W16		6.13	5.71	0.42	**93.14**	**6.85**	0.0		0.0		0.0		1.08
W17		5.15	4.75	0.4	**92.23**	**7.76**	0.0		0.01	**0.217**	0.0		0.91
W18		6.41	6.03	0.38	**94.07**	**5.92**	0.0		0.0		0.0		0.67
W19		6.57	6.03	0.54	**91.78**	**8.21**	0.0		0.0		0.0		2.99
W20		6.59	6.03	0.56	**91.5**	**8.49**	0.04	**1.01**	0.0		0.0		1.36
W21		6.37	5.92	0.45	**92.93**	**7.06**	0.0		0.0		0.0		1.46
W22		4.91	3.72	1.19	**75.76**	**24.23**	0.0		0.0		0.0		1.56
W23		7.92	7.47	0.45	**94.31**	**5.68**	0.0		0.0		0.06	**0.77**	1.21
W24		5.89	5.22	0.67	**88.62**	**11.37**	0.0		0.0		0.0		1.43
W25		6.08	5.36	0.72	**88.15**	**11.84**	0.01	**0.289**	0.0		0.0		2.32
W26		11.22	10.24	0.98	**91.26**	**8.73**	0.0		0.03	**0.389**	0.03	**0.24**	1.40
W27		7.17	6.34	0.83	**88.42**	**11.57**	0.0		0.0		0.0		1.89

W28	6.23	5.87	0.36	**94.22**	**5.77**	0.0		0.0		0.0		1.99
W29	5.51	4.93	0.58	**89.47**	**10.52**	0.0		0.0		0.0		1.20
W30	6.07	5.69	0.38	**93.73**	**6.26**	0.05	**1.42**	0.0		0.0		1.94
W31	6.56	5.97	0.59	**91**	**8.99**	0.0		0.0		0.0		1.77
W32	7.62	6.93	0.69	**90.94**	**9.05**	0.0		0.04	**0.589**	0.09	**0.759**	0.55

(TN: Tooth Number, G: Group, VC: Volume of Canal, VO: Volume of Obturation, D: difference of volume, POV: percentage of obturated volume, S-2: 2-D Slices at 2mm coronal, S-6: 2-D Slices at 6mm coronal, S-9: 2-D Slices at 9mm coronal and E: Extrusion)

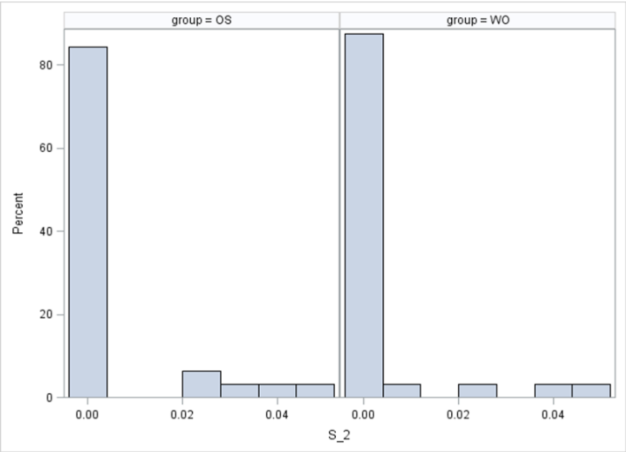
APPENDIX 4

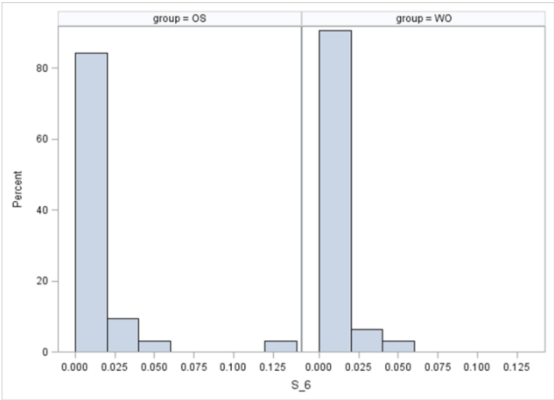
Histograms Show the Distribution of the Data



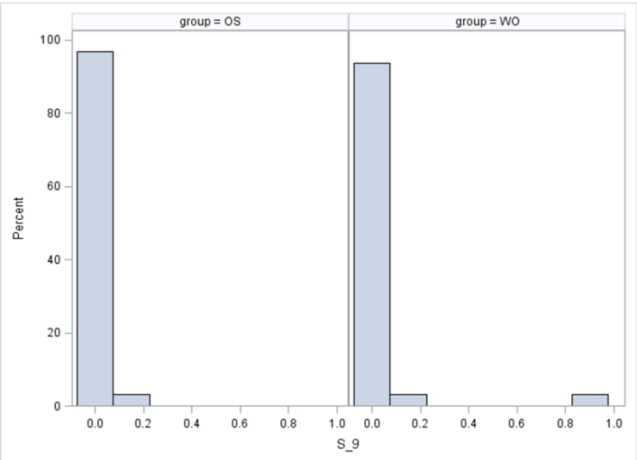
Percentage difference (D%) between the two groups

a **b**

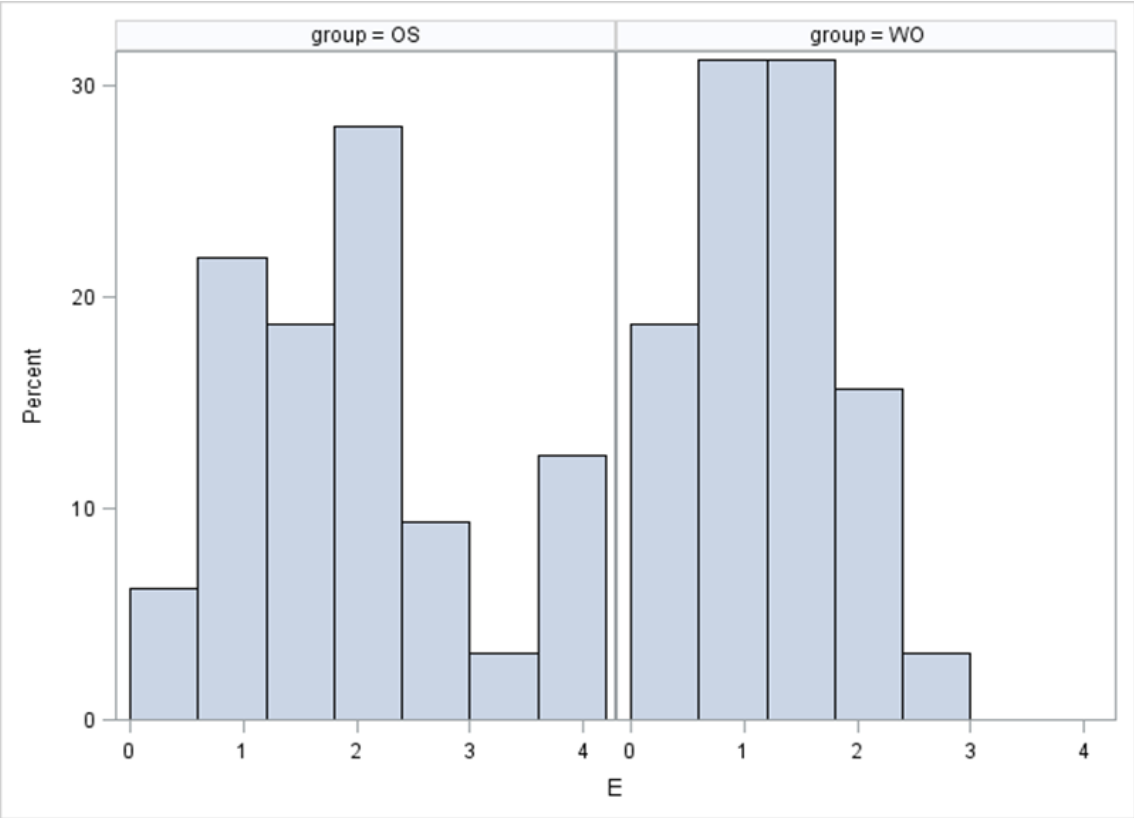




C



Percentage of area of voids at 2-D slices. (a): S-2, (b): S-6 and (c): S-9



Percentage volume of extrusion (E) (μm^3)

APPENDIX 5

Protocol Approval

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

19 August 2016
Person No: 1124955
PAG

Dr AOA Hassan
P O Box 7933
Sixty Street
Sixty Office
11123
Sudan

Dear Dr Hassan

Master of Science in Dentistry: Approval of Title

We have pleasure in advising that your proposal entitled *Comparison of the effect of fixed and variable taper on the quality of obturation* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

UBenn

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

APPENDIX 6

Plagiarism Report

1124955:COMPARISON_OF_THE_EFFECT_OF_FIXED_AND_VARIABLE_TAPER_ON_THE_QUALITY_OF_OBTURATION.docx

by Almeqdad Hassan

Submission date: 21-Dec-2017 08:38PM (UTC+0200)
Submission ID: 898828659
File name: CT_OF_FIXED_AND_VARIABLE_TAPER_ON_THE_QUALITY_OF_OBTURATION.docx (1.46M)
Word count: 16003
Character count: 93649

1124955:COMPARISON_OF_THE_EFFECT_OF_FIXED_AND...

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