A COMPARISON BETWEEN ROOT CANAL TRANSPORTATION OF WAVEONE® GOLD AND PROTAPER NEXT® FILES, USING MICRO-COMPUTED TOMOGRAPHY

Abdulrzag Gajoum

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

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Supervisors: Dr.S. Tootla; Dr.E. Patel

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

Johannesburg, South Africa

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DECLARATION

I, Abdulrzag Salah Gajoum declare that this research report is my own work. It is being submitted for the degree of MScDent at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

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This is 14th day of February 2017.

DEDICATION

This research report is dedicated to my family, parents and friends who have supported me.

ABSTRACT

Purpose: Transportation is one of the main preparation errors in root canal treatment and has been used as a tool to evaluate the shaping ability of filing systems. This study compared the root canal transportation and centering ability produced between WaveOne Gold (WOG) and ProTaper Next (PTN) files in curved permanent teeth using Micro-computed tomography (µCT).

Methods: Twenty-four teeth with curved roots were divided randomly into two groups. Pre-instrumentation µCTs were taken for all the teeth. One group was filed using WOG files, and the other group using PTN files. Following post-instrumentation: cross-sectional images were taken at 3, 5 and 7mm from the radiographic apex of the pre-and the post-instrumentation images of each tooth. The dentine thickness of the pre-and the post-instrumentation cross sections was measured at eight different points by two dentists using µCT software. The data was analysed using one-way ANOVA, at a 5% significance level.

Results: The WOG file exhibited significantly less root canal transportation compared to the PTN file (p=*0.001*). However, the findings of apical root canal transportation was within an acceptable range in both groups, between 0.0229 and 0.0621mm. Use of the WOG file showed a significantly ($p < 0.001$) higher mean centering ratio of 0.4286 when compared to PTN which showed a centering ability ratio of 0.2448.

Conclusions: Within the limitations of this study, the WOG files showed superior ability to shape root canals with fewer errors as well as the ability to keep the root canal centred when compared with PTN files.

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LIST OF ABBREVIATIONS AND SYMBOLS

ISO: International Standards Organization

NiTi: Nickel Titanium

SEM: Scanning Electron Microscope

µCT: Micro-Computed Tomography

CBCT: Cone-Beam Computed Tomography

PTN: ProTaper Next

CW: Clockwise

CCW: Counter Clockwise

WOG: WaveOne Gold

KV: Kilovolt

µA: Micro Amber

EDTA: Ethylenediaminetetraacetic Acid

ANOVA: Analysis of Variance

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Background

The root canal system in teeth is compromised when the natural barrier of the pulp is disturbed. Examples of factors that may disturb the sanctity of the pulpal chamber include dental caries, trauma and restorative procedures. Bacterial intrusion into the coronal pulp chamber can quickly spread to the rest of the root canal system. This can initially present as a pulpitis or later as an apical periodontitis (Hargreaves and Berman, 2016). Root canal treatment is performed mainly when the pulp is irreversibly damaged, and in order to eliminate microbial infection.

Root canal treatment depends mainly on three processes: chemo-mechanical preparation, disinfection, and three dimensional obturation of root canal system (Castellucci, 2004). However, there is a preliminary step of root canal treatment which is creating an access cavity. Preparation of the access cavity has been argued to be just as important as the previously mentioned processes (Castellucci, 2004). Creating an access cavity is the removal of the roof of the pulp chamber to gain entry to the root canal/s of a tooth. Following the access cavity preparation, a glide path is established for each canal to ensure smooth reproducible insertion of the first rotary file (Hargreaves and Berman, 2016).

Chemo-mechanical preparation involves removal of the infected pulpal and dentinal tissue, as well the enlargement of the canal to facilitate disinfection and adaptation of the obturation material. This is achieved by using files in conjunction with irrigation materials (American

Association of Endodontists, 2016). The files used may be manual files such as K-files or engine driven rotary and reciprocation files. Regardless of the filing system used, usually each system starts with a small size and ends with a larger file. When a series of manual ISO files are used, they generally enlarge the canal and create an apical stop. The apical stop is a matrix of dentine at the apical end of the root which prevents the file or the obturation material from further advancement. Unlike manual files, rotary files result in a wide tapered shaped canal which controls the length of the obturation material (Hargreaves and Berman, 2016).

Obturation refers to the filling of the prepared root canal using specific obturation materials. Obturation aims to prevent any subsequent bacterial invasion into the obturated root canal by ensuring a good coronal and apical seal.

Several techniques have been described to prepare root canals, including: the standardized technique, step-down technique, balanced force technique and crown-down technique. In the standardized technique, the working length is the same in all files used. So, the standardized technique depends on the final file to impart the final shape of the root canal (Hargreaves and Berman, 2016). In the step-back technique there is a reduction of 0.5 or 1mm in working length with each larger file introduced. A 1mm reduction of the working length results in a 0.05 taper canal while a reduction of 0.5mm results in a 0.10 tapered root canals. The Step-down technique advocates enlargement of the coronal two thirds of the root canal before enlargement of the apical part (Hargreaves and Berman, 2016). This technique reduces the amount of the infected dentine that may extrude in to the periapical area (Hargreaves and Berman, 2016). The Crown-down technique is a modification of the step-down technique, where the coronal flaring is done before the determination of the working length. An engine driven instrument is usually used to enlarge the coronal two thirds of the root canal in this technique. Balanced force is a filing technique rather than a preparation technique; and can be used in any aforementioned preparation techniques. This technique involves a 90 degree clockwise (CW) rotation after insertion of a file to work progressively to full working length. This movement engages the file with the dentine. The CW movement is followed by a counter clockwise (CCW) movement to break the dentine engagement. Again, the clockwise movement is repeated with withdrawal of the file to clean it. This technique is better able to maintain the natural anatomy of curved canals (Roane et al, 1985).

Reducing the number of microorganisms is a primary goal of root canal preparation, the aim of which is to prevent any future infection in the root canal system (Byström and Sundqvist, 1981). Biomechanical preparation should result in a tapered root canal preparation that maintains the original path of the canal. In addition, the apical foramen should keep its original shape and form. Ultimately, there should be a continuously tapered canal from root apex to canal orifice (going in the opposite direction), in other words, a narrowing of the cross section of the prepared canal as it advances apically. Furthermore, there should be a flow of the preparation with the original canal anatomy (Schilder, 1974).

Despite revolutionary developments in the instruments, and techniques for root canal preparation, complications do still occur. These complications include root fracture, ledge formation, zipping, perforation and root canal transportation (Sathorn et al, 2005; Hargreaves and Berman, 2016). Excessive removal of the dentinal wall is an important factor in root fracture (Hargreaves and Berman, 2016). A Ledge (Figure 1A) is an artificial irregularity in the surface of the canal wall usually created by a file and can prevent full insertion of the file. Perforation (Figure 1C, D and E) is mechanical or pathological communication between the root canal system and the periodontium (American Association of Endodontists, 2016). There are three types of perforations; strip perforation which occurs towards the root canal furcation (Danger zone, Figure 2) in multirooted teeth, curvatures perforation which occurs toward the convexity of the curvature, and perforation through the apical foramen. (Hargreaves and Berman, 2016).

According to the American Association of Endodontists (2016) root canal transportation, refers to the deviation or straightening of a curved root canal from its original anatomical position either on the outside curve, or any undesirable deviation (Peters 2004). Root canal transportation is a straightening of a curved root canal which can occur in any direction over the length of the root canal. Hence root canal transportation can be due to (i) over preparation of the curved surface at the curvature leading to canal straightening and even strip perforation leading to a higher degree of canal transportation; (ii) canal straightening in the apical region beyond the curvature on the outer surface which leads to the elbow formation (Figure 1B and C). An elbow is the narrower part of canal next to a wider zipped or transported part of the root canal (Association of Endodontists, 2016). Zipping, or elliptication of the apical part of the root canal, occurs due to the tendency of the file to retain a straight shape while filing, resulting in a wider canal near the apical foramen (Hargreaves et al, 2011). A Zip is "a tear-drop shape that may be formed in the apical foramen" (American Association of Endodontists, 2016).

Root canal transportation occurs on the outside curve because Nickel Titanium (Ni-Ti) files have a tendency to retain their original shape in curved canals (shape memory) (Schäfer and Dammaschke, 2006). However, root canal transportation occurs also with stainless steel files which indicates that not only the lack of shape memory is responsible for transportation but also the rigidity of the file is an important causative factor. Root canal transportation can predispose to further iatrogenic errors such as elbow formation, zip formation, and perforation.

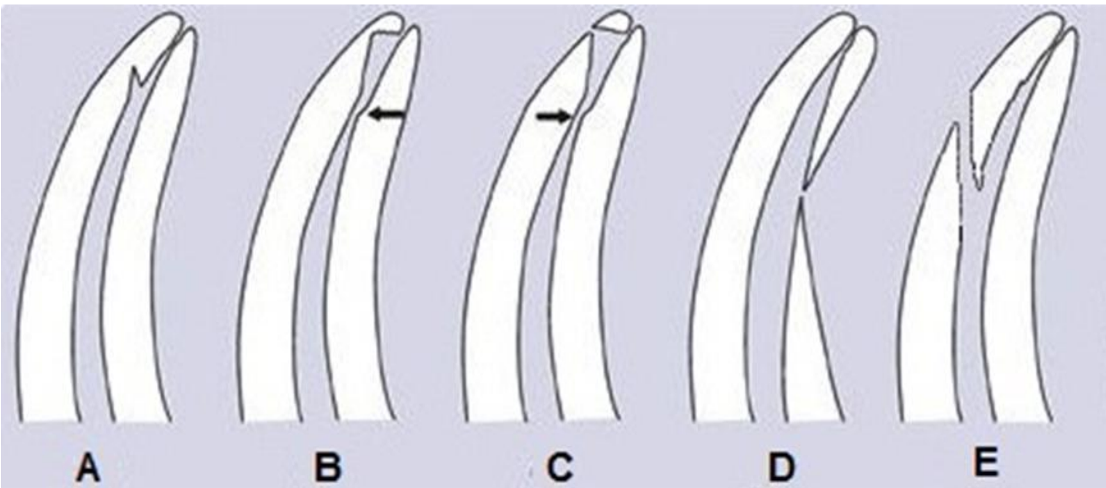

Figure 1: Iatrogenic errors that may occur during root canal preparation. A, Ledging; B, apical zip; C; perforation; D, strip perforation; E, curvature perforation. The narrowest part of the root canal indicated by an arrow in B and C is called an elbow. Source; (Carrotte, 2004).

Centred root canal preparation is another way to express an ideal root canal preparation without transportation. The centering ability of a file is the ability of the file to maintain the long axis of a root canal or the ability of a file to keep centred in the canal during the instrumentation. Centering ability of a file is important for ideal root canal enlargement and to avoid weakening of root canal structure (Kandaswamy et al., 2009). While root canal transportation is usually measured in millimetre or micrometre, centering ability is measured using a ratio of 0 to 1. Zero centering ability ratio means that a part of root canal wall was left untouched; uncleaned.

The amount of root canal transportation and the centering ability ratio have been used as tools to compare different root canal preparation systems (Short et al, 1997; Gluskin et al, 2001; Parvathaneni et al, 2010). The lower degree of canal transportation produced by a system used for shaping the canal, indicates that the system can maintain the canal shape better than the system that has a higher degree of canal transportation. The closer the centering ratio is to 1 the more superior the centering ability of the file and vice versa.

Canal transportation has undesirable effects which might endanger the success of root canal treatment. The convex outer surface of the root canal wall may be over-prepared leading to other areas of the canal wall being left unprepared. This invariably impacts negatively on the removal of bacteria (Wu et al, 2000). In addition, root canal transportation may result in loss of the apical stop which might lead to extrusion of irrigants and obturation materials that will inevitably cause irritation to the periapical tissues (Hülsmann et al, 2005; Haapasalo and Shen, 2013). Root canal transportation may also affect the apical seal when the prepared tooth is obturated using lateral compaction (Wu et al, 2000). In addition, researchers assessed fluid leakage, which is a method used to evaluate the seal of an obturated canal, using the fluid transportation model. These studies have deduced a high incidence of leakage in groups with high root canal transportation (Wu et al, 2000). It may even result in a lack of taper which may hinder proper cleaning and obturation of the apical third of the root canal (Hülsmann et al, 2005). Taper here is defined as a gradual and uniform decrease in the size of the canal in coronal-apical direction.

1.2 Types of Root Canal Transportation

Root canal transportation according to the common definition is any deviation of a root canal from its normal anatomical position; either this transportation occurred in apical, middle or coronal part of the root canal. So, root canal transportation can be categorized depending on the location in which root canal transportation occurs to apical, middle and coronal root canal transportation. However, research tends to focus more on apical root canal transportation because of its effect on the apical seal.

Apical root canal transportation has been classified into three categories.

- Type one refers to a minor movement of the physiological foramen leading to slight iatrogenic relocation.
- Type two refers to a moderate movement of physiological foramen leading to considerable iatrogenic relocation, and
- Type three refers to a severe movement which leads to significant iatrogenic relocation of the apical foramen (as cited in Bürklein and Schäfer 2013).

This classification of root canal transportation is rather descriptive and does not use standardised values to diffentiate between the three types. In addition to that it refers just to transportation which occurs near the apical foramen and not to any undesirable deviation along the root canal length. However, Kunert et al. (2010) found that rotary Ni-Ti files usually produced root canal transportation ranging from 0.1mm to 0.2mm. Hand stainless steel and hand Ni-Ti instruments were found to create transportation between 0.37mm and 0.53mm, and 0.20mm to 0.50mm transportation respectively (Parvathaneni et al, 2010).

Root canal transportation generally occurs toward the outer surface of the curvature in the apical part of the root canal and the inner surface of the root canal curvature in the middle part of the root (Figure. 2) (Hargreaves and Berman, 2016). The amount of transportation often depends on the severity of the curvature of the root and therefore the curvature should be evaluated before starting root canal treatment (Bergmans et al, 2001).

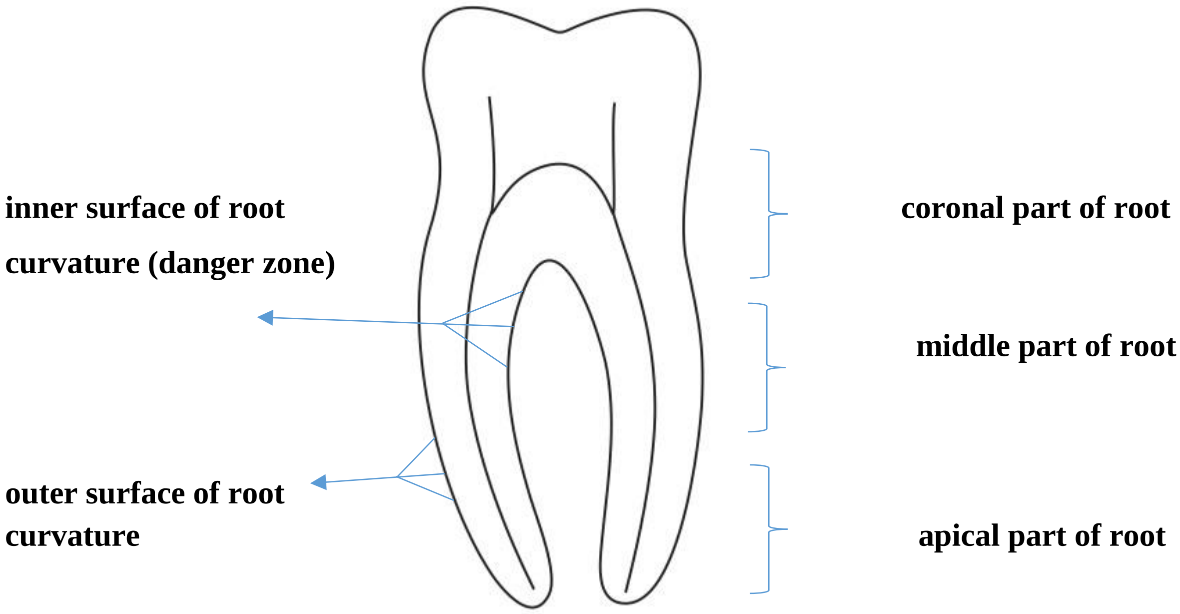

Figure 2: Surfaces of root curvatures

1.7 Assessment of Root Canal Curvature

Root canal curvature has been assessed by many authors. Schneider (1971) was the first to develop a method to measure root canal curvature. In this approach, after taking an image of a file in the root canal, a point is measured on the middle of the file at the root canal orifice indicated as point A (Figure 3A). A parallel line to the file image is extended to a point where this line deviates from the root canal (point B). Another point on the file image at the root canal apex is drawn (point C), and then a straight line is drawn from point C to point B. The acute angle which is formed between the two lines is the curvature of the root canal. Schneider classified the root canals according to their curvature as straight (5° degrees or less), moderately curved (10° to 20° degrees) or severely curved (20° to 70° degrees).

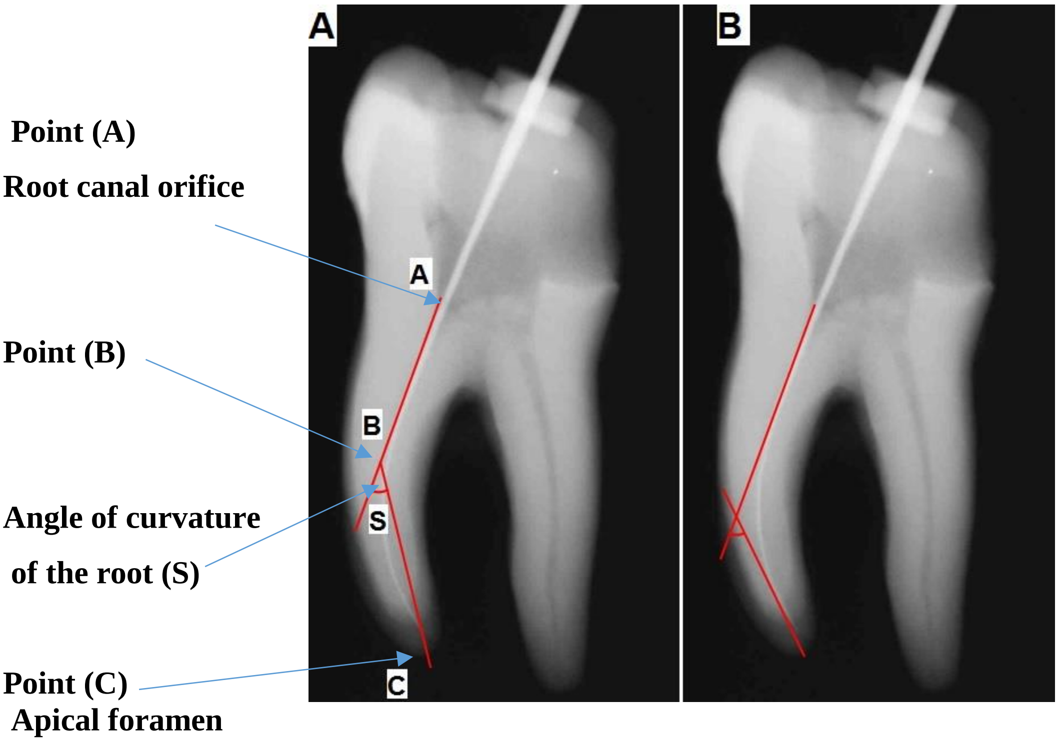

Figure 3: A, Graphic representation of the Schneider method; B, Graphic representation of the Weine method.

In the newer Weine technique, a straight line is extended from the root canal orifice through the coronal portion of the curve; the direction of the straight line from the orifice is determined by the coronal first part of the canal. Then, another straight line is extended from the apex through the apical portion of the curve. The Weine angle is the intersection of the prescribed lines (Weine, 1982). (Figure 3B)

The Weine and Schneider methods were compared by Zhu, et al (2003) with regards to their reliability to measure root canal angulation. The study revealed no significant differences between the results of the two methods and concluded that both approaches are reliable to measure root canal curvature.

1.3 Incidence of Transportation

Various studies have documented the incidence of root canal transportation. The studies vary by person doing the work to the severity of the curvature of the roots which make them difficult to compare.

A study performed by Dervenis et al (2015) used 287 root canals of extracted teeth. In this study, root canals were prepared using 0.02 taper stainless steel K-files with the step back technique. Pre-operative and post-operative digital radiographs, using the paralleling technique, were taken for each root canal. An incidence of 3.1% root canal transportation and 7% ledge formation was found (Dervenis et al, 2015). However, this study was carried out by undergraduate students and used only anterior teeth which have less curved roots than posterior teeth. This may explain the relatively low incidence. An 87% apical transportation was found in severely curved roots (21-38 degrees) prepared with K-files compared to a 19% incidence of apical transportation in curved roots prepared with Light-speed instruments (Wu et al, 2000). The differences in the outcomes between the two studies may be attributed to the experience of the operator, curvature of canals, patency of canals, type of instruments used and lastly on the methods of assessment used. A limitation of the two studies above is that both of them used conventional digital radiographs which offer less detail, an undesired quality and just two dimensions images when compared to micro-computed tomography (µCT).

Many factors are responsible for canal transportation including the type of alloy used in the file, the design feature of the root canal instrument, and sharpness of the instrument tip. According to Saberi et al (2017) Ni-Ti alloys are manufactured in different shapes, sizes, tapers and also different surface or structural, pre-or post manufacturing treatments. As a result of this not all Ni-Ti instruments behave in the same manner when used in canals of similar shape, size, length and curvature. In addition, inadequate usage of irrigation solutions and using large inflexible files (above #20) in severely curved canals could increase the risk of root canal transportation (Saunders, 2005). The degree of the root canal transportation is positively correlated to the degree of curvature of the root canal and negatively correlated to the radius of the curvature (Bergmans et al, 2001; Hülsmann et al, 2005; Saunders, 2005). Radius of curvature indicates how abruptly a curvature is. Radius of curvature can be measured using the Pruett et al (1997) method described in Figure 4. In this method, a line parralel to the long axis of the coronal part of the root canal is drawn. Another line is drawn parallel to the long axis of the apical part of the root canal. On these lines there is a point where the lines deviates from the long axis of the root; point (A) and points (B). Two perpendicular lines is drawn on point A and B until these lines intersect. The length of these lines is the radius of the root canal curvature (R) in Figure 4.

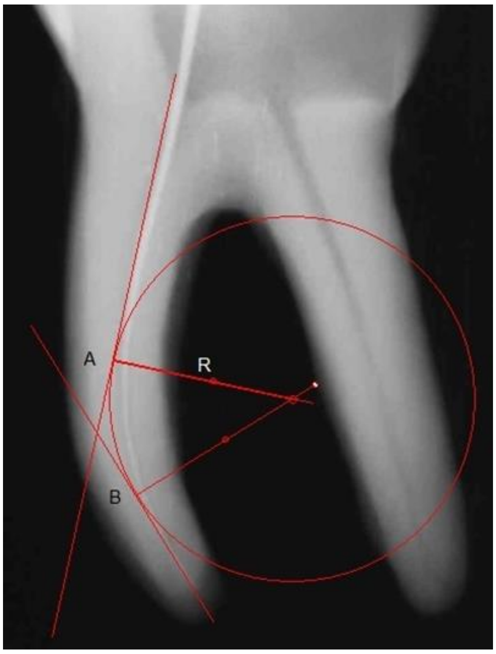

Figure 4: A diagram showing the Pruett et al method to measure root canal curvature radius.

The design of the access cavity may also affect the degree of transportation. An underprepared access cavity leads to improper guidance of the file. The file should not touch the walls of the access cavity during the preparation, as the file should be directed by the root canal wall and not by the access cavity wall (Castellucci, 2004; Hargreaves and Berman, 2016). This clearly emphasizes the need for creating straight-line access and to develop a continuously tapering funnel from the root apex to the coronal access cavity, the cross-sectional diameter of the root canal preparation should be narrower at every point apically, and wider at each point as the access cavity is approached. The root canal preparation should occupy as many planes as are presented by the root and the canal. The root canal preparation should flow with the shape of the original canal, and the apical foramen should remain in its original spatial relationship both to the bone and to the root surface (Schilder, 1974). Thus, correct access cavity is essential step in preparation of the root canal and to minimize transportation.

1.4 Methods to Evaluate Root Canal Preparation

The purpose of assessing the shape of the final root canal preparation is to evaluate the taper, the conical shape and the flow of the prepared root canal. Several parameters have been used to evaluate root canal shape including canal area, shaped form, centering ability and transportation. Canal area refers to the area of cross sections of a canal after instrumentation while evaluation of shaped form assesses the cross section of the instrumented canal and to evaluate whether the shaped form is regular or not (Jungmann et al, 1975).

Various parameters have been used to assess root canal preparations by filing instruments and techniques including assessment of cleaning ability, shaping ability, and fracture properties of an instrument. Assessment of cleaning ability of an instrument is based on the evaluation of root canal debris and un-instrumented root canal wall, or by histological evaluation of remaining pulp tissue. Histological evaluation can be done by serial sectioning to prepare histological slides. Assessment of root canal debris in an un-instrumented canal wall can be assessed using scanning electron microscope (SEM) and sectioning the root canal into two sections with examination of the remaining pulp tissue (De-Deus and Garcia-Filho, 2009). However, sectioning of the tooth produces debris, and the amount of debris produced may be different depending on the type of instrument used. This makes the assessment of cleaning ability of the instrument difficult to assess and very subjective.

Several methodologies have been used to assess root canal shape. Those include:

(i) Plastic models, (Weine et al, 1975),

Compared to extracted human teeth, plastic models are standardized and easily available. They also confer the advantage of being complete. The plastic models can be removed to review the endodontic procedure step-by-step in three dimensions. In this way, they improve the understanding of biomechanical root canal preparation. Plastic models allow standardisation of learning conditions that result in enhanced learning and are a valuable aid for self-assessment. The major advantage is that there is no risk of infection. However, plastic models cannot precisely represent the natural teeth with regards to the hardness of dentin and the anatomy of the root canals.

(ii) Silicone impression of shaped root canals (Abou-Rass, and Jastrab, 1982).

In this technique, the tooth is dissolved to obtain an impression, but it is difficult to get an accurate pre-operative assessment. However, the silicone impressions do not represent the actual situation that the student will encounter. In addition, this technique requires very viscous impression materials with high tear strength. Furthermore, it is limited to relatively large size canals and canals of moderate curvature (Chen and Messer, 2002).

(iii) Serial sectioning technique developed by Bramante et al. (1987)

The serial sectioning technique was amongst the first methods described and which enabled the examination of horizontal root sections pre-and post-instrumentation. The Bramante et al method involved fabricating a plaster block around a resin index (muffle system) (Bramante et al, 1987). This muffle system enabled the exact repositioning of sectioned parts of the root canal. This method involves sectioning of root canals before instrumentation and taking a radiograph of the sectioned area. Thereafter the sectioned areas are repositioned to allow for instrumentation of the root canals, after which another radiograph is taken. However, this method involves a complicated setup and requires pre-instrumentation sectioning of the root canal which creates an unknown loss of root material (Gambill, et al, 1996).

(iv) Radiographic comparison (Southard et al, 1987).

Radiographic comparison techniques using conventional radiographs were limited to just two-dimensional measurements of the resultant images (Backman et al, 1992).

1.5 The Use of Root Canal Transportation as a Measure to Compare Filing Systems

In endodontic treatment, root canal shaping is still regarded as an integral procedure (Abou-Rass et al., 1980; Schäfer, and Schlingemann, 2003) together with cleaning and widening of the canal system (Vallaeys et al., 2016). In curved canals, root canal instrument navigation is challenging because of the tendency of the instruments to divert the prepared canal away from its original axis (Gergi et al., 2014). When the instrument returns to the original linear shape, this movement often leads to straightening of the root canal during preparation subsequently giving rise to procedural errors such as ledging, zipping, and transportation (Gergi et al., 2010). Of the three procedural errors of interest in the present study is the measurement of root canal transportation. Root canal preparation was intended to preserve the apical foramen, and at the same time maintain the original canal curvature, but that is often not the case (Schilder, 1974).

The degree of the canal transportation in the prepared teeth gives an indication of the efficacy of the instrument being used in the shaping of the canal. The amount of root canal transportation can be used as a criterion to compare between two filing systems (Gambil et al, 1996). This measurement can be combined with µCT to compare the root canal transportation of different Ni-Ti and stainless steel instruments. Many studies followed Gambil et al, and compared two or more filing systems and techniques in which either root canal transportation or centering ability or both were used to test the shaping ability of filing systems and techniques (Short et al, 1997; Gluskin et al, 2001; Parvathaneni et al, 2010).

Different techniques were used in the aforementioned studies; Short et al (1997) used a modified Bramante technique, Gluskin et al (2001) used a high-resolution CT, while Parvathaneni et al (2010) used a double exposure radiographic technique. However, methods involving µCT and CBCT have recently become more popular (Marzouk and Ghoneim, 2013; McRay et al, 2014; Zhao et al, 2014; Gergi et al, 2014; Baek et al, 2014).

Micro-computed tomography is used for the evaluation of root canal anatomy and morphology before and after instrumentation. µCT is a preferred method because it conserves specimens and provides 3-D high resolution images (Freire et al., 2012; Shen and Cheung, 2013). Cone-beam computed tomography (CBCT) is also capable of producing 3-D images, however, the spatial resolution of CBCT is inferior to µCT (Freire et al., 2012; Shen and Cheung, 2013), which also influenced the decision of choosing µCT over the CBCT.

1.6 Cone-Beam Computed Tomography (CBCT) and Micro-Computed Tomography (μCT)

Micro-computed tomography was developed in 1980 and consists of a series of images on a sensor when a series of x-rays hit a target. These images are reconstructed via software to produce high-quality two and three-dimensional images (Marciano et al, 2012). The voxel size of images that μCT produces ranges from 5 to 50 μm which is about 1,000,000 times smaller in volume than normal CT voxels (Swain, and Xue, 2009). The lower the pixel, the higher the quality of the images.

μCT has been used in endodontics to assess root canal anatomy, root canal instrument shaping ability as well as techniques and materials used in root canal treatment instruments. μCT does not require sectioning to provide three-dimensional images and thus, together with CBCT have become the preferred techniques to use. Furthermore, μCT provides high-quality images with a high resolution, can measure the changes in volume of the root canal and allows evaluation of the canal transportation in three dimensions (Peters et al, 2001).

CBCT has been used in oral and maxillofacial surgery, orthodontics, endodontics (Hargreaves and Berman, 2016) and implantology (as cited in Scarfe et al, 2006) as well as in dental research. CBCT is used generally in dentistry for preoperative diagnosis and post-operative assessment (Hargreaves and Berman, 2016). CBCT is superior to conventional and digital intraoral periapical (IOP) as CBCT provides three-dimensional visualization without surrounding structures being superimposed (Mozzo et al, 1998). CBCT has the advantage that almost all structures can be seen in one image (Hargreaves and Berman, 2016). CBCT is an augmentative diagnostic tool and is not a replacement for the conventional x-ray (Hargreaves and Berman, 2016). CBCT provides spatial resolution ranging from 0.4mm to 0.076mm or the equivalent to 1.25 to 6.5 line pairs per mm^{-1}[lp.mm^{-1}]. However conventional intra-oral radiographs provide enhanced resolution (ranging from 8–20 lp.mm^{-1}). CBCT has a lesser exposure time (10-70 second) compared to conventional CT and µCT (Scarfe et al, 2010) and thus about 15 times lower radiation dose compared to conventional CT (Scarfe et al, 2006). Whereas, CBCT is more suitable for in vivo studies, µCT is not suitable for in vivo research as it requires a high radiation dose, and long scanning time when compared to CBCT. For instance, to get images of 15 microns resolution of a tooth, about 50 minutes of exposure time will be required. Thus, µCT is suitable for in vitro studies because the quality of the image is more important than time constraints. It has been recommended that µCT should be the first choice for laboratory research (Gluskin et al, 2001; Marciano et al, 2012).

1.7 Rotary Filing Systems

Rotary files were introduced to save effort and time spent using manual files. The first rotary endodontic file was released in the market in 1992. It was 2% tapered and made from Ni-Ti alloy and used in a continuous rotation (Haapasalo & Shen, 2013). The taper of a file refers to the percentage by which the file increases in diameter each millimetre starting from its apex. For example, a size 10 file with 0.02 taper means that the diameter of the tip of the file is 0.1mm and its diameter increases by 0.02mm every millimetre toward the shank of the file. The flexibility of the Ni-Ti files made it possible to use continuous rotation instead of reciprocating rotation which had been previously used with stainless steel files. Reciprocating rotation is any repetitive back and forth motion. Using Ni-Ti files reduced the error of root canal preparation and file failure (Hargreaves and Berman, 2016).

The first generation of rotary files had negative cutting radial lands ("peripheral portion of a rotary instrument that is flat and smooth"), a fixed taper and they required several files of varying tapers to fully prepare the canal (Haapasalo & Shen, 2013). Examples of this generation of files are ProFile 0.04 tapered series and ProFile 0.06 tapered. Rotary files have continued to evolve with improvement in design and metallurgy to increase the performance and the flexibility of files. The 2nd generation of rotary files had cutting edges without radial lands to increase the cutting efficacy. An example of these files is ProTaper® (Dentsply Tulsa). A characteristic feature of 3rd generation files is a thermomechanical treatment in order to improve file mechanical properties like flexibility (Haapasalo & Shen, 2013). Vortex Blue^{TM} (Dentsply Tulsa Dental Specialties) and ProFile GT series X are examples of this generation of files. The 4th generation of rotary files are characterised by the fact that they are operated by a reciprocating rotation engine. 5th generation files have a characteristic offset centre of rotation (Haapasalo & Shen, 2013). Currently there are more than fifty types of rotary systems which use different rotation movements with continuous rotation being predominant.

Even though continuous rotation systems represent a significant improvement on Ni-Ti files, recent studies have shown that they are not without problems. Hargreaves and Berman, (2016) have shown that rotary systems do have inherent problems like fatigue fracture, taper lock (Yared, 2008; Peters, 2004) and threading-in.

As it is not possible to do a full review of all the different files, only PTN and WOG files will be discussed as they will be used in this study.

1.7.1 Reciprocating Rotation

While continuous rotation is fairly easy to understand, reciprocal rotation can be defined as any repetitive back and forth motion. Since 1958, all reciprocating motors have used equal 90 degrees clockwise (CW) and counter-clockwise (CCW) motions (Deutsch, 2015).

Thereafter virtually all the reciprocating motors started to use smaller yet equal reciprocation angles. One such example is Endo-Express (Essential Dental Systems) reciprocating system which uses 30 degrees equal reciprocating motion (Haapasalo & Shen, 2013). These equal reciprocating movements had limitations such as a higher inward pressure required, decreased cutting efficiency and limited capacity to get debris out of the canal (Ruddle et al, 2013). In 1998 Ben Johnson and Professor Pierre Machtou discovered the advantages of unequal reciprocation movement (as cited in Ruddle, 2012) which eliminated the problems listed above. An example of the unequal reciprocal motion are 150°CCW and 30° CW rotation which is used with WaveOne, WOG (Ruddle, 2016) and Reciproc files (Gergi et al, 2014). This precise unequal movement was recognised by Yared (2008). This reciprocating movement according to Yared enabled using only a single file to completely prepare a root canal. In fact, reciprocating movement better mimics the manual file movement used in the balanced force technique, introduced by Roane for the preparation of curved canals, but in a reverse direction (Roane et al, 1985; Webber et al, 2011). The reciprocating rotary movement has many advantages over the continuous rotation technique, including decreased torsional fatigue and thereby the probability of fracture. Many studies have shown that reciprocal movement decreases the torsional fatigue of files compared with files driven by continuous rotation (Yared, 2008; Plotino et al, 2010; You et al, 2010).

Decreased torsional fatigue means that the file is less prone to separation. This raises the discourse of whether files should be used once only or used multiple times to prepare root canals. The argument is that multiple use of files would not increase the incidence of file fracture (Yared et al, 1999; Gambarini, 2001; Wolcott et al, 2006). The United Kingdom Department of Health advocated the single use of files to prevent prior cross-contamination (Gagliardi, 2015) However, no study has deduced that multiple use of files increases cross-contamination (Scully et al, 2003). With regards to multiple use of files and root canal transportation: there is no evidence or even a claim that multiple uses of Ni-Ti files will affect root canal transportation. Furthermore, many studies advocate the single use of files just to avoid file separation (Young et al, 2007; Yared, 2008). One ProTaper F2 file was safely used up to six times in curved canals under reciprocating motion (You et al, 2010). This interesting finding will probably encourage multiple use of files in reciprocating motion.

1.7.2 ProTaper Next (PTN) File

The PTN file was introduced in 2013. Like most rotary files, PTN files are run by a clockwise (CW) continuous rotation endodontic motor. PTN files are available in the following sizes: 17, taper 0.04 (X1); 25, taper 0.06 (X2); 30, taper 0.07 (X3); 40, taper 0.06 (X4) and 50, taper 0.06 (X5). The given taper refers to taper of the apical part of the file and is not fixed over the file length. The active cutting part of the files is divided to 16 millimetres starting from distance 1 (D1) at the tip to distance 16 (D16) at the shank, where D0 refers to the tip of the file. X1 and X2 both have an increasing and decreasing percentage taper over the active portion of the file while X3, X4 and X5 have fixed tapers from D1 to D3 then a decreasing percentage taper over the rest of the file length (Haapasalo & Shen, 2013).

A PTN file is made from M-wire alloy which is a thermomechanically treated Ni-Ti to produce alloy in a high flexibility form (martensite). M-wire technology has resulted in an increased resistance of the file to cyclic fatigue of up to 400% compared to other files (Johnson et al, 2008).

PTN files fall under the fifth generation of Ni-Ti rotary files. The main characteristic of this generation of files is that the centre of the file mass is offset (off centre). This off-centredness was claimed to add some advantages to this file such as decreasing the engagement between the file and dentin, decreasing torque, and reducing the screw effect. Furthermore, it was thought to reduce the possibility of blocking the dentinal tubules by pushing debris laterally (Haapasalo & Shen, 2013) and to enhance the ability to remove debris out of the root canal (Saber et al, 2015). Additionally, the offset centre of the PTN file gives it an ability to prepare a size of canal that would otherwise require larger and stiffer files with a centred axis of rotation (Saber et al, 2015). The progressively decreasing percentage tapered design that can be found in any ProTaper file is claimed to increase the flexibility of PTN files, limit the preparation to the body of the canal and conserve the coronal root canal structure (Ruddle, 2016).

1.7.3 WaveOne Gold File

The WaveOne Gold (WOG) reciprocating file system is a new filing system launched in 2015. Similar to its predecessor, WaveOne (introduced in 2011), the WOG files use a reciprocating motion (150° CCW and 30° CW) and a single file concept. Thus, one rotary file is used to adequately shape the root canal after initial glide path preparation (Webber et al, 2011). WOG files have a non-shape memory feature at low temperature but seem to lose this property at body temperature. WOG files are available in the following sizes: Small, 20, taper 0.07; Primary, 25, taper 0.07; Medium, 35, taper 0.06; Large, 45, taper 0.05. WOG file has off-centred parallelogram cross section, similar to PTN (Elsaka et al, 2016).

The WOG files have been compared head to head with other files in the literature. The WOG Primary (25, 0.07) file size, in two studies, has been shown to have greater resistance to cyclic fatigue when compared with Reciproc R25 (25.08) files and WaveOne primary (25.08) size files in double curved canals (Topçuoğlu et al, 2016; Özyürek, 2016). However, Reciproc R25 files reported significant cyclic fatigue resistance when compared to WaveOne files.

The manufacturer claims that the WOG file has improved strength and flexibility compared to conventional Ni-Ti files due to thermocycling during the manufacturing process. They also claim that the WOG file is significantly more flexible than the standard Ni-Ti rotary file systems. Elsaka et al (2016) proved these claims and reported that WOG file had significantly greater flexibility and resistance to torsional stress compared to Reciproc and Twisted File Adaptive.

Many root canal instruments have been compared by measuring the amount of canal transportation produced. The results are inconsistent. Yang et al (2007) conducted a study to compare the shaping ability of a constant taper file (Hero Shaper) with a progressive taper file (ProTaper). A modified Bramante muffle system (previously described) was used. The measurements of root canal transportation were recorded on three different sections of the root: apical, middle and coronal. In the coronal and the middle section of the root, there was no significant difference in root canal transportation between the two groups in either direction. However, ProTaper had a larger mean value of root canal transportation in the apical third in the direction of maximum curvature. Furthermore, Hero Shaper showed better centering ability compared to ProTaper. Bergmans et al (2003) compared root canal transportation and centering ratio of a progressive taper file (ProTaper) with constant taper file (K3). µCT was used to scan the root canal pre-and post-instrumentation. The progressive taper file reported better apical centering ability, however, ProTaper showed a tendency of root canal transportation more toward the furcation in the coronal third of the root (Bergmans et al, 2003).

A study in 2013 conducted by Marzouk and Ghoneim, compared the canal transportation produced by two file systems, WaveOne (reciprocating) file and Twisted file (continuous rotation). In this study, 20 mesial roots of mandibular first molars with a range in root canal curvature limited to between 25 and 35 degrees were used in each group. CBCT was used to compare root canal transportation and showed a significantly higher canal transportation in the WaveOne group. Zhao et al. (2014) examined three filing systems: ProTaper Universal (PTU), PTN and WaveOne (WO). In this study, 36 root canals with curvatures of between 5° and 40° were used for each group. µCT was used to compare root canal transportation. They found that the use of PTN files in this study produced less canal transportation compared to WO and PTU files. Zanesco et al (2017) measured the apical transportation, centering ratio and volume increase of a manual file system (k-files), a rotary system (PTN) and a reciprocating file system (Reciproc) and found very little difference between the three systems. The three above studies contradict earlier studies which suggested that reciprocation motion decreases root canal transportation (Roane, 1985; Berutti et al, 2012).

Gergi et al (2014) compared three Ni-Ti instruments regarding root canal transportation and centering ratio: Reciproc, WaveOne, and Twisted Files Adaptive (TF) files. In this study, 16 mandibular mesial roots were used for each group. Both mesiobuccal and mesiolingual canals of mandibular molars of severe (25-30 degrees) root curvature were used. µCT was used to compare pre-and post-instrumentation root canal anatomy. There was a significant difference between the three systems used. Adaptive TF produced the least canal transportation and better centering ability among the three groups followed by WaveOne files. The mean degree of canal transportation produced by Reciproc filing was the highest among the three filing systems. The difference was in favour of TF Adaptive files which uses a different type of reciprocation motion. TF Adaptive uses an adaptive motion according to the load applied on the file which allows for a change is the degree of the CCW and CW rotation (Gergi et al, 2014). Baek et al. (2014) compared the root canal transportation of ProFile (PF), Twisted File (TF) and WaveOne (WO) using µCT. They used eighteen extracted mandibular molars with two separate root canals and found no significant difference between the three filing systems. The limitation of this study was the fact that only 12 roots were used for each group.

From the literature it can be concluded that the difference in rotary motion does not necessarily affect root canal transportation. This indicates that other factors may play a role between different filing systems such as flexibility, the design of the file, as well as the experience of the dentist.

CHAPTER 2
AIM AND OBJECTIVES

2.1 Justification of the Study

Instrumentation used in root canal preparation has evolved over time. The PTN file system is regarded as the gold standard system for use in root canal preparation based on some studies conducted in the past. Technology continues to evolve and, the WOG is a new file system which is considered a major advancement based on experimental evidence, but this has not been evaluated extensively. These two systems have different operating mechanisms. To date, no study has been conducted to compare the WOG filing system and the PTN file system with regards to the root canal transportation and centering ability during the root canal preparation. PTN has been chosen as the opposing file system as it has been shown to produce less canal transportation in previous studies.

The purpose of this research report was to investigate whether the PTN file system has better root canal transportation and centering ability compared to the WOG file system

2.2 Aim and Objective of the Study

The aim of this study was to measure and compare the amount of root canal transportation produced between the WOG reciprocating file system and PTN rotary file system in root canal treatment using µCT scans.

The objectives of the study were:

1. To measure the amount of canal transportation produced in extracted teeth prepared with WOG and PTN files.

2. To compare the amount of root canal transportation in the apical, middle and coronal parts of root canals prepared with WOG and PTN filing systems.
3. To compare the centering ability of root canals prepared with WOG and PTN files.

CHAPTER 3
METHODS AND MATERIALS

3.1 Study Design and Randomization Procedure

The study involved the collection of extracted molar teeth from the Gauteng district clinics (Johannesburg, South Africa), which were placed immediately after extraction in a 37% formalin solution. Access cavities of sufficient size were prepared using round diamond burs and the Endo Z bur. Underprepared access cavities were particularly avoided as they may increase risk of root canal transportation. The canals of selected teeth were explored with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland), which was advanced passively into the canal until the tip reached the apical foramen. The working length was established from a standardised coronal point to the anatomical apical foramen minus 1mm performed under X 31.25 magnification using a Zeiss Microscope. The occlusal surface of the teeth was ground down so that the working length of all teeth was 17mm.

The Schneider's method was used to measure the curvature of the root canal (Schneider, 1971). A number 10 K-file was inserted into the root canal, and then a digital radiograph taken. The radiographs were taken in the buccolingual direction of mandibular and maxillary first molars. The angle of curvature of the root canal was calculated using the Digimizer 4 image analysis software (MedCalc®), according to the Schneider method.

Thereafter the teeth were embedded in acrylic resin to facilitate their handling and positioning during the µCT acquisition. The acrylic resin block had the following dimensions; 25mm height x15mm length x15mm width; a plastic mould was used for this purpose. Base plate wax was used to prevent the acrylic resin from entering the apical foramen. The teeth were inserted in the acrylic resin so that the long axis of the tooth was parallel to the long axis of the mould to standardise the samples for tomographic imaging. Pre-instrumentation CTs were done for all teeth using a Nikon Metrology XTH 225/320 LC Micro- CT scanner at a voxel size of 15µm, 80 KV and 95µA (Figure 5).

Figure 5: Nikon Metrology XTH 225/320 LC Micro- CT scanner.

The glide path was then prepared with ProGlider (Dentsply), where the ProGlider system was used according to manufacturer instructions at 300 revolutions per minute and 2.0N/cm torque. The teeth were then randomly assigned to the two filing systems.

The X-Smart™ Plus micro-motor (Dentsply, South Africa) was used to drive the files and adjusted according to the manufacturer's instructions, for the two file systems. One group was instrumented using the primary size (25/.07) WOG file according to manufacturer instructions and the other group instrumented using the PTN file. PTN file X1 (017/0.04) followed by a X2 (025/0.06) file were used for each root canal in the PTN group to shape them at 300 revolutions per minute and 2.0N/cm torque. A #10 K-file was used in both groups between every step to maintain canal patency. 10 to 12 mg of 17% EDTA (RC-Prep®) was loaded on every rotary file to lubricate the root canal.

The individual canals were irrigated with 3ml of 2.5% sodium hypochlorite between each rotary file. A final irrigation with saline was applied to each root canal. Each instrument was discarded after use in four canals. Moreover, any instrument that deformed was discarded immediately.

3.2 Sample Size

Previous studies by Gergi et al. in 2010 found that when using PathFile-ProTaper files there was a mean (SD) transportation of 0.72 (0.42); and with WaveOne files the mean (SD) transportation was 0.04 (0.08) (Gergi et al, 2014). Given the findings from these two studies, and using G*Power software, an effective sample size of 20 canals per group was required to prevent the study from failing to observe a difference between the two procedures at a 5% level of significance with a power of 99%. In this study 24 root canals were used for each group.

3.3 Inclusion Criteria

1. Extracted maxillary and mandibular first molars with complete root apices.

2. Mesiobuccal and distobuccal roots of maxillary first molars, mesiobuccal and mesiolingual roots of mandibular first molars.

3. Roots which had separate root canals and root canal curvatures between 20 and 40 degrees.

3.4 Exclusion Criteria

1. Calcified root canals, root canals which do not allow a size 8K-file to be inserted to the major foramen and those that allowed the passive placement of 15 K-file to within 1 mm of the major foramen.
2. Teeth with fractured roots.
3. Teeth with any previous attempts of endodontic treatment.

3.5 Measurement of the Outcome

After root canal preparation, additional µCT images were taken using the same settings as the original scans concerning resolution and voltage. Two qualified dentists assessed and compared the pre-and post-instrumentation images using VGStudio MAX 3.0 software. The two dentists assessed the root canal transportation of each root canal by taking measurements of the cross sections. Results of the two examiners were tested for inter-rater reliability using an intraclass correlation coefficient (ICC) and showed high agreement between the two examiners (Table 1). When the value between the two raters was different, the mean value of the examiners reading was taken as a final value.

The technique used to measure root canal transportation was modified from the technique developed by Gambill et al. (1996). Whereas they used 2 measurements along the canal curvature, this study used 8 measurements. In this method, after superimposition of pre-and post-instrumentation images, a cross section of pre-and post-instrumentation images was measured in eight directions (Figure 6A). The direction of the convexity of the curvature of the root canal (direction A), and direction opposite to direction A (direction B), two directions vertical to root canal curvature (E and F), and in another four directions (Direction

C, D, G and H) 45 degrees between the directions AB and EF (Figure 6A). The centering ability ratio was measured in four directions as shown in Figure 6B.

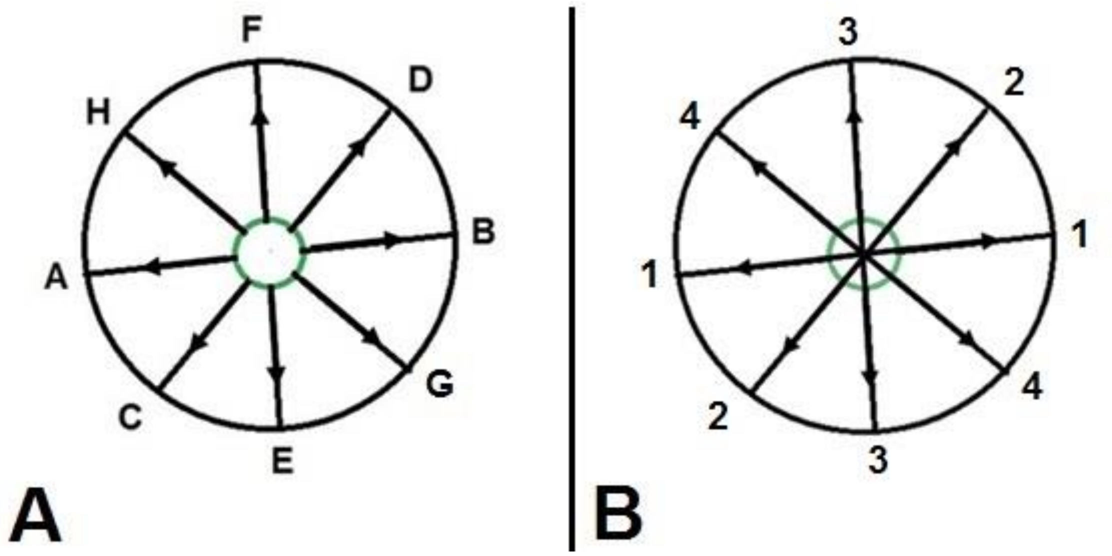

Figure 6: A: Directions of measurements for analysis of root canal transportation. B: directions for measuring centering ability.

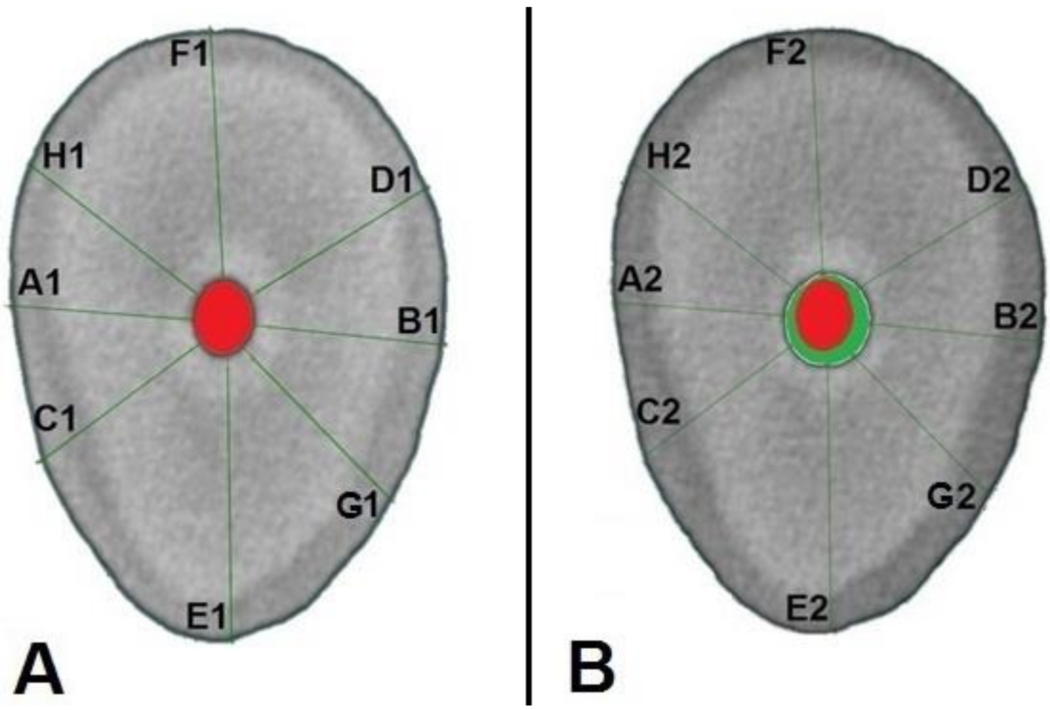

Figure 7: Names of measurements taken on each tooth as seen on a real tooth – A: pre-instrumentations measurements, B: post-instrumentations measurements.

*The red area depicts the pre-instrumentation canal dimensions, whilst the green area depicts the post-instrumentation canal.

Pre-instrumentation values were given the number 1 and post-instrumentation values given the number 2. This meant that post-instrumentation cross sections of the root canals were measured at eight different points: A2, B2, C2, D2, E2, F2, G2, and H2 (Figure 7B). A2 represents the shortest distance from the outside of the curved root to the periphery of the instrumented canal, whereas B2 is the shortest distance from the periphery of the instrumented canal to the inside of the curved root i.e. in a direction opposite to A2 distance.

Pre-instrumentation measurements were guided by the cross-sectional measurements taken on the post-instrumentation images. These measurements were named A1, B1, C1, D1, E1, F1, G1 and H1. A1 was superimposed on A2, B1 superimposed on B2 and so on (Figure 7A). The measurements (A1, etc.) started from the outer surface of the root to the inner surface of the root canal wall (on the pre-instrumentation image).

The readings of pre-and post-instrument images were taken at three intervals for each root canal; at 3mm, at 5mm and 7mm from the apex of the root. To measure root canal transportation the post-instrumentation distance was subtracted from the pre-instrumentation distance (e.g. A1-A2) for all 8 points.. After that the values from opposing distances (e.g. A versus B) were subtracted from each other. A result of zero for the equation (e.g (A1-A2) – (B1-B2)) as mentioned above, was interpreted as no transportation. A positive value for the equation means that the direction of canal transportation is in the direction of the first part of the equation (e.g in direction of A in example given), and a negative value for the equation means the direction of transportation is in the direction of second part of the equation (in the direction of B).

By using the aforementioned equation root canal transportation could be measured in eight directions: A, B , C, D, E, F, J, and H (Figure 6A). A result of up to 0.15 mm was considered acceptable root canal transportation as most rotary nickel-titanium instruments produce 0.15 mm or less. (Peters, 2004). A result greater than 0.30 mm at the apical end was unacceptable root canal transportation (Wu et al, 2000). Values between 0.15 and 0.30 transportation were considered as borderline root canal transportation.

The following formulas were used to determine the centering ability,

$CA = \frac{(A1-A2)}{(B1-B2)}, \frac{(C1-C2)}{(D1-D2)}, \frac{(E1-E2)}{(F1-F2)}, \frac{(G1-G2)}{(H1-H2)}$, or $\frac{(B1-B2)}{(A1-A2)}, \frac{(D1-D2)}{(C1-C2)}, \frac{(F1-F2)}{(E1-E2)}, \frac{(H1-H2)}{(G1-G2)}$ depending on the result of each equation, one of the formula will be used. For example if the result of $\frac{(A1-A2)}{(B1-B2)}$ is more than 1 that means $\frac{(B1-B2)}{(A1-A2)}$ must be used instead to get value between 0 and 1. $\frac{(A1-A2)}{(B1-B2)}$ represent the centering ability in direction 1, $\frac{(C1-C2)}{(D1-D2)}$ represents centering ability in direction 2, $\frac{(E1-E2)}{(F1-F2)}$ represents centering ability in direction 3 (direction vertical to curvature convexity) and, $\frac{(G1-G2)}{(H1-H2)}$ represents centering ability in direction 4. This formula measures the centering ability in four directions (Figure 6B). A result of 1 means optimal centering ability while a result of zero means the worst centering ability. The closer the result is to 1 the better the centering ability.

3.6 Statistical Analysis

The data used was numerical and so intra- and inter-observer agreement was assessed using Intra-Class Correlation Coefficient (ICC). For ICC values, less than 0.73 is considered not acceptable, 0.73 to 0.9 equals a good correlation, and more than 0.94 is considered excellent. Root canal transportation and centering ability results obtained using the two methods were subjected to preliminary tests to verify the normality of the distribution. The data were normally distributed and were analysed using a one-way ANOVA, using Stata Version 13.1 (Stata Corp LP, Lakeway Drive, College Station, Texas, USA). Where there was a statistically significant difference, the Tukey's multiple comparison *post-hoc* test was performed to show the site of the difference. A p value of <0.05 was considered statistically significant.

CHAPTER 4
RESULTS

The present study evaluated the working efficacy of two file systems: WOG files and PTN files. For the two file systems, a total of 48 specimens were evaluated; 24 specimens per system. Three X2 PTN files separated during the procedure, while no WOG files separated in this study. The teeth with the separated files were used as all three files broke after the full working length was reached. The average curvature of the root canals in the PTN group was 26.43° and 26.54° in the WOG group. The average radius of curvature in the PTN group was 5.49mm and 5.52mm in the WOG group.

4.1 Reliability Analysis

Inter-rater agreement was assessed using an intraclass correlation coefficient. ICC results showed excellent agreement between the two examiners who collected the data independently (Table 1).

Table 1: Intraclass correlation coefficient (ICC) for root canal transportation of rater 1 and 2.

Rater 1 and 2	**ICC**
WOG group	0.94
PTN group	0.91

4.2 Overall Transportation and Centering Ability

The mean values and standard deviations for root canal transportation and centering ability across the sections of each tooth are shown in Table 2. The mean for transportation with the PTN filing method was significantly higher than that observed in the WOG file system (0.0961 vs 0.0575 ($p<0.001$)).

Table 2: The mean values and standard deviations for centering ability and transportation across the tooth sections.

	Transportation (mm)		Centering ability (mm)	
	Mean	**SD**	**Mean**	**SD**
PTN	0.0961	0.0813	0.2448	0.2802
WOG	0.0575	0.0671	0.4286	0.3254

The mean centering ability with the PTN filing system was 0.2448 mm, whereas for the WOG it was 0.4286 mm. The centering ability was significantly affected ($p < 0.001$) by the filing system.

4.3 Transportation

The comparison between the transportation across the different virtual tooth sections cut at 3mm, 5mm and 7mm with both the PTN and WOG filing methods is shown in Table 3. The transportation was significantly different ($p < 0.001$) between the filing systems, with the PTN system having significantly higher values than in the WOG system at all levels. The amount of canal transportation increased significantly from the apical section of the tooth to the coronal section under both filing systems. The transportation was significantly affected ($p<0.001$) by both the filing method and the level at which the root canals were cut (Table 3).

Table 3: Comparison of the transportation between the two filing systems at various distances from the apex.

	Level of cutting (thickness)			
Filing method	3mm	5mm	7mm	p-values
PTN	0.0621 ± 0.0454	0.0956 ± 0.0753	0.1306 ± 0.9935	***p<0.0001***
WOG	0.0229 ± 0.0240	0.0566 ± 0.0451	0.0931 ± 0.0922	***p<0.0001***
p-values	***p<0.0001***	***p<0.0001***	***p=0.0073***	

Data are shown as mean ± SD. All the p-values written in bold mean that the values are significantly different

4.4 Centering Ability

The centering ability was significantly different ($p< 0.0001$) between the two systems, with the WOG method having a significantly greater value than the respective value in the PTN when measured at 3 mm, 5 mm and 7 mm (Table 4).

There were no significant differences ($p>0.05$) in the centering ability with the WOG filing system between the three different levels at which the root of each tooth was cut. However, there were significant differences ($p=0.0241$) in the centering ability with the PTN filing system between the three different levels at which the root of the tooth was cut. For the PTN system the centering ability at 7mm was significantly greater than the respective value measured at 3mm. There were no differences between the values obtained at 5mm compared to both 3 mm and 7 mm in PTN.

Table 4: Comparison of the centering ability between the two filing systems at various distances from the apex.

	Level of cutting			
Filing method	3mm	5mm	7mm	p-value
PTN	0.1858 ± 0.2389[a]	0.2538 ± 0.2986	0.2947 ± 0.2913[b]	***p= 0.0241***
WOG	0.4074 ± 0.3442	0.4302 ± 0.3381	0.4481 ± 0.2938	*p= 0.6873*
p-values	***p<0.0001***	***p=0.0002***	***p=0.0004***	

[a, b] Within a row, means without a common superscript differ at $P < 0.05$
Data are shown as mean ± SD.
All the p-values written in bold mean that the values are significantly different

4.5 Direction of Centering Ability

The comparison of the centering ability between the four directions at the three levels of cutting between the two filing systems is shown in Table 5. There were statistically significant differences ($p<0.01$) in the centering ability in direction 1 between the two filing methods, with the WOG filing system having significantly greater centering ability values than in the PTN system. In direction 2, the centering ability was statistically significantly different at 3 mm and 7 mm (both $p=0.0049$) with greater centering ability with the WOG files compared to the PTN filing system. There was no significant difference between the two systems at the 5mm level.

Table 5: Comparison of the centering ability between the four directions at the three levels of cutting between the two filing methods.

Directions	Level of cutting	**PTN**	**WOG**	*p-value*
1	3 mm	0.3144 ± 0.3095	0.6092 ± 0.2935	***p=0.0015***
	5 mm	0.2902 ± 0.2758	0.5615 ± 0.2947	***p=0.0019***
	7 mm	0.3248 ± 0.2454	0.5007 ± 0.2260	***p=0.0131***
2	3 mm	0.1542 ± 0.1972	0.3947 ± 0.3463	***p=0.0049***
	5 mm	0.3170 ± 0.3307	0.4128 ± 0.3099	*p=0.2906*
	7 mm	0.2631 ± 0.2834	0.4987 ± 0.2689	***p=0.0049***
3	3 mm	0.0825 ± 0.1532	0.2679 ± 0.3698	***p=0.0279***
	5 mm	0.1044 ± 0.1489	0.2505 ± 0.3551	*p=0.0695*
	7 mm	0.1659 ± 0.2417	0.2735 ± 0.2827	*p=0.1630*
4	3 mm	0.1921 ± 0.2195	0.3572 ± 0.2843	***p=0.0288***
	5 mm	0.3079 ± 0.3626	0.5048 ± 0.3067	***p=0.0481***
	7 mm	0.4360 ± 0.3292	0.5194 ± 0.3324	*p=0.3874*

Data are mean ± standard deviation. Statistical analysis was by one-way ANOVA
All the p-values written in bold mean that the values are significantly different

In direction 3, the centering ability was statistically different at 3mm (*p=0.0279*) only with a significantly higher centering ability for the WOG system compared to the PTN method. There were no statistically significant differences (*p>0.05*) at the 5mm and 7mm levels. In direction 4, the centering ability was statistically higher for the WOG system at 3mm (p=0.0288) and 5mm (*p=0.0481*) when compared to the PTN system but the centering ability was not statistically significantly different (*p>0.05*) at the 7mm level.

4.6 Magnitude of Canal Transportation

On assessing the magnitude of canal transportation in the eight different directions of the two file systems over three thickness levels of 3mm, 5mm and 7mm, the results showed significant differences between the WOG and PTN file systems. Multiple directions (A, C, E, G and H) were significantly different at 3mm; fewer (A, B and F) at 5mm and only one at 7mm (*B*) (Table 6). In other directions, the canal transportation was not significantly different ($p>0.05$).

Table 7 shows the differences in the root canal transportation between the opposing directions on the cross-section of a root. There were generally no differences in the magnitude of the root canal transportation between the two directions in the same plane under the PTN filing system. There were statistical significant differences in the WOG filing system at 5 mm with a significantly higher value for H versus direction G and at 7 mm with a significantly higher value for D versus direction C.

Table 6: Comparison between magnitude of root canal transportation in eight directions in PTN group and its corresponding directions in WOG group.

	3 mm			**5 mm**			**7 mm**		
	PTN	**WOG**	**p-value**	**PTN**	**WOG**	**p-value**	**PTN**	**WOG**	**p-value**
A	0.075 ± 0.048	0.023 ± 0.032	***0.0025***	0.116 ± 0.076	0.066 ± 0.040	***0.0271***	0.080 ± 0.059	0.011 ± 0.023	*0.2028*
B	0.032 ± 0.040	0.010 ± 0.018	*0.3545*	0.095 ± 0.055	0.043 ± 0.029	***0.0433***	0.186 ± 0.098	0.096 ± 0.099	***0.0115***
C	0.083 ± 0.046	0.033 ± 0.033	***0.0013***	0.088 ± 0.071	0.058 ± 0.042	*0.2085*	0.077 ± 0.081	0.054 ± 0.041	*0.4930*
D	0.037 ± 0.025	0.010 ± 0.012	*0.0570*	0.047 ± 0.045	0.067 ± 0.035	*0.2783*	0.151 ± 0.094	0.145 ± 0.107	*0.8711*
E	0.061 ± 0.034	0.018 ± 0.025	***0.0177***	0.091 ± 0.073	0.018 ± 0.030	*0.0819*	0.092 ± 0.117	0.079 ± 0.093	*0.7881*
F	0.035 ± 0.035	0.016 ± 0.014	*0.0756*	0.109 ± 0.089	0.042 ± 0.050	***0.0313***	0.116 ± 0.085	0.062 ± 0.060	*0.1238*
G	0.032 ± 0.022	0.012 ± 0.013	***0.0461***	0.046 ± 0.059	0.019 ± 0.014	*0.2036*	0.119 ± 0.114	0.097 ± 0.110	*0.6148*
H	0.060 ± 0.061	0.018 ± 0.016	***0.0315***	0.094 ± 0.091	0.078 ± 0.059	*0.5655*	0.061 ± 0.066	0.013 ± 0.026	*0.2590*

Data are mean ± standard deviation. Statistical analysis was by one-way ANOVA
All the p-values written in bold mean that the values are significantly different

Table 7: Comparison of the magnitude of root canal transportation in each opposing directions in PTN and WOG group.

	3 mm		**5 mm**		**7 mm**	
	PTN	**WOG**	**PTN**	**WOG**	**PTN**	**WOG**
A	0.075 ± 0.048	0.023 ± 0.032	0.116 ± 0.076	0.066 ± 0.040	0.080 ± 0.059	0.011 ± 0.023
B	0.032 ± 0.040	0.010 ± 0.018	0.095 ± 0.055	0.043 ± 0.029	0.186 ± 0.098	0.096 ± 0.099
p-values	*0.1107*	*0.4589*	*0.6071*	*0.1480*	*0.0507*	*0.2570*
C	0.083 ± 0.046	0.033 ± 0.033	0.088 ± 0.071	0.058 ± 0.042	0.077 ± 0.081	0.054 ± 0.041
D	0.037 ± 0.025	0.010 ± 0.012	0.047 ± 0.045	0.067 ± 0.035	0.151 ± 0.094	0.145 ± 0.107
p-values	*0.1081*	*0.2622*	*0.1553*	*0.5743*	*0.2102*	***0.0159***
E	0.061 ± 0.034	0.018 ± 0.025	0.091 ± 0.073	0.018 ± 0.030	0.092 ± 0.117	0.079 ± 0.093
F	0.035 ± 0.035	0.016 ± 0.014	0.109 ± 0.089	0.042 ± 0.050	0.116 ± 0.085	0.062 ± 0.060
p-values	*0.0941*	*0.8231*	*0.6095*	*0.3859*	*0.5841*	*0.6513*
G	0.032 ± 0.022	0.012 ± 0.013	0.046 ± 0.059	0.019 ± 0.014	0.119 ± 0.114	0.097 ± 0.110
H	0.060 ± 0.061	0.018 ± 0.016	0.094 ± 0.091	0.078 ± 0.059	0.061 ± 0.066	0.013 ± 0.026
p-values	*0.1676*	*0.4123*	*0.2381*	***0.0179***	*0.1827*	*0.2207*

Data are mean ± standard deviation. Statistical analysis was by one-way ANOVA. All the p-values written in bold mean that the values are significantly different

The frequency and direction of root canal transportation in each sector of the root canal using the PTN and WOG filing systems is shown in Table 8. Both filing methods caused more root canal transportation toward the outside than toward the inside of the curvature in the 3mm and 5mm sections. The 7mm level there was more canal transportation towards the inside of the curvature for both WOG and PTN filing systems than towards the outside of the curvature in the permanent teeth preparation. The percentage of transportation toward the outer surface of root canal curvature tend to be less as the level of cutting go coronally in both filing systems. (Table 8). The PTN filing system had a lower percentage of no transportation (4.2 to 8.3%) than the WOG filing system overall (8.3 to 33.3%). A frequency of 0 (indicated by column labelled none) was found to be higher under the sections prepared using the WOG than the PTN filing system at all three levels (Table 8).

Table 8: Frequency and direction of root canal transportation in each sector of the root canal associated with permanent teeth preparation using the PTN and WOG filing methods.

		PTN			**WOG**		
		Outside	**Inside**	**None**	**Outside**	**Inside**	**None**
3 mm	A – B	19 (79.2%)	4 (16.7%)	1 (4.2%)	12 (50.0%)	4 (16.7%)	8 (33.3%)
	C – D	21 (87.5%)	3 (12.5%)	-	14 (58.3%)	6 (25.0%)	4 (16.7%)
	E – F*	16 (66.7%)	8 (33.3%)	-	5 (20.8%)	15 (62.5%)	4 (16.7%)
	H – G	11 (45.8%)	11 (45.8%)	2 (8.3%)	12 (50.0%)	7 (29.2%)	5 (20.8%)
5 mm	A – B	20 (83.3%)	4 (16.7%)	-	15 (62.5%)	9 (37.5%)	-
	C – D	15 (62.5%)	8 (33.3%)	1 (4.2%)	12 (50.0%)	12 (50.0%)	-
	E – F*	10 (4.7%)	13 (54.2%)	1 (4.2%)	4 (16.7%)	12 (50.0%)	8 (33.3%)
	H – G	17 (70.8%)	6 (25.0%)	1 (4.2%)	15 (62.5%)	7 (29.2%)	2 (8.3%)
7 mm	A – B	4 (16.7%)	20 (83.3%)	-	2 (8.3%)	15 (62.5%)	7 (29.2%)
	C – D	3 (12.5%)	21 (87.5%)	-	11 (45.8%)	11 (45.8%)	2 (8.3%)
	E – F*	7 (29.2%)	16 (66.7%)	1 (4.2%)	13 (54.2%)	8 (33.3%)	3 (12.5%)
	H – G	9 (37.5%)	14 (58.3%)	1 (4.2%)	3 (12.5%)	13 (54.2%)	8 (33.3%)

N.B: The E – F (marked with an asterisk *) direction is considered to be neutral. Column labelled none indicates zero transportation.

CHAPTER 5
DISCUSSION

The aim of the present study was to compare the canal transportation produced by the PTN and WOG Ni-Ti derived filing systems used in extracted permanent teeth for preparing curved root canals. In the present study, freshly extracted teeth were used, since they more accurately mimic the clinical situation (Nagaraja and Murthy, 2010), unlike in studies that used simulated root canals. Apical, middle and coronal transportation and centering ability assessment were performed using micro-computed tomography.

5.1 Root Canal Transportation

Although, the results of this study show that the PTN filing system produces more canal transportation and poorer centering ability compared to the WOG filing system, the canal transportation obtained by PTN system was similar to that obtained by Silva et al., (2016) that ranged between 0.061 and 0.144 mm. In addition, this study is in agreement with the study done by Zhao et al (2014), and Zanesco et al (2017) with regards to amount of apical root canal transportation produced by PTN which was 0.62mm and 0.055 to 0.081mm respectively. Apical canal transportation of up to 0.15mm is acceptable and should not be greater than 0.30mm at the apical region of the tooth (Peters, 2004) as it negatively affects apical sealing and the resultant root canal treatment (Wu et al., 2000). The WOG system had lower canal transportation than the PTN at all the three levels that were compared. From the results obtained in this study, it appears that both systems are good, but the WOG system was better than the PTN system. In both the systems tested in this study the apical canal transportation is within the acceptable range and compares favourably with other studies, although this study does show that WOG had less root canal transportation than PTN.

This study is different from most studies in that it considered the canal transportation in eight root directions, and not only in one direction as done in several previous studies (Gergi et al., 2010; Gergi et al., 2014). Measurement in only one direction might not highlight other weaknesses that may come about during shaping. In this current study, the changes in the root canal were circumferentially investigated, whereas other studies only looked at specific area in one dimension. The examination in these eight directions allows for a wider scrutiny of the mechanical action of the file systems that were being tested. Table 8 shows that transportation occurred in all directions circumferentially and not limited to a single plane, as examined and shown in previous studies. Directions E and F which are 90° to A and B directions, showed considerable root canal transportation.

In the current study, the PTN showed lower average root centering ability (0.24) compared to the WOG which had a higher centering ability (0.43). The two filing systems had similar ranges of readings for both the centering ability (0.000 – 1.000) and root canal transportation (0.000 – 0.400). In the current study, the PTN filing system had more root canal transportation at all the three levels of root canal compared to the WOG filing system. The current results are similar to those reported by Maitin et al., who also demonstrated that the ProTaper had more root canal transportation in all the three regions of the root canal (Maitin et al, 2013). The difference in canal transportation may be attributed to the different kinematics used by each system and also the degree of dentin removed during canal preparation. Besides, these instruments have different tapers; X1 and X2 PTN have a progressive percentage increasing and decreasing taper and 6% tip taper while the WOG

Primary have 7% tip taper and variable taper over its length which may have affected the canal transportation in the apical section. The results of this study also agree with those reported by Tambe et al (2014) who demonstrated that the WaveOne files caused lesser canal transportation in the canal than the Rotary ProTaper (Tambe et al, 2014).

Tambe et al (2014) also noted that the crown-down technique using ProTaper rotary files gave less canal transportation which was attributed to instrumentation technique, and/or to the type and structure of the instruments (Tambe et al, 2014). The crown-down technique improves access for subsequent files but is somewhat dependent on the higher flexibility of Ni-Ti alloys (Ehsani et al., 2011). This superior flexibility decreases the risk of canal transportation in the process of enlarging the curved canals (Schäfer and Schlingemann, 2003). Indeed, it has been shown that ProTaper instruments may even be more effective in shaping narrow canals than wide canals (Peters et al., 2003). The reciprocating motion permits a more centralised chemo-mechanical preparation in comparison to continuous rotary motion, particularly in the apical third of the root canal (Berutti et al, 2012). Our study indicates that the direction of canal transportation in the 3mm and 5mm sections under both methods was toward the outside curvature while in 7mm section it was toward the inside of the curvature. The observation in the apical section corroborates previous studies that reported that the super-elasticity of the instruments allows them to follow the canal curvature (Taşdemir et al., 2005; Merrett et al., 2006; Pasternak-Júnior et al., 2009). The results of the current study are similar to those reported by Maitin et al, in which they compared the shaping ability of four different rotary endodontic instruments (Maitin et al 2013).

In the current study, the direction of transportation in the apical region was more toward the outside of root curvature. A similar direction was observed in previous studies (Tasdemir et al, 2005; Pasternak et al, 2009) that also noted the same inclination which may be attributed to the files flexibility that allowed the instrument to follow the canal curvature.

5.2 Centering Ability

The second parameter that was evaluated was centering ability, which indicates whether or not the dentine removal over the prepared area is spread evenly by the instrument. Good centering ability reduces the risk of transportation, zips, elbows, and other errors. Centering ability is, at least in part, determined by the flexibility of the Ni-Ti instruments. We found that the WOG filing system had superior centering ability compared with the PTN filing system, in all the three sections of the root canal. According to the formula that was used in the current study to calculate centering ability, a result value of 1 or closer to 1 shows perfect centering ability (Gambill et al., 1996) whereas the values closer to zero indicate poor centering ability. The good centering ability of WOG may be attributed to three factors, one is the reciprocating motion of the file, as reciprocal motion suggested to make the preparation of file more centred (Roane et al, 1985), second is the technique of using just a single file as instructed by the manufacturer. This technique involves gradual introduction of the working length of the file, where the file probably reaches the full working length after the coronal part is partially prepared by a file. The third factor is the flexibility of WOG due to the thermal treatment. Flexibility of a file makes it follow the root canal anatomy without considerable resistance. Although results on both systems were not low, it appears that the PTN filing method had a poorer centering ability compared to the WOG filing method. This could be because of the continuous rotation of PTN and the possible rigidity of the file.

The ability of an instrument/technique to remain centred within the natural canal path during preparation is regarded as a positive property that is essential for the provision of a correct enlargement, without weakening of the root structure (Kandaswamy et al., 2009). The results in the current study concur with the findings by Tambe et al (2014) who demonstrated that the WaveOne files remained better centred in the canal than the ProTaper files (Tambe et al, 2014). That could be because of the use of a reciprocation movement which was suggested to increase file centering (Roane et al, 1985). However, this is in contrast with McRay et al, who showed no significant difference between WaveOne (reciprocation) file and ProTaper Universal (continuous rotation) (McRay et al, 2014). This could be because WaveOne and ProTaper Universal files have similar design; taper and size.

The difference in WOG and PTN is that one is activated by reciprocating movement and the other by continuous rotary movement. These factors in conjunction with the tooth factors and high flexibility of the WOG filing system might have led to the differences in the measurements reported in this study as a result of the differences in the designs and flexibility of the instruments. Both filing systems, the PTN and WOG, are designed so that the centre of rotation and the centre of gravity are counterbalanced. However, the relatively long lifespan of WOG compared to that of PTN showed in this study could be explained in the following. The WOG filing system works in a reciprocating mode and completes preparing the root canal using only a single file. The WOG works based on a reciprocation movement at different speeds and angles. The engaging angle of the CCW motion is five times the disengaging angle of the CW motion and is designed to be less than the elastic limit of the file. The WOG reciprocating system comprises of biomechanical preparation involving a solitary file that presents greater elasticity and offers opposition to repeated fatigue compared with the conventional Ni-Ti alloy, due to treatment of the M-Wire alloy. On the other hand, the PTN rotary system has adjustable taper and stiffness due to the substantial quantity of metal in its structure (Barbosa-Ribeiro et al., 2015) and these factors might reduce its use in curved and flattened root canals. This is attributable to the likelihood of the instrument locking in the cervical third and might not properly contact the dentinal walls (Park et al., 2014). Furthermore, their active part has little difference in taper, and that might give clinicians greater control of the instrument (Bürklein et al., 2012; Castelló-Escrivá et al., 2012; Basmaci et al., 2013; Versiani et al., 2013). Comparison of the PTN file systems that performs a continuous rotation and the WOG that uses the reciprocation systems shows that the files that perform a reciprocation movement reduces stress on file by rotating in CCW direction before completing the cycle in CW direction and this movement has been reported to improve the files' fatigue life. The improved fatigue life can be explained by the fact that reciprocating rotation decreases the number of rotations of files.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

From the results of this study, the WOG filing system had better outcomes, as measured by less transportation and better centering ability, compared to the PTN filing system Although none of the systems used in this study had perfect centering, the WOG filing system showed a mixture of both good and poor centering ability while the PTN system had lower values.

Furthermore, this study evaluated the teeth in eight directions and thus allowed for a more accurate examination of the tooth sections after preparation with either file system. Overall the WOG filing system had better outcomes for root canal transportation and the centering ability that were evaluated compared to the PTN filing system.

Because this study was in agreement with other studies which indicated that Primary size of WOG file had a high cyclic fatigue resistance compared to other Ni-Ti files, this study recommends the use of the WOG Primary or smaller size file in severely curved root canals to get better shaping and centering ability, and to avoid file fracture. Further studies are needed to evaluate root shaping ability of larger sizes of WOG files because larger sizes of WOG are supposed to have different flexibility than the Primary size.

Limitations

The processes of tooth superimposition took a significant part of the data collection time. This was due to the time taken to fulfil the prerequisites for superimposition using surface determination tool. Some teeth could not be precisely superimposed using the best fit registration tool, which is an automatic tool to get superimposition of two images. So simple registration had to be used instead, which is a manual superimposition tool. Although this study used a relatively wide range of root lengths and root canal curvature radius, it was able to detect differences between the two filing systems. Unfortunately, comparing the cyclic fatigue resistance and the flexibility of PTN and WOG were not within the scope of this study. If it was done it would have given more information about the cause of differences between WOG and PTN performance. This study used mixed maxillary and mandibular root canals, However, maxillary first molar mesial canals are preferred because they have more rounded cross section and do not have anastomosis.

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APENDIX A

AETHICS WAIVER CERTIFICATE

R14/49 Dr Adulrzag Gajoum

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160262

NAME: **(Principal Investigator)**	Dr Adulrzag Gajoum
DEPARTMENT:	School of Oral Health Sciences University of the Witwatersrand
PROJECT TITLE:	Comparison Between Root Canal Transportation of Waveone® Gold and Protaper Next® Files, Using Micro-Computed Tomography
DATE CONSIDERED:	26/02/2016
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Saida Tootla, Dr Ebrahim Patel and Dr Ismail Munshi
APPROVED BY:	Professor P. Cleaton-Jones,Chairperson, HREC (Medical)
DATE OF APPROVAL:	14/03/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004, 10th floor, Senate House/2nd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature ____________ Date ____________

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX B

FACULTY 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

06 January 2017
Person No: 917040
PAG

Dr A Gajoum
404 Juliana court 4 princess place, Parktown
Parktown
2193
Libyan Arab Jamahiriya

Dear Dr Gajoum

Master of Science in Dentistry: Approval of Title

We have pleasure in advising that your proposal entitled *Comparison between root canal transportation of Waveone Gold and Protaper Next files, using micro-computed tomography* 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

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences