Comparison of Canal Transportation and Centering Ability of K-files, the ProGlider file and G-Files: A Micro-Computed Tomography Study of Curved Root Canals

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'You must live life with the full knowledge that your actions will remain. We are creatures of consequence.'

Zadie Smith

Declaration

I Farzana Paleker, declare that this dissertation entitled **"Comparison of Canal Transportation and Centering Ability of K-files, the ProGlider file and G-Files: A Micro-Computed Tomography Study of Curved Root Canals"**, which I herewith submit to the University of Pretoria in partial fulfilment of the requirements for the degree MSc (Odont) is my own original work, and has neither been submitted for any academic award to this University, nor to any other institution of higher learning.

20 July 2015

SIGNATURE **DATE**

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Abbreviations

º	-	Degree/s
ºC	-	Degrees celsius
%	-	Percentage
2D	-	Two-dimensional
3D	-	Three-dimensional
ANOVA	-	Analysis of Variance
B	-	Buccal
CT	-	Computed tomography
D	-	Distal
D1	-	1 mm from the apical foramen
D_{mc}	-	At the point of maximum curvature
D7	-	7 mm from the apical foramen
DL	-	Distolingual
DB	-	Distobuccal
Fig	-	Figure
ISO	-	International Organization for Standardization
kg	-	Kilogram
M	-	Mesial
MB	-	Mesiobuccal
ML	-	Mesiolingual
M-wire	-	Memory nickel-titanium wire
mm	-	Millimetre/s
MIXRAD	-	Micro-focus X-ray Radiography and Tomography Facility
NiTi	-	Nickel-titanium
n	-	Number/s
Ncm	-	Newton per centimetre
NECSA	-	South African Nuclear Energy Corporation
rpm	-	Rotations per minute
s	-	Second/s

Summary

The aim of this *in vitro* study was to investigate the canal centering ability and apical root canal transportation of pre-curved stainless steel K-files, the ProGlider file and G-Files after glide path enlargement in curved root canals of extracted human mandibular molars using micro-CT scanning. The working times for the different glide path enlargement methods were also recorded.

Ninety untreated curved root canals from extracted molars were randomly divided into three groups (n = 30). Group 1: manual glide path preparation with size 0.10 K-file and enlargement with size 0.15 and 0.20 hand K-files; Group 2: manual glide path preparation with size 0.10 K-file and enlargement with NiTi rotary G-Files; and Group 3: manual glide path preparation with size 0.10 K-file and enlargement with the NiTi rotary ProGlider file (ISO tip size 16).

Micro-computed tomography was used to scan the teeth before and after glide path enlargement. Three-dimensional images were reconstructed from the pre- and post-instrumentation scans to enable a comparison of the centring ability at three selected levels: 1 mm from the apical foramen (D1), at the point of maximum root curvature (D_{mc}) and 7 mm from the apical foramen (D7). Canal transportation was assessed at 1 mm from the apical foramen in eight directions (MB, B, DB, D, DL, L, ML, M). The time it took to enlarge the glide paths for each group was also calculated. One-way Analysis of Variance was performed to assess if significant differences existed between the three groups for the variables being compared ($p<0.05$). A Bonferroni adjusted p value of 0.016 was used for pairwise comparisons of centring ability.

K-files displayed statistically significantly higher centering ratios than G-Files at D1. At all levels the ProGlider file exhibited statistically significantly lower centering ratios than K-files. At D_{mc}, the ProGlider file demonstrated statistically significantly lower centering ratios than G-Files. Ratios were significantly similar between K-files and G-Files at D7 as well as between G-Files and the ProGlider file at D7 ($p<0.016$). Apical canal transportation for K-files was significantly more than G-Files in five directions and the ProGlider file in six directions ($p<0.05$). Glide path enlargement time for K-files was significantly slower (74.92 s ± 2.60 s) than G-Files (41.87 s ± 20.19 s) and the

ProGlider file (27.95 s ± 8.55 s)($p<0.05$). There was no statistically significant difference between glide path enlargement times of G-Files and the ProGlider file.

Findings suggest that NiTi rotary glide path files are suitable for safe glide path enlargement because they cause less apical canal transportation than stainless steel hand K-files. Of the two NiTi rotary glide path file groups, the ProGlider file showed an overall significantly better centering ability around the entirety of the original canals, particularly at the point of maximum curvature. Glide path enlargement with the NiTi rotary glide path file groups was significantly faster than K-files ($p<0.05$).

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Chapter 1: Introduction and Literature Review

1.1. The Objectives of Endodontics

Biomechanical instrumentation of the root canal system during root canal treatment is essential for the prevention and elimination of apical periodontitis (Berutti et al. 2004). It is well established that intra-radicular microbial infection is the primary cause of apical periodontitis (Kakehashi, Stanley and Fitzgerald, 1965; Moller et al. 1981). Technically, the goal of endodontic instrumentation is to remove all necrotic and vital pulp tissue along with heavily infected radicular dentine as well as the microorganisms that infect this space. Cleaning and shaping principles must aim to respect the continuously tapering funnel from the coronal access cavity to the root apex, follow the original canal shape, and maintain the apical foramen in its original spatial relationship to the peri-apical tissues and root surface (Schilder, 1974). Instrumentation shapes the root canal to facilitate improved irrigation and obturation to a high technical standard (Haapasalo et al. 2005).

1.2. The Use of Nickel-Titanium in Endodontics

Nickel-titanium (NiTi) rotary files are manufactured from the NiTi alloy and were first introduced for endodontic procedures in 1988 (Walia, Brantley and Gerstein, 1988). Prior to the advent of NiTi files, stainless steel files were used for canal shaping. The exclusive use of stainless steel files in curved root canals and at the apical foramen has been shown to cause procedural errors such as canal straightening, zipping, elbow formation, perforation and instrument separation. These mishaps have been ascribed to the rigidity of the instruments (Pettiette et al. 1999). Nickel-titanium files have been shown to significantly decrease errors such as canal transportation and deviation from the canal axis during preparation when compared to manual techniques, particularly in the apical area of the curved canal (Setzer, Kwon and Karabucak, 2010). These instruments allow for consistent and efficient canal shaping with relatively few instruments (Glosson et al. 1995; Thompson and Dummer, 1997).

Despite the advantages of using NiTi rotary instruments, instrument separation is the most frequent procedural accident observed during their clinical use. The extreme flexibility and non-cutting tips of NiTi files make them unsuitable for initial negotiation of the root canal (Peters, Peters and Scho, 2003).

1.3. Initial Canal Negotiation

Negotiation and glide path enlargement are the initial phases of chemo-mechanical procedures and can be regarded as essential steps for assessment of the root canal anatomy. The endodontic glide path can be defined as a smooth radicular tunnel from the orifice of a root canal to the physiologic terminus of a root (Berutti et al. 2004). An established glide path minimises torsional and bending stresses of subsequent shaping files.

Instruments used for initial canal negotiation should ideally be of small size and flexible to permit their progression in an apical direction with safety and efficiency (Lopes et al. 2011; Allen, Glickman and Griggs, 2007). An initial brief manual instrumentation enables torsional stress to be drastically reduced because the canal width becomes at least equal to the diameter of the tip of the next instrument to be used (Berutti et al. 2004). It also provides the clinician with an understanding of the original canal anatomy (Berutti et al. 2004). Initial negotiation of canals can be facilitated by the use of flexible hand files. These files have a triangular cross-section and are more flexible than those with square cross-sections. Flexible stainless steel hand files are generally used in easily negotiated canals. Clinician preference dictates whether to use flexible stainless steel files or NiTi hand instruments (Mounce, 2013). Nickel-titanium hand instruments include Mani Flexible Files (Mani, Tochigi-ken), Lexicon Flex SSK Files (Dentsply/Maillefer, Ballaigues, Switzerland), Flexofile and Senseus ProFinder (Dentsply/Maillefer).

Dodds, Holcomb and McVicker (1985) outlined helpful hints in finding, instrumenting and negotiating small canals. They emphasised the use of multiple good-quality radiographs as well as making sufficient access openings for proper visualisation. Others have provided systematic approaches for negotiation of constricted canals, including coronal pre-flaring in conjunction with copious irrigation and ample lubrication (Stabholz, Rotstein and Torabinejad, 1995; Buchanan, 1989; Allen and Whitworth, 2004).

1.4 Challenges during Canal Negotiation

The clinician may incur procedural difficulties during the initial canal scouting and pre-flaring (Kobayashi, Yoshioka and Suda, 1997). Negotiation and assessment of long, thin curved canals and canals with multi-planar curvatures can be especially challenging (Buchanan, 1989; Allen and Whitworth, 2004; Schilder, 1974). Further complications may occur as a result of flexural stresses resulting from canal curvature and cannot be significantly influenced by the clinician (Jafarzadeh and Abbott, 2007; Peters and Paqué, 2010). As a result, difficulties may arise whilst attempting to achieve this negotiation path (Jafarzadeh and Abbott, 2007). Both hand file and NiTi instrumentation can create procedural errors that include instrument fracture, canal zipping or transportation, elbow formation, damage to the apical foramen, ledge formation, perforation and apical blockage (Cunningham and Senia, 1992; Hülsmann, Peters and Dummer, 2005; Walia et al. 1988). When instrumenting curved canals, the incidence of procedural errors increases, especially if stainless steel files are used (Pettiette et al. 1999). These complications are often difficult and sometimes impossible to overcome and can lead to incomplete debridement of the root canal system and risk of subsequent endodontic failure (Hülsmann et al. 2005).

1.4.1. Ledging

Ledging may occur because of preparation of a curved root canal using inflexible instruments with sharp, inflexible cutting tips particularly when they are used in a rotational motion. A ledge occurs as a platform on the inside of the greater curvature and may be difficult to bypass (Hülsmann et al. 2005). It may form in the original canal path or create a new false canal (Lambrianidis, 2009). The presence of a ledge can result in blockage of the apical part of the root canal, incomplete instrumentation and disinfection of the root canal system and incomplete obturation of the canal. The root canal space apical to the ledge is difficult to thoroughly clean and shape and therefore reduces the possibility of achieving an adequately shaped canal preparation that reaches working length. Ledges frequently result in ongoing peri-apical pathosis after the endodontic treatment. A causal relationship may exist between ledges and unfavourable endodontic treatment success (Jafarzadeh and Abbott, 2007).

1.4.2. Perforation

A perforation is a passage created through the root canal wall that is associated with the destruction of cementum and the irritation and/or infection of the periodontal ligament in the corresponding area. A perforation of a curved root canal wall may also occur because of preparation with inflexible instruments with sharp cutting tips that are used in a rotational motion. This type of defect is difficult to seal and can result in a part of the original root canal remaining unprepared if it is not possible to bypass the perforation to reach the original root canal (Hülsmann et al. 2005). A strip perforation results from over-preparation and straightening along the inner wall of a curved root canal. A study by Plotino et al. (2007) found an increased risk of strip perforation on the concave aspect of the curved roots following excessive coronal flaring. The mesiobuccal roots of maxillary molars and mesial roots of mandibular first molar are vulnerable to strip perforation at around 2 mm below the furcation particularly at their distal aspect (Kessler, Peters and Lorton, 1983; Allam 1996). The root walls facing the furcal aspect of roots are often extremely thin and are therefore termed 'the danger zone' (Hülsmann et al. 2005).

1.4.3. Transportation

According to the Glossary of Endodontic Terms (American Association of Endodontists, 2012, p.49) canal transportation is defined as 'Removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation; may lead to ledge formation and possible perforation.' The main axis of the root canal is transported and there is deviation of the canal from its original axis. Canal transportation is also referred to as 'canal straightening' and 'zipping' (Hülsmann et al. 2005). Stainless steel files have a high stiffness that increases with increasing instrument size and causes high lateral forces in curved canals (Craig, McIlwain and Peyton, 1968). This stiffness is responsible for straightening the canal and resulting changes in the apical, middle and coronal third of the canal (Craig et al. 1968; Alodeh, Doller and Dummer, 1989). Lam et al. (1999) found that apical and mid curve transportation increased with an increase in file size; they also found a significantly greater deviation in the apical area after using ISO size 0.25 hand files. Canal transportation in a curved canal can result in elbow formation. An elbow is a narrow region of the root canal at the point of maximum curvature. This region can occur between an irregular widening along the inner wall coronal to the curve and along the outer wall apically of the curve. The irregular taper and flow associated with elbow may jeopardise cleaning and filling the apical part of the root canal (Hülsmann et al. 2005).

Incorrect working length determination, straightening of curved root canals and over-extension and over-preparation of the root canal can cause transportation and enlargement of the apical foramen. Apical canal transportation compromises the apical seal (Wu, Fan and Wesselink, 2000). Lack of an apical stop may result in extrusion of irrigants and/or obturation materials and cause irritation to the peri-radicular tissues (Hülsmann et al. 2005; Schäfer and Dammaschke, 2009).

1.4.4. Apical Blockage

Apical blockage of the root canal occurs because of tissue or debris collection and results in a loss of working length and of patency of the canal. As a consequence complete disinfection of the most apical portion of the root canal system may become impossible (Hülsmann et al. 2005).

1.4.5 Instrument Stresses and Canal Anatomy

In clinical practice, NiTi instruments are associated with a risk of fracture, mainly because of flexural (bending) stresses and torsional (shear) stresses (Berutti et al. 2003; Parashos and Messer, 2006). In most clinical situations the breakage of the instrument occurs in the apical third of the canal and the remaining portion is often difficult to remove (Berutti et al. 2003; Peters, 2004). The fragment that remains blocks the root canal system and impedes adequate cleaning, shaping and sealing (Haikel et al. 1999). The NiTi rotary instrument rotates continually within the root canal system and its durability is directly proportional to the working stress it undergoes (Yared et al. 1999; Gambarini, 2001). This is closely related to the number of cycles performed (Pruett, Clement and Carnes, 1997). Flexural stress depends on the original anatomy of the canal and therefore cannot be influenced significantly by the clinician. Although flexural stress is most significant in terms of fatigue, excessive torsional stress is the main cause of instrument breakage (Sattapan et al. 2000).

Torsional failure might occur in case of shear stresses exceeding the elastic limit of the alloy, producing plastic deformation and eventually fracture (Parashos and Messer, 2006). Torsional stresses can be avoided by careful clinical considerations and instrument choice. Factors that contribute to an increase in stresses include excessive pressure on the handpiece (Kobayashi et al. 1997); a wide area of contact between the canal walls and the cutting edge of the instrument (Peters et al. 2003); or if the canal section is smaller than the dimension of the non-active or non-cutting tip of the instrument (Blum et al. 1999).

1.5. The Importance of Glide Path Enlargement

Once established, a successful glide path permits unrestricted access to the apical part of the canal (Peters and Peters, 2010) and it also allows for an understanding and appreciation of the original anatomy (Berutti et al. 2004). According to West (2010), the minimal size of the glide path should be a 'super loose number 10' endodontic file. He further states that the glide path must be discovered if already present in the endodontic anatomy or prepared if it is not present. Coronal enlargement and manual or mechanical glide path enlargement allow for safer use of NiTi rotary shaping instruments because it decreases the fracture risk of torsion instruments as well as shaping aberrations (Berutti et al. 2004).

Glide path enlargement generally reduces the contact of the instrument with the root canal walls, rendering the canal patent to receive the rotary files and thereby permits a more effective and safer action (Knowles et al. 2006; Berutti et al. 2004). A glide path that is smooth and centred from its orifice to the physiologic terminus (Peters and Koka, 2008) will enable further shaping of the root canal with NiTi instrumentation (Di Fiore, 2007) because it allows for the tip of the rotary instrument to follow (Ruddle, 2005; Patiño et al. 2005). Ultimately, the glide path ensures that the root canal diameter is larger than or equal to the size of the tip of the first rotary instrument used (Berutti et al. 2004). An established glide path allows for predictable radicular cleaning and shaping to follow and therefore must be the starting point of all root canal preparations.

Various studies have illustrated the benefits of glide path formation (Roland et al. 2002; Nahmias, Cassim and Glassman, 2013; Berutti et al. 2012; Berutti et al. 2004). In a study by Patiño et al. (2005), the breakage rate of shaping systems K3 (Kerr Europe, Herts, UK), ProFile (Dentsply/Maillefer) and ProTaper (Dentsply/Maillefer) were compared. They found a breakage rate of only 12% amongst the shaping systems used after manual glide path enlargement, compared to 26% in a previous study where shaping commenced without glide path enlargement (Martin et al. 2003). They used size 0.10-0.20 stainless steel K-files to prepare a sufficiently wide and smooth-walled glide path in the apical third of the canal, before introducing rotary files to the working length. They concluded that the significant decrease in file separation was because of the glide path, which reduced the risk of stress and binding along the canal during subsequent, shaping.

These findings are in line with those of Roland et al. (2002) who also examined the influence of glide path enlargement on the rate of NiTi file fracture. They demonstrated that glide path enlargement of the canal followed by rotary instrumentation resulted in a lower rate of separation than the technique recommended by the manufacturer. According to these authors, the procedure reduces the risk of fatigue and instrument locking along the root canal walls, and thereby possible separation (Wolcott et al. 2006; Knowles et al. 2006; Iqbal, Kohli and Kim, 2006; Diemer and Calas, 2004). A clinical study by Ehrhardt et al. (2012) showed a low rate of instrument separation of the Mtwo (VDW, Munich, Germany) rotary system when preceded by cervical pre-flaring with stainless steel K-files and Gates-Glidden burs.

In a separate study examining canal curvature and axis modification following the WaveOne single-file reciprocating system (Dentsply/Maillefer) in Endo Training Blocks, with and without glide path Berutti et al. (2012) observed that fewer pecking motions were needed to reach full working length with WaveOne files where a prior glide path was performed. They also found that the absence of a previous glide path affected the performance of WaveOne NiTi files by altering the canal curvature considerably more than WaveOne files used following an established glide path. A study by Berutti et al. (2004) examining ProTaper S1 (Dentsply/Maillefer) showed that manual glide path enlargement avoided the tip of S1 developing torsion on entering a canal region with a small cross-sectional diameter. This large reduction in torsional stress increased the average instrument life by almost six-fold.

1.6. Glide Path Enlargement Techniques

1.6.1. Stainless Steel K-files Manual

A number of authors have recommended using stainless steel K-files (Fig. 1.1) for manual glide path enlargement (Berutti et al. 2004; Walsch, 2004; West, 2006; Mounce, 2005). According to West (2006) stainless steel K-files, which have a constant 2% taper, should be used in a vertical in-and-out motion with initial amplitudes of 1mm, gradually increasing as the dentine wall wears away and the file advances apically. West (2010) recommends a 'watch-winding' motion to remove restrictive dentine in very narrow canals. This 'watch-winding' motion is described as the back-and-forth oscillation of a file (30° to 60°) clockwise and counter-clockwise as the instrument is pushed apically into the canal.

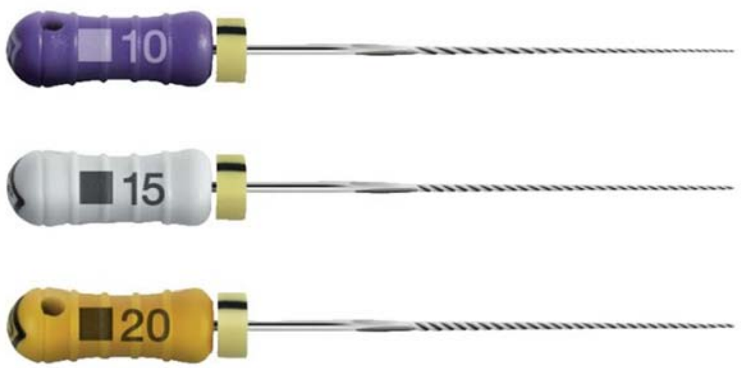

Figure 1.1: Stainless steel K-files sizes 0.10 (purple), 0.15 (white), 0.20 (yellow)

Roane, Sabala and Duncanson (1985) described the 'balanced force' motion technique to reduce the risk of ledge formation when using file sizes 0.15 and larger. This involves turning the handle of the file clockwise, and then turning it counter-clockwise using slight apical pressure so that the file does not 'unscrew' its way out of the canal. The clockwise motion allows the blades of the file to cut into the dentine while the loose dentine is collected into the file's flutes during the apical counter-clockwise motion. This motion can be repeated several times as the file is advanced apically. After having carved a wider glide path the file is turned clockwise and removed (West, 2010).

Schilder (1974) recommends using pre-curved hand instruments for curved canals. A 'watch-winding' motion here creates an 'envelope of motion' when the curved file is advanced into the canal short of maximum resistance, then removed while simultaneously being rotated in a clockwise direction, The rotation of the curved file as it is withdrawn from the canal gradually widens the canal creating an 'envelope of motion' that allows larger files to follow (West, 2010). This technique facilitates the suspension of debris in the irrigation solution (Ruddle, 2008).

Both Schilder (1974) and West (2010) emphasise the importance of following the canal rather than forcing the file apically through any obstructions. The file should be withdrawn in 1 mm increments from 1 mm to 5 mm and the clinician should ensure that the file can slide to working length after each increment to confirm the glide path (Van der Vyver, 2011). According to West (2010), a glide path is present when a size 0.10 K-file fits loosely in the canal. According to Van der Vyver (2011), a size 0.15 or 0.20 K-file should slide easily to working length without the need for rotation.

The advantages of using stainless steel K-files compared with rotary NiTi files for enlarging the glide path include improved tactile sensation; decreased risk of file fracture (Mounce, 2005) and decreased cost. Stainless steel K-files also provide an appreciation of curvatures in the anatomy when a file that is removed from a canal maintains the canal shape (Berutti et al. 2004; Jerome and Hanlon, 2003; Van der Vyver, 2011). The stiffness of stainless steel K-files allow for negotiation of canal blockages and calcifications (Young, Parashos and Messer, 2007; Mounce 2005) and there is no need for a dedicated handpiece (Cassim and Van der Vyver, 2013a). The disadvantages of enlarging a glide path with hand instruments include operator and hand fatigue; increased enlargement time (Berutti, et al. 2009); risk of canal aberrations with the use of larger file sizes (West, 2010); greater change to the original canal anatomy (Pasqualini et al. 2012); and increased apical extrusion of debris (Greco, Carmignani and Cantatore, 2011).

In two separate studies, three different NiTi rotary instruments were used following the sequences suggested by the manufacturer, at three different rotational speeds (150, 250 or 350 rpm) to instrument canals with an angle of curvature less or greater than

30º (Martin et al. 2003; Zelada et al. 2002). The rotary instruments included K3 files (SybronEndo, Orange, USA), ProFile (Dentsply/Maillefer) and ProTaper (Dentsply/Maillefer). No breakages occurred in canals with a curvature of less than 30º. These results suggest that the risk of breakage increases as the angle of curvature of the canal increases, and that rotational speed is also relevant. These findings are in line with the previous results of Uei-Ming et al. (2002) who established that fracture time decreases when the operating rpm and/or angles of curvature increase.

A study by Tygesen, Steiman and Ciavarro (2001) examined the fracture of NiTi rotary instruments in the apical third of canals with an angle of curvature greater than 30° after a glide path had been enlarged with stainless steel K-files. They found that all instrument breakages occurred in the apical portion of the canal, a few millimetres from the tip of the file. Similar observations were made by Martin et al. (2003) who found a breakage rate that was significantly lower than in previous investigations by the same authors (Zelada et al. 2002) where similar canals were shaped without prior glide path enlargement. They attributed the decreased breakage rate to the glide path enlargement procedure, which reduces the risk of stress and binding along the canal. These findings are in line with those of other authors (Roland et al. 2002).

1.6.2. Stainless Steel K-files Reciprocation

Reciprocation is a technique whereby the clinician can use a reciprocating handpiece attachment to replicate manual hand file watch winding. K-files are mounted in a reciprocating handpiece (Fig. 1.2) to prepare the glide path (Mounce, 2008; Kinsey and Mounce, 2008). Clinically, reciprocation is used after the canal has been negotiated to the working length by hand using a small size K-file. Reciprocation proceeds with the first file that binds at working length.

Figure 1.2: The M4 Safety Reciprocating Handpiece (SybronEndo) with a size 0.08 stainless steel K-file attached

According to Mounce (2013), this technique is especially helpful in early enlargement of calcified canals, particularly the second MB canal of upper molars. The handpiece is then moved vertically up and down, with amplitudes of 1 mm to 3 mm and bursts of reciprocation for approximately 15 to 30 seconds in each root canal. Sequentially larger size K-files (0.06 to 0.10) are inserted to just beyond the apical constriction to reduce the risk of blockage. Due to the relative stiffness of a size 0.20 K-file, van der Vyver (2011) recommends placing this file 1 mm short of the apex during this method of glide path enlargement to avoid apical transportation.

Reciprocation is also valuable for rubbing out iatrogenic ledges. Once the stainless steel K-file can negotiate around the ledge, it is left in place and reciprocated as suggested by Mounce (2013). The M4 Safety Reciprocating Handpiece (SybronEndo) and Endo-Express Reciprocating Handpiece (Essential Dental Systems, NJ, USA) have a 30° equi-angle arc of reciprocation. The NSK Ti-Max Ti35L 10:1 Reciprocating Handpiece (NSK, Nakanishi, Japan) has a 90° angle of reciprocation.

The advantages of using a stainless steel K-file in a reciprocating handpiece for glide path enlargement include a reduction in preparation time; reduced operator and hand fatigue; and reduced risk of instrument separation compared with rotary NiTi methods (Kinsey and Mounce, 2008). The disadvantages include the need for a dedicated handpiece; risk of apical transportation with files larger than a 0.15 K-file

(Van der Vyver, 2011); risk of excess dentine removal as a result of the clinician instrumenting the canal longer than necessary (Wagner et al. 2006); risk of apical extrusion of debris if the handpiece is forced apically (Kinsey and Mounce, 2008); and decreased tactile sensation.

A recent study by Cassim and Van der Vyver (2013b) compared modification of canal curvature and the incidence of canal aberrations after glide path enlargement with stainless steel K-files used manually, stainless steel K-files used in a reciprocating M4 Safety Reciprocating Handpiece, rotary NiTi PathFiles (Dentsply/Maillefer) and X-Plorer Navigation files (Clinician's Choice Dental Products Inc., New Milford, USA). The first part of the study used a quantitative analysis through observation of changes between pre-instrumentation and post-instrumentation curvature. The stainless steel K-files in the M4 Safety Reciprocating Handpiece performed better in maintaining the canal curvature compared to their use by hand only. The improved performance of the stainless steel K-files in the reciprocating handpiece was attributed to the smaller arc of reciprocation of the handpiece (30°) compared to the quarter turn-and-pull motion employed during hand filing (90°). The second part of the study comprised a qualitative observation of any canal aberrations. The use of stainless steel K-files by hand resulted in the highest number of canal aberrations compared to stainless steel K-files used in the M4 reciprocating handpiece. The ledges created with stainless steel K-files by hand were located between the apical curvature and the foramen, while the ledges created with hand K-files in the M4 Safety Reciprocating Handpiece were located between the coronal and apical curves. This difference in position of the ledges was attributed to keeping the M4 Safety Reciprocating Handpiece stationary for a prolonged period at a particular position along the length of the canal or repeatedly taking it to a particular length with the vertical amplitude of motion. The PathFile and X-Plorer Navigation file groups performed significantly better than the K-files in the M4 Safety Reciprocating Handpiece. Both the NiTi rotary glide path systems used exhibited significantly less canal curvature modifications and aberrations.

1.6.3. PathFiles (Dentsply/Maillefer)

PathFile NiTi rotary files (Dentsply/Maillefer) were introduced to the market in 2009 specifically for the purpose of glide path enlargement. The system consists of three instruments that are available in 21 mm, 25 mm and 31 mm lengths. They have a square cross-section and a 2% taper, which make them resistant to cyclic fatigue, ensure flexibility and improve cutting efficiency. The tip angle is 50° and is non-cutting thereby reducing the risk of ledge formation. PathFile no.1 (purple) has an ISO 13 tip size, PathFile no.2 (white) ISO 16 tip size and PathFile no.3 (yellow) has an ISO 19 tip size (Fig. 1.3). The gradual increase in tip size facilitates progression of the files. The manufacturer suggests using the PathFile no.1 only after a size 0.10 stainless steel K-file has been used to explore the root canal to working length (Berutti et al. 2009). The use of a small size stainless steel K-file followed by a more flexible and less tapered NiTi rotary PathFile might be a less invasive and safer method to enlarge a glide path that better maintains the original canal anatomy, compared with manual glide path enlargement performed with stainless steel K-file.

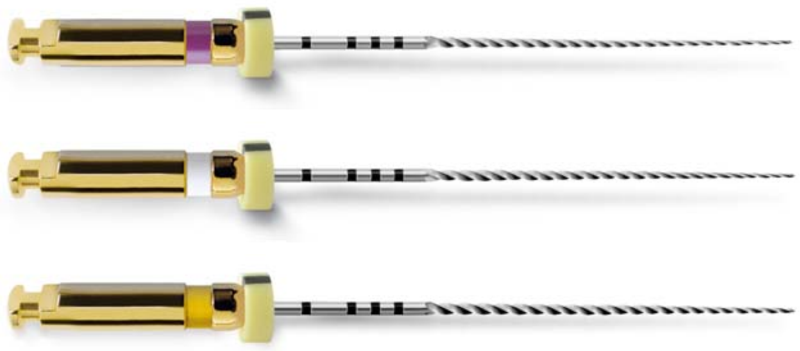

Figure 1.3. PathFile no.1 (purple), PathFile no.2 (white) and PathFile no.3 (yellow) (Dentsply/Maillefer)

A comparison of the flexibility and torsional resistance of rotary NiTi PathFile, RaCe ISO 10 (FKG Dentaire, La Chaux-de-Fonds, Switzerland), Scout RaCe (FKG Dentaire) and stainless steel K-file hand instruments showed results that displayed the superior flexibility of NiTi instruments (Nakagawa et al. 2014). This result indicated that the use of NiTi rotary glide path instruments could more effectively obtain the glide path with subsequent maintenance of the original path during instrumentation of curved root canals. PathFiles were the most flexible and the least torque-resistant compared with Scout RaCe and RaCe ISO 10 instruments, whilst the stainless steel instruments were the least flexible. They were however more torque-resistant than the NiTi rotary glide path instrument. The first stage of the study comprised a quantitative analysis through observation of changes between pre-instrumentation and post-instrumentation curvature followed by a qualitative observation of any canal aberrations. The experimental method used appeared to be reliable in representing changes in canal curvature and for extrapolating the results. PathFile produced significantly less modification in the coronal and apical canal curvature and fewer canal aberrations compared with manual glide path enlargement with stainless steel K-files. Nakagawa et al. (2014) proposed that PathFiles displayed a superior respect for the original canal anatomy when compared to the other instruments tested.

A separate study by Pasqualini et al. (2012) used micro-computed tomography (micro-CT) to examine curved root canals where glide paths were prepared to full working length using PathFiles and stainless steel K-files. Scans were performed before treatment and again after treatment. Scan analyses focused on observable changes at the apical level and at the point of maximum curvature level. Canal modifications were statistically significantly reduced in the PathFile group when compared with the stainless steel K-file group. These researchers concluded that PathFiles have a higher root canal centering ability, cause fewer modifications of the canal curvature and fewer canal aberrations, and therefore maintain the original canal shape considerably better than stainless steel K-files.

The use of a small-size stainless steel K-file followed by a more flexible and less tapered NiTi Rotary PathFile could provide advantages in the form of a less invasive and safer approach to the subsequent canal instrumentation with any NiTi Rotary system. In a study by Berutti et al. (2009) comparing stainless steel K-files and PathFiles, both the endodontist and the inexpert clinician groups produced similar results when using PathFile. The study showed that the less expert clinician had an increased tendency to straighten the canal and a higher incidence of canal aberrations such as apical zips and elbows when using manual glide path enlargement with stainless steel K-files. However, the inexpert clinicians obtained better results with PathFile than those offered by manual glide path enlargement performed by expert endodontists. This suggests that the PathFile NiTi rotary system is less technique-sensitive, and that even the inexpert clinician might feel confident when using it under the conditions of this study.

Nickel-titanium rotary PathFiles therefore appear to be suitable instruments for the safe and easy creation of the glide path before use of NiTi rotary shaping of the canal. PathFiles demonstrate better maintenance of the original canal anatomy with less modification of canal curvature and fewer canal aberrations than manual glide path enlargement performed with stainless steel K-files (Berutti et al. 2009).

A more recent study by Berutti et al. (2012) evaluated the influence of glide path on canal curvature and axis modification after instrumentation with WaveOne Primary reciprocating files (Dentsply/Maillefer). Endo Training Blocks (Dentsply/Maillefer) were shaped with WaveOne Primary reciprocating files at working length after glide path enlargement with PathFiles of one group of training blocks and another group where no glide path was prepared. Results showed significantly fewer canal modifications when WaveOne was used after glide path enlargement.

1.6.4. X-Plorer Canal Navigation NiTi Files (Clinician's Choice Dental Products Inc., New Milford, USA)

The X-Plorer Canal Navigation NiTi Files (Clinician's Choice Dental Products Inc.) were introduced in 2011 for the purposes of glide path enlargement. The system consists of four instruments available in lengths of 21 mm and 25 mm (Fig. 1.4). The unique design features of these instruments are their cutting surfaces, tapers and cross-sections. The cutting surface is limited to the apical 10 mm of the file, which decreases surface contact and torsion and increases tactile feedback. The non-cutting tip has a 75° tip angle.

The manufacturer recommends using the X-Plorer series after a size 0.08 or size 0.10 stainless steel K-file has been used to penetrate the canal to working length. The first X-Plorer file has an ISO 15 tip size and a 1% taper with a triangular cross-section. The second has an ISO 20 tip size with a 1% taper and square cross-section. The third has an ISO 20 tip size with a 2% taper and square cross-section. The fourth has an ISO 25 tip size and a 2% taper with a square cross-section. The reduced taper increases flexibility and facilitates apical progression of the files. The X-Plorer files are available as rotary and hand files (Nahmias et al. 2013). The fourth file was recently added to the sequence for clinicians who want to establish a working length up to a size 0.25 and for use in tiny canals for clinicians who want to have a larger diameter at working length before using rotary shaping files.

Figure 1.4: X-Plorer Canal Navigation NiTi Files (Clinician's Choice Dental Products Inc.) ISO 15 tip (white ring, marked 01), ISO 20 tip (yellow ring, marked 01), ISO 20 tip (yellow ring, marked 02) and ISO 25 tip (red ring, marked 02)

The NiTi rotary systems outperformed the stainless steel K-file systems in Cassim and Van der Vyver's study (2013b) comparing modification of canal curvature and the incidence of canal aberrations after glide path enlargement with stainless steel K-files used manually, stainless steel K-files used in a reciprocating handpiece, rotary NiTi PathFiles (Dentsply/Maillefer) and X-Plorer files. They found no significant differences between the X-Plorer and PathFile file systems. These authors concluded that the instruments' performance might be as a result of an increased fidelity to the original canal anatomy.

1.6.5. EndoWave Mechanical Glide Path (J Morita, California, USA)

The EndoWave Mechanical Glide Path kit (J Morita) consists of three files that can be used to enlarge the glide path. File no.1 (purple) has an ISO 10 tip size, file no.2 (white) has an ISO 15 tip size and file no.3 (yellow) has an ISO 20 tip size (Fig. 1.5). All three instruments have a constant taper of 2% and can be rotated at 800 rpm at a torque 0.3Ncm (Cassim and Van der Vyver, 2013a). Low torque levels are required as a result of the triangular design. The triangular shape also provides a multiple cutting interface.

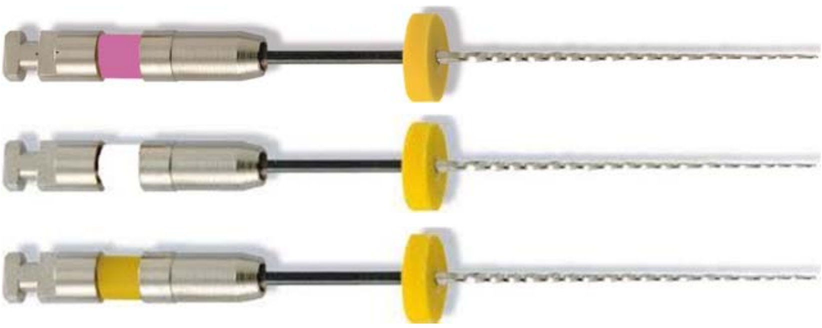

Figure 1.5: EndoWave Mechanical Glide Path Files (J Morita) (2% taper): ISO 10 tip (purple ring), ISO 15 tip (white ring) and ISO 20 tip (yellow ring)

1.6.6. Scout Race (FKG Dentaire)

Scout-RaCe files (FKG Dentaire)(Fig. 1.6) are 2% tapered instruments, which have been electro-polished to remove any irregularities formed during grinding, and have a triangular cross-section. The system consists of three instruments with a RaCe flute design (alternating cutting edges) and non-cutting tip. They are available in ISO tip size 10 (purple), 15 (white) and 20 (yellow) and should be used in a sequential manner after initial canal exploration with a size 0.06 or 0.08 K-file to working length (Cassim and Van der Vyver, 2013a).

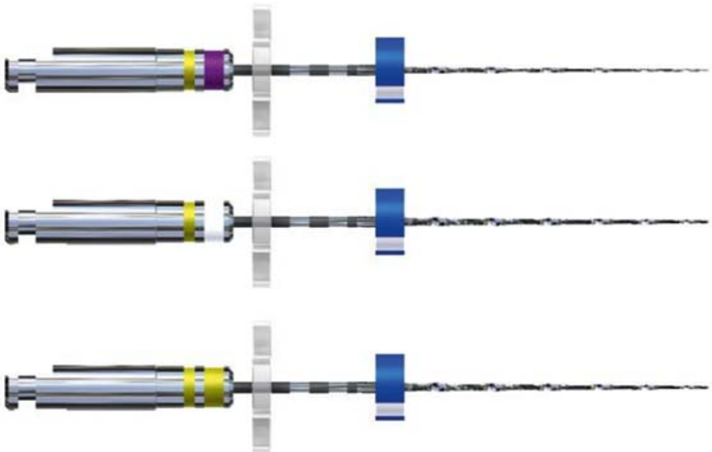

Figure 1.6: Scout-RaCe files (FKG Dentaire) ISO size 10 (purple), ISO size 15 (white) and ISO size 20 (yellow)

A study by Lopes et al. (2012) compared the mechanical properties of the path finding instruments C-Pilot (VDW), PathFile (Dentsply/Maillefer), and Scout RaCe They found that the results varied according to the mechanical property tested. The C-Pilot instrument showed increased resistance to buckling but decreased flexibility when compared with the NiTi path finding instruments. PathFile instruments showed the highest resistance to cyclic fatigue, and Scout RaCe files exhibited the highest angular deflection to fracture.

A study by Ajuz et al. (2013) compared changes to canal curvature and incidence of canal aberrations after glide path enlargement in S-shaped canals in resin blocks with stainless steel K-files, PathFiles and Scout RaCe files. PathFile instruments generated less modification of curvature and fewer canal aberrations. Scout RaCe however, showed significantly better performance in shaping double-curved canals.

1.6.7. RaCe ISO (FKG Dentaire)

RaCe ISO 10 (FKG Dentaire) (Fig. 1.7) is a system consisting of three files that progressively increase in taper: 2% (yellow ring), 4% (red ring) and 6% (blue ring). All have the same apical diameter of 0.1 mm. The main indications for these instruments are constricted and obliterated canals, as well as abrupt coronal curvatures

(Debelian and Trope 2012). These files will scout the canal and also create coronal pre-flaring because of the increasing taper of the instruments (Cassim and Van der Vyver, 2013a).

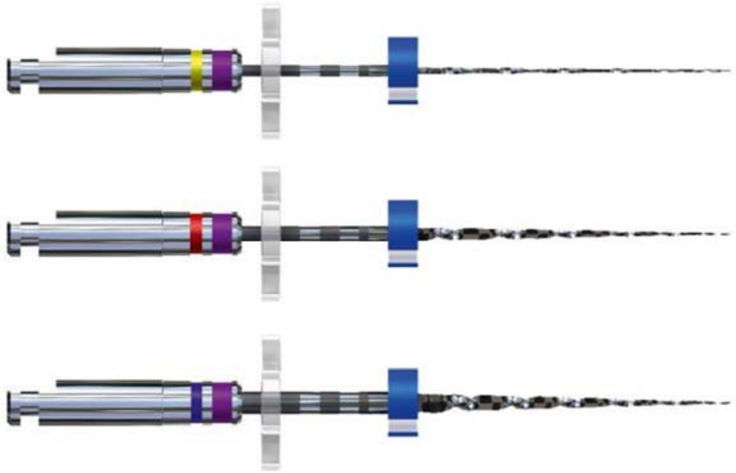

Figure 1.7: RaCe ISO 10 (FKG Dentaire) 2% (yellow), 4% (red) and 6% (blue) tapered files

1.6.8. G-Files (Micro-Mega, Besancon, France)

G-Files (Micro-Mega) are glide path enlargement instruments that were introduced in 2011. The system consists of two files, which are available in 21 mm, 25 mm and 29 mm lengths. The G1 file (red ring) has an ISO 12 tip size and the G2 file (white ring) an ISO 17 (Fig. 1.8). The tips are non-cutting tip and asymmetrical to aid in the progression of the file. The files have a 3% taper along the length and an evolving cross-section that varies along the instrument. The cross-section has blades on three different radii to aid in the removal of debris and to reduce torsion. The files have an electro-polished surface to improve efficiency. The manufacturer recommends their use after a size 0.10 hand file has been used to explore the canal to working length.

Figure 1.8: G-Files (Micro-Mega) G1 (red ring) and G2 (white ring)

A recent study by D'Amario et al. (2013) compared the maintenance of canal anatomy, the occurrence of apical transportation and the working time observed after glide path enlargement in curved root canals using G-Files, PathFiles (Dentsply/Maillefer) and manual instrumentation with stainless steel K-files. Each group was allocated 15 curved mesial canals of mandibular molars. The canals were evaluated by taking a series of radiographs following the methodology of Iqbal et al. (2003). The examiners found no statistically significant differences in the angle of canal curvature and apical transportation between the groups. According to these authors, none of the instrument groups tested had any influence on the occurrence of apical transportation, nor did they produce a change in the angle of canal curvature. G-Files, however, were shown to enlarge glide paths significantly faster than the other two groups.

1.6.9. ProGlider (Dentsply/Maillefer)

The ProGlider (Dentsply/Maillefer) (Fig. 1.9) is a new single mechanical glide path file with progressive tapers from 2% to 8% over its length. This NiTi file is manufactured using Memory nickel-titanium wire (M-wire) technology making it almost 400% more resistant to cyclic fatigue (Johnson et al. 2008). This decreases the potential for file fracture and increases flexibility. Manufacturers claim that it allows for a smoother glide path transition by making use of a controlled, smooth, inward-cutting action. The ProGlider file has a square cross-section with a diameter of 0.16 mm at D0 and 0.82 mm at D16. A small-size stainless steel K-file is initially used to scout, expand, and refine the internal walls of the canal. Once the canal can be manually reproduced, the single ProGlider file may be used to expand the working width in preparation for shaping procedures (Van der Vyver, 2014).

A recent study compared the preparation times of glide path enlargement using stainless steel K-files, PathFiles (Dentsply/Maillefer), X-Plorer files (Clinician's Choice Dental Products Inc.) and the single ProGlider file in plastic blocks (Van der Vyver, Paleker and Jonker, 2015). The ProGlider file demonstrated significantly shorter glide path enlargement times with a mean preparation time of 11.3 seconds. PathFile followed with a mean preparation time of 17.2 seconds.

Figure 1.9: The ProGlider file (Dentsply/Maillefer)

Elnaghy and Elsaka (2014) recently carried out a study to evaluate and compare the volume of removed dentine, transportation, and centering ability of the ProTaper Next (Dentsply/Maillefer) system with and without glide path enlargement by using CBCT imaging. Curved MB canals of mandibular molars were shaped using ProTaper Next after glide path enlargement with either PathFiles or the ProGlider file; and ProTaper Next (Dentsply/Maillefer) after no glide path enlargement. Canals were scanned before and after instrumentation by using a CBCT scanner to evaluate root canal transportation and centering ratio at 3, 5 and 7 mm from the apex and volumetric changes. There was no significant difference among the tested groups regarding the volume of removed dentine and centering ratio. They authors found no significant difference in canal transportation among the groups at the 7 mm level. The ProGlider-ProTaper Next group showed significantly reduced mean transportation values at the 3 mm and 5 mm levels. Elnaghy and Elsaka (2014) concluded that using this method produced better performance with fewer canal aberrations than instrumentation performed with PathFile-ProTaper Next or ProTaper Next only.

1.6.10. One G (Micro-Mega)

One G (Micro-Mega) was recently launched as a single file system for glide path enlargement. This NiTi rotary glide path file has an ISO size 0.14 non-cutting tip with a 3% taper (Fig. 1.10). One G has three cutting edges situated on three different radii relative to the canal axis, which enhances the cutting action and allows for more space for debris elimination. The variable pitch between the cutting edges further limits the screwing effect and the inactive tip reduces the risk of ledge formation.

Figure 1.10: One G file (Micro-Mega)

A study published by Ha et al. (2015) examined the One G prototype for its size optimisation and other properties. Ha et al. found that this file had a higher cyclic fatigue resistance than the G2 file (Micro-Mega). The One G prototype exhibited intermediary torsional strength and screw-in forces between those of G1 and G2 files (Micro-Mega). These authors concluded that the increased fatigue resistance and flexibility may enable maintenance of the original canal anatomy during glide path enlargement as well as reduced risk of ledge formation or transportation. According to the authors, the minimized contact area from the shaft of 3% taper may reduce the torque during instrumentation.

1.7. Micro-computed tomography

There are various modalities that enable researchers to view the complexities of the root canal system. Two-dimensional (2D) radiographs do not reveal the morphological variations of canals in different spatial planes (Kartal and Cimilli, 1997; Cunningham and Senia, 1992). Computed tomography (CT) has been used by researchers to assess three-dimensional (3D) changes in root canal geometry (Bjørndal et al. 1999; Gambill, Alder and del Rio, 1996) but the modality is not able to detect subtle changes in canal anatomy after preparation (Dowker, Davis and Elliott, 1997). Micro-computed tomography is a non-destructive analytical method that has enabled researchers to examine root canals in three-dimensions allowing for qualitative and quantitative assessments of root canal (Rhodes, Pitt Ford and Lynch, 2000; Bergmans, Van Cleynenbreugel and Wevers, 2001). Micro-CT essentially uses the same method as CT but it can be performed on a smaller scale and offers a superior resolution quality.

Micro-computed tomography scans have enabled researchers to view canal systems in their entirety. The scans provide anatomical insight that is vital to the clinical process. These scans can however only be carried out on extracted teeth. Micro-computed tomography studies on extracted teeth have shown that root canals can have multiple geometric planes and curve significantly more than the roots within which they occur (Bjørndal et al. 1999; Rhodes et al. 1999).

The XTH 225 ST micro-focus X-ray tomography system (Nikon Metrology, Leuven, Belgium) is a micro-CT facility that consists of four separate functional units, a lead-lined cabinet, an external control module, an external chiller and computers (Fig. 1.11). These computers have software that allow for the acquisition of x-rays, reconstruction of the x-rays into a 3D virtual image and visualisation and analysis of the image (Hoffman and De Beer, 2012).

Figure 1.11: XTH 225 ST (Nikon Metrology, Leuven, Belgium)

This type of micro-focus X-ray system has an intrinsic 0.001-0.006 mm spatial resolution capability. The XTH 225 ST sample manipulator ensures stability of samples weighing up to 50 kg during scanning. The manipulator can be adjusted to allow for horizontal optimization to ensure maximum enlargement of the tooth for optimal spatial resolution. This adjustment ensures that samples are horizontally included in each 2D radiograph at all angles of rotation and for correct normalisation during the tomography reconstruction process (Hoffman and De Beer, 2012)(Fig. 1.12).

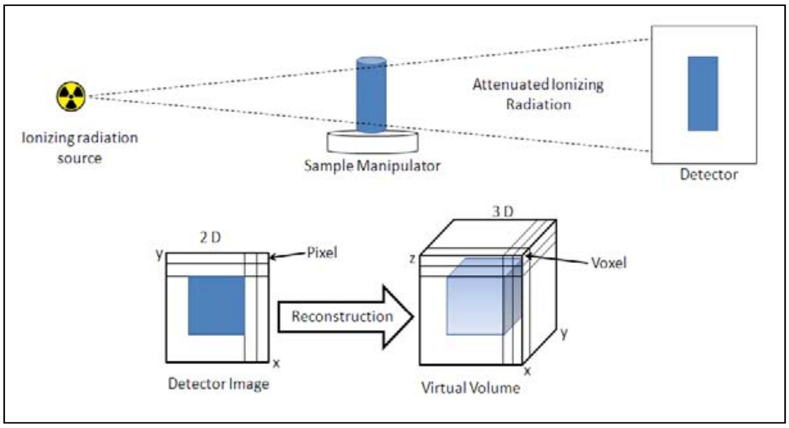

Figure 1.12: The tomographic process of the XTH 225 ST micro-CT system (Nikon Metrology, Leuven, Belgium)

Chapter 2: Aim and Objectives

2.1 Aim

The aim of this *in vitro* study was to investigate and compare the canal centering ability and apical root canal transportation of pre-curved stainless steel K-files, the ProGlider file and G-Files after glide path enlargement in curved root canals of extracted human mandibular molars using micro-CT scanning. In addition, the working times for the different glide path enlargement methods were recorded and compared.

2.2 Objectives

The broad objectives of this study were to:

2.2.1 Acquire 3D images of uninstrumented mandibular molars with curved canals via micro-CT scanning;

2.2.2 Enlarge glide paths in curved molar root canals using pre-curved stainless steel hand K-files and two NiTi rotary glide path file systems, G-Files and the ProGlider file, and subsequently obtain 3D images via micro-CT scanning;

2.2.3. Compare pre-instrumentation and post-instrumentation 3D images to assess the ability of the three instrument groups to remain centered in the canal during glide path enlargement at levels 1 mm from the apical foramen, the point of maximum root curvature and 7 mm from the apical foramen;

2.2.4. Compare pre-instrumentation and post-instrumentation 3D images of the three instrument groups for transportation of the canal at a level 1 mm from the apical foramen in eight directions; and

2.2.5. Calculate and compare the time it takes to enlarge a glide path for each of the three instrumentation methods.

2.3 Hypothesis

G-Files and the ProGlider file will remain better centred in the entirety of the canal during glide path enlargement; will cause less apical canal transportation in the eight directions examined; and more rapidly prepare a glide path when compared to manual glide path enlargement with pre-curved stainless steel K-files.

2.4 Statistical Null/Zero Hypotheses

There will be no differences in canal centering ability and apical canal transportation values between the pre-curved stainless steel K-files, G-Files and the ProGlider file for glide path enlargement. The total glide path enlargement time for the canals will be significantly similar for all the test groups.

Chapter 3: Materials and Methods

The materials and methods used in this study are similar to those proposed by Gergi et al. (2010) and Yamamura et al. (2012). The techniques applied in this study have been modified from studies by Hartmann et al. (2011) and Calhoun and Montgomery (1988).

3.1. Collection of Material

Permanent mandibular molars with curved mesial roots were chosen from a pool of extracted human teeth collected from the outpatient dental extraction clinic of the Oral and Dental Hospital, School of Dentistry, Faculty of Health Sciences, University of Pretoria. The teeth collected for the purposes of this experiment were extracted for reasons unrelated to the objectives of this study.

Each patient who attended this facility for dental extraction was asked to complete an informed consent form (Addendum A). Patients who gave this written consent granted permission for their extracted teeth to be used for the purposes of scientific research. Every aspect of this research project was conducted in line with the ethical and safety guidelines for handling human tissues and conducting laboratory research, as prescribed by South African law: The Health Professions Act 56 of 1974 (Health Professions Council of South Africa, 2008).

Directly after extraction, the teeth were rinsed under cold running tap water for one minute. They were then placed in distilled water in a Clean50 ultrasonic water bath (Woson, Ningbo, China) for several cycles of 15 minutes each (Fig. 3.1). Fresh distilled water was used for each new cycle and cycles were repeated until all evident soft tissue had been removed from the root surfaces. In order to avoid dehydration, the teeth were stored in glass jars filled with distilled water at 4°C.

Figure 3.1: Clean50 ultrasonic cleaner (Woson)

3.2. Selection of Teeth

Conventional x-rays using the RVG 6000 System (Eastman Kodak, Anaheim, USA) were taken to determine which teeth met the selection criteria (Fig. 3.2). Fifty mandibular molars with previously untreated intact mesial roots with closed apices and separate ML and MB canals with curvatures of 25° to 30° as determined by Schneider (1971) were ultimately chosen for this study. An Endo Access Bur (size 1)(Dentsply/Maillefer) was used to engrave the selected teeth using numbers from 1 to 50 for identification purposes (Fig. 3.3).

Figure 3.2: Radiograph depicting separate, untreated ML and MB canals in a curved mesial root of a mandibular molar

Figure 3.3: Mandibular molar engraved with a number to identify the specimen – tooth number 41

3.3. Scan 1: Pre-Instrumentation Scan and Mounting of Teeth

The fifty teeth selected for the study were scanned using the XTH 225 ST micro-focus X-ray computed tomography system (Nikon Metrology, Leuven, Belgium). The South African National Centre for Radiography and Tomography has made micro-focus X-ray imaging equipment in the form of a Micro-focus X-ray Radiography and Tomography facility (MIXRAD) at the South African Nuclear Energy Corporation (NECSA) available for postgraduate research (Fig. 1.12). Each tooth was mounted into a custom-made mould by embedding the roots into Aquasil Hand Putty (Dentsply/Maillefer)(Fig. 3.4). The mould facilitated mounting of each individual tooth onto the sample manipulator of the micro-focus x-ray cabinet.

Figure 3.4: Reusable mould custom made for the specimens

Inspect-X (Nikon, Metrology) software was used to acquire the projections for the CT scan after which the projections were transferred via CAT-6 connection cable from the image acquisition PC to a 64-bit reconstruction PC. CT-Pro (Nikon, Metrology) reconstruction software was used to transform the 2D projections into a 3D volume. The final product from a reconstruction in CT-Pro, a RAW 3D volume file, was imported using VGStudioMax visualisation software (Volume Graphics GmbH, Heidelberg, Germany). This software was used to distinguish between tooth samples after which all samples were saved into folders according to their engraved numbers (Fig. 3.5).

Figure 3.5: Three-dimensional rendering of tooth number 49 from multiple 2D x-ray images

VGStudioMax software was used to recheck the canal curvatures of the MB and ML canals. The angles of curvature were confirmed by applying the method described by Schneider (1971) to an axial slice of each scanned tooth using VGStudioMax software.

A line (A) was scribed parallel to the long axis of the canal. A second line (B) was drawn from the apical foramen to intersect with the first at the point where the canal began to leave the long axis of the tooth. The acute angle formed (S) was measured by means of the angle measurement tool available on the VGStudioMax system (Fig. 3.6).

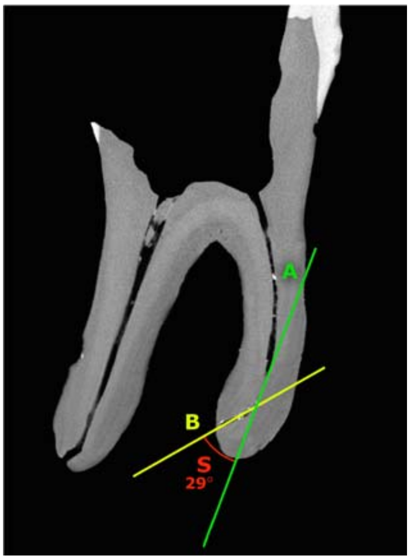

Figure 3.6: The curvature determination technique of Schneider using VGStudioMax software in the mesiobuccal root of a mandibular molar

A total of ninety separate MB and ML root canals with 25° to 30° canal curvatures were selected from the fifty molars. The molars were randomly assigned to three experimental groups of 30 canals each for glide path enlargement.

3.4. Preparation of Teeth

Standard endodontic access cavities were prepared for each group (Fig. 3.7) using Endo Access Burs (size 3)(Dentsply/Maillefer)(Fig. 3.8).

Figure 3.7: Standard endodontic access cavity

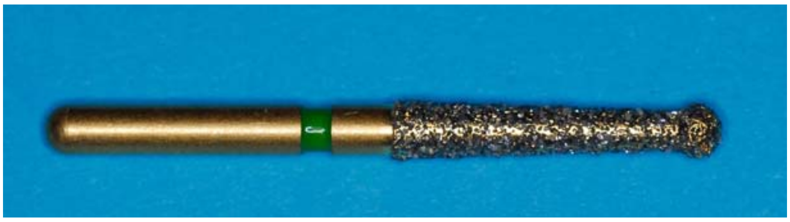

Figure 3.8: Endo Access Bur (Dentsply/Maillefer)

The selected curved canals were explored with a pre-curved size 0.10 K-file (Dentsply/Maillefer). The working length of each root canal was determined by advancing this file passively into the root canal until the tip of the file was just visible at the apical foramen. Working length was determined by subtracting 0.5 mm from this measurement (Fig. 3.9).

Figure 3.9: Determination of working length

3.5. Group 1: Glide Path Enlargement using Pre-Curved Stainless Steel K-files

A total of 30 canals were assigned to the manual glide path enlargement technique with pre-curved size 0.10, 0.15 and 0.20 stainless steel K-files (Dentsply/Maillefer) (Fig. 3.10).

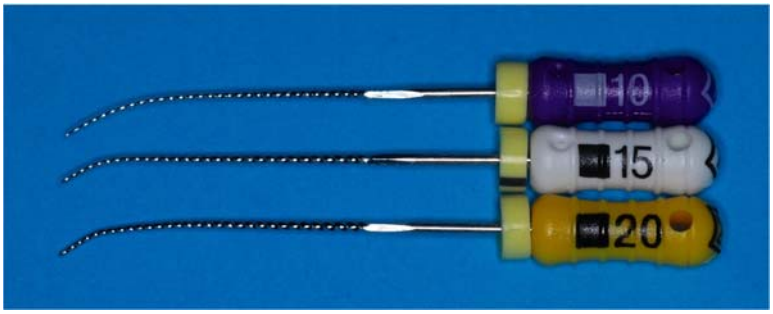

Figure 3.10: Pre-curved size 0.10, 0.15, and 0.20 stainless steel K-files (Dentsply/Maillefer)

First, each canal was negotiated to working length using a pre-curved stainless steel size 0.10 K-file to ensure an initial manually reproducible glide path. This was done by moving the K-file in and out of the root canal with amplitudes of 1 mm. Once the K-file moved more freely, the amplitude was increased to 2 mm, then 3 mm, until the K-file moved freely to working length.

This motion was repeated with a pre-curved stainless steel size 0.15 K-file followed by the same motion with a pre-curved stainless steel size 0.20 K-file. A final reproducible glide path to an ISO size 20 was confirmed when the stainless steel size 0.20 K-file could be placed at working length, pulled backwards for 4 mm and pushed back to full working length using light finger pressure without any interference or obstruction (Fig. 3.11).

The time taken to enlarge this glide path in each canal was recorded by means of an iPhone stopwatch (Apple Inc., Cupertino, California). The time taken to change files was not recorded. New instruments were used for each tooth.

Figure 3.11: Pre-curved size 0.20 stainless steel K-file at working length

Glyde Root Canal Conditioner (Dentsply/Maillefer) (Fig. 3.12) was used as a chelator in all canal preparations and Jik (3% sodium hypochlorite) (Rekitt Benckiser, South Africa (Pty) Ltd., Elandsfontein, Gauteng, South Africa) was used for canal irrigation after the use of each file (Fig. 3.13).

Figure 3.12: Glyde Root Canal Conditioner (Dentsply/Maillefer)

Figure 3.13: Sodium hypochlorite (3%) (Rekitt Benckiser)

3.6. Group 2: Glide Path Enlargement using the G-File system

Thirty canals were allocated to the G-File (Micro-Mega)(Fig. 3.14) group.

Figure 3.14: G-Files (Micro-Mega)

For each canal, a pre-curved stainless steel size 0.10 K-file was negotiated to working length with increasing amplitudes of 1-3 mm to ensure an initial manually reproducible glide path. The X-Smart Plus motor (Dentsply/Maillefer)(Fig. 3.15) was used with the G1 file (Fig. 3.16) and G2 file (Fig. 3.17) according to the manufacturer's instructions to enlarge each canal in this group (n = 30). Glyde Root Canal Conditioner (Dentsply/Maillefer) was used as a lubricating agent during the glide path enlargement and 3% sodium hypochlorite was used for canal irrigation after the use of each file.

The time taken to enlarge this glide path in each canal was recorded by means of an iPhone stopwatch (Apple Inc.). The time taken to change files was not recorded. New instruments were used for each tooth.

Figure 3.15: X-Smart Plus motor (Dentsply/Maillefer)

Figure 3.16: Glide path enlargement using the G1 file

Figure 3.17: Glide path enlargement using the G2 file

3.7. Group 3: Glide Path Enlargement using the ProGlider Instrument

The remaining 30 canals were assigned to the ProGlider (Dentsply/Maillefer) group (Fig. 3.18). An initial manually reproducible glide path was first established in each canal with a pre-curved stainless steel size 0.10 K-file. The K-file was negotiated to working length with increasing amplitudes of 1 – 3 mm after which a single ProGlider file was used with the X-Smart Plus motor (Dentsply/Maillefer) according to the manufacturer's instructions (Fig. 3.19).

Figure 3.18: ProGlider file (Dentsply/Maillefer)

Figure 3.19: Glide path enlargement with the ProGlider file.

Glyde Root Canal Conditioner (Dentsply/Maillefer) was used as a chelator in all canal preparations and 3% sodium hypochlorite was used for canal irrigation after the use of each file. ProGlider files were discarded after glide path enlargement of each tooth. The time taken to enlarge this glide path in each canal was recorded by means of an iPhone stopwatch (Apple Inc.).

Canal enlargement time for each segment was recorded. An iPhone stopwatch (Apple Inc.) was started at the point of entry into the canal and stopped at the point of instrument retrieval. The time it took to clean debris from the instrument flutes, irrigate, recapitulate and to re-irrigate the canal was not recorded.

A single operator prepared all the access cavities as well as glide path enlargement. All teeth were placed in glass jars filled with distilled water and stored at 4°C after glide path enlargement.

3.8. Scan 2: Post-Instrumentation Scan to Assess Glide Path

All canals were dried using paper points (Fig. 3.20) prior to Scan 2.

Figure 3.20: Canals dried with paper points before Scan 2 (post-instrumentation scan)

The teeth were placed in the same custom moulds as for Scan 1 and scanned using the XTH 225 ST micro-focus X-ray computed tomography system (Nikon Metrology). The changes in the canals were observed using VGStudioMax (Volume Graphics GmbH), an advanced volume rendering software, which enabled merging of the pre-instrumentation and post-instrumentation 3D images for each tooth. Each root canal from Scan 1 was superimposed over the same canal from Scan 2 (Fig. 3.20).

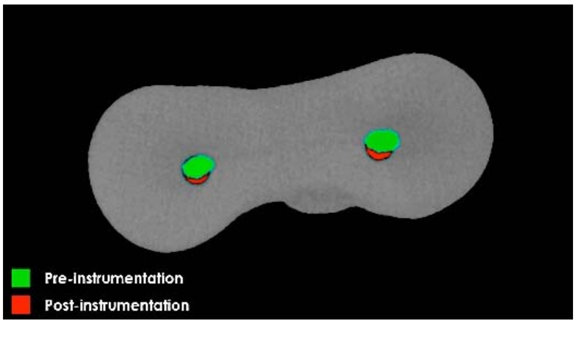

Figure 3.21: Merged Scans 1 and 2 with the pre-instrumentation canal highlighted in green and the post-instrumentation canal highlighted in red.

3.9. Evaluation of Centering Ability

VGStudioMax (Volume Graphics GmbH), software was used to evaluate changes in root canal diameter at three different levels:

- D1 = 1 mm from the apical foramen
- D_{mc} = at the point of maximum root curvature (a point between D1 and D7)
- D7 = 7 mm from the apical foramen

Measurements were taken using the VGStudioMax software (Volume Graphics GmbH) to evaluate whether the files remained centred during instrumentation. Values were measured three times, averaged, and a mean centering ratio was calculated by the formula (X1-X2)/Y described by Calhoun and Montgomery (1988). The pre-instrumentation canal diameter (Z) was measured on Scan 1 (Fig. 3.22). This diameter was superimposed over the post-instrumentation canal on Scan 2 to determine X1, X2 and Y (Figs. 3.23 – 3.25). The X1 and X2 measurements are determined from Scan 2 by extending the pre-instrumentation Z-diameter to meet the post-instrumentation canal wall. Measurement X1 represents the maximum canal movement in one direction; X2 is the movement in the opposite direction and Y is the diameter of the post-instrumentation canal. Ratios closest to zero indicate a superior centering ability.

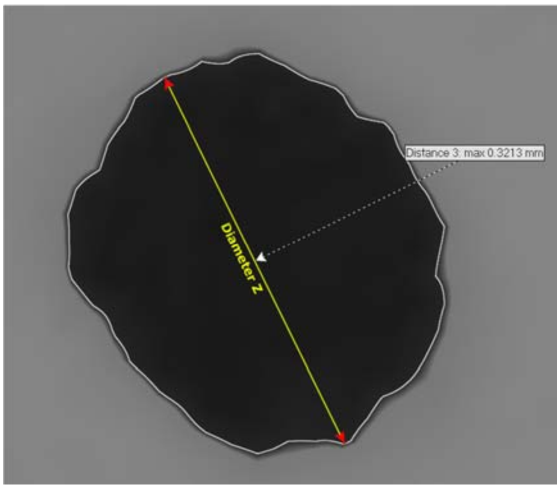

Figure 3.22: Pre-instrumentation canal diameter (Z) measured on Scan 1

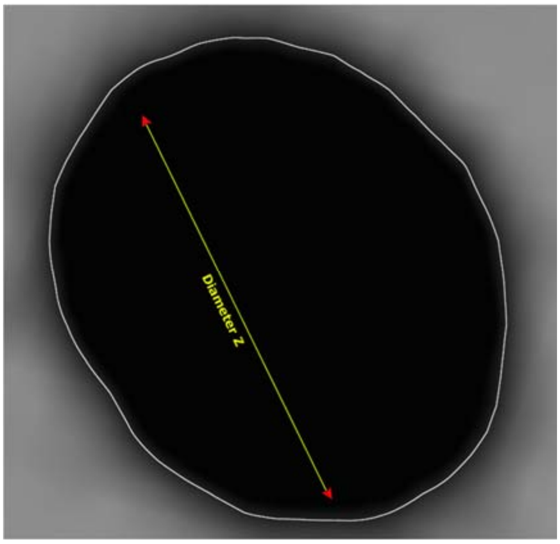

Figure 3.23: Pre-instrumentation canal diameter (Z) visible within the post-instrumentation canal on Scan 2

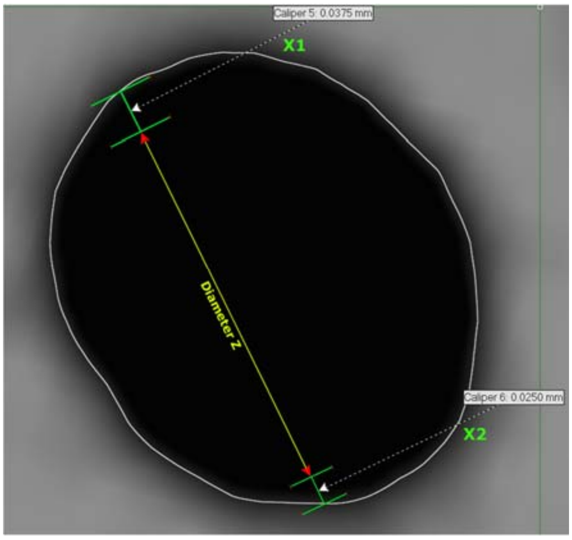

Figure 3.24: Scan 2 depicting X1 and X2 movements on the post-instrumentation canal measured by extending the pre-instrumentation canal diameter (Z)

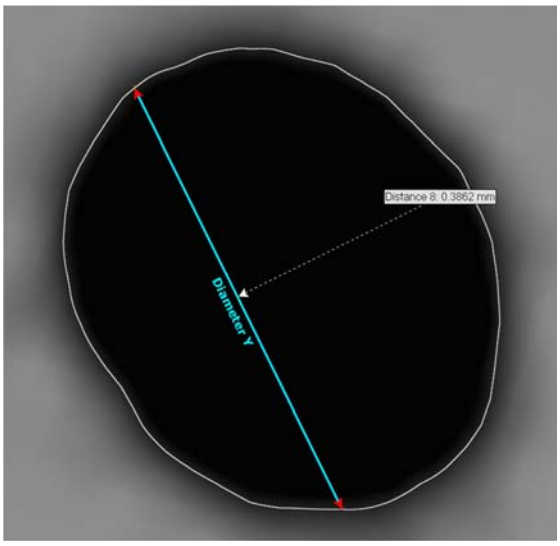

Figure 3.25: Post-instrumentation diameter (Y) measured on Scan 2

3.10. Evaluation of Apical canal transportation

VGStudioMax software (Volume Graphics GmbH) was used to evaluate apical canal transportation at a distance of 1 mm from the apical foramen (D1) using a method described by Bergmans et al. (2001).

The software was used to locate a central axis point at D1 within each uninstrumented (pre-instrumentation) canal on Scan 1. Using this axis as a reference point, polar co-ordinates were mapped at eight points on the pre-instrumentation canal wall in 360°. The eight points were mapped at 45° increments in a clockwise rotation – mesial (M), mesiobuccal (MB), buccal (B), distobuccal (DB), distal (D), distolingual (DL), lingual (L), mesiolingual/mesiopalatal (ML) (Fig. 3.26).

The co-ordinates mapped within the pre-instrumentation canal images from Scan 1 were then superimposed over the post-instrumentation canal images from Scan 2. In this way the distance between the post-instrumented canal walls and the pre-instrumented canal walls were measured in eight directions (Fig. 3.27) by extending the co-ordinate points determined from Scan 1. These measurements were used to determine transportation values and the direction of transportation.

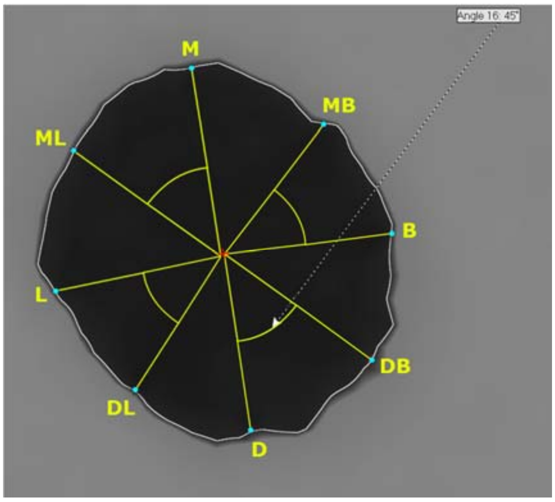

Figure 3.26: Circumference of the pre-instrumentation canal mapped in 45° angles from a central axis point resulting in eight co-ordinate points

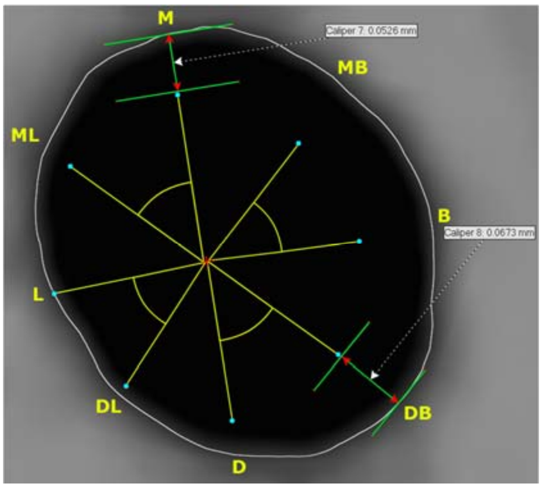

Figure 3.27: Pre-instrumentation canal circumference and co-ordinates superimposed onto the post-instrumentation canal to measure transportation in eight directions

3.11. Statistical Analysis

The centering ability of the three instrumentation techniques was compared using a one-way Analysis of Variance (ANOVA) to analyse the mean values of the ratios obtained at D1 (1 mm from the apical foramen), D_{mc} (point of maximum curvature) and D7 (7 mm from the apical foramen). This was followed by pairwise comparisons of the ratios, if indicated. A Bonferroni adjusted p value of 0.016 was used in the pairwise comparisons. Significance of differences between the three instrumentation groups was also tested.

Apical canal transportation in eight directions from the centre of each canal in the apical third was analysed by comparing the distances between the post-instrumented canal walls and the pre-instrumented canal walls using ANOVA.

ANOVA was also used to statistically compare the mean glide path enlargement times for the three groups.

All statistical procedures were performed on SAS Release 9.3 (SAS Institute Inc., Cary, USA) running under Microsoft Windows (Microsoft Corp., Redmond, Washington) for a personal computer.

Chapter 4: Results

4.1. Canal Centering Ability

The mean centering ratios at D1 (1 mm from the apical foramen), D_{mc} (point of maximum root curvature) and D7 (7mm from the apical foramen) for each glide path technique were determined using the formula (X1-X2)/Y. Large differences in X-values, when X1 was far greater than X2, resulted in higher centering ratios. The lower the value of the ratio, the better the technique centered instrumentation in relation to the uninstrumented canal.

4.1.1. Centering Ability of Pre-Curved Stainless Steel K-files

Figure 4.1 depicts the mean centering ratios for the 30 canals instrumented with pre-curved stainless steel K-files at D1, D_{mc} and D7. At D1, K-files exhibited a mean centering ratio of 0.2494 mm. The mean centering ratios were 0.1778 mm at D_{mc} and 0.2217 at D7.

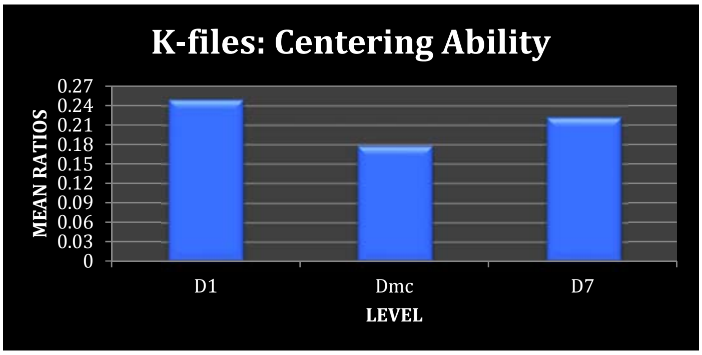

Figure 4.1

At all D levels the mean ratios for the stainless steel K-file group were higher than for the other groups because most X1 movements were far greater than movements for X2. Figure 4.2 displays a post-instrumentation canal image representative of the K-file group depicting a large movement in the direction of X1 at D1 indicative of an instrument that is not well centered.

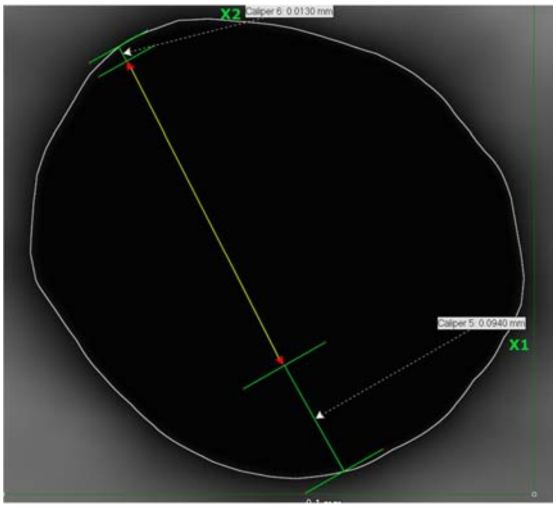

Figure 4.2

Figure 4.3 shows a large movement in the direction of X1, indicative of an instrument that is not well centered, at D_{mc} seen in a post-instrumentation canal image representative of the K-file group.

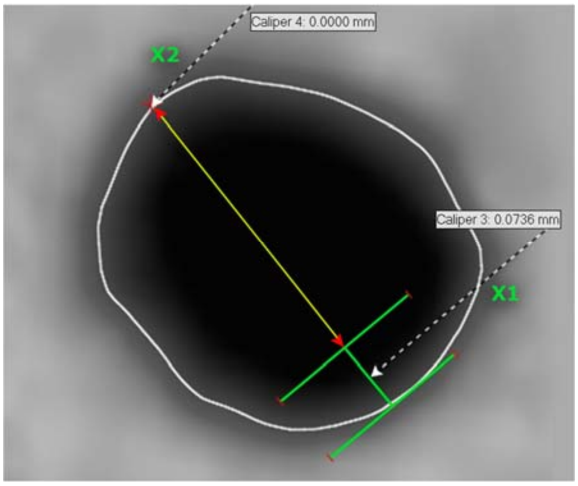

Figure. 4.3

Figure 4.4 depicts a post-instrumentation canal image representative of the K-file group, illustrating a large movement in the direction of X1 at D7 (7 mm from the apical foramen) indicative of an instrument that is not well centered.

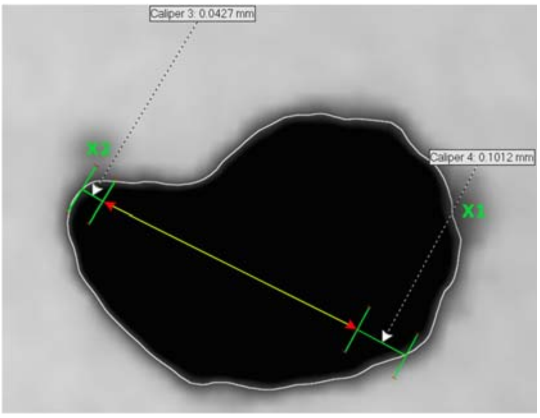

Figure 4.4

4.1.2. Centering Ability of G-Files

Figure 4.5 represents the mean centering ratios for the 30 canals instrumented with G-Files (Micro-Mega) at D1, D_{mc} and D7. G-Files demonstrated mean centering ratios of 0.1143 mm at D1, 0.917 mm at D_{mc} and 0.1753 at D7.

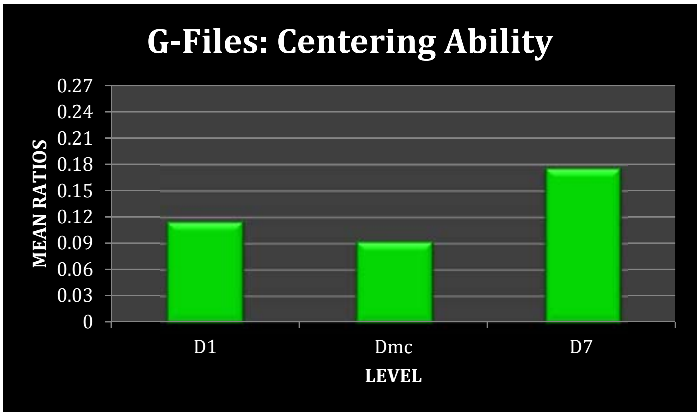

Figure 4.5

At D1, X values for the G-File group were generally similar resulting in a good centering ratio. Centering ratio values of X1 at D_{mc} and D7 for the G-File group were generally higher than X2, indicative of a poor centering ability.

Figure 4.6 shows similar X1 and X2 movements depicted in a post-instrumentation canal image representative of the G-File group, signifying the use of a well-centered instrument at D1.

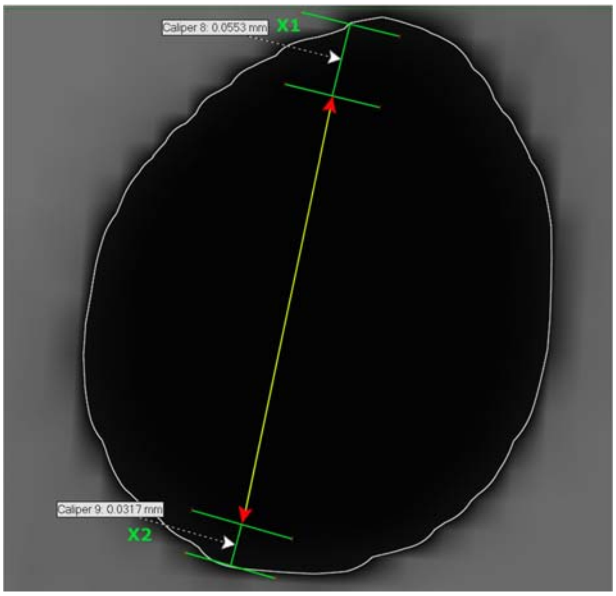

Figure. 4.6

A post-instrumentation canal image representative of the G-File group depicting a large movement in the direction of X1 at D_{mc} (point of maximum root curvature) is shown in Figure 4.7, indicative of an instrument that is not well centered.

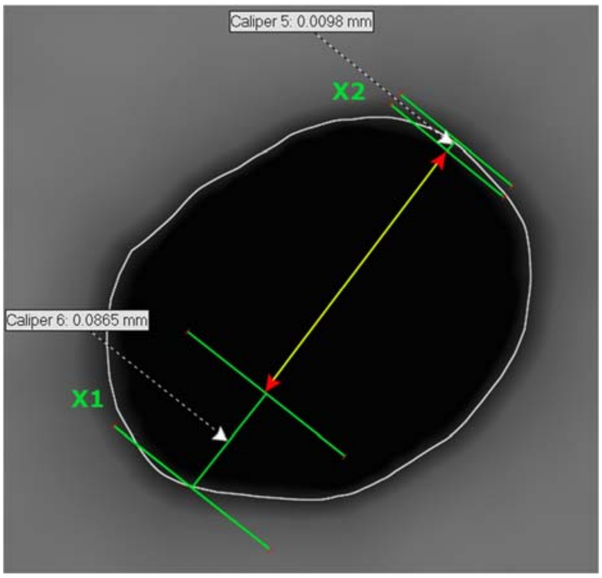

Figure 4.7

Figure 4.8 displays a large movement in the direction of X1 at D7 (7 mm from the apical foramen) observed in a post-instrumentation canal image representative of the G-File group, signifying use of an instrument that is not well centered.

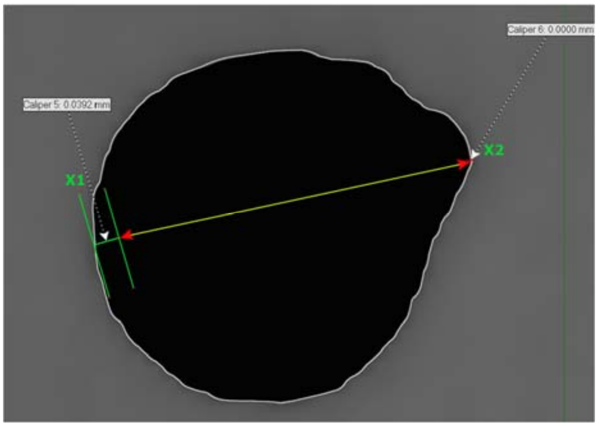

Figure 4.8

4.1.3. Centering Ability of the ProGlider File

Figure 4.9 portrays the mean centering ratios for the 30 canals instrumented with the ProGlider file (Dentsply/Maillefer) at D1, D_{mc} and D7. The ProGlider file exhibited a mean centering ratio of 0.116 mm at D1, 0.0371 mm at D_{mc} and 0.0571 at D7.

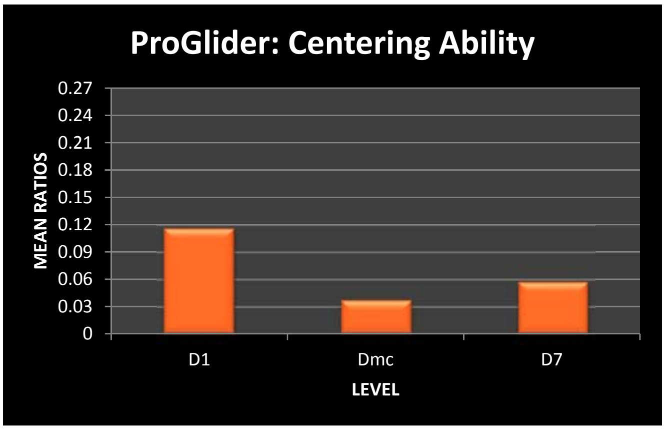

Figure 4.9

A post-instrumentation canal image representative of the ProGlider group is shown in Figure 4.10 portraying similar X1 and X2 movements indicative of the use of a well-centered instrument at D1.

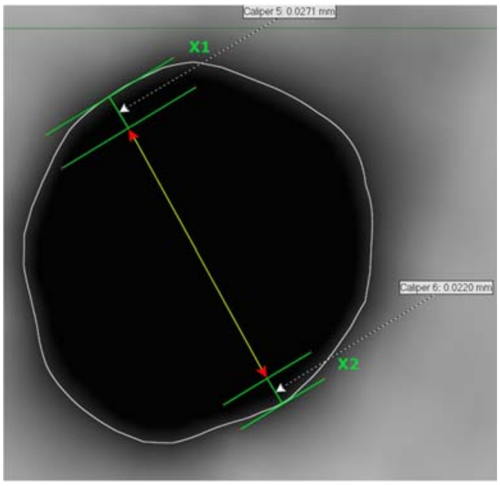

Figure 4.10

Figure 4.11 illustrates similar X1 and X2 movements displayed in a post-instrumentation canal image representative of the ProGlider group, signifying the use of a well-centered instrument at D_{mc}.

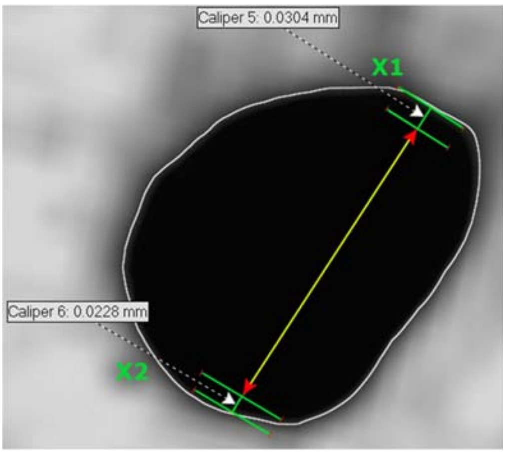

Figure 4.11

A post-instrumentation canal image representative of the ProGlider group is seen in Figure 4.12, showing similar X1 and X2 movements indicating the use of a well-centered instrument at D7.

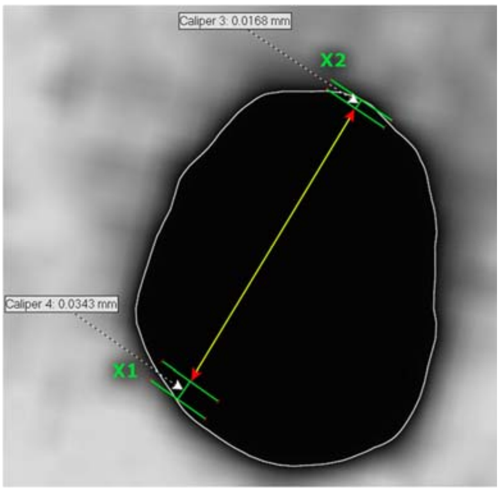

Figure 4.12

4.1.4. Comparison of Data for Centering Ability

Figure 4.13 illustrates the mean centering ratios of the three glide path instrumentation groups at D1, D_{mc} and D7 combined before statistical analysis. Stainless steel K-files displayed the highest mean centering ratios at all levels. At D1, G-Files exhibited the lowest mean centering ratio. Lower mean ratios are indicative of a favourable centering ability. The ProGlider file showed the lowest mean centering ratios at D_{mc} and D7.

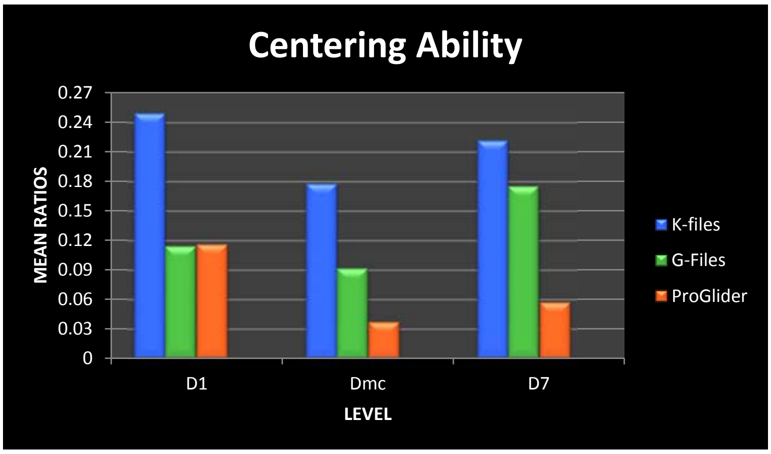

Figure 4.13

4.1.5. Statistical Analysis of Centering Ability

The centering ability of the three glide path instrumentation techniques was compared at D1, D_{mc} and D7 using ANOVA followed by pairwise comparisons at the Bonferroni adjusted significance p value of 0.016. At all D levels the mean ratios for the stainless steel K-file group were statistically significantly higher than for the other two groups.

At D1 pairwise comparisons at the Bonferroni adjusted significance level of 0.016 demonstrated that there were statistically significant differences when G-Files and stainless steel K-files were compared as well as when the ProGlider file was compared to stainless steel K-files ($p<0.016$). There was no statistically significant difference between the ProGlider file and G-Files at D1. Results at D1 showed that glide path enlargement with stainless steel K-files produced statistically significant higher mean centering ratios indicative of canals that were less centered than those enlarged with G-Files and the ProGlider file. Data for centering ability at D1 for all groups is summarised in Table 4.1 using descriptive statistics.

Table 4.1 Descriptive statistics for canal centering ability at D1 (1 mm from the apical foramen)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.2494[a]	0.1695	0.2146	0.0107	0.5937
G-File	30	0.1143[b]	0.1176	0.0700	0.0018	0.4731
ProGlider	30	0.1160[b]	0.1405	0.0413	0.0012	0.5215

Mean values with the same superscript letters were not statistically different at $p<0.016$.

Pairwise comparisons at the Bonferroni adjusted significance level of 0.016 demonstrated that there were statistically significant differences when the ProGlider file and stainless steel K-files were compared as well as when the ProGlider file was compared to G-Files at the point of maximum root curvature (D_{mc}). There was no statistically significant difference between stainless steel K-files and G-Files ($p<0.016$) at D_{mc}. Results at the point of maximum curvature showed that the ProGlider file produced statistically significant lower mean centering ratios indicative of enlarged canals that were more centred than those in the stainless steel K-file and G-File groups. Data for centering ability at D_{mc} for all groups is summarised in Table 4.2 using descriptive statistics.

Table 4.2 Descriptive statistics for canal centering ability at D_{mc} (point of maximum curvature)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.1778[a]	0.1602	0.1188	0.0171	0.5612
G-File	30	0.0917[a]	0.0908	0.0667	0.0001	0.3289
ProGlider	30	0.0371[b]	0.0349	0.0208	0.0011	0.1147

Mean values with the same superscript letters were not statistically different at $p<0.016$.

At D7 pairwise comparisons at the Bonferroni adjusted significance level of 0.016 demonstrated that there were no statistically significant differences when G-Files and stainless steel K-files were compared or when the ProGlider file was compared to G-Files (Figs. 4.6-4.8). There was a statistically significant difference between stainless steel K-files and the ProGlider file at D7 ($p<0.016$). Results at D7 showed that glide path enlargement with stainless steel K-files produced statistically significant higher mean centering ratios than the ProGlider group, indicative of canals that were less centered than those enlarged with the ProGlider file. The G-File group produced centering ratios that ranged between those for the other two groups, but the G-File group was not statistically different to either of the other groups. Data for centering ability at D7 for all groups is summarised in Table 4.3 using descriptive statistics.

Table 4.3 Descriptive statistics for canal centering ability at D7 (7 mm from the apical foramen)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.2217[a]	0.3817	0.0454	0.0027	1.9491
G-File	30	0.1753[a,b]	0.2256	0.0724	0.0031	0.8261
ProGlider	30	0.0571[b]	0.0642	0.0238	0.0004	0.2049

Mean values with the same superscript letters were not statistically different at $p<0.016$.

4.2. Apical Canal Transportation

Apical canal transportation in eight directions for each group at D1 (1 mm from the apical foramen) was determined by the superimposition of eight polar co-ordinate points obtained from the pre-instrumentation canal onto the post-instrumentation canal. The directions of the polar co-ordinates were designated as follows:

- Mesial (M)
- Mesiolingual (MB)
- Buccal (B)
- Distobuccal (DB)
- Distal (D)
- Distolingual (DL)

- Lingual (L)
- Mesiolingual (ML)

The distances between the eight points on the post-instrumentation canal walls were measured and mean values were calculated. The direction of apical canal transportation produced by each instrumentation technique was determined in relation to the canal walls and was classified according to the eight directions.

4.2.1. Apical Canal Transportation of Pre-Curved Stainless Steel K-files

Transportation at D1 in the eight directions and the measurement in millimetres for the K-file group are depicted in Figure 4.14. Mean transportation values ranged from 0.0530 mm in a lingual direction to 0.0923 mm in a mesiobuccal direction.

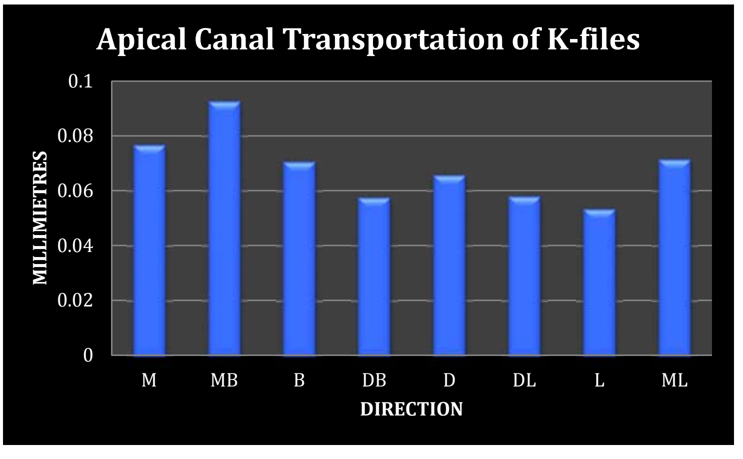

Figure 4.14

Figure 4.15 is a representative image of a canal enlarged with stainless steel K-files displaying a large distance between the pre-instrumentation mesiolingual co-ordinate and the post-instrumentation canal wall. The greatest movement is concentrated in this direction indicating apical canal transportation in a mesiolingual direction.

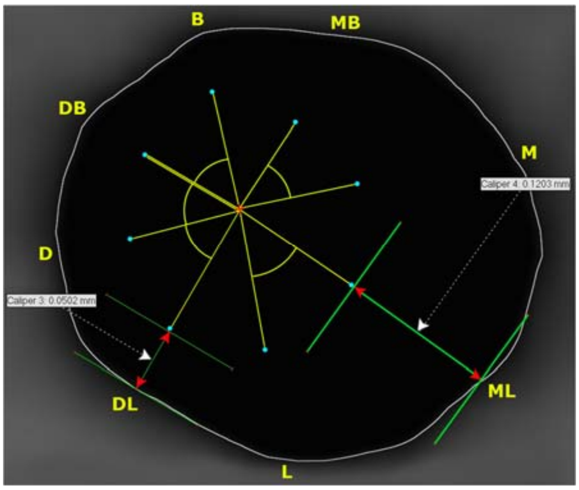

Figure 4.15

Figure 4.16 is a representative image apical canal transportation following the use of stainless steel K-files at D1 (1 mm from the apical foramen) evident by highlighting the pre-instrumentation canal in green and the transported post-instrumentation canal in red.

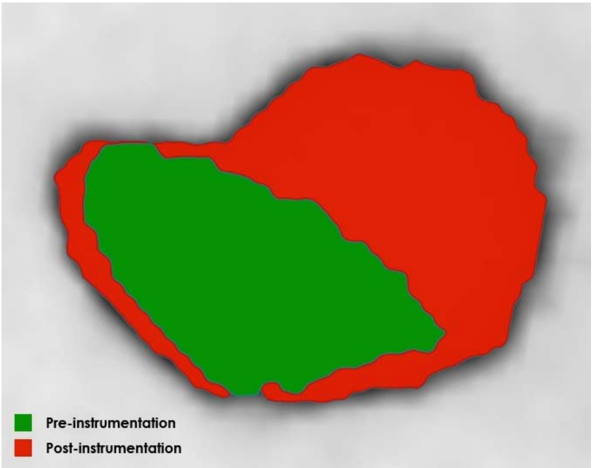

Figure 4.16

4.2.2. Apical Canal Transportation of G-Files

Figure 4.17 demonstrates apical canal transportation in millimetres following the use of G-Files at D1 in the eight directions. Mean transportation values ranged from 0.0305 mm in a mesial direction to 0.0553 mm in a distolingual direction.

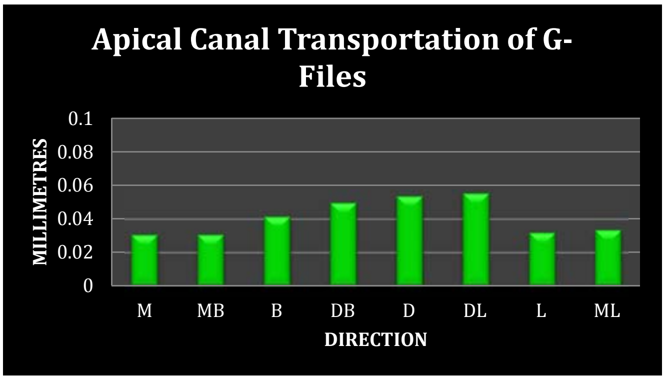

Figure 4.17

Figure 4.18 illustrates short and similar distances between the pre-instrumentation co-ordinates and the post-instrumentation canal wall in an image representative of the G-File group at D1.

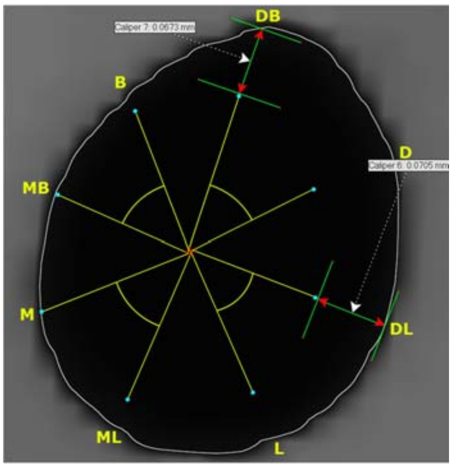

Figure 4.18

Similar movements in X1 and X2 indicate that minimal apical canal transportation has occurred after glide path with G-Files at D1.

Figure 4.19 illustrates merged canals representative of the G-File group showing a minimally transported post-instrumentation canal highlighted in red and the pre-instrumentation canal highlighted in green at D1.

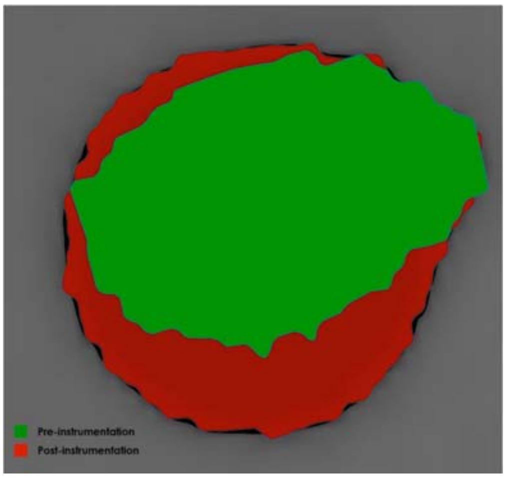

Figure 4.19

4.2.3. Apical Canal Transportation of the ProGlider file

Apical canal transportation at D1 in the eight directions and the measurement in millimetres for the ProGlider group are depicted in Figure 4.20. Mean transportation values ranged from 0.0289 mm in a mesial direction to 0.0436 mm in a buccal direction.

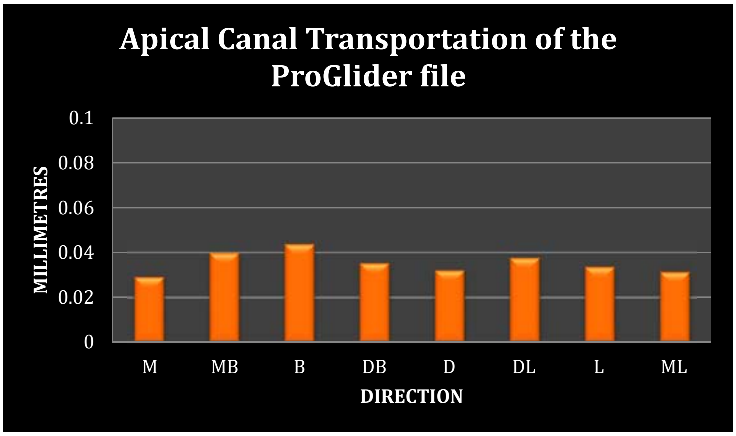

Figure 4.20

Figure 4.21 is a representative image displaying short and similar distances between the pre-instrumentation co-ordinates and the post-instrumentation canal wall indicating that minimal canal transportation occurred at D1 after glide path enlargement using the ProGlider file.

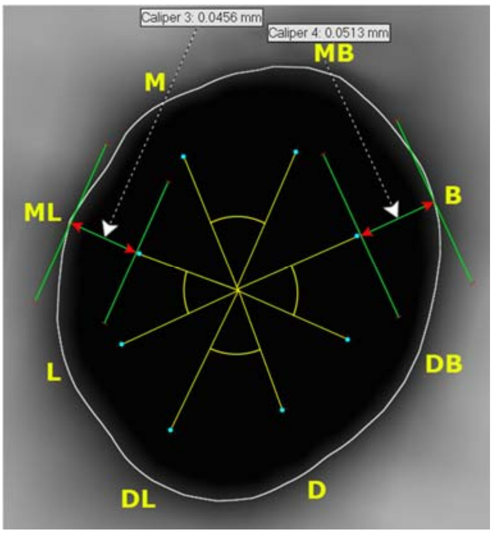

Figure 4.21

Figure 4.22 is a representative image of the merged scans demonstrating minimal transportation following the use of the ProGlider file at D1 by highlighting the pre-instrumentation canal in green and the post-instrumentation canal in red.

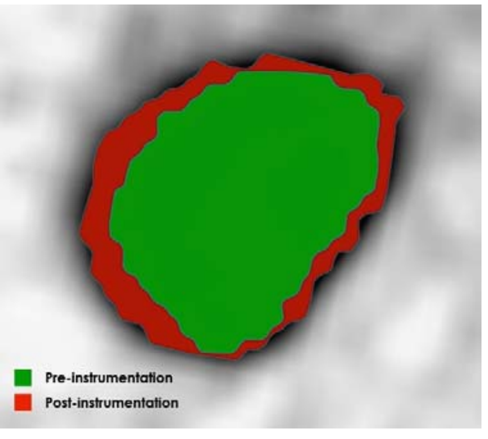

Figure 4.22

4.2.4. Comparison of Data for Apical Canal Transportation

Figure 4.23 illustrates the results of the apical canal transportation values in eight directions for the three glide path instrumentation groups at D1 combined before statistical analysis. K-files displayed the highest transportation values in all directions.

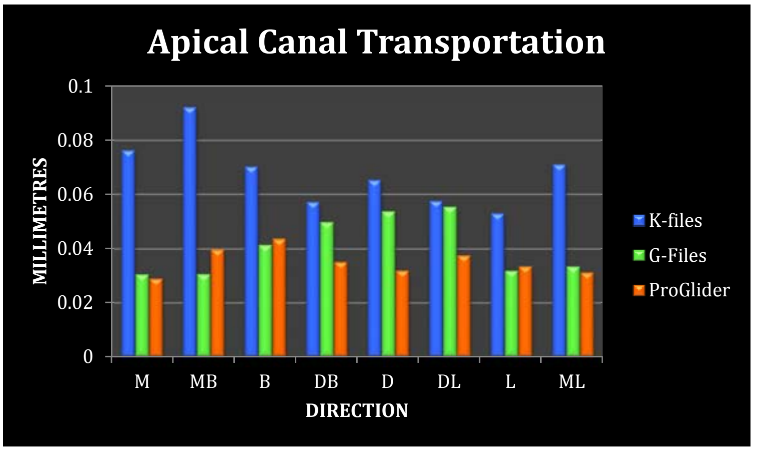

Figure 4.23

4.2.5. Statistical Analysis of Apical Canal Transportation

Table 4.4 shows the means and standard deviation of apical canal transportation produced by the three instrumentation techniques at D1 of molar root canals instrumented in eight different directions. The results were analysed using ANOVA.

Table 4.4 Means (in mm) and standard deviation of apical canal transportation produced by each instrumentation technique at D1, according to the direction of dentine removal

Direction	Technique		
	K-file	G-Files	ProGlider
Mesial	0.0763±0.0488[a]	0.0305±0.0302[b]	0.0289±0.0138[b]
Mesiobuccal	0.0923±0.0716[a]	0.0306±0.0360[b]	0.0397±0.0189[b]
Buccal	0.0703±0.0509[a]	0.0414±0.0255[b]	0.0436±0.0236[b]
Distobuccal	0.0572±0.0288[a]	0.0496±0.0329[a,b]	0.0351±0.0251[b]
Distal	0.0653±0.0465[a]	0.0536±0.0389[a,b]	0.0319±0.0235[b]
Distolingual	0.0576±0.0361[a]	0.0553±0.0361[a]	0.0375±0.0255[a]
Lingual	0.0530±0.0306[a]	0.0318±0.0306[b]	0.0335±0.0230[a,b]
Mesiolingual	0.0711±0.0551[a]	0.0334±0.0279[b]	0.0312±0.0186[b]

Mean values with the same superscript letters were not statistically different at $p<0.05$.

Stainless steel K-files were found to transport the canal statistically significantly more than G-Files in five directions - mesial, mesiobuccal, buccal, lingual and mesiolingual. These two groups exhibited statistically significantly similar apical canal transportation values in the remaining three directions, distobuccal, distal and distolingual.

The ProGlider file exhibited statistically significantly less apical canal transportation than stainless steel K-files in six directions - mesial, mesiobuccal, buccal, distobuccal, distal and mesiolingual. Apical canal transportation values for these groups were statistically significantly similar in the remaining two directions, distolingual, and lingual.

Transportation values for G-Files and the ProGlider file were statistically significantly similar in all directions ($p<0.05$).

4.3. Glide Path Enlargement Times

Figure 4.24 represents the mean glide path enlargement times (in seconds) for the three groups in a comparative graph.

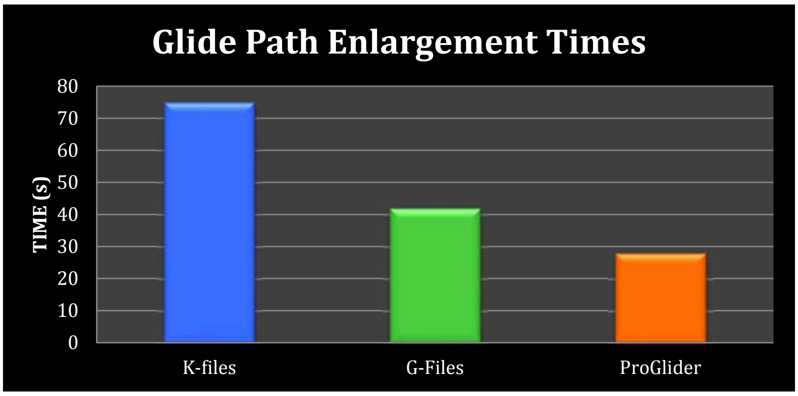

Figure 4.24

The mean total time for glide path enlargement with stainless steel K-files, G-Files and the ProGlider file along with other descriptive statistics, is presented in Table 4.6.

Table 4.5 Descriptive statistics for the total preparation time for the different test groups

Technique	Number	Mean	Standard deviation	Minimum	Maximum
K-file	30	74.92[a]	56.91	13.53	224.85
G-File	30	41.87[b]	20.19	15.31	105.01
ProGlider	30	27.95[b]	8.55	13.25	44.79

Mean values with the same superscript letters were not statistically different at $p<0.05$.

Glide path enlargement with the ProGlider file and G-Files were shown to be statistically significantly faster than stainless steel K-files using ANOVA ($p<0.05$). There was no statistically significant difference observed between the mean preparation times of the ProGlider file and G-Files ($p<0.05$).

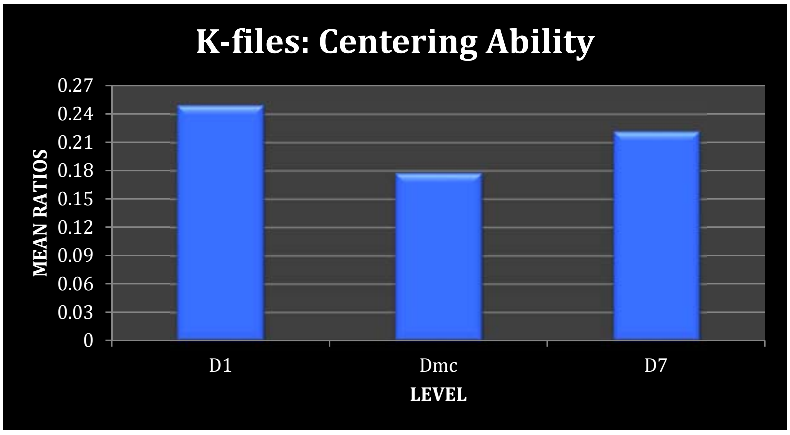

Figure 4.1: Mean centering ratios of the stainless steel K-files at D1 (1 mm from the apical foramen), D_{mc} (point of maximum curvature) and D7 (7 mm from the apical foramen)

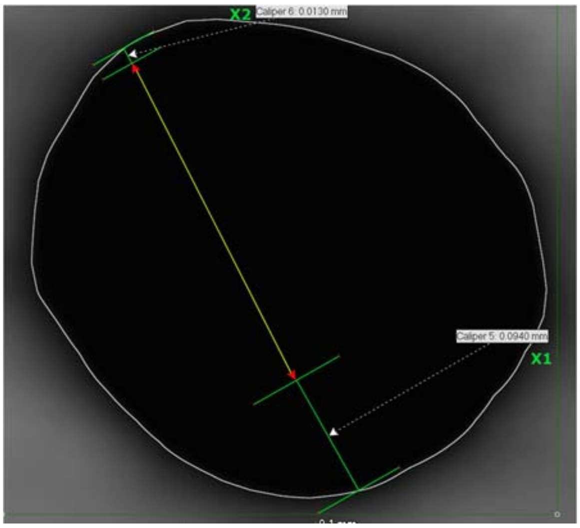

Figure 4.2: A post-instrumentation canal image representative of the K-file group depicting a large movement in the direction of X1 at D1 (1 mm from the apical foramen), indicative of an instrument that is not well centered

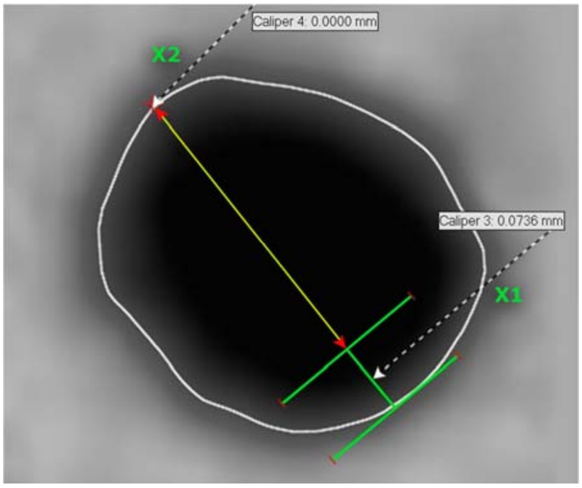

Figure 4.3: A large movement in the direction of X1, indicative of an instrument that is not well centered, at D_{mc} (point of maximum root curvature) seen in a post-instrumentation canal image representative of the K-file group

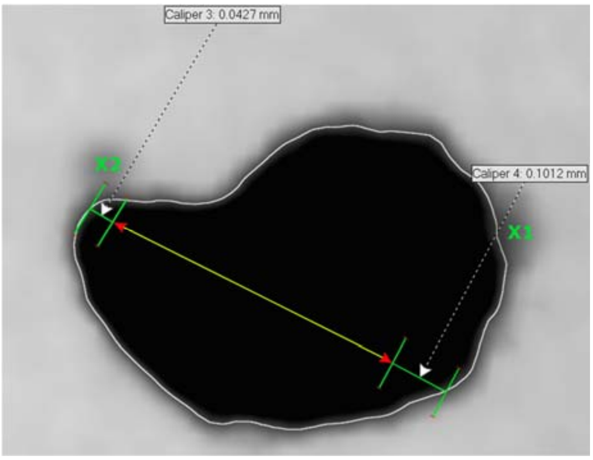

Figure 4.4: A post-instrumentation canal image representative of the K-file group depicting a large movement in the direction of X1 at D7 (7 mm from the apical foramen) indicative of an instrument that is not well centered

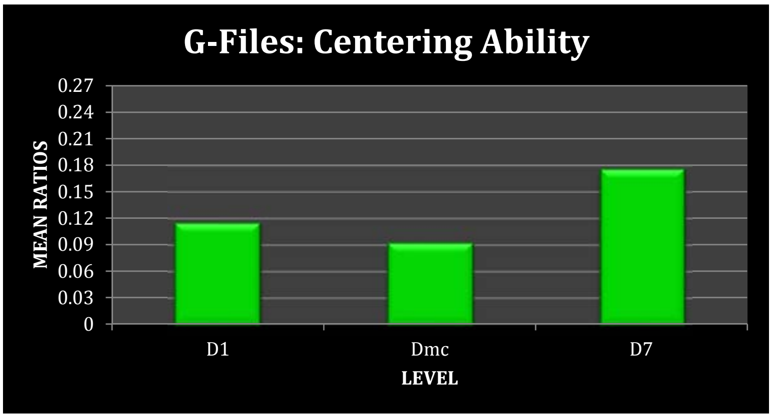

Figure 4.5: Mean ratios of G-Files at D1 (1 mm from the apical foramen), D_{mc} (point of maximum curvature) and D7 (7 mm from the apical foramen)

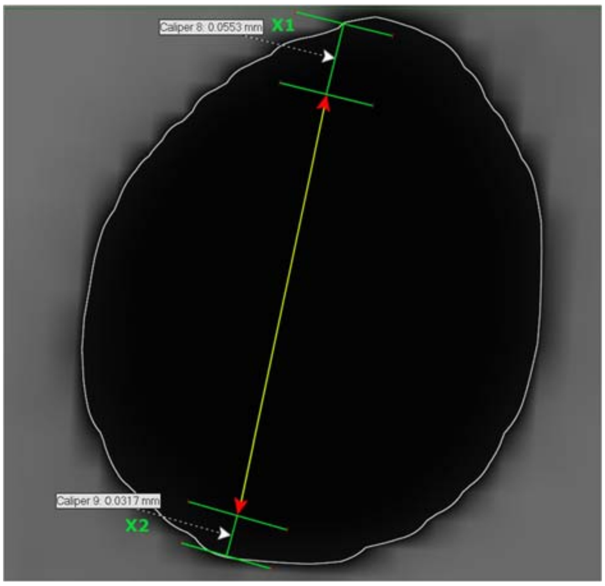

Figure 4.6: Similar X1 and X2 movements shown in a post-instrumentation canal image representative of the G-File group signifying the use of a well-centered instrument at D1 (1 mm from the apical foramen)

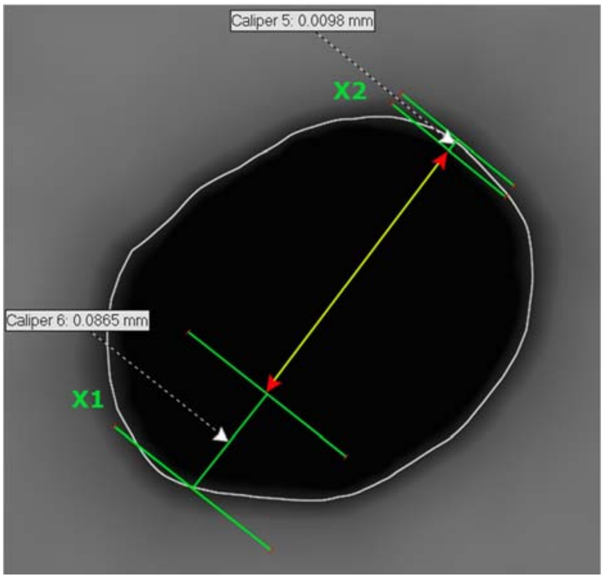

Figure 4.7: A post-instrumentation canal image representative of the G-File group depicting a large movement in the direction of X1 at D_{mc} (point of maximum root curvature) indicative of an instrument that is not well centered

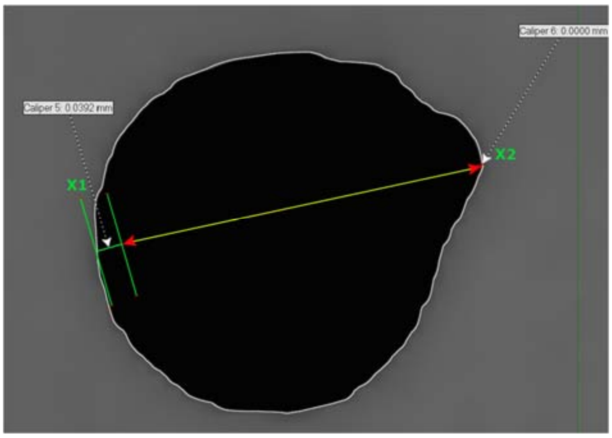

Figure 4.8: A large movement in the direction of X1 at D7 (7 mm from the apical foramen) observed in a post-instrumentation canal image representative of the G-File group signifying use of an instrument that is not well centered

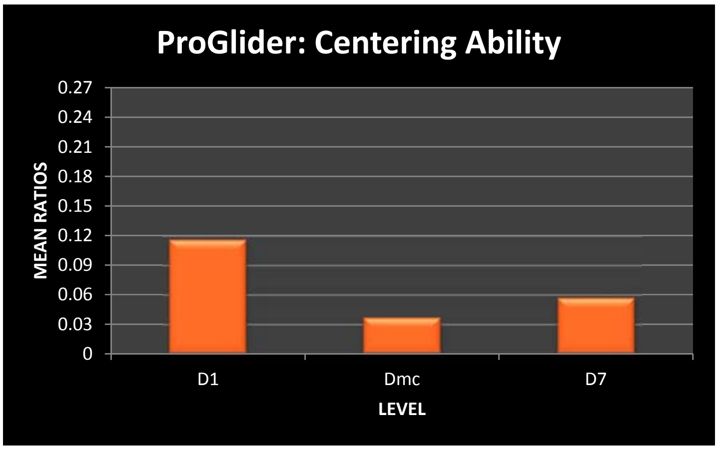

Figure 4.9: Mean ratios indicating the centering ability of the ProGlider file at D1 (1 mm from the apical foramen), D_{mc} (point of maximum curvature) and D7 (7 mm from the apical foramen).

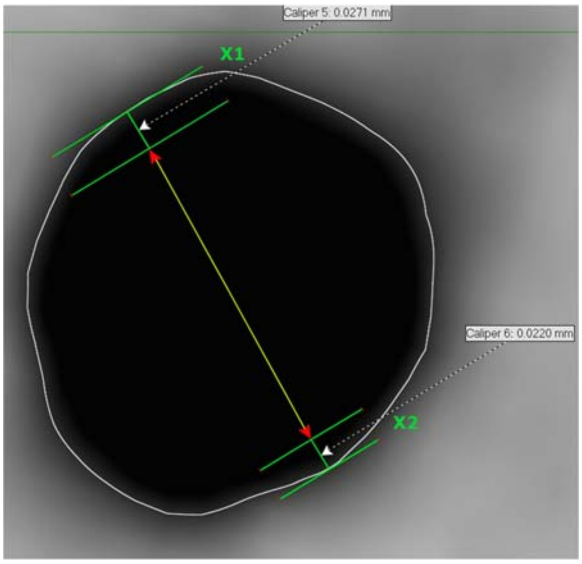

Figure 4.10: A post-instrumentation canal image representative of the ProGlider group showing similar X1 and X2 movements, indicating the use of a well-centered instrument at D1 (1 mm from the apical foramen)

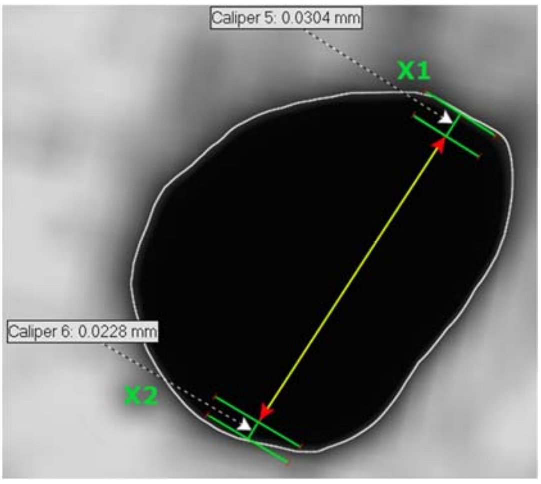

Figure 4.11: Similar X1 and X2 movements shown in a post-instrumentation canal image representative of the ProGlider group signifying the use of a well-centered instrument at D_{mc} (point of maximum root curvature)

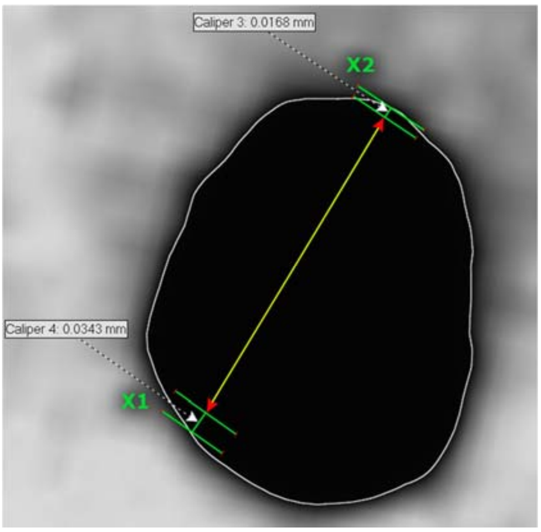

Figure 4.12: A post-instrumentation canal image representative of the ProGlider group showing similar X1 and X2 movements, indicating the use of a well-centered instrument at D7 (7 mm from the apical foramen).

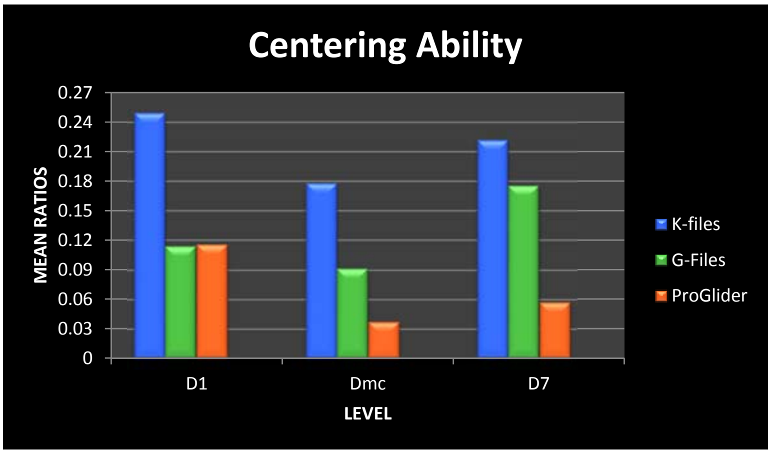

Figure 4.13: Comparative graph portraying centering ability for the three glide path instrumentation groups at D1, D_{mc} and D7 – lower mean ratios indicate a favourable centering ability

Table 4.1 Descriptive statistics for canal centering ability at D1 (1 mm from the apical foramen)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.2494[a]	0.1695	0.2146	0.0107	0.5937
G-File	30	0.1143[b]	0.1176	0.0700	0.0018	0.4731
ProGlider	30	0.1160[b]	0.1405	0.0413	0.0012	0.5215

Mean values with the same superscript letters were not statistically different at $p<0.016$.

Table 4.2 Descriptive statistics for canal centering ability at D_{mc} (point of maximum curvature)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.1778[a]	0.1602	0.1188	0.0171	0.5612
G-File	30	0.0917[a]	0.0908	0.0667	0.0001	0.3289
ProGlider	30	0.0371[b]	0.0349	0.0208	0.0011	0.1147

Mean values with the same superscript letters were not statistically different at $p<0.016$.

Table 4.3 Descriptive statistics for canal centering ability at D7 (7 mm from the apical foramen)

Technique	n	Mean	Standard deviation	Median	Minimum	Maximum
K-file	30	0.2217[a]	0.3817	0.0454	0.0027	1.9491
G-File	30	0.1753[a,b]	0.2256	0.0724	0.0031	0.8261
ProGlider	30	0.0571[b]	0.0642	0.0238	0.0004	0.2049

Mean values with the same superscript letters were not statistically different at $p<0.016$.

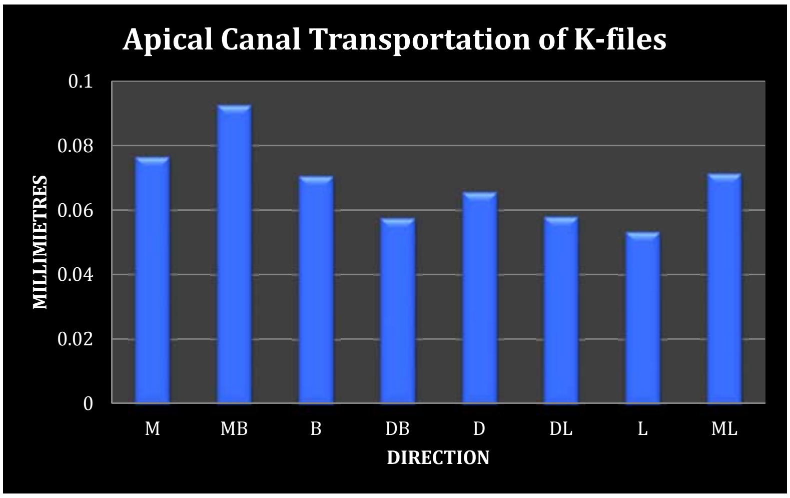

Figure 4.14: Apical canal transportation values for stainless steel K-files in eight directions at D1 (1 mm from the apical foramen)

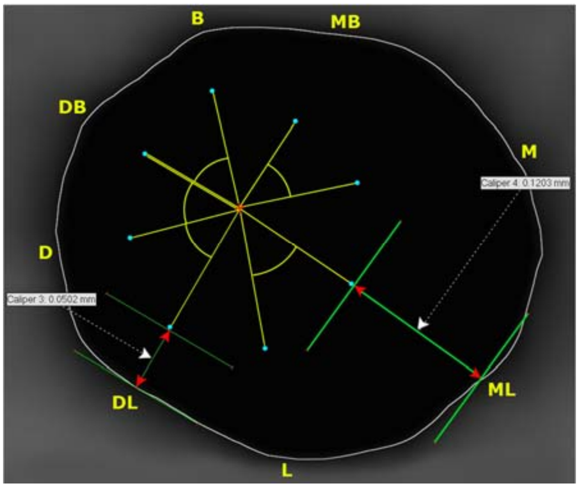

Figure 4.15: A representative image of a canal enlarged with stainless steel K-files displaying transportation in a mesiolingual direction at D1 (1 mm from the apical foramen)

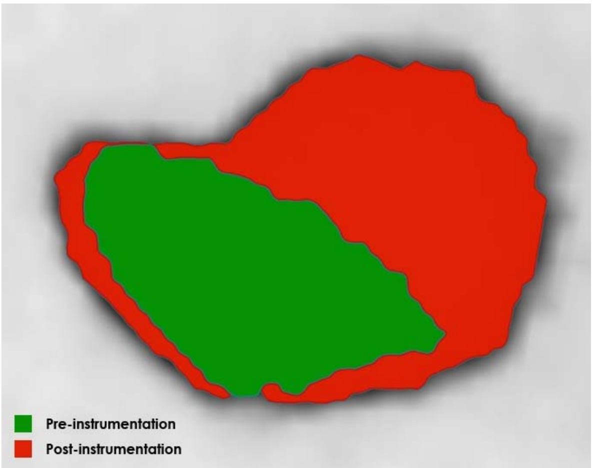

Figure 4.16: Merged canals in an image representative of the K-file group showing a transported post-instrumentation canal highlighted in red and the pre-instrumentation canal highlighted in green at D1 (1 mm from the apical foramen)

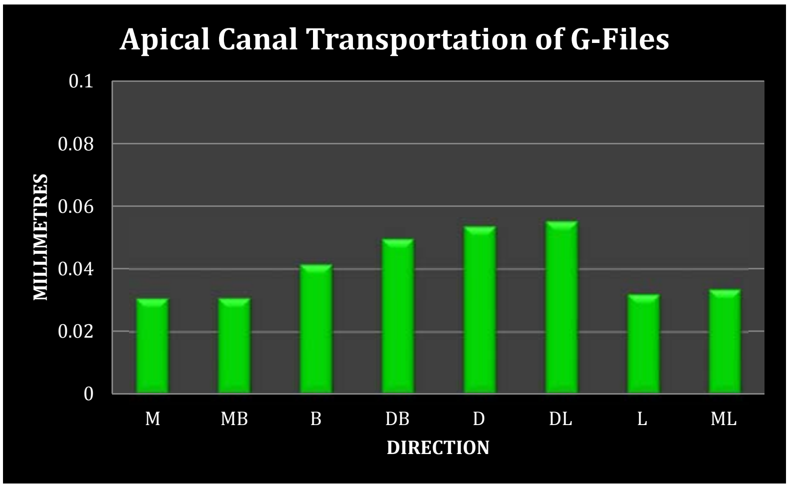

Figure 4.17: Apical canal transportation values for G-Files in eight directions at D1 (1 mm from the apical foramen)

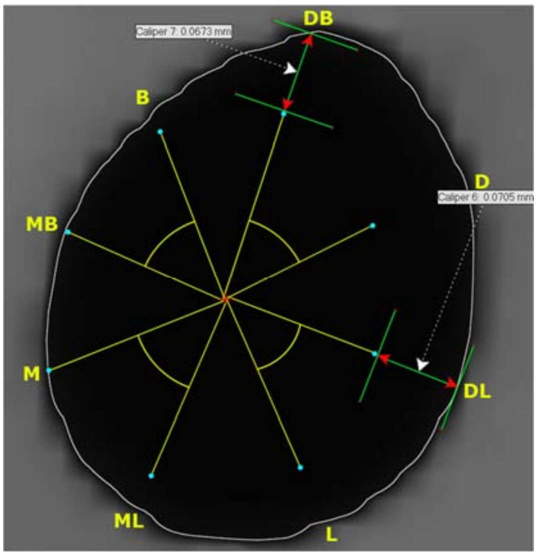

Figure 4.18: Minimal apical canal transportation evident at D1 (1 mm from the apical foramen) after glide path enlargement seen in a post-instrumentation canal image representative of the G-File group – calliper measurements are similar in length

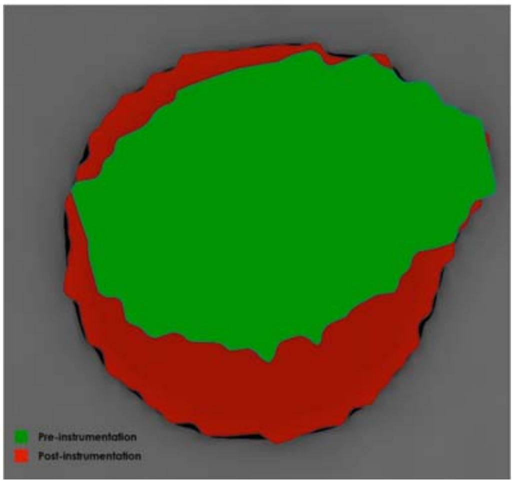

Figure 4.19: Merged canals in an image representative of the G-File group showing a minimally transported post-instrumentation canal highlighted in red and the pre-instrumentation canal highlighted in green at D1 (1 mm from the apical foramen)

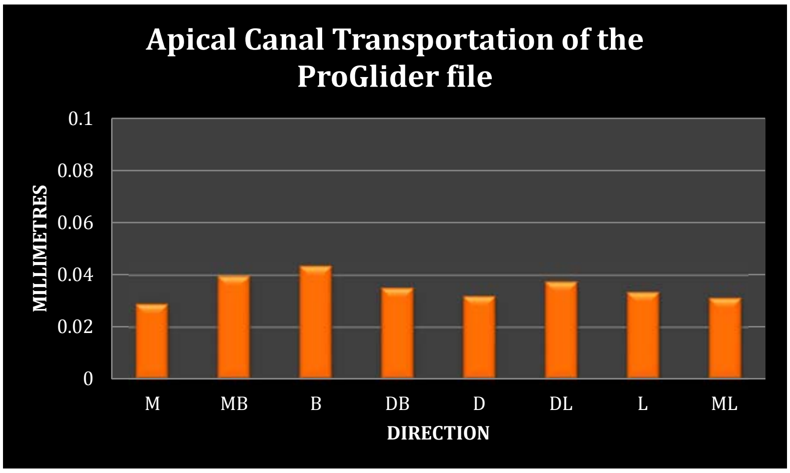

Figure 4.20: Apical canal transportation values for the ProGlider file in eight directions at D1 (1 mm from the apical foramen)

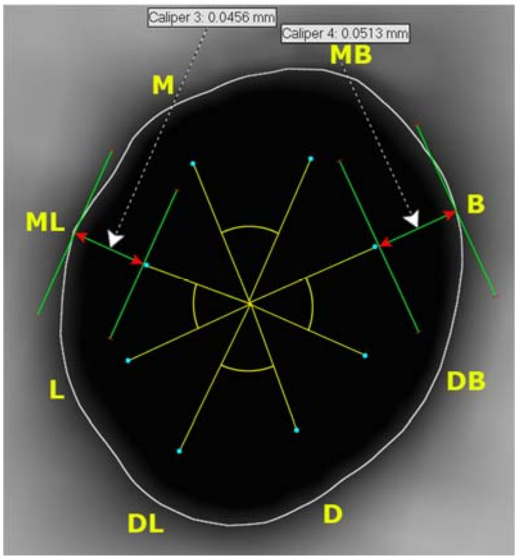

Figure 4.21: Minimal canal transportation evident at D1 (1 mm from the apical foramen) in an image representative of the ProGlider group – calliper measurements are similar in size

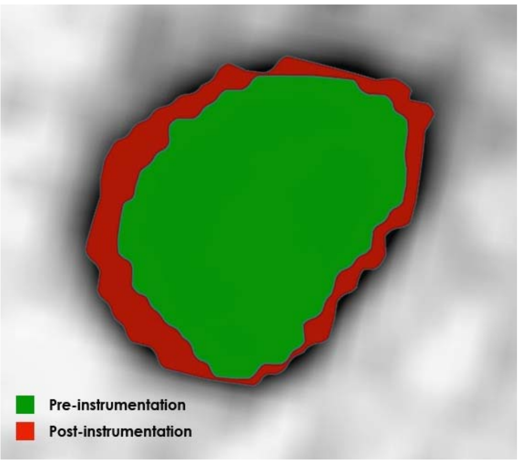

Figure 4.22: Merged canals representative of the ProGlider group showing a minimally transported post-instrumentation canal highlighted in red and the pre-instrumentation canal highlighted in green at D1

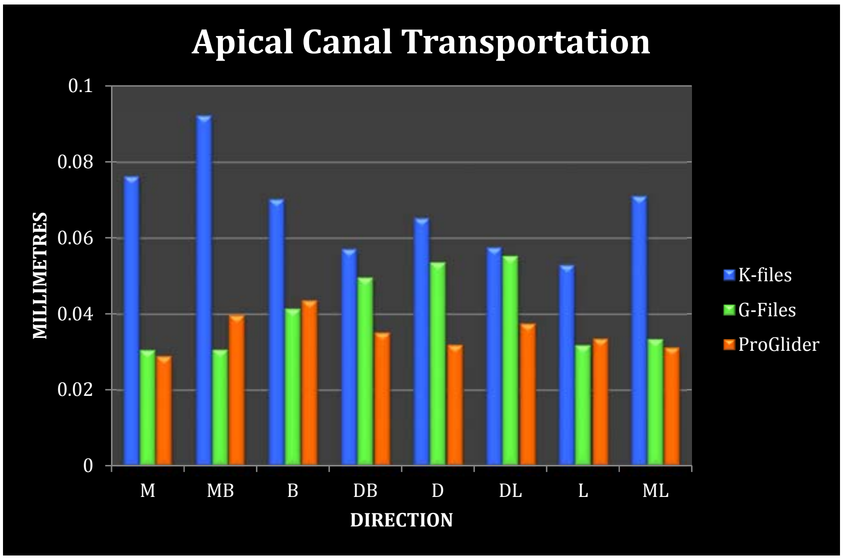

Figure. 4.23: Comparative graph depicting apical canal transportation at D1 (1 mm from the apical foramen) for the three glide path instrumentation group in eight directions

Table 4.4 Means (in mm) and standard deviation of apical canal transportation produced by each instrumentation technique at D1, according to the direction of dentine removal

Direction	Technique		
	K-file	G-Files	ProGlider
Mesial	0.0763±0.0488[a]	0.0305±0.0302[b]	0.0289±0.0138[b]
Mesiobuccal	0.0923±0.0716[a]	0.0306±0.0360[b]	0.0397±0.0189[b]
Buccal	0.0703±0.0509[a]	0.0414±0.0255[b]	0.0436±0.0236[b]
Distobuccal	0.0572±0.0288[a]	0.0496±0.0329[a,b]	0.0351±0.0251[b]
Distal	0.0653±0.0465[a]	0.0536±0.0389[a,b]	0.0319±0.0235[b]
Distolingual	0.0576±0.0361[a]	0.0553±0.0361[a]	0.0375±0.0255[a]
Lingual	0.0530±0.0306[a]	0.0318±0.0306[b]	0.0335±0.0230[a,b]
Mesiolingual	0.0711±0.0551[a]	0.0334±0.0279[b]	0.0312±0.0186[b]

Mean values with the same superscript letters were not statistically different at $p<0.05$.

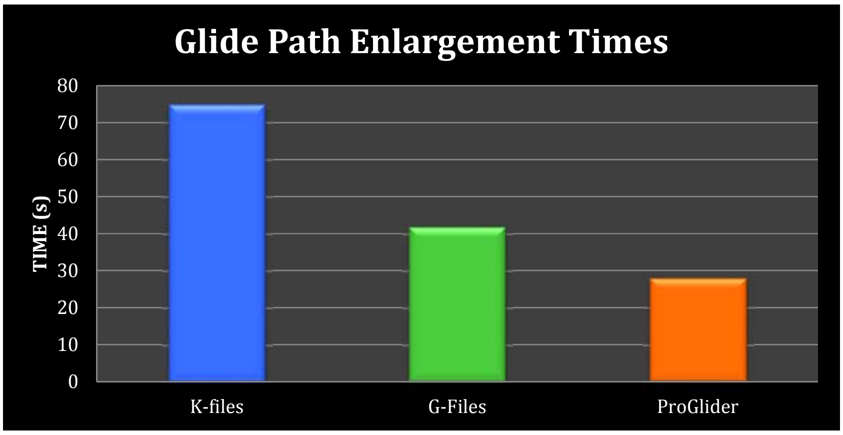

Figure 4.24: Mean total glide path enlargement times for stainless K-files, G-Files and the ProGlider file

Table 4.5 Descriptive statistics for the total preparation time for the different test groups

Technique	Number	Mean	Standard deviation	Minimum	Maximum
K-file	30	74.92[a]	56.91	13.53	224.85
G-File	30	41.87[b]	20.19	15.31	105.01
ProGlider	30	27.95[b]	8.55	13.25	44.79

Mean values with the same superscript letters were not statistically different at $p<0.05$.

Chapter 5: Discussion

The present study aimed to compare the root canal centering ability and apical canal transportation of stainless steel K-files, G-Files and the ProGlider file after glide path enlargement in curved roots of human extracted molars using micro-CT scanning. In addition, the time it took to prepare and enlarge the glide paths for each group was recorded and compared.

Predictable endodontic success is dependent on accurate 3D cleaning, shaping and obturation of the root canal system (Schilder, 1967; Schilder, 1974). However the complex anatomy of root canals however presents cleaning and shaping challenges during endodontic treatment (Hülsmann et al. 2005). Effective 3D obturation depends on careful cleaning and shaping procedures that can often be complicated by procedural errors such as transportation and ledge formation (Berutti et al. 2012). Root canal shaping instruments such as NiTi rotary shaping files are not suitable for initial canal negotiation by virtue of their large size, taper and design (Peters and Paqué, 2010; Young et al. 2007). Berutti et al. (2004) recommend manual pre-flaring of the root canal to create a glide path before using NiTi rotary instrumentation. According to these authors, glide path enlargement reduces torsional stress and increases the lifespan of NiTi rotary instruments. Patiño et al. (2005) also found that the fracture rate of NiTi rotary instruments is significantly reduced when their use is preceded by glide path enlargement.

Proper glide path enlargement allows for the expansion of an already existing root canal pathway to the full working length, reduces procedural errors such as transportation and ledge formation (Berutti et al. 2012) and decreases the risk of excessive binding of subsequent canal shaping instruments (Zanette et al. 2014). West (2006, p. 287) defined the glide path as ‘which represents a smooth, though perhaps narrow, tunnel from the orifice to the electronic portal of exit or the radiographic terminus.’ West noted that a glide path is achieved when the file forming it can enter from the orifice and follow the smooth canal walls uninterrupted to the terminus. A successful glide path is much more likely to be maintained with larger rotary NiTi shaping instruments (West, 2006). It allows for sufficient space for rotary NiTi shaping instruments to complete the shaping required before obturation

(Blum et al. 2003).

Minimally invasive root canal enlargement and shaping techniques maintain the original canal shape and are associated with better endodontic outcomes (Glosson et al. 1995). It has been suggested that the evaluation of changes in canal shape after instrumentation is a reliable process to assess the ability of an instrumentation technique to preserve the original canal shape (Berutti et al. 2012; Merrett, Bryant and Dummer, 2006). To investigate the efficiency of instruments and techniques developed for root canal preparation, a number of methods have been used to compare canal shape before and after instrumentation. These methods include radiography and the serial sectioning technique. Conventional radiography only provides a 2D image and it is impossible to observe a cross-section of the root canal (Dowker et al. 1997). The serial sectioning technique involves physically slicing the teeth into predetermined sections and photographing them before instrumentation. After this the sections are pieced back together, instrumented, separated and photographed again (Bramante, Berbert and Borges, 1987). This technique can result in unknown tissue changes and loss of material (Gambill et al. 1996). Computed tomography imaging techniques have been evaluated as non-invasive methods for the analysis of canal geometry and efficiency of shaping techniques (Rhodes et al. 1999; Bergmans et al. 2001). With this technique, it is possible to compare the anatomic structure of the root canal before and after instrumentation.

In the present study, the micro-CT tool was used to evaluate the centering ability and apical canal transportation of the tested groups. Micro-computed tomography is x-ray imaging in 3D, by the same method as CT scans, but on a small scale with far superior resolution. When using micro-CT no destructive sectioning of the specimens is required and the potential of a radiographic or photographic transfer error is avoided. A major advantage of micro-CT scanning is the precise evaluation of root canal shape by the superimposition and measurement of 3D renderings. It is an easy to repeat method and provides data that allows for the identification of morphologic changes associated with different biomechanical preparations including canal transportation and dentine removal (Peters and Paqué, 2011; Paqué, Ganahl and Peters, 2009).

Previous studies found that instrumentation that is not well centered in the canal causes inappropriate dentine removal with a high risk of straightening of the original canal curvature, formation of procedural defects in the dentine wall and excessive apical foramen enlargement (Jafarzadeh and Abbott, 2007; Loizides et al. 2007). Apical canal transportation changes the position of the apical foramen as well as the working length (Wu et al. 2000). Apical canal transportation and foramen widening may remove the apical stop causing extrusion of infected debris and microorganisms with resultant postoperative discomfort and a poor endodontic treatment outcome (Peters, 2004; Siqueira et al. 2002). Studies show that instrumentation that is centered throughout the canal with little or no apical canal transportation preserves the original canal, is associated with higher antimicrobial and sealing efficiency and does not excessively weaken tooth structure (Moore, Fitz-Walter and Parashos , 2009; Wu et al. 2000).

The present study examined the centering ability and apical canal transportation of stainless steel K-files, G-Files and the ProGlider file in curved root canals of extracted human molars. For the examination of centering ability, three levels were chosen: 1 mm from the apical foramen (D1), the point of maximum root curvature (D_{mc}) and 7 mm from the apical foramen (D7). These measurements represent areas within the root canal where curvatures with high vulnerability to iatrogenic mishaps typically exist. Curved canals are frequently used as specimens in research studies because these canals present greater challenges to instrumentation (Alves et al. 2012; Schneider, 1971). These challenges have been linked to the observation of performance differences between various instrument systems during the shaping of curved canals (Berutti et al. 2009; Hülsmann and Stryga, 1993). Statistically however, the standard deviation of observations may increase when curved specimens are used (Alves et al. 2012). Some studies have used standardised artificial canals in plastic training blocks to minimise this problem (Alves et al. 2012; Van der Vyver et al. 2015). However, the benefits derived from testing file systems in the natural dentine of extracted teeth is probably greater than those derived from observing smaller standard deviations in artificial canals (Alves et al. 2012). Natural teeth were used in this study to capitalise on these benefits and make use of the advantages of micro-CT.

This is the first study on curved root canals of extracted molars to compare the centering ability, apical canal transportation and mean glide path preparation times of stainless steel K-files, G-Files and the ProGlider file. No comparative data regarding the centering ability and apical canal transportation for G-Files and the ProGlider file was found in the literature.

Results in the present study showed that glide path enlargement with stainless steel K-files was less centered than for G-Files and the ProGlider file at D1, D_{mc} and D7. At all levels examined the mean centering ratios for the stainless steel K-file group were higher than for the NiTi rotary glide path file groups. Statistically similar observations were made for the G-File and ProGlider groups at D1 ($p<0.016$). At the point of maximum curvature however, the ProGlider group demonstrated significantly better centering ratios than both the G-File and stainless steel K-file groups, which were found to be statistically similar. At D7, the ProGlider group produced better centering ratios than both the stainless steel K-file and G-File groups but the values were not significantly different from the latter group. The ProGlider file showed a trend toward centering its instrumentation around the entirety of the original canal to a greater extent than the other groups evaluated.

This study confirmed the results of previous studies that have demonstrated the ability of NiTi rotary path files to create more centered root canal preparations than stainless steel K-files (Berutti, et al 2009; Pasqualini et al. 2012). The study by Pasqualini et al. (2012) also used micro-CT to examine glide path enlargement of curved canals. Their study confirmed that NiTi rotary PathFiles (Dentsply/Maillefer) enable an optimal glide path for the subsequent use of NiTi rotary shaping instruments. They compared PathFiles with stainless steel K-Files and concluded that these NiTi rotary glide path files have a high root canal centering ability and cause fewer modifications of the canal curvature and fewer canal aberrations. This was in accordance with the results of the present study, which showed the superior centering ability of the NiTi rotary ProGlider file over stainless steel K-files at all levels examined. Results for G-Files, a NiTi rotary file system, however demonstrated a statistically similar centering ability to that of stainless steel K-files at D_{mc}.

The significant differences in centering ability between the two NiTi rotary file groups at D_{mc} in this study might be explained by the standard deviation of observations that can occur amongst curved canals of natural teeth, instrument design factors or operational techniques like rotational speed and torque. The ProGlider file provided a centered preparation and closely maintained the original shape of the curved canal. ProGlider instrument factors that may be relevant include its M-wire construction, variable progressive taper, square cross-section and smaller ISO tip size of 0.16. The flexibility of an endodontic instrument is influenced by the composition and thermo-mechanical treatment of the metallic alloy as well as by the size of the instrument and its cross-sectional design (Tripi, Bonaccorso and Condorelli, 2006; Turpin, Chagneau and Vulcain, 2000). Flexibility may influence the instrument's ability to properly shape curved root canals. Several studies have shown that more flexible instruments produce more centered preparations (Gergi et al. 2010; Short, Morgan and Baumgartner, 1997).

Gergi et al. (2010) compared canal transportation and centering ability of Twisted Files (SybronEndo), a combination group consisting of PathFile (Dentsply/Maillefer) and ProTaper files (Dentsply/Maillefer) and stainless steel K-files. The results of this study showed that Twisted Files produced significantly less transportation and exhibited a significantly better mean centering ratio, than the combined technique using PathFiles and ProTaper and stainless steel K-files. The superior shaping results of the Twisted File were ascribed to its twisting NiTi wire construction, which make these files more flexible than NiTi grinded instruments. The ProGlider file used in this study is manufactured from M-wire NiTi alloy while G-Files are made from conventional NiTi. Heat-treated M-wire alloy has a control memory feature that makes this alloy extremely flexible and more resistant to cyclic fatigue than non-control memory NiTi alloy (Shen et al. 2011). Pereira et al. (2011) compared the chemical composition, transformation temperatures and Vickers micro-hardness measurements of conventional NiTi wire and thermo-mechanically treated NiTi, M-wire. The results of their study were in accordance with another that concluded that M-Wire had physical and mechanical properties that can render endodontic instruments more flexible and fatigue-resistant than those made with conventionally processed NiTi wires (Pereira et al. 2103). The superior centering ability of the ProGlider file in the present study could be due to its increased flexibility, particularly at D_{mc} (the point of maximum curvature).

The fact that G-Files remained less centered at the point of maximum curvature in the present study may also be due to their constant 3% taper and/or to the wedging of its non-cutting tip against the apical dentinal wall, leaving the file to cut freely at the curve. The ProGlider file, however, has a semi-active tip with a progressive taper from 2% to 8.5% over its active cutting zone. Differences in the cross-sections of the two NiTi rotary path file systems may also contribute to the differences observed at D_{mc}. The ProGlider file has a centred, square cross-section while G-Files have a varied evolving cross-section. In their study, Gergi et al. (2010) also postulated that the inferior centering ability and increased transportation values of a combination group consisting of PathFile (Dentsply/Maillefer) and ProTaper files (Dentsply/Maillefer), compared to the Twisted File (SybronEndo) in their study, were as a result of its cross-sectional design and sharp cutting edges. Similarly, the sharp cutting edges because of the cross-sectional design of G-Files in the present study may further explain why the files were not centered at the point of maximum root curvature.

The results of this study showed statistically similar apical canal transportation mean values for the G-File and ProGlider groups in all directions. Stainless steel K-files were found to transport the canal significantly more than G-Files in five directions - mesial, mesiobuccal, buccal, lingual and mesiolingual. These two groups exhibited statistically similar apical canal transportation values in the remaining three directions. The ProGlider file exhibited significantly less apical canal transportation than stainless steel K-files in six directions - mesial, mesiobuccal, buccal, distobuccal, distal and mesiolingual. Apical canal transportation values for these groups were statistically similar in the remaining two directions ($p<0.05$). All three groups exhibited statistically similar transportation in the distolingual direction. This observation may be as a result of single operator performing all the enlargements with a possible tendency to instrument towards distolingual.

A study by D'Amario et al. (2013) however reported no statistically significant differences in the angle of canal curvature and apical canal transportation between two NiTi rotary glide path file systems and stainless steel K-file manual glide path enlargement. Their study examined glide path enlargement with G-Files, PathFiles (Dentsply/Maillefer) and stainless steel K-files using a digital double radiographic technique. They concluded that none of the groups had any influence on the occurrence of apical transportation nor did they produce a change in the angle of canal curvature. The difference in results can be explained by the study technique used, the digital double radiographic technique, that is evidently not as accurate as micro-CT.

Many studies have shown that NiTi rotary glide path file systems tend to transport canals less than stainless steel K-files (Glosson et al. 1995; Pasqualini et al. 2012; Tasdemir et al. 2005). The results for apical canal transportation in the present study are in accordance with the results of these studies. A micro-CT study by Moore et al. (2009) investigated the morphological changes in the apical third of the root canal after preparation with three techniques: stainless steel K-files, stainless steel K-files with final apical preparation with size 0.04 taper FlexMaster (VDW) instrument and a hybrid technique combining ProTaper (Dentsply/Maillefer) and FlexMaster. They noted that there was a trend for less canal transportation using NiTi rotary instruments, especially in canals with more severe curvatures where undesired apical dentine removal by stainless steel instruments was more pronounced. Their study concluded that stainless steel hand preparation was not conservative of apical dentine and that NiTi rotary instruments were able to precisely prepare a canal to larger apical sizes with minimal risk of iatrogenic damage. Pasqualini et al. (2012) reported similar findings in their study of curved canals.

The relative stiffness of stainless steel K-files explain why these instruments exhibit a poor centering ability and higher apical canal transportation values in this study examining curved canals. The problems posed by the rigidity of these files in curved canals were noted as long as four decades ago in a study by Craig et al. (1968), which examined the bending and torsion properties of endodontic instruments. The performance of stainless steel K-files may also be attributed to the fact that the final apical preparation sizes differed between the three groups tested in this study. The final stainless steel K-file used for glide path enlargement was an ISO size 20, while that of G-Files was an ISO size 17 and for the ProGlider file an ISO size 16. The glide path study by Ajuz et al. (2013) however examined canal deviations in S-shaped canals in training blocks following the use of stainless steel K-files, PathFiles and Scout

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RaCe files (FKG Dentaire). The final apical preparation sizes in their study were ISO size 20 for the stainless steel K-file group, ISO size 19 for the PathFile group and ISO size 20 for the Scout RaCe group. The NiTi rotary path file groups in their study performed significantly better than the stainless steel K-file group, with an overall significantly better performance by Scout RaCe. The results of the present study are similar to their findings where they conclude that canal deviations were more evident in the stainless steel K-file group. This suggests that the final apical preparation sizes differences may be of little relevance with respect to the outcomes of the present study.

Apical canal transportation can cause procedural errors such as ledges, strip-perforations as well as leakage (Peters, 2004). A study by Wu et al. (2000) concluded that apical transportation greater than 0.300 mm may have a negative effect on the apical seal during obturation. Transportation values in this glide path study did not exceed 0.093 mm. Further shaping studies using the same samples in this study are therefore required to ascertain whether subsequent shaping instrumentation will exacerbate already transported areas beyond the 0.300 mm threshold. The occurrence of apical preparation errors has previously been linked to hand and rotary instruments with sharp tips (Griffiths, Bryant and Dummer, 2000; Powell, Simon and Maze, 1986). Pettiette, Delano and Trope (2001) evaluated clinical cases treated with NiTi instruments and found a low incidence of preparation errors, satisfactory obturation as judged from radiographs, and significantly improved healing compared with a control group treated with stainless-steel instruments.

In the present study, glide path enlargement time was fastest in the ProGlider group. A study by D'Amario et al. (2013) compared glide path enlargement times of G-Files, PathFiles (Dentsply/Maillefer) and stainless steel K-files. In their study, G-Files prepared a glide path more rapidly than the other two groups. The results of their study can be explained by the fact that the PathFile system consists of three files while the G-File system has only two files. A study by Van der Vyver et al. (2015) compared glide path enlargement times of the ProGlider file, PathFiles, X-Plorer Canal Navigation NiTi Files (Clinician's Choice Dental Products Inc.) and stainless steel K-files. They found that the enlargement time of the ProGlider file was significantly faster than all the other groups. The statistically significant longer glide path enlargement times of

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PathFiles and X-Plorer Canal Navigation NiTi Files were due to the fact that three different instruments in each of the other two groups had to be used to enlarge the glide path in comparison with single ProGlider file.

The difference in enlargement times between the NiTi rotary file groups in the present study can be explained by the fact that the G-File system makes use of two rotary instruments while the ProGlider system consists of one instrument. There was however no statistically significant difference observed between the mean preparation times of the ProGlider file and G-Files. In this study, it is important to note that the NiTi rotary file systems were used only after initial instrumentation with a size 0.10 stainless steel K-file. The time it took for this initial instrumentation was also recorded and included in the total preparation times for the NiTi rotary file groups. The time it took to change between the different instruments used for each group was not recorded. Taking this into account, the ProGlider file and G-Files enlarged a glide path significantly faster than stainless steel K-files.

The findings of this study may have implications in the clinical setting. A poorly centered instrument increases the risk of procedural errors along the canal and apical canal transportation may change the anatomical shape of the apical foramen undesirably and create further challenges. So, while it is acknowledged that the establishment of a reproducible glide path is essential, the appropriate instrumentation is necessary to achieve the desired result. Utilisation of the NiTi rotary files used for glide path enlargement in this study may result in a reduction in clinical chair time with a minimal risk of apical canal transportation and its sequelae. Of the two NiTi rotary glide path file systems used, the ProGlider file may be more suited to enlarging a glide path in curved canals in the clinical situation.

Chapter 6: Conclusions

Within the limitations of the present study the following can be concluded:

1. Both rotary NiTi glide path enlargement files (G-Files and the ProGlider file) displayed statistically significantly better mean centering ratios at a level 1 mm from the apical foramen (D1) than stainless steel K-files ($p<0.016$).

2. The ProGlider file displayed a statistically significantly better mean centering ratio at the point of maximum curvature (D_{mc}) than both G-Files and stainless steel K-files, which were shown to be statistically similar ($p<0.016$) at this level.

3. The mean centering ratio of the ProGlider file was statistically significantly better than stainless steel K-files at a level 7mm from the apical foramen (D7). There were no statistically significant differences between the mean centering ratios of G-Files and stainless steel K-files at D7 or the mean centering ratios of the ProGlider file compared to G-Files ($p<0.016$).

4. The centering ability of the ProGlider file was favourable at all three levels examined within the instrumented root canals.

5. Apical canal transportation was significantly higher for the K-file group when compared to G-Files in five directions - mesial, mesiobuccal, buccal, lingual and mesiolingual. Statistically similar observations were made between these two groups in the distobuccal, distal and distolingual directions ($p<0.05$).

6. Apical canal transportation was significantly higher for the K-file group when compared to the ProGlider file in six directions - mesial, mesiobuccal, buccal, distobuccal, distal and mesiolingual. Statistically similar observations were made between these two groups in the distolingual and lingual directions ($p<0.05$).

7. Overall, apical canal transportation values were more favourable in the NiTi rotary file groups. The ProGlider file and G-Files produced statistically similar apical canal transportation values in all directions ($p<0.05$).

8. Glide path enlargement with the NiTi rotary file groups was significantly faster compared to stainless steel K-files ($p<0.05$).

The null hypothesis is therefore rejected.

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Addendum A: Informed Consent Form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ORAL AND DENTAL HOSPITAL

Dear Patient,

The personnel and students of Oral and Dental Hospital of the University of Pretoria (which is a teaching hospital) appreciate your confidence in us for dental treatment. Although we strive to complete treatment as speedily as possible, our primary task is the training of students. For this reason, the treatment of patients will necessarily be more time-consuming compared to the private sector.

The student who is responsible for your treatment is dependent on your promptness, co-operation and availability. While we strive to train students to treat you in the best possible manner, we kindly request your indulgence with the progress of your treatment plan. We would appreciate you informing us of any unfavourable circumstances. In this way, we shall be able to improve our service to you.

Refusal by a patient to be treated by a particular student/dentist to whom he/she is allocated, is not acceptable. In such circumstances, further routine treatment for a patient will be refused. We appreciate your co-operation in this regard. If you have any enquiries, please discuss it with a lecturer/dentist on duty.

The Oral and Dental Hospital is a service rendering unit which is part of the University of Pretoria. Research, apart from teaching, is aimed at the continuous improvement of dental treatment and dental materials. The teaching and research that is done, is partly dependent on obtaining suitable material from our patients. We kindly request that you study the consent form below and if you approve, to please complete it. Should you have any enquiries, please feel free to discuss it with a lecturer/ dentist on duty.

CONSENT

By this I (full names and surname) ___________________________
________________ patient/parent/guardian) grant permission to be treated/that _____________________________ be treated by the Oral and Dental Hospital. I realise that the Oral and Dental Hospital of the University of Pretoria is a teaching hospital and, as such, part or all of my treatment may be given by a student. I realise that information and materials obtained from me during dental procedures may be used for dental training and/or research. I understand that, in the case of my information or materials being used in research, that research will be approved in advance by the Research Ethics Committee of the Faculty of Health Sciences of the University of Pretoria. In the event of such research being of a genetic nature (ie. if my genetic material is studied in the research), the researchers will ask my permission to use my material before they do so. I understand that, if I refuse to give permission for my information or materials to be used in research, this will not in any way affect the treatment I receive at the Oral and Dental Hospital. I understand that, in addition to research, the Oral and Dental Hospital from time to time will audit its patient records as part of the clinical audit process. My permission is granted on the understanding that in all circumstances my identity will remain confidential (secret) and that all my personal details will be dealt with confidentially.

Name: ____

Signature: ____

File No: ____

HOSPITAAL VIR TAND- EN MONDHEELKUNDE

Geagte Pasiënt,

Die personeel en studente van die Hospitaal vir Tand- en Mond-heelkunde (HTM) van die Universiteit van Pretoria, (wat 'n Opleidings-hospitaal is) waardeer die vertroue wat u in ons stel deur hier vir u tandheelkundige behandeling aan te meld. Alhoewel ons daarna streef om behandeling so spoedig moontlik af te handel, is ons primêre taak om studente op te lei. Daarom verloop pasiënte se tandheelkundige behandeling noodwendig stadiger as byvoorbeeld in die privaatsektor.

Die student wat verantwoordelik is vir u behandeling, is afhanklik van u samewerking en daarom versoek ons u vriendelik om gereeld, getrou en betyds u afsprake na te kom. Terwyl ons poog om studente op te lei om u as pasiënt reg te hanteer en te benader, vra ons u begrip indien dinge van tyd tot tyd nie ideal verloop soos u dit sou verkies nie. Ons sal dit egter waardeer indien u ons in kennis sal stel indien dinge nie heeltemal aan u verwagtinge voldoen nie. So kan ons die diens aan u verder verbeter.

'n Beroep word op u bereidwilligheid gedoen om behandel te word deur die student/tandarts aan wie u toegeken word. Indien 'n pasiënt nie bereid is om behandeling te ondergaan by die student/tandarts aan wie hy/sy toegewys is nie, sal verdere roetine behandeling vir die pasiënt geweier word. Indien u enige navrae het, bespreek dit asseblief met 'n dosent/tandarts aan diens.

Die HTM vorm deel van die Universiteit van Pretoria as 'n diens-leweringseenheid. Benewens opleiding, word navorsing om voortgesette verbetering van tandheelkundige behandeling en materiale te verseker ook gedoen. Die opleiding en navorsingswerk wat gedoen word is deels afhanklik van beskikbare pasiënt materiaal. Ons versoek u dus vriendelik om die toestemmingsvorm hier onder te bestudeer en as dit u goedkeuring wegdra, dit asseblief te voltooi. Indien u enige navrae het, bespreek dit asseblief met 'n dosent/tandarts aan diens.

TOESTEMMING

Hiermee verleen ek, (volle name en van) ________________________
________________ as pasiënt/ouer/voog toestemming om behandel te word/dat __________________________ behandel mag word deur die HTM. Ek besef dat die HTM van die Universiteit van Pretoria 'n opleidingshospitaal is en daarom mag my volledige behandeling of gedeelte daarvan deur 'n student uitgevoer word. Ek besef dat inligting en materiaal wat tydents tandheelkundige behandelingsprosedures van my verkry word, vir tandheelkundige opleiding en/of navorsing gebruik mag word. Ek verstaan dat in die geval dat my inligting of materiaal vir navorsing gebruik word, sal enige navorsing eers deur die Navorsingsetiekkomitee van die Fakulteit Gesondheidswetenskappe van die Universiteit van Pretoria goedgekeur moet word. In geval die navorsing van 'n genetiese aard is (bv. indien my genetiese materiaal bestudeer word in die navorsing), die navorsers eers my toestemming sal verkry. Ek verstaan dat, indien ek toestemming weier dat my inligting of materiaal vir navorsing gebruik word, dit op geen wyse my tandheelkundige behandeling wat ek by die HTM ontvang nadelig sal beïnvloed nie. Ek verstaan, dat bykomend tot die navorsing, die HTM van tyd tot tyd pasiëntrekords sal oudit as deel van die kliniese ouditproses. My toestemming word verleen met dien verstande dat my identiteit onder geen omstandighede openbaar gemaak sal word nie en dat al my persoonlike besonderhede vertroulik hanteer sal word.

Naam: ____

Handtekening: ____

Lêer nr: ____

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