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AN IN VITRO COMPARISON OF THREE DIFFERENT TECHNIQUES TO CREATE A GLIDE PATH PRIOR TO NICKEL TITANIUM ROTARY INSTRUMENTATION

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DECLARATION

I Imran Cassim, declare that this dissertation entitled, **"An in vitro comparison of three different techniques to create a glide path prior to nickel titanium rotary instrumentation"**, 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 never been submitted for any academic award to any other institution of higher learning.

31 October 2013

SIGNATURE **DATE**

Seek Knowledge
from the Cradle
to the Grave.

Hazrat Muhammed
Sallallahu alaihi wa sallam

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SUMMARY

The preparation of a glide path prior to the use of rotary nickel titanium instrumentation reduces torsional stress and the risk of rotary nickel titanium instrument separation.

The objective of this *in vitro* study was to evaluate 3 different glide path preparation techniques in respect of:

- Percentage change of curvature from original canal anatomy; and
- The occurrence of aberrations in canal anatomy (ledging, zipping and elbows).

One hundred and twenty S-shaped Endo-Training-Blocks were selected. The canals were injected with India ink dye. The blocks were indexed with 3 bur marks and placed into a template before pre-instrumentation images were acquired digitally. The blocks were randomly divided into four groups of thirty each. Glide paths were prepared by a single operator with stainless steel hand K-files only, up to ISO size 20 (group 1, control), stainless steel hand K-files in the M4 reciprocating hand-piece up to ISO size 20 (group 2), hand K-files to ISO size 10 then NiTi rotary PathFiles (group 3) and hand K-files to ISO size 10 then NiTi rotary X-Plorer files (group 4). After glide path preparation the blocks were replaced into the template and post-instrumentation images were digitally acquired.

Percentage change of curvature from original canal anatomy:

Pre-instrumentation and post-instrumentation images were imported into Rhinoceros software to determine the end points of the canal curves and calculate the percentage change of canal curvature for the radii of apical and coronal curves.

The data was collected and tabulated. Differences in canal curvature modification were statistically analysed with respect to logarithmic transformed change from baseline using ANCOVA ($p<0.001$) with logarithmic transformed pre-instrumentation values as covariate. After establishing preparation differences, both for change from baseline (pre-instrumentation) for apical and coronal curves, specific differences were tested using Fisher's LSD for pairwise comparisons. Prepared groups differed significantly ($p<0.001$) and in particular, group 1 (Hand K-files) (control) and group 2

(Hand K-files in M4 Safety reciprocating hand piece) differed significantly from all the other groups while group 3 (Hand K-files and PathFiles) and group 4 (Hand K-files and X-Plorer files) did not differ significantly. Group 3 (Hand K-files and PathFiles) and group4 (Hand K-files and X-Plorer files) were also superior to group1 (Hand K-files) (control) and group2 (Hand K-files in M4 Safety reciprocating hand piece).

<u>The occurrence of aberrations in canal anatomy (ledging, zipping and elbows)</u>:

Pre-instrumentation and post-instrumentation images were superimposed using Adobe Photoshop software. The images were imported into a PowerPoint presentation and examined by three different blinded clinicians independently, for the presence of aberrations. There were no differences between the examiners in their assessment of the images.

The data was collected and tabulated. The incidence of canal aberrations was analysed using Fisher's exact test ($p<0.05$). The groups differed significantly regarding the number of aberrations ($p=0.005$). In particular, group 1 (control) (Hand K-files) and group 2 (Hand K-files in the M4 reciprocating hand piece) did not differ statistically ($p=0.254$; 20% and 6.67%). However group 2 (hand K-files in the M4 reciprocating hand piece) also did not differ significantly from group 3 (Hand K-files and PathFiles) and Group 4 (Hand K-files and X-Plorer files) ($p=0.326$). There were no aberrations detected in the rotary NiTi groups (group 3 and group 4).

CHAPTER 1: INTRODUCTION

The word "endodontic" comes from two Greek words meaning "inside" and "tooth". Endodontic therapy helps to save teeth that would otherwise need to be extracted, unless the teeth have vertical root fractures, are deemed unrestorable coronally or are hopelessly compromised periodontally. The aim of endodontic treatment is to prevent or cure apical periodontitis (Ørstavik and Pitt Ford, 1998). Several studies have documented that bacterial infection of the root canal is the primary cause of apical periodontitis (Kakehashi, Stanley and Fitzgerald, 1965; Sundqvist, 1976; Möller et al., 1981; Siquera et al., 2007). Successful endodontic therapy and tooth retention involves the inter-relationship of biomechanical preparation, chemotherapeutic disinfection, three dimensional sealing of the root canal system, good coronal seal and preservation of healthy tooth structure (Glassman and Serota, 2001; Kirkevang and Horsted-Bindslev, 2002; Clark and Khademi, 2010; Cassim, 2013).

The basic purpose of root canal instrumentation is to provide a biological environment that is favourable for healing and to provide a canal shape that facilitates sealing of the canal space (McSpadden, 2007). The instrumentation and preparation of the root canal system is regarded as being one of the most important stages of endodontic treatment (Schilder, 1974; Peters, 2004) and it has an influence on the efficacy of subsequent procedures in endodontic therapy. The movement of instruments and the space created during and after instrumentation facilitate the penetration and movement of irrigants within the canal system for chemical debridement (Paqué et al., 2010). The resultant shape created by the instruments is conducive to adequate sealing of the root canal system.

Hülsmann, Peters and Dummer (2005) outline the major goals of root canal preparation:

(1) conservation of sound root dentine;
(2) removal of necrotic and vital tissues from the root canal system;
(3) creating sufficient space for irrigation and medication;
(4) avoiding iatrogenic damage to the canal system and the root;
(5) avoiding further irritation and /or infection of periradicular tissues;

(6) preserving the location and integrity of the canal apex; and
(7) facilitating obturation of the canal.

Root canal preparation remains one of the most difficult tasks in endodontic therapy (Hülsmann, Peters and Dummer, 2005). Canal scouting and preflaring are the first phases of canal instrumentation during which the clinician might more frequently encounter procedural difficulties (Jafarzadeh and Abbott, 2007).

Among the difficulties encountered are location, access, preparation of the canals without procedural errors, establishment and maintenance of working length. The risk of missing root canal anatomy is high because of the complexity of the root canal system. Calcifications may impede access to canal orifices and all categories of teeth may have extra roots and/or canals. Lateral ramifications, irregular canal cross-sections and apical deltas of the root canal system may be present in all teeth and are mostly inaccessible to mechanical instrumentation which increases the probability of leaving untreated spaces after root canal therapy (Ida and Gutmann, 1995; Siqueira and Araujo, 1997; Cantatore, Berutti and Castellucci, 2009; Verma and Love, 2011). Vertucci (2005) states that roots with a tapering canal and single foramen should be considered an exception rather than the norm. Canal systems can have multiple geometric planes and curve significantly more than the roots that house them (Schilder, 1974). Two-dimensional radiographs may not reveal these morphological variations of canals in spatial planes (Schilder, 1974; Cunningham and Senia, 1992; Kartal and Cimilli, 1997). Instrumentation of multiplanar curvatures can cause loss of length and ledging during hand file instrumentation (Cunningham and Senia, 1992).

1.1 Evolution of instrumentation strategies

Initially instrumentation was aimed at facilitating the placement of medicaments in the root canal with little attempt to remove the organic contents from the root canal system. Later the focus of instrumentation shifted to preparing the root canal space to facilitate the placement of root canal fillings but the methods employed were mostly unrelated to the anatomy of the canal system or the properties of the obturation materials (Schilder, 1974).

Schilder (1974) radically altered endodontic protocols with his innovative and revolutionary concepts that defined the design and biologic objectives for optimally shaping canal spaces and debriding root canal systems. The five design objectives are:

(1) a continuously tapering funnel from the access cavity to the apex;
(2) the cross sectional diameter should be narrower at every point apically;
(3) the root canal preparation should flow with the shape of the original canal;
(4) the apical foramen should remain in its original position;
(5) and the apical foramen should be kept as small as is practical.

The four biological objectives are:

(1) confinement of instrumentation to the root canal;
(2) there should be no forcing of necrotic debris beyond the apical foramen;
(3) all tissue should be removed from the root canal space;
(4) there should be sufficient space created for intracanal medicaments.

If the biological objectives are considered, the goals of chemo-mechanical preparation are to eliminate microorganisms from the root canal system, to remove pulp tissue that may support microbial growth, and to avoid forcing debris beyond the apical foramen which may sustain inflammation (Young, Parashos and Messer, 2007). Mechanical instrumentation is one of the important contributors to bacterial reduction in the infected root canal, though instrumentation alone does not eliminate bacteria from the root canal space (Byström and Sundqvist, 1981; Dalton et al., 1998; Chuste-Guillot et al., 2006). Using micro-CT data to analyse the preparation of root canals of maxillary first molars after instrumentation using K-type hand files and three rotary NiTi file systems, Peters, Schönenberger and Laib (2001) found that all instrumentation techniques left 35% or more of the canal's dentine surface untouched. The study also showed very little difference between the four instrument types.

The use of irrigants with strong antimicrobial properties is recommended as an adjunct to instrumentation, to further reduce bacterial populations (Shuping et al., 2000; Card et al., 2002; Chuste-Guillot et al., 2006). Wu and Wesselink (1995) recommend enlarging the canals to over size 40 files to achieve better cleaning in the apical thirds of the root canals. Khademi, Yazdizadeh and Feizianfard (2006) found that apical instrumentation to a size 30 file tip with a 0.06 coronal taper is effective for the penetration of irrigants, removal of debris and smear layer from the apical portion of root canals. Shuping et al. (2000) found that the additional antibacterial effect of sodium hypochlorite became evident only after canal preparation exceeded a size 30 to 35. Another study also demonstrated increased bacterial reduction at these apical sizes, with even better results at size 40 (Siquera et al., 1999). Brunson et al. (2010) found that an apical preparation size of 40 with a 4% taper was needed for adequate tooth structure preservation and maximum volume of irrigation at the apical third when the apical negative pressure irrigation system is used. In contrast Yared and Bou Dagher (1994) found no difference in apical disinfection between canals prepared to a size 25 and those prepared to a size 40 and a calcium hydroxide intracanal medicament placed for one week. Several authors have recommended the additional use of intracanal medicaments to optimise the disinfection protocol (Byström and Sundqvist, 1985; Siqueira et al., 2002; Nair et al., 2005; Vera et al., 2012).

Considering the design objectives, most root canals are curved (Schilder, 1974). In contrast, endodontic instruments are manufactured from straight metal blanks and this leads to uneven force distribution in areas where the file contacts the canal walls (Roane, Sabala and Duncanson, 1985) in curved canals. The instrument then has a tendency to straighten itself in the canal (Wildey, Senia and Montgomery, 1992). This results in wider canal shapes to compensate for the presence of the curves (Ingle, 1961). Historically 2% tapered stainless steel hand files were used to achieve a tapered preparation of the canal space with Gates-Glidden burs for coronal enlargement and taper (Bergmans and Lambrechts, 2010; Ikram, 2013).

Technical protocols for shaping canals have evolved to achieve the objectives outlined by Schilder (1974). Serial instrumentation (Schilder, 1974) involves using multiple curved hand files and reamers. The step-back technique involves preparation of the apical region of the root canal first, followed by coronal flaring to facilitate obturation (Mullaney, 1979). Crown-down techniques commence preparation with the use of larger instruments at the canal orifice and then proceed down the root canal with progressively smaller files (Goerig, Michelich and Schultz, 1982; Fava, 1983; Morgan and Montgomery, 1984). The balanced force technique

(Roane, Sabala and Duncanson, 1985) enables shaping of curved canals to larger sizes using modified stainless steel files.

1.2 Procedural errors

When instrumenting curved canals, the incidence of procedural errors increases, especially if stainless-steel files are used (Pettiette et al., 1999). Some of the potential procedural errors that may occur during root canal instrumentation traditionally with stainless steel files in curved canals are zips, elbows, ledging, perforation, strip perforation, apical blockage, damage to the apical foramen and file separation (Hülsmann, Peters and Dummer, 2005; Walia, Brantley and Gerstein, 1988).

1.2.1 Zipping

Zipping is the result of the tendency of an instrument to straighten inside a curved root canal. This results in over enlargement of the outer wall of the curve and under preparation of the inner wall of the curve at the apex. The main axis of the root canal is transported and there is deviation of the canal from its original axis. "Canal straightening" and "canal transportation" are also used to describe this type of defect (Hülsmann, Peters and Dummer, 2005).

1.2.2 Elbow

The creation of an elbow is associated with zipping of a curved canal. An elbow is a narrow region of the root canal at the point of maximum curvature as a result of the irregular widening that occurs coronally along the inner wall and apically along the outer wall of the curve. The irregular taper and flow associated with elbow may jeopardise cleaning and filling the apical part of the root canal (Hülsmann, Peters and Dummer, 2005).

1.2.3 Ledging

Ledging of the curved root canal may occur as a result of preparation with inflexible instruments with sharp, inflexible cutting tips particularly when they are used in a rotational motion. The ledge is found on the outer side of the curvature as a platform, which may be difficult to bypass as it is frequently associated with blockage of the apical part of the root canal. The occurrence of ledges is related to the degree of curvature and design of instruments (Hülsmann, Peters and Dummer, 2005). Ledges may form in the original canal path or by creating a new false canal (Lambrianidis, 2009). The presence of a ledge might reduce the possibility of achieving an adequately shaped canal preparation that reaches working length. This can result in incomplete instrumentation and disinfection of the root canal system as well as incomplete obturation of the canal. The root canal space apical to the ledge is difficult to thoroughly clean and shape. Ledges frequently result in ongoing periapical pathosis after the endodontic treatment. A causal relationship may exist between ledges and unfavourable endodontic treatment success (Jafarzadeh and Abbott, 2007).

1.2.4 Perforation

Perforations of the root canal wall may occur as a result of preparation with inflexible instruments with sharp cutting tips when they are used in a rotational motion. Perforations are associated with destruction of the cementum and irritation and or infection of the periodontal ligament in the area of the perforation. Perforations are difficult to seal. Perforations can result in a part of the original root canal remaining unprepared if it is not possible to regain access to the original root canal apical to the perforation (Hülsmann, Peters and Dummer, 2005).

1.2.5 Strip perforation

Strip perforations result from over-preparation and straightening along the inner wall of the curved root canal. They usually occur on the distal aspect of mesiobuccal roots of maxillary molars and mesial roots of mandibular molars near the furcation area (Kessler, Peters and Lorton, 1983; Allam, 1996). Midroot perforations are also associated with destruction of the root cementum and irritation of the periodontal ligament. Strip perforations are difficult to seal. The root walls facing the furcal aspect of roots are often extremely thin and are, therefore, termed “the danger zone” (Hülsmann, Peters and Dummer, 2005).

1.2.6 Apical blockage

Apical blockage of the root canal occurs as a result of packing of tissue or debris 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, Peters and Dummer, 2005).

1.2.7 Damage to the apical foramen

Transportation and enlargement of the apical foramen may occur as a result of incorrect determination of working length, straightening of curved root canals, over-extension and over-preparation of the root canal. This may lead to irritation to the periradicular tissues by extruded irrigants or filling materials because of the loss of an apical stop (Hülsmann, Peters and Dummer, 2005; Schäfer and Dammaschke, 2009). Apical transportation negatively impacts apical seal (Wu, Fan and Wesselink, 2000). 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 of the canal and its consequences in the apical, middle and coronal third (Abou-Rass, Frank and Glick, 1980; Alodeh, Doller and Dummer, 1989). Lam et al. (1999) found that apical and mid curve transportation increased with an increase in file size. These same authors also found a significantly greater deviation in the apical area with size 25 files. Nickel Titanium (NiTi) rotary systems solved most of the deficiencies of traditional stainless steel instruments (Bergmans et al., 2001).

1.3 Nickel Titanium alloys

Nickel Titanium was developed by a metallurgist, W.F. Buehler while he was investigating alloys for metallic materials for the nose cone of the U.S. Navy Polaris re-entry vehicle in the space programme at the Naval Ordnance Laboratory in Maryland, USA. In 1959 Buehler named his discovery **NITINOL** (**Ni**ckel **Ti**tanium **N**aval **O**rdnance **L**aboratory), an acronym for the elements from which the material was composed; **Ni** for nickel, **Ti** for titanium and NOL from the place of discovery - Naval Ordnance Laboratory (Kauffman and Mayo, 1996). The mechanical memory discovery was made accidentally during a presentation of the fatigue resistance of

NiTi in 1961, when Dr. David S. Muzzey applied heat to a compressed strip of NiTi wire using his pipe lighter and the compressed strip of wire began to elongate longitudinally. In 1962 Dr. Frederick E. Wang joined Buehler's research group and the commercial applications of Nitinol that were to come would not have been possible without Dr. Wang's discovery of how the shape-memory property of Nitinol worked (Kauffman and Mayo, 1996).

Nitinol was introduced to dentistry by Dr. Andreasen in 1971 who developed its use for orthodontics (Andreasen and Hilleman, 1971; Andreasen and Morrow, 1978). The first investigation of the use of nitinol in endodontics was conducted by Walia, Brantley and Gerstein (1988) who used nitinol orthodontic wire to manufacture endodontic files. In 1991, the first hand and rotary NiTi files were made commercially available by NT Co. In 1994, NT Co. also introduced the first series of NiTi rotary files having larger tapers (McSpadden, 2007). The composition of Nitinol used to construct endodontic instruments is 56% nickel and 44% titanium and is generically known as 55-Nitinol (Thompson, 2000).

1.3.1 Basic metallurgy of Nickel Titanium

Nitinol is the name given to a family of alloys of nickel and titanium which have been found to have unique properties of shape memory and super-elasticity (Thompson, 2000). An alloy with a shape memory requires certain basic atomic structural characteristics. The first requisite is an atomically ordered solid-state parent phase-classically called "austenite" (named after English metallurgist Sir William Chandler Roberts-Austen, 1843–1902) that exists at higher temperatures. The second requisite is, at a lower temperature, the atoms of the ordered austenite phase must be capable of solid-to-solid deformation into a new atomic arrangement or phase, called "martensite" (named after German metallographer, Adolf Martens, 1850–1914). The austenite and martensite inter-transformation occurs through temperature change or with applied stress and strain, termed "stress-induced martensite" (Kauffman and Mayo, 1996).

Nitinol has an inherent ability to alter its type of atomic bonding which causes unique and significant changes in the mechanical properties and crystallographic arrangement of the alloy. In the austenite phase the crystals are cuboidal and in the martensite phase they are hexagonal (Thompson, 2000). Nitinol can have three different forms: austenite, martensite and stress-induced martensite (super-elastic). Austenite nitinol is non-elastic and hard; in its martensite form, it is relatively soft and can be easily deformed; and super-elastic nitinol is highly elastic. When external stress is applied, the austenite crystalline form of nickel titanium transforms into the stress induced martensite crystalline structure that can accommodate greater stress without increasing the strain (McSpadden, 2007). When the stress is removed without permanent deformation, the nitinol returns to its austenite structure (original shape) provided that the temperature remains within a specific range, this phenomenon is called a stress-induced thermo-elastic transformation (Bergmans et al., 2001).

The super-elasticity of NiTi allows deformations of as much as 8% strain to be fully recoverable whereas stainless steel can withstand only a maximum of less than 1% strain before permanent deformation occurs (Thompson, 2000). Other alloys that possess super elastic properties are copper-zinc, copper-aluminium, gold-cadmium and nickel–niobium (Buehler and Wang, 1968). However, none of these have the magnitude of strain or heat recovery, general corrosion resistance, human tissue and body fluid compatibility of nitinol (Kauffman and Mayo, 1996).

1.3.2 Benefits of Nitinol instruments in Endodontics

The introduction of NiTi rotary instruments in endodontics revolutionised the shaping of canals. The design and biological objectives outlined by Schilder (1974) could be better realised. Most of the procedural problems associated with achieving ideal shaping during instrumentation of curved canals with the use stainless steel instruments, were due to the stiffness of the instruments, which increases with size (Goldberg and Araujo, 1997). NiTi instruments have a lower modulus of elasticity compared to stainless steel instruments. Therefore, less lateral forces are exerted on the dentine walls in curved canals. Roane, Sabala and Duncanson (1985) state that less force on the canal wall will ultimately decreases canal transportation during instrumentation. The tips of stainless steel files tend to undergo plastic deformation when they are introduced into curved canals, which lead to successive irregular interaction between the instrument and the canal walls. In contrast, NiTi files bend uniformly along the blade, following the original curvature of the canal (Necchi et al., 2008).

The shape memory and super-elastic properties of NiTi enabled the manufacture of files with tapers greater than 2% and facilitated the preparation of canals in a mechanical rotary motion. This enables a more conical preparation of larger tapers and allows more space for penetration of irrigants, better cutting efficiency of the instruments and placement of master gutta-percha points of greater taper (Bergmans et al., 2001). A greater tapered preparation offers more resistance to apical displacement of gutta-percha during condensation (Musikant, Cohen and Deutsch, 1998) thereby reducing the incidence of overfills.

There are several benefits to the use of rotary NiTi instrumentation. Procedural errors such as loss of working length, instrument separation, canal transportation, zip or elbow formation, strip perforation, and excessive weakening of the root occurs less when root canals of extracted teeth are shaped with rotary NiTi instruments (Weiger, El Ayouti and Löst, 2002; Hülsmann, Herbst and Schäfers, 2003; Guelzow et al., 2005; López et al., 2008; Çelik, Taşdemir and Kürşat, 2013).

Most rotary NiTi instruments allow wider apical preparations even in severely curved canals than stainless-steel hand files without major preparation errors or over-reduction of root dentine (Peters, 2004; Schäfer, Schulz-Bongart and Tulus, 2004). NiTi instruments can also prepare most root canals faster compared to manual instrumentation (Schäfer, 2001; Silva et al., 2004; Nagaratna, Shashikiran and Subbareddy, 2006; Kummer et al., 2008; Pinheiro et al., 2012) and fewer instrumentation visits were required by general dentists in the clinical setting (Koch et al., 2012).

There is also a lower susceptibility to fracture in roots prepared with rotary NiTi instruments compared to those prepared by hand instrumentation (Lam, Palamara and Messer, 2005). It is easier for novice operators to achieve adequate preparation of root canals with less procedural errors occurring if they use rotary NiTi instruments (Baumann and Roth, 1999; Pettiette et al., 1999; Kleier and Averbach, 2006). In general there are more favourable and better clinical outcomes for teeth prepared by rotary NiTi instruments (Pettiette, Delano and Trope, 2001; Peters, Barbakow and Peters, 2004; Kleier and Averbach, 2006; Cheung and Liu, 2009).

1.3.3 Fracture of NiTi rotary instruments

Grossman stated that a dentist who has not separated an instrument has not done enough root canals (Grossman, 1969). Fracture is the most common procedural error that occurs during clinical use of rotary NiTi instruments (Spanaki-Voreadi, Kerezoudis and Zinelis, 2006). The fracture of stainless steel hand files usually occurs after a visible distortion or deformation of the instrument (Zuolo and Walton, 1997). Even though NiTi instruments are stronger and more flexible than their stainless steel counterparts (Walia, Brantley and Gerstein, 1988) these instruments can fracture within their elastic limit and without any visible signs of previous permanent deformation (Pruett, Clement and Carnes, 1997; Gambarini, 2001) and without prior use (Arens et al., 2003; Baumann 2004; Shen et al., 2009). Some authors have reported that NiTi rotary instrument fracture was seven times more likely than hand instrument fracture (Iqbal, Kohli and Kim, 2006) in an endodontic residency programme.

Tzanetakis et al. (2008) also reports a higher frequency of rotary NiTi instrument separation compared to stainless steel instruments (0.55% -stainless steel and 1.55%-NiTi). Spili, Parashos and Messer (2005) reported that the frequency of rotary instrument fracture was slightly higher than hand stainless steel instruments in a specialist endodontic practice. Parashos and Messer (2006) state that on the basis of best available clinical evidence, the frequency of fracture of rotary NiTi instruments may actually be lower than that of stainless steel hand files.

The fear of instrument fracture is the biggest deterrent to clinical adoption of rotary NiTi instruments (Bergmans et al., 2001; Kuhn, Tavanier and Jordan, 2001; Parashos and Messer 2006). Conflicting results have been reported in the literature regarding the clinical significance of retaining fractured files within treated root canals (Madarati, Watts and Qualtrough, 2008). However, Spili, Parashos and Messer (2005) report a reduction in healing of periapical lesions when fractured fragments were left in teeth with necrotic pulps or periapical lesions.

1.3.4 Factors influencing mechanisms of NiTi instrument fracture

NiTi instruments are used in a rotary motion and are therefore subjected to structural fatigue that eventually leads to fracture when the fatigue resistance of the file is exceeded (Pruett, Clement and Carnes, 1997). Fractured rotary NiTi instruments have been classified into those that fail as a result of torsional (shear) failure and cyclic flexural fatigue (bending stress) (Serene, Adams and Saxena, 1995; Sattapan et al., 2000). Sattapan et al. (2000) found visible defects associated with files fractured due to torsion and a sharp break without any accompanying defects in files fractured due to cyclic flexural fatigue and proposed a classification based on this presence or absence of visible defects. Recently some authors have suggested that fracture is caused by a single overloading incident rather than the fatigue mechanism after a large number of loading cycles (Alapati et al., 2005; Cheung et al., 2005; Spanaki-Voreadi, Kerezoudis and Zinelis, 2006; Kosti et al., 2011).

1.3.4.1 Torsional stress

Torsional (shear) stress fracture occurs when the tip or any part of the instrument binds in a canal while the shaft continues to rotate, the elastic limit of the metal is exceeded and the instrument undergoes plastic deformation followed by fracture (Sattapan et al., 2000). This usually occurs when an operator exerts excessive apical force on the rotating instrument in the root canal (Kobayashi, Yoshioka, Suda, 1997; Sattapan et al., 2000). Torsional stress fracture can also occur when there is a wide area of contact between the cutting flutes of the instrument and the canal walls or if the canal cross section is smaller than the dimension of the non-cutting or non-active tip of the instrument. As the instrument wedges into the canal or when the root canal preparation begins to acquire the shape and taper of larger constant taper instruments as they progress deeper into the canal, a taper-lock effect will be created (Blum et al., 1999; Yared et al., 2002; Peters et al., 2003; Berutti et al., 2004; DiFiore, 2007; Peters and Paqué, 2010).

Torsional stress is influenced by tip size and taper of the instrument and canal size (Sattapan, Palamara and Messer, 2000; Schrader and Peters, 2005), curvature angle and radius (Booth et al., 2003; Best et al., 2004), speed of penetration (Blum et al., 2003) and surface area of contact between the instrument and canal walls

(Schrader and Peters, 2005). The difference in tip diameter between a size 20 and 30 file is 50% but the cross-sectional surface area increase is 129% because the cross-section surface area increases as a square of the radius. Generally a file with greater taper and larger diameter is more susceptible to flexural fatigue failure but more resistant to torsional failure. An acute canal curvature located coronally is more likely to lead to instrument fracture than a gradual apical curve because the instrument is subjected to the maximum stress in the area in which its diameter is the largest (Grande et al., 2006; Peters and Paqué, 2010).

Clinical measures recommended to reduce torsional stress fractures are: (1) use a crown-down sequence of instrumentation incorporating instruments of different tapers or hybrid instrumentation protocol as this will reduce the contact surface area between the files and dentine walls (Walsch, 2004; Shrader and Peters, 2005; Parashos and Messer, 2006); (2) advance files slowly into a canal until resistance is met and withdraw without pushing hard on file (Parashos and Messer, 2006; Cheung, 2009); (3) ensure finger rests to compensate for patient movement and reduce risk of taper lock (Walsch, 2004; Parashos and Messer, 2006); (4) use a torque control motor with manufacturer recommended settings for each instrument (Cheung, 2009); (5) avoid triggering the auto-reverse mode in torque control motors frequently as this leads to increased torsional fatigue in the file making it more susceptible to fracture (Cheung, 2009; Berutti et al., 2004); (6) use chelators and lubricants to reduce friction (DiFiore, 2007; Boessler, Peters and Zehnder, 2007); (7) frequently recapitulate, irrigate and wipe instrument blades to reduce clogging of file blades by dentine debris and reduce friction (Walsch, 2004; DiFiore, 2007); (8) manually pre-flare and prepare a glide path with hand instruments to working length (Peters et al., 2003; Berutti et al., 2004; Cheung, 2009).

1.3.4.2 Flexural fatigue

Flexural fatigue (bending stress) fracture occurs when a file is rotating freely in a curved canal, resulting in alternating tension and compression cycles at the point of maximum flexure which is the midpoint of the curve until fracture occurs as a result of metal fatigue. This is akin to taking a piece of wire and bending and straightening it repeatedly. As an instrument is held in a static position in a curved canal and continues to rotate, one half of the instrument shaft on the outside of the curve is in tension, whereas the half of the shaft on the inside of the curve is in compression. This repeated tension-compression cycle, caused by rotation within curved canals, increases flexural fatigue of the instrument over time (Pruett, Clement and Carnes, 1997; Haikel et al., 1999; Bahia and Buono, 2005; Plotino et al., 2009).

Flexural fatigue is influenced by the radius and angle of the canal (Haikel et al., 1999; Li et al., 2002; Zelada et al., 2002; Lopes et al., 2007; Necchi et al., 2008), location of curvature (Necchi et al., 2008; Peters and Paqué, 2010), rotational speed (Zelada et al., 2002; Martín et al., 2003; Lopes et al., 2009), number of uses of instruments (Plotino et al., 2006; Ounsi et al., 2007; Viera et al., 2008) and taper and diameter of the files (Haikel et al., 1999).

Various designs and manufacturing methods have been employed to make NiTi files more resistant to flexural fatigue and torsional stress (Sleiman, 2011; Gutmann and Gao, 2012, Lopes et al., 2013). Clinically some measures recommended to reduce flexural fatigue are:

(1) obtaining straight-line access to the apical half of the canal, in this way increasing the radius of curvature and minimising the amount of curves (Bahcall et al., 2005; Cheung, 2009);

(2) avoid using a rotary file of 6% taper or higher for canals with a mid-root curvature (Cheung, 2009);

(3) lowering the rotation speed to postpone the onset of fatigue (Cheung, 2009);

(4) using a constant in and out axial movement when the file is inserted into the canal, in this way reducing the concentration of bending stress at any particular point along the length of the file (Dederich and Zakariasen, 1986; Li et al., 2002; Parashos and Messer, 2006);

(5) limiting the number of uses of the NiTi files (Ounsi et al., 2007) especially after use in very curved canals (Parashos and Messer, 2006).

1.3.4.3 Other factors

Other factors that can contribute to instrument fracture include instrumentation technique (Blum et al., 2003; Walsch, 2004; Schrader and Peters, 2005; Boessler, Peters and Zehnder, 2007), accessibility of canals (Cheung, 2009), instrument surface condition (Anderson, Price and Parashos, 2007; Condorelli et al., 2010; Lopes et al., 2010), instrument design (Peters et al., 2003; Parashos, Gordon and Messer, 2004; Xu et al., 2006; Ray, Kirkpatrick and Ruthledge, 2007; Yum et al., 2011), use of torque-controlled motor (Gambarini, 2000; Berutti et al., 2004; Cheung, 2009), sterilisation procedure (O'Hoy, Messer and Palamara, 2003; Silvaggio and Hicks, 1997; King et al., 2012) and operator proficiency (Yared, Bou Dagher and Machtou, 2001; Parashos, Gordon and Messer, 2004).

1.3.4.4 Clinical significance

Clinically, instruments are subjected to a combination of stresses created by torsion and cyclic fatigue (Blum et al., 2003; Peters et al., 2003; Spanaki-Voreadi, Kerezoudis and Zinelis, 2006; Ounsi et al., 2007). Most NiTi rotary instrument fractures occur in the mesial canals of mandibular and maxillary molars (Iqbal, Kohli and Kim, 2006; Tzanetakis et al., 2008; Wu et al., 2011). In mandibular molars the mesial canals join to form one major foramen in 49% of the cases (Green, 1973). The mesiobuccal canal of the mandibular molar is known for its greater curvature (Cohen and Burns, 2002). The canals join each other in the apical third, with the main canal gradually curving to its apex and the other joining it at an abrupt angle. Jerome and Hanlon (2003) state that preparing teeth with multiplanar curves is more likely to result in fracture from torsional stress. Iqbal, Kohli and Kim (2006) and Tzanetakis et al. (2008) found that fractures were more common in the apical third followed by the middle and coronal thirds of canals respectively.

Fractures were also more common in retreatment cases compared to initial endodontic treatment (Tzanetakis et al., 2008). Sattapan et al.(2000) and Parashos, Gordon and Messer (2004) studying eight different brands of files after clinical use and Shen et al. (2009) after examining three different types of files after single clinical use, reported that most file fractures were due to torsional stress. In contrast Peng et al. (2005) reported most of the files that they analysed following clinical use, fractured due to flexural fatigue.

1.4 Importance of a glide path in rotary NiTi mechanical root canal preparation

A glide path is defined as a smooth, though possibly narrow, tunnel or passage from the orifice of the canal to the radiographic terminus or electronic portal of exit (West, 2006). The maintenance of a glide path means having a smooth passage that is reproducible by successive files used in the canal (Khatavkar and Hegde, 2010). All available NiTi rotary instruments have non-end cutting tips (Peters and Paqué, 2010) and because of their extreme flexibility NiTi instruments are not designed for initial negotiation of the root canal (Young, Parashos and Messer, 2007). Bergmans et al. (2001) stated that during preparation, no rotary instrument should be used where a hand instrument has not been placed before.

Roland et al. (2002) show that coronal preflaring can reduce the incidence of instrument fracture. The use of small hand files to confirm patency of the canal and to ensure sufficient space for rotary instruments to passively follow would greatly improve the safety of rotary NiTi instrument use (Blum et al., 2003). Teeth requiring endodontic therapy may have calcifications present in the canals that have developed over time, especially in the aging population (West, 2010; Katavkar and Hegde, 2010). The denticles may vary in size from 50 microns to several millimetres and may be present at any level along the canal walls (Goga, Chandler and Oginni, 2008). The passage of small hand files to the terminus of the canal beyond the pulp stones and denticles allows the clinician to determine and establish patency of the canal before mechanical preparation (West, 2010; Katavkar and Hegde, 2010) and reduces the risk of ledge formation (Young, Parashos and Messer, 2007), which is one of the major causes of retreatment (Castellucci, 2011).

Peters et al. (2003) reported that no instrument fractures occurred in their study using extracted teeth, even when high forces were used during preparation of constricted canals in the presence of a patent glide path. This is a significant finding as it is the main cause of fracture that results from torsional stress. In the presence of a glide path, the reduction in the amount of torsional stress increases the average lifespan of a rotary instrument almost six-fold (Berutti et al., 2004). Patino et al. (2005) studied the influence of a manual glide path on the separation rate of rotary NiTi instruments. These authors used three different file systems and tested them in roots with a curvature larger than 30 degrees and found that separation was significantly reduced (12% with a glide path as opposed to 26% without a glide path). No difference existed between the types of file designs (K3, ProFile and ProTaper) (Patino et al., 2005). In a study where files were examined after single clinical use, it was found that there was a high incidence of distortion and separation of rotary NiTi files when their use was not preceded by glide path preparation (Shen et al., 2009).

The use of NiTi instruments in a reciprocating movement with unequal back and forth motion is another novel way in which the risk of file separation is reduced (Yared, 2008; You et al., 2010; Varela-Patiño et al., 2010). Berutti et al. (2012) found that fewer insertions of the WaveOne single file (Dentsply/Maillefer) were needed to reach working length when a glide path was prepared. The authors also found that preparation of a glide path resulted in less alteration to the original curvature of the canal.

1.5 Glide path preparation methods

1.5.1 Hand stainless steel K-files

Several authors have recommended using stainless steel K-files by hand for preparing the glide path (Berutti et al., 2004; Walsch, 2004; Gambarini, 2005; Mounce, 2005; Ruddle, 2005; West, 2006; West, 2010).

The advantages of using stainless steel hand files and K-files compared to rotary NiTi files for creating the glide path are:

- K-files have better tactile sensation (Mounce, 2005).
- Less potential for separation (Mounce, 2005).
- When a small size K-file is removed from the canal, the file often has an impression of the canal, and in this way guides the operator to the curvatures present in the canal (Jerome and Hanlon, 2003; Berutti et al., 2004; Mounce, 2005).
- The stiffness of stainless steel hand files aids in path-finding, negotiating blockages and calcifications (Mounce, 2005; Young, Parashos and Messer, 2007).

- Low cost
- No need for a dedicated hand piece.

West (2006) recommends using stainless steel K-files in vertical in and out motion with an amplitude of 1 mm and gradually increasing the amplitude as the dentine wall wears away and the file advances apically. In very narrow canals a watch-winding motion is recommended to remove restricted dentine, as well as an "envelope of motion" (West, 2010). West and Roane (1998) describe the watch-winding motion as a back and forth oscillation of a file (30 to 60 degrees) right and left as the instrument is pushed forward into the canal. It is a definite inward progression of the file in a filing motion. An envelope of motion occurs when a precurved file is followed into the canal short of maximum resistance; the file is then removed while it is being rotated in a clockwise direction (Schilder, 1974; West, 2006). Schilder emphasises the need to use precurved hand instruments. The "envelope of motion" created by the rotation of the curved file as it is withdrawn from the canal scribes at random contact points the side walls of the canal, gradually widening and evolving the root canal shape to be adequate enough for larger files to follow. This technique facilitates the suspension of debris in the irrigation solution (Schilder, 1974; Ruddle, 2002). Both Schilder and West emphasise the importance of following the canal rather than forcing the file through any obstructions (Schilder, 1974; West, 2011).

Berutti et al. (2004) advocate that the diameter of the canal after glide path preparation should be at least one size larger than the tip of the first rotary file used to prepare the canal. West recommends a minimum of a "super loose" size 10 K-file (West, 2010). This author also emphasises that if a glide path larger than a size 10 is required then it is advisable to use the "balanced force" motion (Roane, Sabala and Duncanson, 1985) for sizes 15 and above in order to reduce the risk of ledge formation. This involves turning the handle of the file clockwise, and then turning it counter-clockwise using slight apical pressure so that the file will not "unscrew" its way out of the canal. During the clockwise motion, the file blades cut into the dentine and during the apical counter-clockwise motion, the dentine is collected into the file's flutes. This motion can be repeated several times as the file is "balanced" apically. The file is then turned clockwise and removed after having carved a wider glide path (West, 2010).

In order to confirm that a glide path is present, a size 15 or 20 file should slide easily to working length. The file is withdrawn 1mm and should slide to working length. Thereafter, the file is withdrawn 2mm and should slide to working length. When the file can be withdrawn 3mm to 5mm and slides to working length a glide path is confirmed (Van der Vyver, 2011a).

Other hand files recommended for path finding and glide-path formation include the Antaeos Stiff "C" file (Schwed, Kew Gardens, NY), C file (Dentsply/Tulsa Dental Specialities, Oklahoma, USA), C file (Roydent, Hoboken, NJ), C+ file (Dentsply/ Maillefer), D finder (Mani, Tochigi-ken, Japan), Hi-5 file (Miltex, York, PA), Pathfinder CS (SybronEndo, Glendora, CA), Pathfinder SS (SybronEndo, Orange, California, USA), S finder (JS Dental, Sendoline, Ridgefield, CT), Stiff K file (Brasseler, Savannah, GA), Flexofile (Dentsply/Maillefer) and Senseus ProFinder (Dentsply/Maillefer). The aforementioned instruments have varying tip dimensions, cross sections, tapers, and pitch and flute design (Allen, Glickman and Griggs, 2007).

The disadvantages of preparing a glide path with hand instruments are:

- Operator fatigue
- Hand fatigue
- Time required to prepare the glide path
- Risk of canal aberrations with larger file sizes (Berutti et al., 2009; West, 2010).
- Greater change to original canal anatomy (Berutti et al., 2009; Pasqualini et al., 2012a).
- More apical extrusion of debris (Greco, Carmignani and Cantatore, 2011).

1.5.2 Hand Files in reciprocating hand piece

This technique involves using a reciprocating hand piece (Figure 1.1) attached to small size K-files in order to prepare the glide path (Mounce, 2008; Kinsey and Mounce, 2008). A small size K-file is used to negotiate the canal to length by hand before a reciprocating hand piece is attached to the file (Fig.1.1). The hand piece is then moved vertically in and out, with an amplitude of 1mm to 3mm and bursts of reciprocation for approximately 15 to 30 seconds in each root canal. K-files, sizes 06 to 10, are placed just beyond the apical constriction to reduce the risk of blockage.

Van der Vyver (2011a) recommends placing a size 20 K-file 1 mm short of the apex to avoid apical transportation with this method of glide path preparation due to the relative stiffness of the file. The M4 reciprocating hand piece (SybronEndo) and Endo-Express reciprocating hand piece (Essential Dental Systems, NJ, USA) have a 30 degree equi-angle arc of reciprocation (five minutes on a clock face). The NSK Ti-Max Ti35L 10:1 reciprocating hand piece (NSK, Nakanishi, Japan) has a 90 degree angle of reciprocation or 15 minutes on a clock face.

Figure 1.1: The M4 Safety hand piece (SybronEndo) being attached to a hand file after the file has been negotiated to working length

The advantages of using a stainless steel K-file in a reciprocating hand piece for glide path preparation are:

- Reduced preparation time.
- Reduced operator fatigue.
- Reduced hand fatigue, especially in canals with multiplanar curves.
- Reduced risk of instrument separation compared to rotary NiTi methods (Kinsey and Mounce, 2008).

The disadvantages are:

- The need for a dedicated hand piece.
- Decreased tactile sensation.

- Risk of apical transportation with files larger than a 15 K-file (Kinsey and Mounce, 2008; Van der Vyver, 2011a).
- Risk of excess dentine removal as a result of the clinician staying in the canal longer than necessary (Wagner et al., 2006).
- Risk of apical extrusion of debris if hand piece is inserted apically with force (Kinsey and Mounce, 2008).

1.5.3 Rotary NiTi files

1.5.3.1 PathFiles (Dentsply/Maillefer) (Fig. 1.2)

PathFile NiTi rotary files (Dentsply/Maillefer) were introduced to the market in 2009 for the purpose of glide path enlargement. The system consists of three instruments. They are available in 21mm, 25mm, and 31mm length. They have a square cross section and a 2% taper, which makes them resistant to cyclic fatigue, ensures flexibility and improves cutting efficiency. The tip angle is 50 degrees and is non-cutting, which reduces the risk of ledge formation.

PathFile No.1 (purple) has an ISO 13 tip size, PathFile No.2 (white) has an ISO 16 tip size and PathFile No.3 (yellow) has an ISO 19 tip size. The gradual increase in tip size facilitates progression of the files. The manufacturer suggests using the PathFile No.1 only after a size 10 K-file has been used to explore the root canal to working length (Berutti et al., 2009).

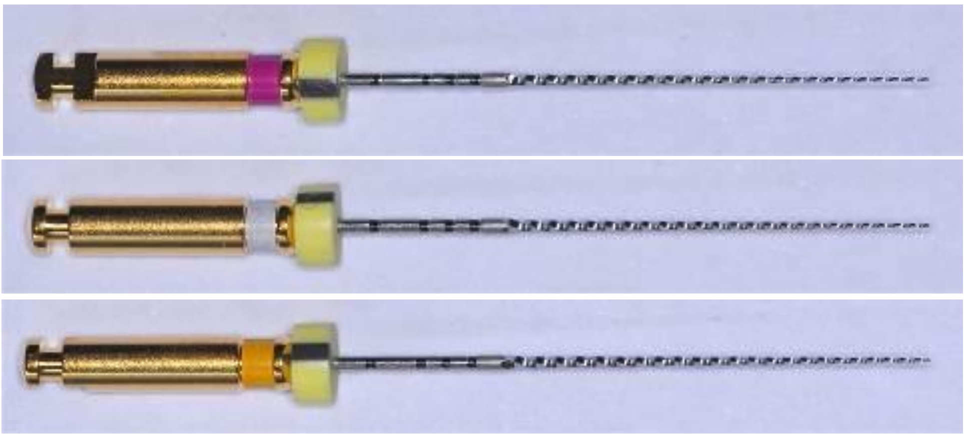

Figure 1.2: PathFiles (2% taper): ISO tip size 13 (purple ring), ISO tip size 16 (white ring) and ISO tip size 19 (yellow ring)

1.5.3.2 X-PLORER™ Canal Navigation NiTi Files (Clinician's Choice Dental Products Inc., New Milford, USA) (Fig. 1.3)

The X-PLORER™ series of rotary NiTi files was introduced in 2010 for glide path enlargement and consists of three instruments. They are available in lengths of 21mm and 25mm. The unique design features are their cutting surface, tapers and cross section. The cutting surface is limited to the apical 10mm of the file, which decreases surface contact and torsion and increases tactile feedback. The non-cutting tip has a 75 degree tip angle. The manufacturer recommends using the X-PLORER series after a size 8 or size 10 hand file has been used to explore 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 file has an ISO 20 tip size with a 1% taper and square cross section. The third file has an ISO 20 tip size with a 2% taper and square cross section. The reduced taper increases flexibility and facilitates progression of the files. The X-PLORER files are also available as hand files (Nahmias, Cassim and Glassman, 2013).

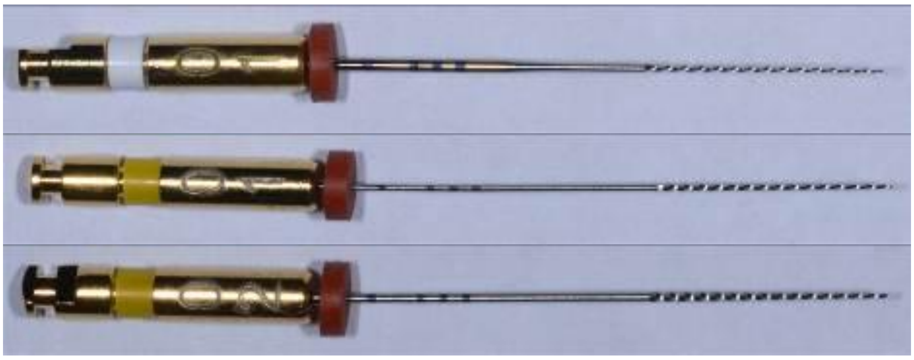

Figure 1.3: X-Plorer Canal Navigation NiTi Files: ISO 15 tip (1% taper) (white ring, marked 01), ISO 20 tip (1% taper) (yellow ring, marked 01) and ISO 20 tip (2% taper) (yellow ring, marked 02)

1.5.3.3 G-Files (Micro-Mega, Besançon, France) (Fig. 1.4)

The G-Files™ were introduced in 2011 for glide-path enlargement. The system consists of two files available in 21mm, 25mm and 29mm lengths. The tip sizes are ISO 12 and ISO 17 and the non-cutting tip is asymmetrical to aid in the progression of the file. The files have a 3% taper along the length. The cross section of the file has blades on three different radiuses 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 10 hand file has been used to explore the canal to working length.

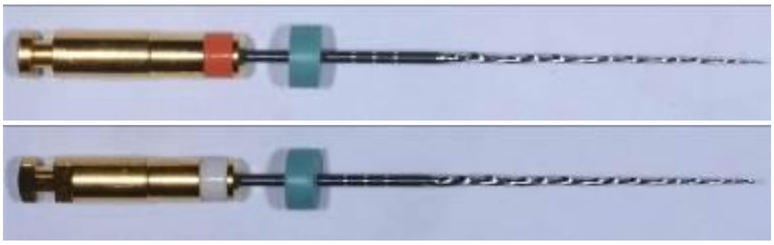

Figure 1.4: G Files (3% taper): ISO 12 tip (orange ring) and ISO 17 tip (white ring)

1.5.3.4 EndoWave Mechanically Glide Path (MGP) (J Morita, California, USA) (Fig. 1.5)

The EndoWave Mechanically Glide Path kit consists of three files that can be used to enlarge the glide path. EndoWave MGP 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. All three instruments have a constant taper of 2% and can be rotated at 800 rpm at a torque of 30g/cm or 0.3N/cm.

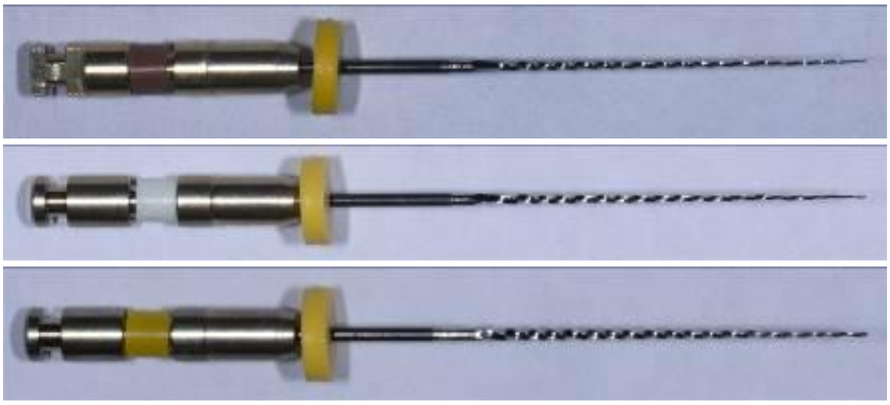

Figure 1.5: EndoWave Mechanically Glide Path Files (2% taper): ISO 10 tip (purple ring), ISO 15 tip (white ring) and ISO 20 tip (yellow ring)

1.5.3.5 Scout-RaCe files (FKG Dentaire, La Chaux-de-Fonds, Switzerland) (Fig. 1.6)

Scout-RaCe files (FKG) are 2% tapered instruments, electro-polished to remove any irregularities during grinding and they have a triangular cross section. The system also consists of three instruments with a RaCe flute design (alternating cutting edges) and non-cutting tips. They are available in ISO tip size 10 (purple), 15 (white) and 20 (yellow) and should be used in a sequential manner (600 rpm) after initial canal exploration with a size 06 or 08 K-file to working length.

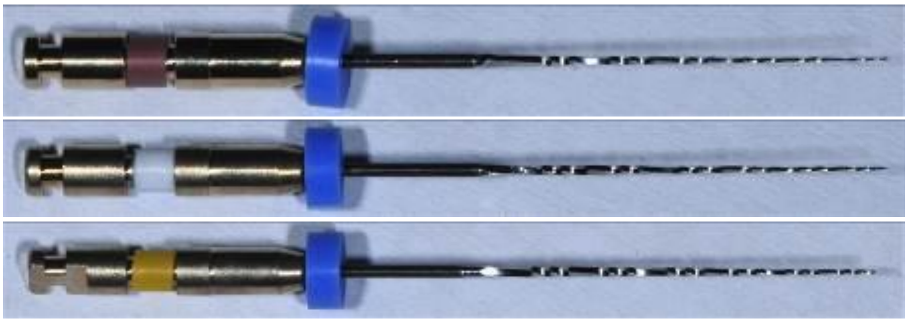

Figure 1.6: Scout Race Files (2% taper): ISO 10 tip (purple ring), ISO 15 tip (white ring) and ISO 20 tip (yellow ring)

1.5.3.6 RaCe ISO 10 (FKG Dentaire) (Fig. 1.7)

RaCe ISO 10 is another system from FKG and consists of three files that progressively increase in taper (2% (yellow disc), 4% (black disc) and 6% (blue disk) but maintain the same apical diameter of 0.1mm. The main indication for these instruments is constricted and obliterated canals, as well as abrupt coronal curvatures (Debelian and Trope, 2012). These files will scout the canal but also create coronal preflaring because of the increasing taper of the instruments.

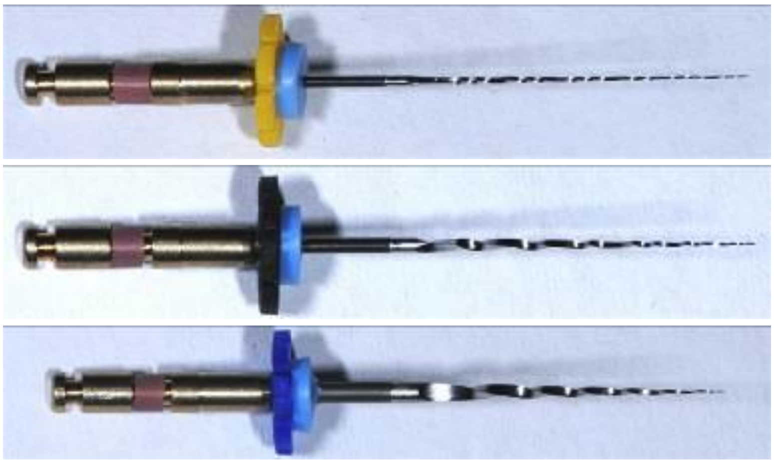

Figure 1.7: RaCe ISO 10: 2% taper (yellow disc), 4% taper (black disc) and 6% (blue disc)

The advantages of glide path preparation using NiTi rotary instruments are:

- Reduced operating time (Berutti et al., 2009).

- Reduced canal aberrations (ledges, zips and apical transportation) (Berutti et al., 2009; Pasqualini et al., 2012a).
- Better maintenance of original anatomy (Berutti et al., 2009; Pasqualini et al., 2012a)
- Less operator fatigue
- Less hand fatigue
- Reduced apical extrusion of debris (Greco, Carmignani and Cantatore, 2011).
- Reduced post-operative pain (Pasqualini et al., 2012b).
- An easy-to-learn technique (Berutti et al., 2009).

The disadvantages of glide path preparation using NiTi rotary instruments are:

- Additional cost
- Increased risk of file fracture
- Decreased tactile sensation

Van der Vyver (2011b) described a method of glide-path preparation combining all three methods. Stainless steel K-files up to size 10 are watch-winded to working length, then a reciprocating hand piece attached and the glide path prepared. This is finally followed by glide path enlargement with rotary NiTi PathFiles (Dentsply/Maillefer).

At present no study has compared the use of stainless steel K-files by hand, in the M4 Safety reciprocating hand piece and rotary NiTi files for glide path preparation.

CHAPTER 2: AIM AND OBJECTIVES

2.1 Aim

The aim of this *in vitro* study was to evaluate 3 different glide path preparation techniques in respect of:

- Percentage change of curvature from original canal anatomy; and
- The occurrence of aberrations in canal anatomy (ledging, zipping and elbows).

2.2 Objectives

The broad objectives of this study were to:

i) Inject simulated S-shaped root canals in plastic blocks with dye and obtain digital images;

ii) Prepare glide paths in these simulated canals with stainless steel hand K-files (control), stainless steel hand K-files in the M4 Safety reciprocating hand piece, PathFiles NiTi rotary files and X-Plorer NiTi rotary files and obtain digital images afterwards; and

iii) Compare pre- and post-instrumentation images for percentage modification of canal curvature and the presence of canal aberrations (ledges, elbows and zipping).

2.3 Hypothesis

PathFiles and X-Plorer NiTi rotary files will maintain canal curvature better and cause fewer aberrations compared to stainless steel hand K-files used manually and in the M4 Safety reciprocating hand piece.

2.4 Statistical Null/Zero Hypothesis:

There will be no difference between PathFiles and X-Plorer NiTi rotary files and stainless steel hand K-files used manually or in the M4 Safety reciprocating hand piece in their modification of canal curvature and in causing canal aberrations.

CHAPTER 3: MATERIALS AND METHODS

The materials and methods used were similar to that of studies done by Ding-ming et al. (2007) and Berutti et al. (2009).

3.1 Standardisation of plastic blocks

One hundred and twenty S-endodontic training blocks (Endo Training Bloc-S, Dentsply/Maillefer, Ballaigues, Switzerland) with simulated root canals were used. The orifice diameter of the canal in each block was 0.35 mm, the apical diameter 0.15 mm, and the canal length was 16 mm.

All the canals in the plastic training blocks were injected with India ink dye (Pelikan, Schindellegi, Germany). The blocks were then indexed with 3 bur marks (arrows), using a template to ensure uniformity of the indices (Fig.3.1). The blocks were then placed in a template on a microscope stage and photographed at right angles to the S-shaped canal using a Leica M165C stereomicroscope with a CCD camera (Leica Microsystems, Heerbrugg, Switzerland).

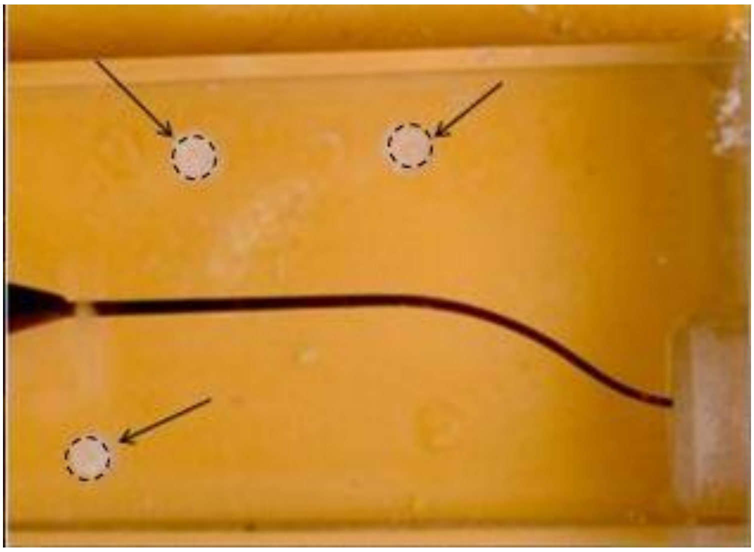

Figure 3.1 S- shaped training block with bur mark indices and canal injected with India ink dye

3.2 Preparation of glide paths in experimental blocks for four experimental groups

The training blocks were randomly divided into 4 groups of 30 samples each (n=30).

- **Group 1: Hand K-files (control)**

  The glide paths in this group were prepared using stainless steel K-files (VDW, Munich, Germany) by hand, in the following sequence: 0.8, then 0.10, then 0.15 and then 0.20 to working length, using a quarter clockwise turn and pull motion (Fig.3.2).

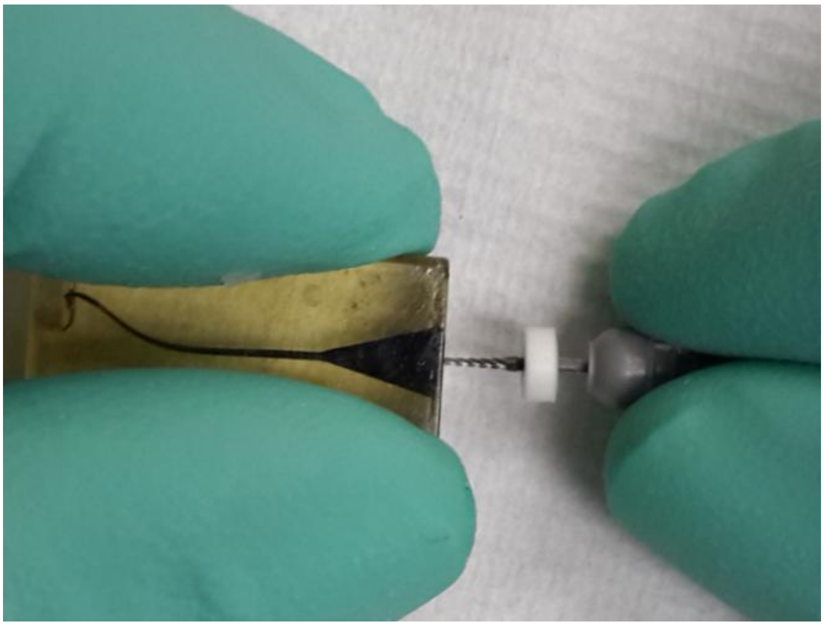

Figure 3.2: Glide path preparation using a size 0.8 stainless steel K-file (VDW)

- **Group 2: Hand K-files in the M4 safety reciprocating hand piece**

  The glide paths in this group were prepared using stainless steel K-files (VDW) in the M4 Safety (SybronEndo, Orange, California, USA) (Fig 3.3) reciprocating hand piece (30 degree reciprocation) driven by the TCM III (SybronEndo) electric motor at 900 rpm at the 18:1 setting. A size 0.8 K-file was watch-winded to working length; thereafter the M4 Safety hand piece was attached to the file (Fig. 3.4). The hand piece was then gently moved apically and coronally in 1-3 mm amplitude strokes until the file moved freely in the canal (Fig. 3.5). This process was repeated with the sizes 0.10 and 0.15.

Finally, a size 0.20 stainless steel K-file was manually watch-winded to 1 mm short of working length before the hand piece was attached and the file reciprocated in the canal.

Figure 3.3: M4 Safety reciprocating hand piece (SybronEndo)

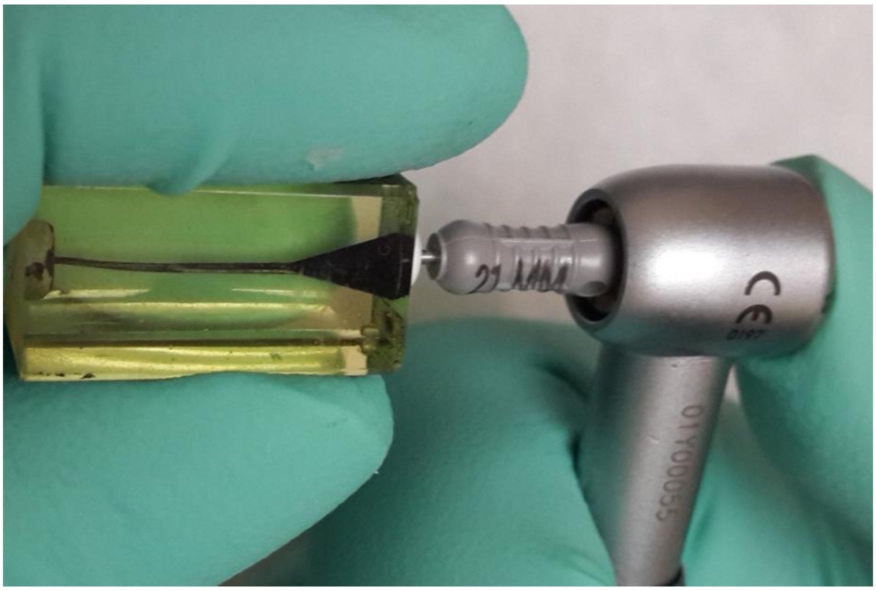

Figure 3.4: The M4 Safety reciprocating hand piece (SybronEndo) being attached to a size 0.8 stainless steel K-file (VDW)

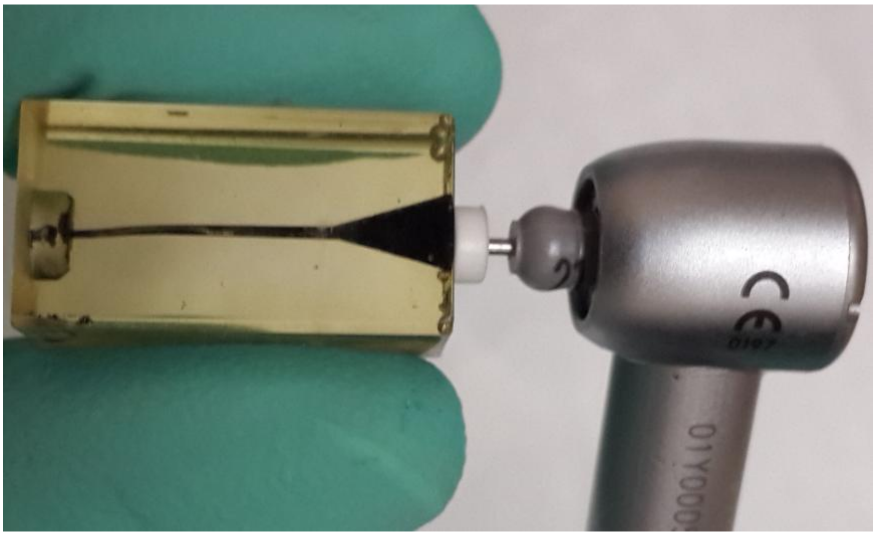

Figure 3.5: The stainless steel K-file (VDW) is moved apically and coronally once the M4 Safety reciprocating hand piece (SybronEndo) is attached

- **Group 3: Hand K-files and PathFiles**

  The glide paths in this group were prepared as follows: first the glide paths were prepared by hand, using stainless steel K-files (VDW) progressively from size 0.8 to 0.10. Thereafter, the glide paths were prepared up to working length using NiTi PathFiles (Dentsply/Maillefer) (Fig. 3.6) ISO tip size 0.13 (Fig. 3.7) followed by ISO tip size 0.16 and ISO tip size 0.19 in an endodontic hand-piece (X-Smart Plus, Dentsply/Maillefer) (Fig. 3.8) operating at 300 rpm, and 4 Ncm torque on display.

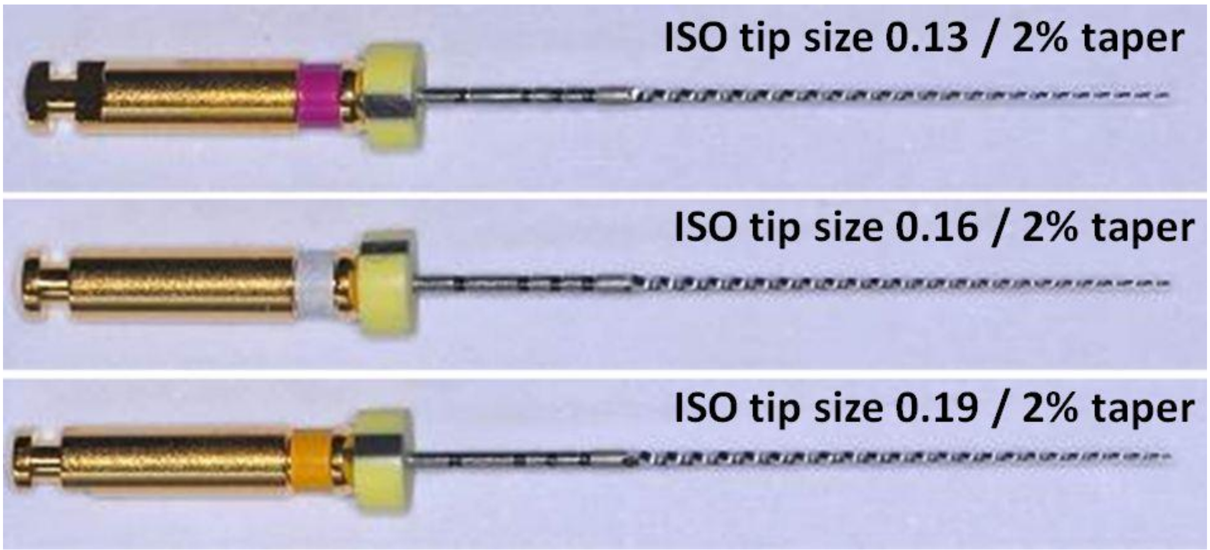

Figure 3.6: NiTi PathFiles (Dentsply/Maillefer)

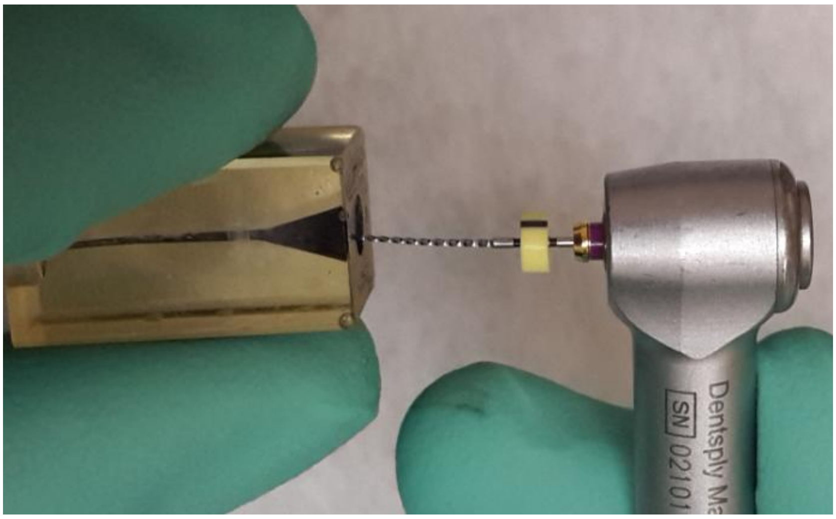

Figure 3.7: The 0.13 NiTi PathFile (Dentsply/Maillefer) being used to prepare the glide path

Figure 3.8: The X-Smart Plus Endodontic Motor (Dentsply/Maillefer) set at 300 rpm and 4 Ncm torque on display

- **Group 4: Hand K-files and X-Plorer files**

  The glide paths in this group were prepared as follows: first the glide paths were prepared by hand, using stainless steel K-files (VDW) progressively from size 0.8 to 0.10. Thereafter the glide paths were prepared up to working length using NiTi X-Plorer files (Clinician's Choice Dental Products Inc., New Milford, USA) (Fig.3.9) ISO tip size 0.15 / 1% taper (Fig. 3.10) followed by ISO tip size 0.20 / 1% taper then ISO tip size 0.20 / 2% taper in an endodontic hand-piece (X-Smart Plus, Dentsply/Maillefer) operating at 300 rpm, and 4 Ncm torque on display.

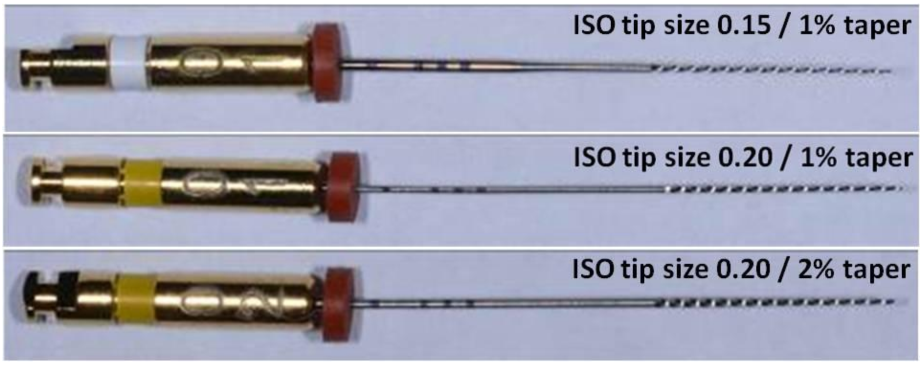

Figure 3.9 NiTi X-Plorer files (Clinician's Choice Dental Products Inc.)

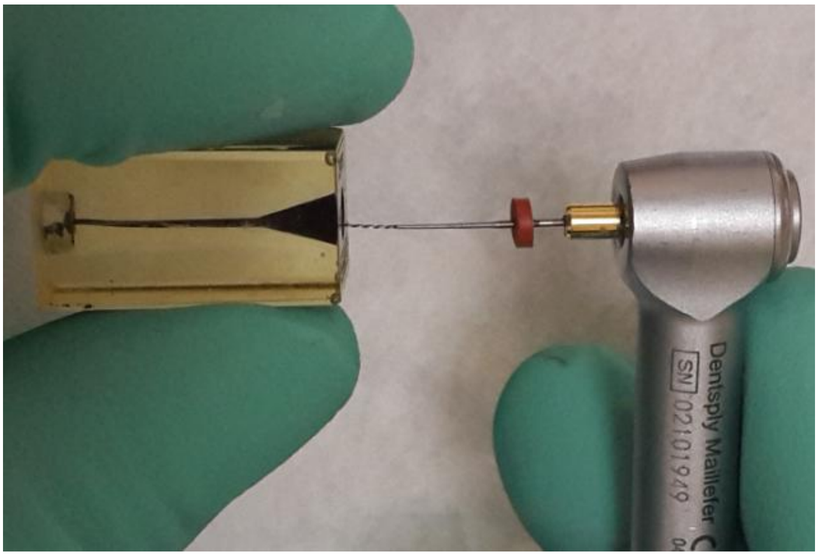

Figure 3.10: The 0.15 / 1% taper X-Plorer file (Clinician's Choice Dental Products Inc.) being used to prepare a glide path

No irrigants were used and every instrument was discarded after preparing five canals. After the completion of glide path preparations, the training blocks were replaced in the photographic template on the microscope stage and digital images were acquired as described earlier. All images were saved in .tiff format.

3.3 Quantitative assessment of images for curvature change

The images of pre-instrumentation and post-instrumentation blocks were used to evaluate the changes in the apical and coronal curvature of the canals as a result of glide path preparation. Rhinocerous Software (ver.4.0; Robert McNeel & Associates, Seattle, WA) was used to identify and evaluate the following:

1. Identify mean axis of canal.
2. Identify the reference points corresponding to the initial and end point of the two main curves of the canal; and
3. Evaluate the apical and coronal radii of curvature using best fitting with circumferences of known radii.

The images were cropped and magnified to highlight the canal geometry. The image of each canal was used to identify its mean axis: starting at the apex 32 points were identified along the canal at 0.25 mm intervals, each point corresponding to the centre of the canal cross-section (Fig.3.11).

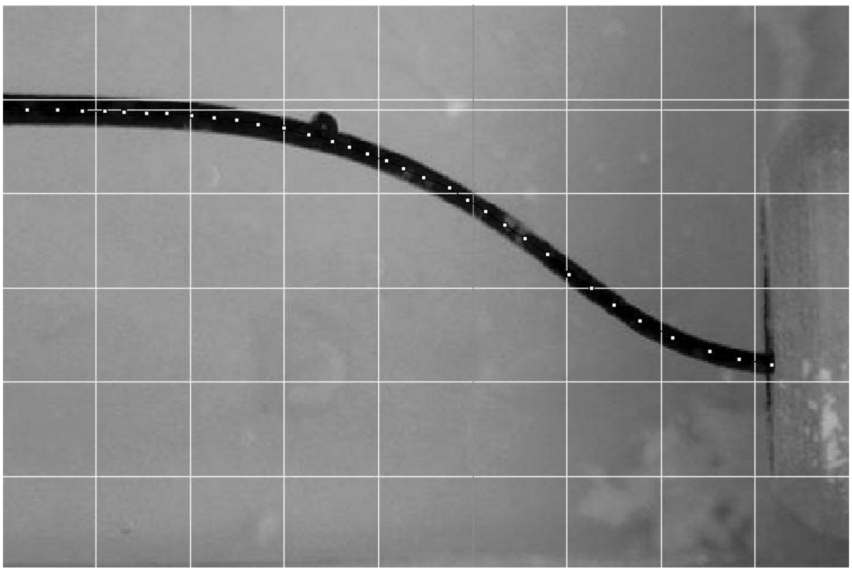

Figure 3.11: Detail of the point-by-point identification and construction of the mean axis of the canal

These points were used as control points for a Bezier curve (Fig.3.12). A visual comparison between the canal geometry and Bezier curve could reveal any errors in the tracing of the mean axis of the canal.

Figure 3.12: A Bezier curve generated from the point-by-point analysis of the centre of the canal

The Bezier curve approximating the mean axis of the canal was analysed to evaluate the curvature, which was in general continuously variable along the axis (Fig. 3.13). The point of curvature change (null curvature) was taken as the flexus in the passage between the apical and the proximal curvatures of the canal and, as a consequence, as one of the extremities to be taken into consideration for quantitative curvature evaluation.

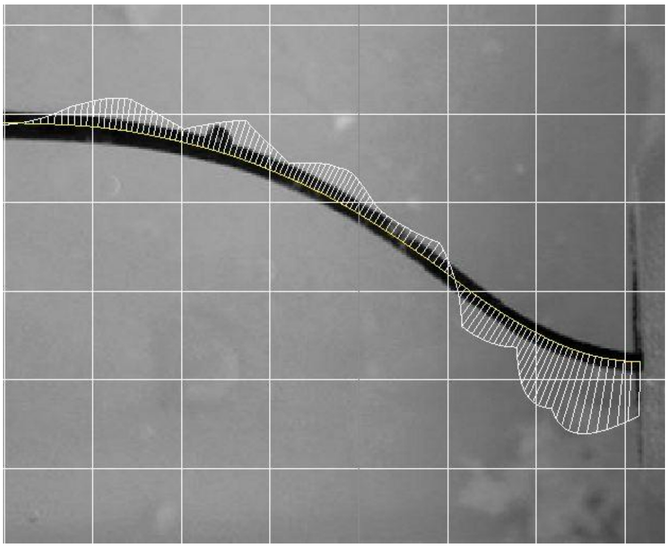

Figure 3.13: The curvature analysis (white) of the Bezier curve (yellow) showing the end points of the curve and the point of curvature change of the apical and coronal curves

The canal apex, the point of curvature change between the extremities, and the first proximal point of the canal having null curvature were selected for each canal to quantitatively evaluate the mean apical and proximal curvature by best fitting with circumferences of different radii (Fig.3.14).

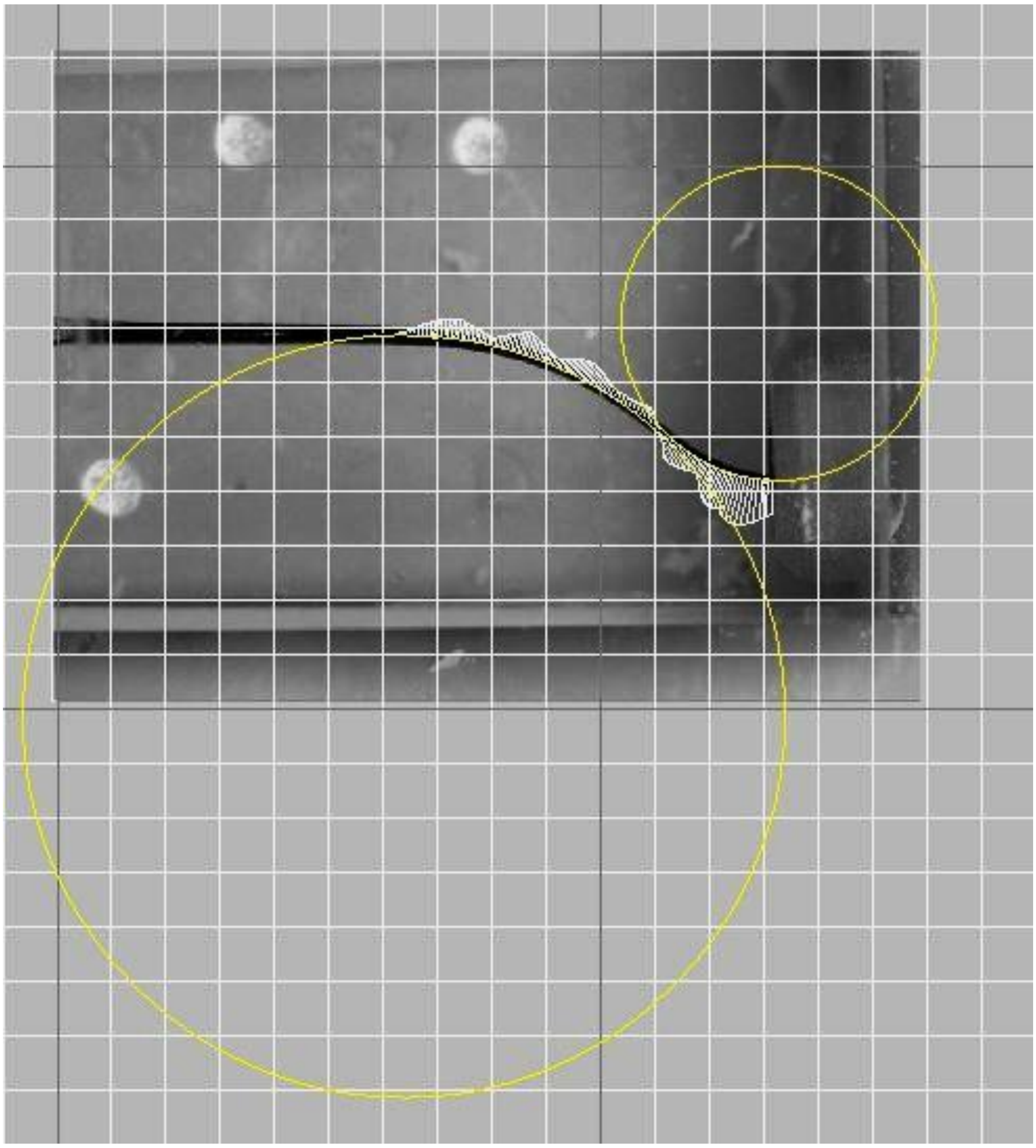

Figure 3.14: Determining the mean radius of apical and coronal curvature using best-fit circle circumferences (yellow) after evaluating the endpoints of the curves (white)

The change in radius of curvature from baseline (pre-instrumentation) and after instrumentation was expressed as a percentage using the formula: {(post instrumentation radius-pre instrumentation radius) / pre instrumentation}*100%. The lower the percentage, the lesser the change to initial canal anatomy and a higher percentage will mean a greater change to initial canal anatomy. This constituted the quantitative assessment.

3.4 Qualitative assessment of incidence of canal aberrations

Using the bur mark indices, the photographs after preparation were super imposed onto the pre-instrumentation photographs before glide path preparation using Adobe Photoshop Digital Software (Adobe Systems Inc, San Jose, CA). The paired images were imported into a Microsoft Office PowerPoint presentation (Microsoft Corporation, Redmond, WA).

The canals were assessed after glide path preparation for aberrations in canal anatomy (ledging, zipping and elbows) and for any deviation from original canal anatomy by three blinded examiners who were experienced clinicians in endodontic treatment independently, as described by Thompson and Dummer (2000). A checklist was given to each examiner to indicate presence of a ledge, zip or elbow for the images examined (Addendum A).

3.5 Data analysis

Data summary per treatment group included summary statistics, mean, SD, median, min, max and 95% confidence interval. Treatment groups were compared with respect to mean radii of curvature using one-way analysis of variance with baseline value as covariate. If data did not conform with the normal distribution an ANCOVA for ranks was employed. Fisher's LSD method was used for pair-wise comparisons. Testing was done at the 0.05 level of significance. Prepared (post-instrumentation) groups were compared with respect to the presence of aberrations using Fisher's exact test. Testing was done at the 0.05 level of significance. All statistical analyses were performed with StataCorp.2009 (Stata: Release 11.) software package (Statistical Software. College Station, TX: Statacorp LP).

CHAPTER 4: RESULTS

4.1 Quantitative analysis of curvature modification

The quantitative measurements of percentage change to the coronal and apical radii were of interest. Figures 4.1 to 4.8 show the percentage change to coronal and apical radii of the samples in the different groups. Figures 4.9 and 4.10 show the comparison of measured percentage change for coronal and apical radii respectively between the different groups after the samples in each group were rearranged from lowest to highest percentage change.

Table 1 shows the observed data: pre- and post- instrumentation as well as percentage change from baseline (pre-instrumentation), which was summarised using descriptive statistics (mean, standard deviation, median, minimum, maximum and 95% confidence interval).

4.1.1 Group 1: Hand K-files (Control) (Figures 4.1 and 4.2)

In this group the highest percentage change for coronal and apical radii was 30.30% and 97.73% respectively. The lowest percentage change for the coronal and apical radii was 4.38% and 13.01% respectively.

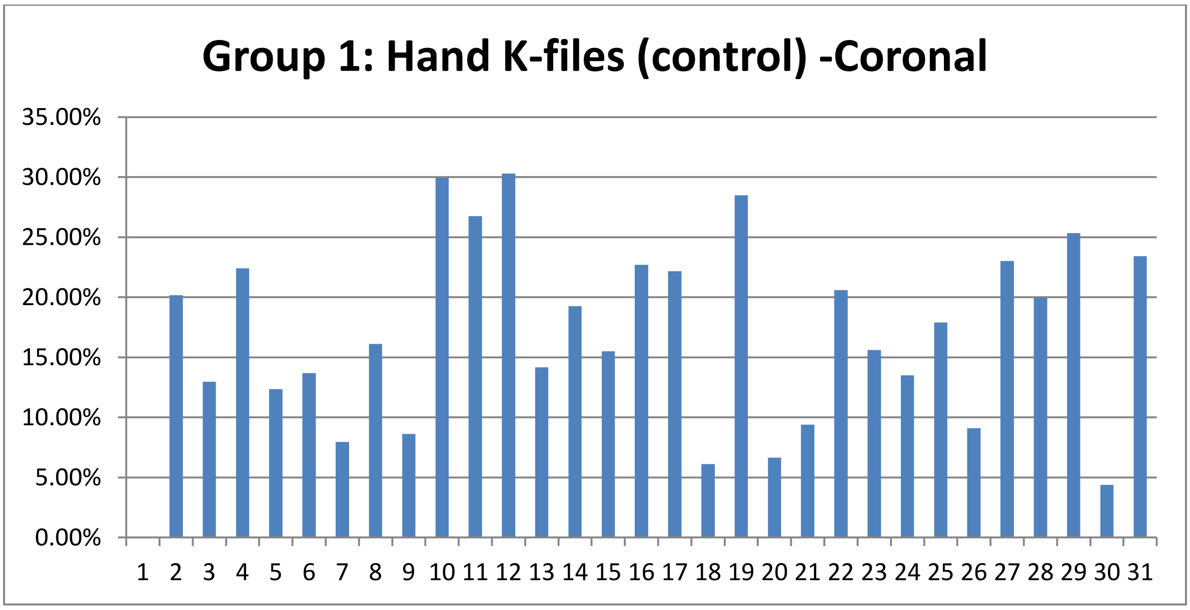

Figure 4.1: The percentage change to coronal radii for all samples in Group 1

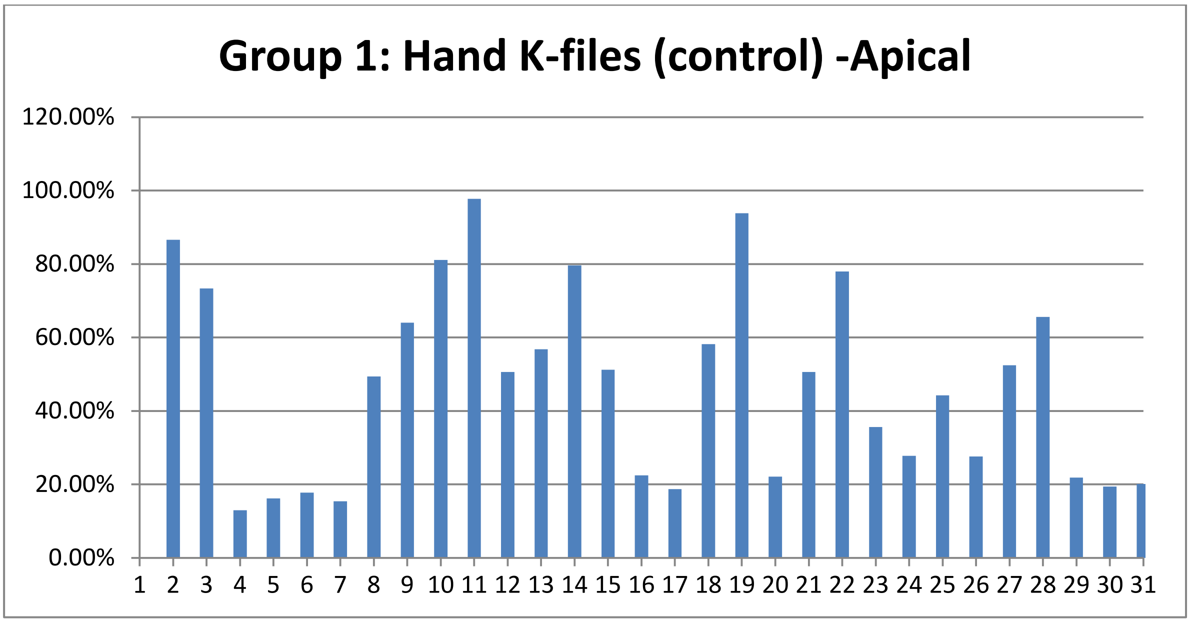

Figure 4.2: The percentage change to apical radii for all samples in Group 1

4.1.2 Group 2: Hand K-files in the M4 Safety reciprocating hand piece (Figures 4.3 and 4.4)

In this group the highest percentage change for coronal and apical radii was 22.97% and 36.85% respectively. The lowest percentage change for the coronal and apical radii was 2.53% and 2.84% respectively.

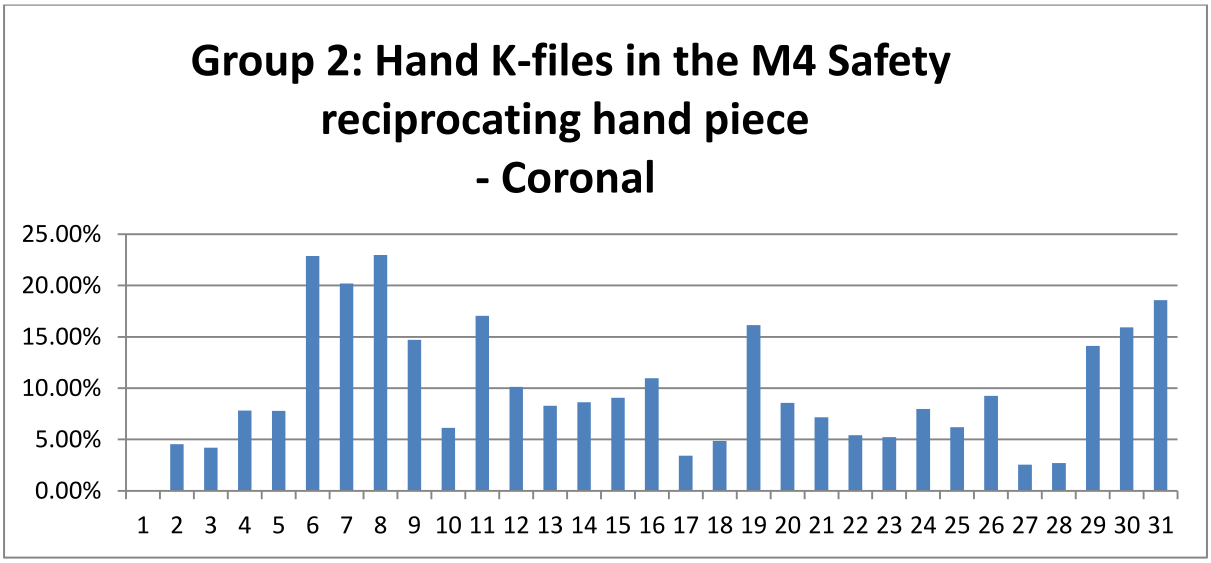

Figure 4.3: The percentage change to coronal radii for all samples in Group 2

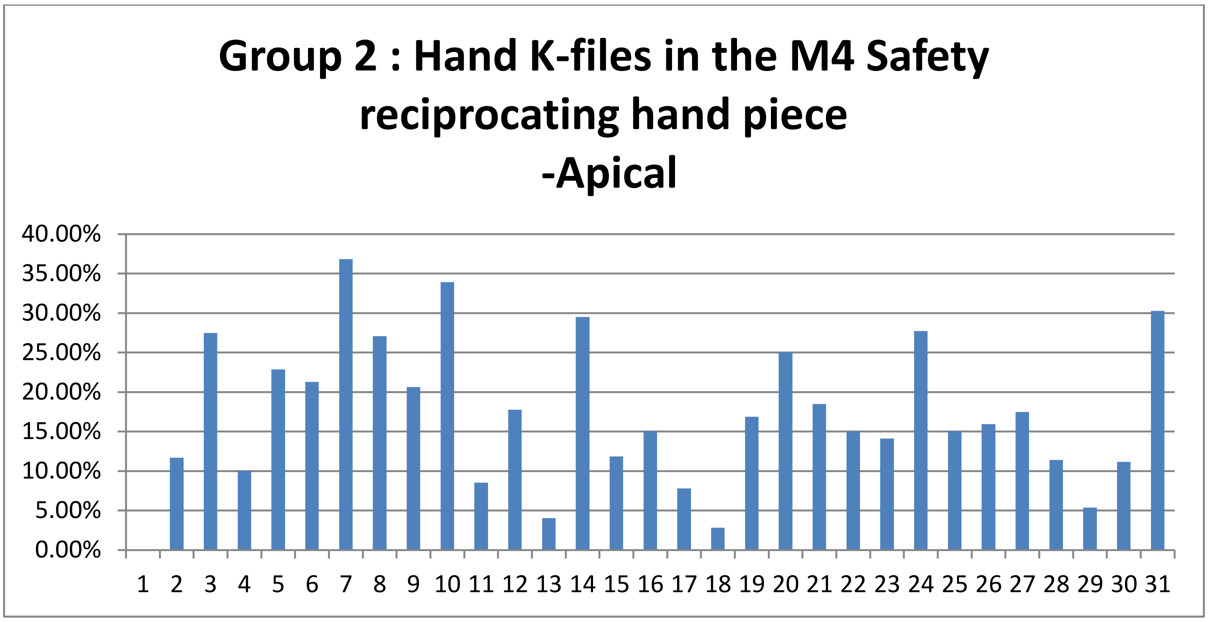

Figure 4.4: The percentage change to apical radii for all samples in Group 2

4.1.3 Group 3: Hand K-files and PathFiles (Figures 4.5 and 4.6)

In this group the highest percentage change for coronal and apical radii was 14.84% and 18.46% respectively. The lowest percentage change for the coronal and apical radii was 1.67% and 1.79% respectively.

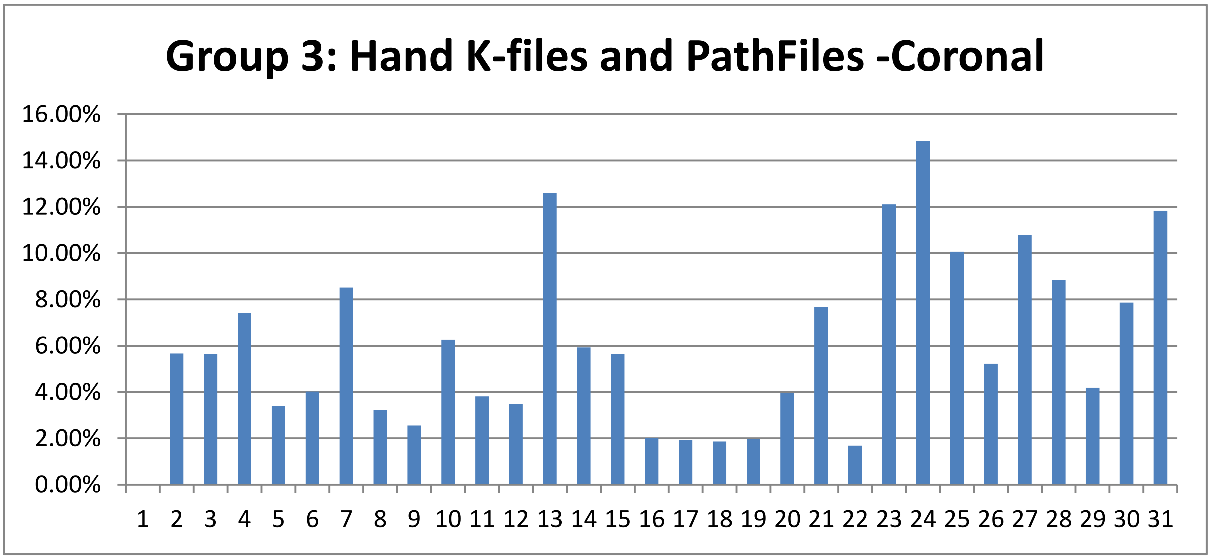

Figure 4.5: The percentage change to coronal radii for all samples in Group 3

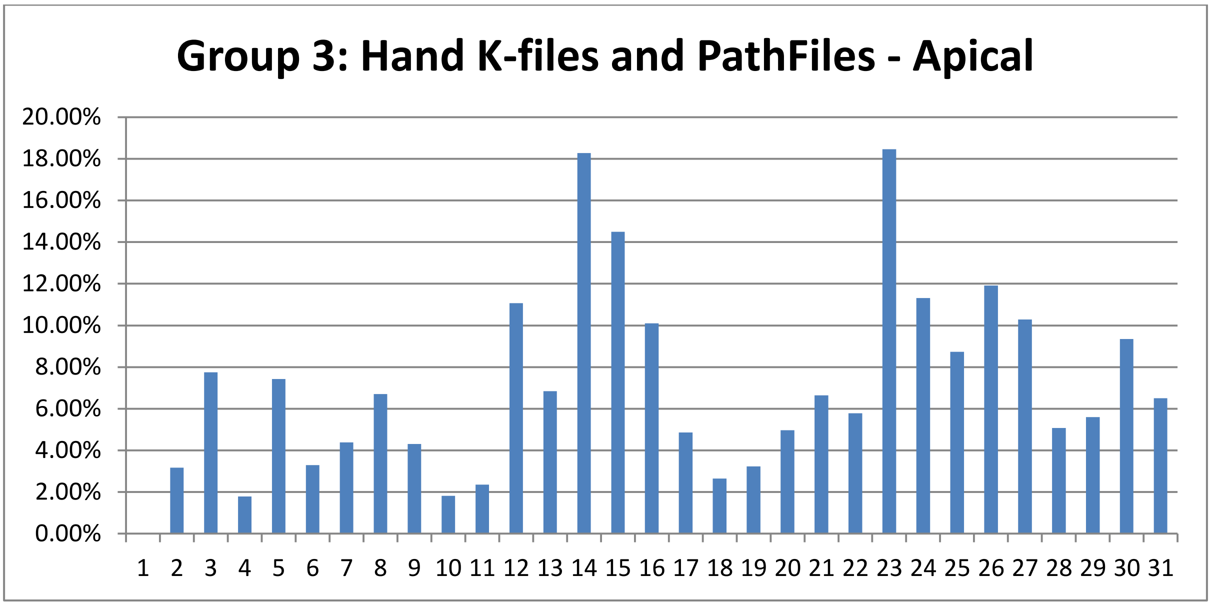

Figure 4.6: The percentage change to apical radii for all samples in Group 3

4.1.4 Group 4: Hand K-files and X-Plorer files (Figures 4.7 and 4.8)

In this group the highest percentage change for coronal and apical radii was 13.50% and 17.75% respectively. The lowest percentage change for the coronal and apical radii was 0.43% and 2.21% respectively.

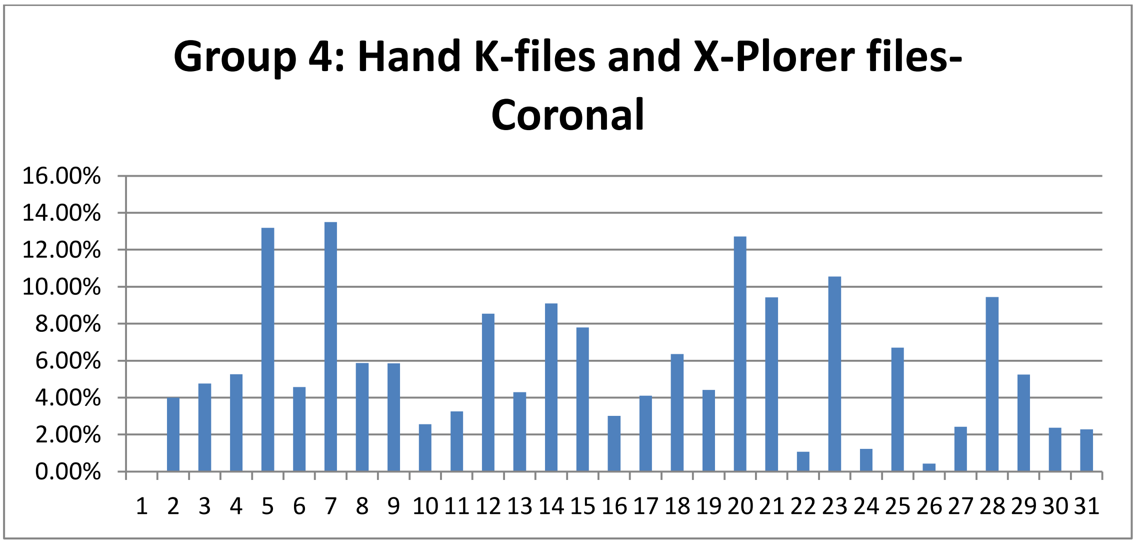

Figure 4.7: The percentage change to coronal radii for all samples in Group 4

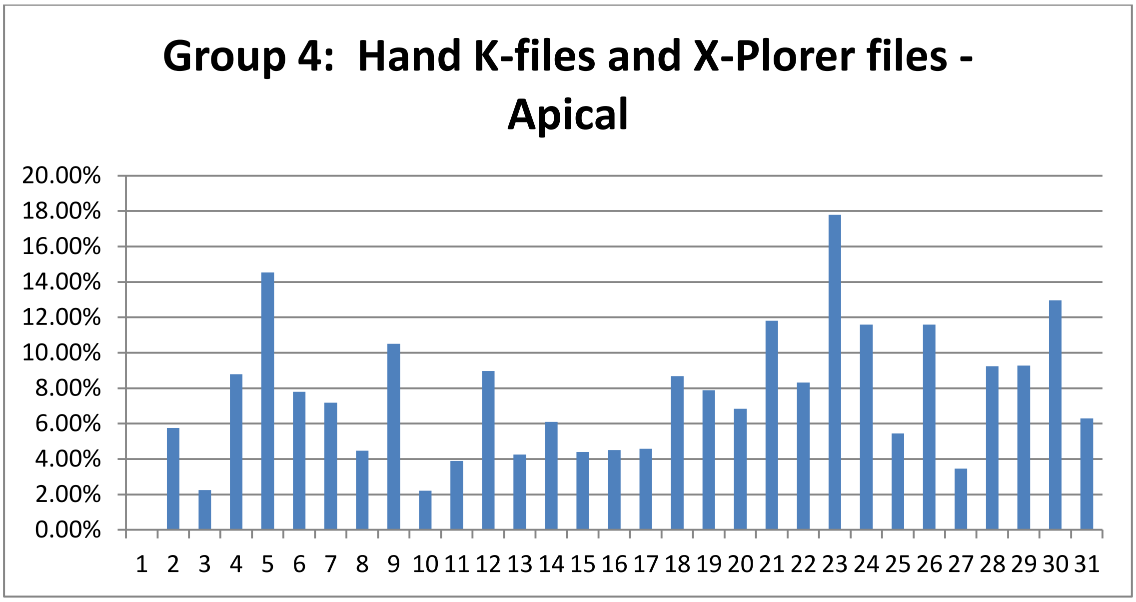

Figure 4.8: The percentage change to apical radii for all samples in Group 4

4.1.5 Comparison of data for percentage change of coronal radii

Figure 4.9 illustrates the results after the samples were rearranged in each group from lowest to highest percentage change to coronal radii before statistical analysis. The graph shows that the changes were similar for group 3 (Hand K-files and PathFiles) and group 4 (Hand K-files and X-Plorer files), while group 2 (Hand K-files in M4 Safety reciprocating hand piece) showed intermediate change and group 1 (Hand K-files) (control) showed the highest percentage change to coronal radii.

4.1.6 Comparison of data for percentage change of apical radii.

Figure 4.10 illustrates the results after the samples were rearranged in each group from lowest to highest percentage change of apical radii before statistical analysis. The graph shows that the changes were similar for group 3 (Hand K-files and PathFiles) and group 4 (Hand K-files and X-Plorer files), while group 2 (Hand K-files in M4 Safety reciprocating hand piece) showed more change and group 1 (Hand K-files) (control) showed considerably higher percentage change to apical radii compared to all the other groups.

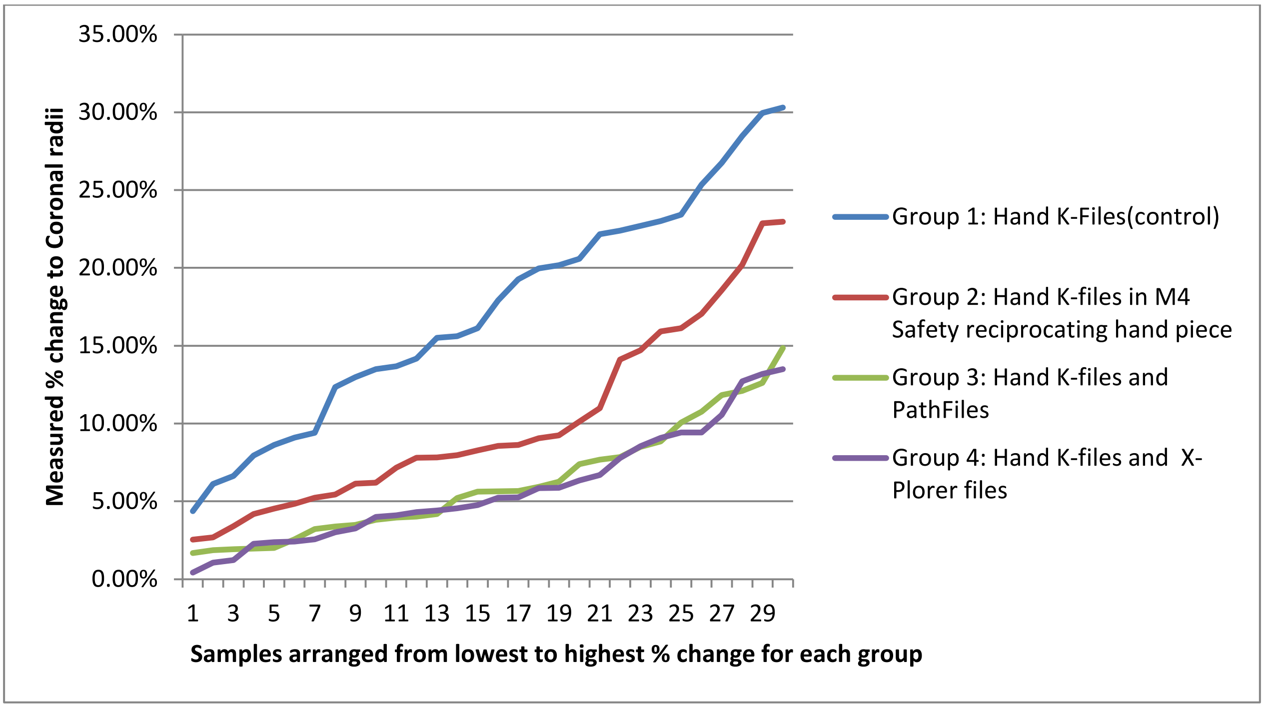

Figure 4.9: Graph showing the post-instrumentation percentage change to coronal radii for the different groups before statistical analysis

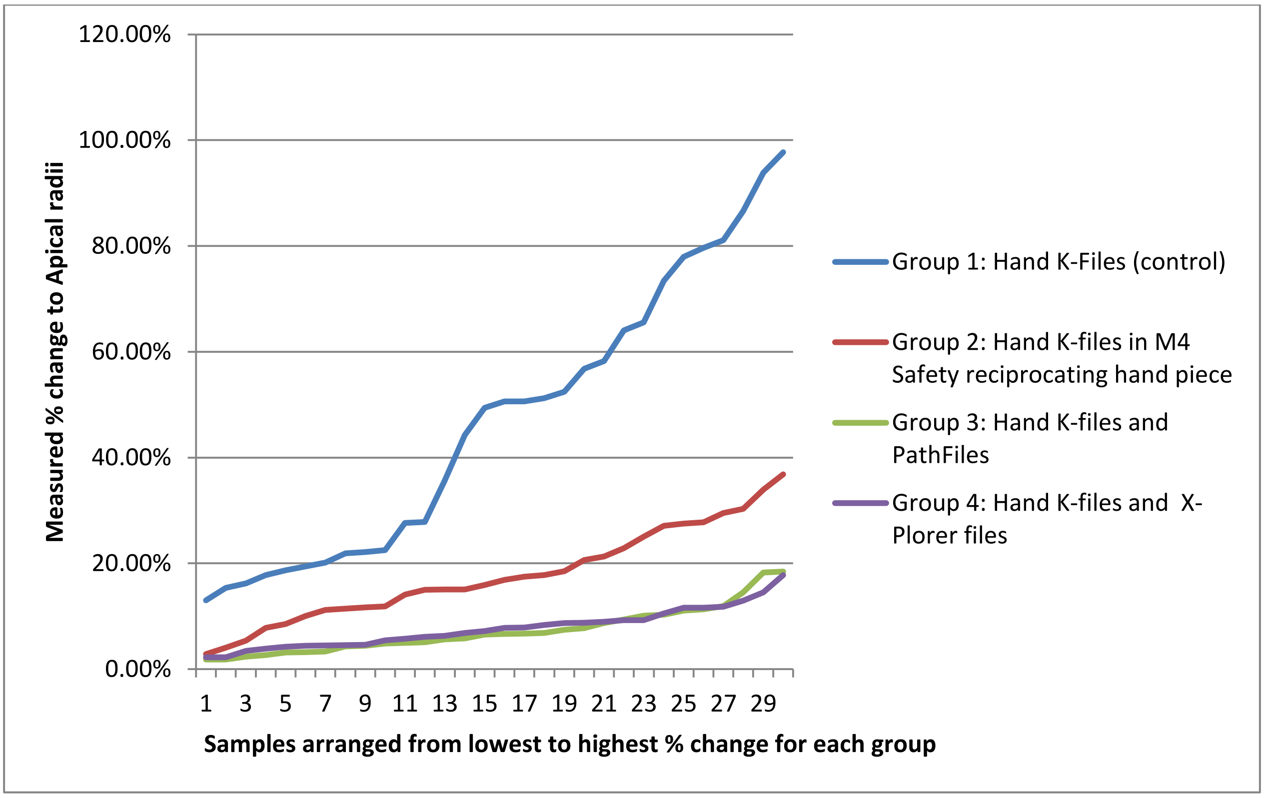

Figure 4.10: Graph showing the post-instrumentation percentage change to apical radii for the different groups before statistical analysis

4.1.7 Statistical analysis

The Shapiro-Wilk test for normality of change from baseline was significant both for apical ($p<0.001$) and for coronal ($p<0.001$) radii overall. After logarithmic transformation for change from baseline, the Shapiro-Wilk test for normality was not significant for any of the prepared (post- instrumentation) groups, both for apical and coronal curvature change.

Prepared groups were then compared with respect to logarithmic transformed change from baseline using analysis of covariance (ANCOVA) with logarithmic transformed pre-instrumentation values as covariate. As confirmation, an ANCOVA for ranks was also performed which reached the same conclusion.

The point and interval estimates for both apical and coronal radii employed the geometric mean and its 95% confidence interval. After establishing preparation differences, both for change from baseline (pre-instrumentation) for apical and coronal curves, specific differences were tested using Fisher's LSD for pairwise comparisons. By ANCOVA, prepared groups differed significantly ($p<0.001$) and in particular, group 1 (Hand K-files) (control) and group 2 (Hand K-files in M4 Safety reciprocating hand piece) differed significantly from all the other groups while group 3 (Hand K-files and PathFiles) and group 4 (Hand K-files and X-Plorer files) did not differ significantly. Group 3 (Hand K-files and PathFiles) and group4 (Hand K-files and X-Plorer files) were also superior to group1 (Hand K-files) (control) and group2 (Hand K-files in M4 Safety reciprocating hand piece) (Geometric means, Table 2, Table 3, Figs. 4.11 and 4.12).

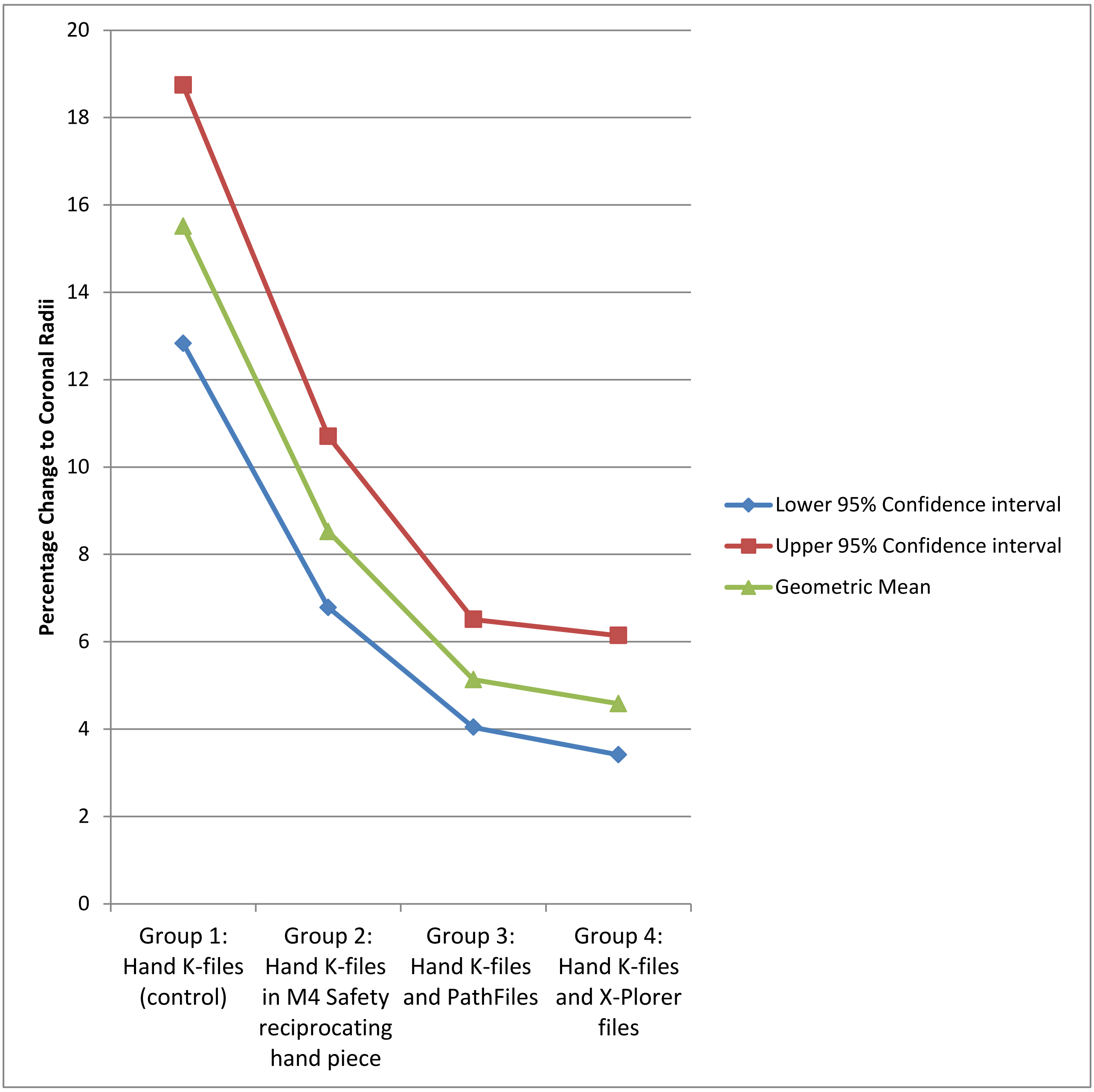

Figure 4.11: A graph displaying the geometric mean of the percentage change to coronal radii, and the upper and lower 95% confidence intervals for the different group

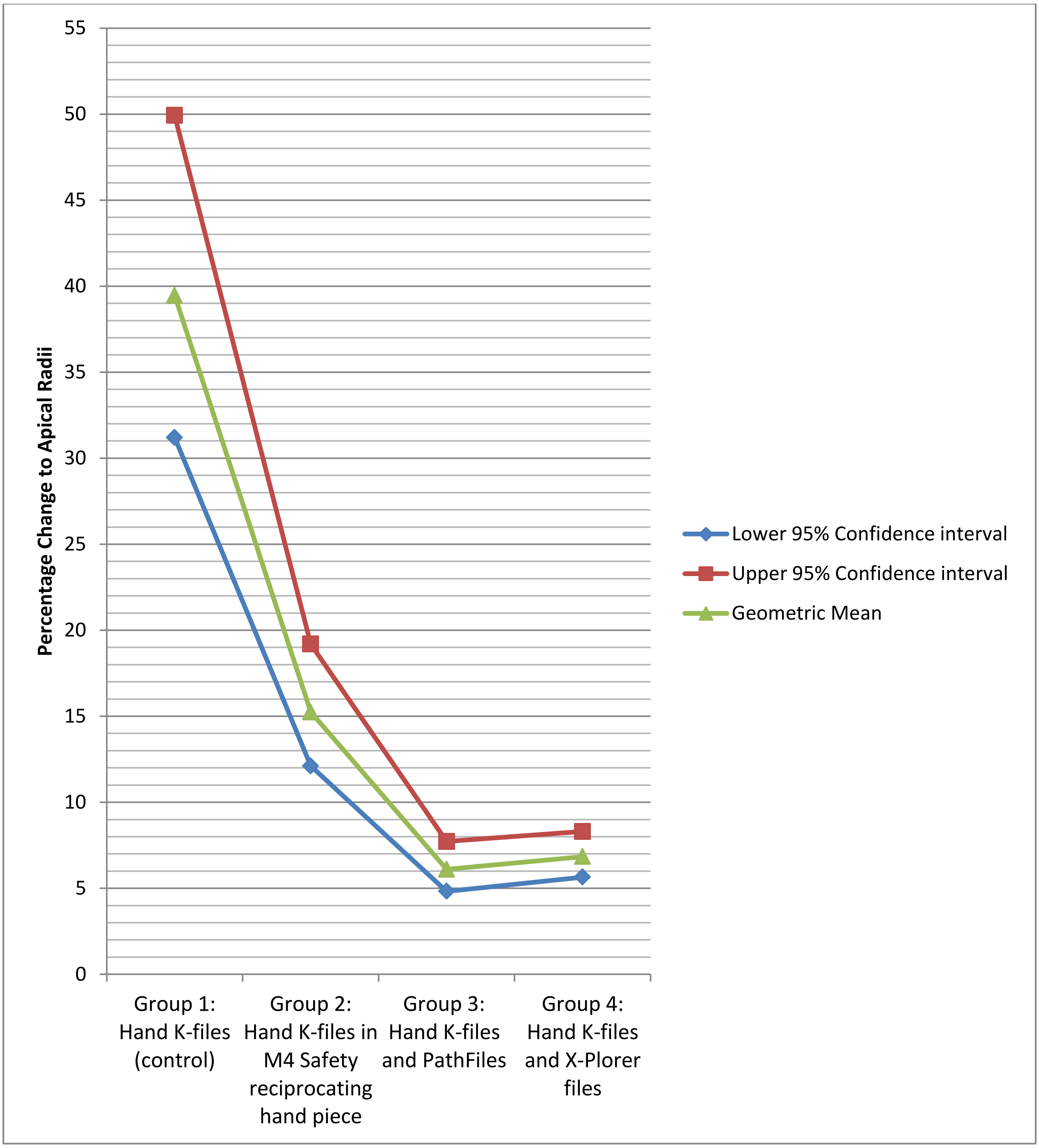

Figure 4.12: A graph displaying the geometric mean of the percentage change to apical radii, and the upper and lower 95% confidence intervals for the different groups

4.2 Presence of aberrations

The results for this part of the study are presented in Figure 4.13 and Table 4. There was no difference between the three blinded examiners in their assessments of the images. Observation of canal aberrations showed a higher incidence of ledges, elbows and apical zips for the group in which glide paths were prepared with hand K-files only (Group 1) compared to all the other groups. The only other group that showed evidence of ledge formation was group 2 (Hand K-files in M4 Safety reciprocating hand piece). The ledges in this group were located between the coronal and apical curve while in group 1 (Hand K-files) they were located around the apical curve towards the apical foramen.

The presence of canal aberrations in the different groups is shown in Figure 4.13 and representative samples from the different groups are shown in Figure 4.14.

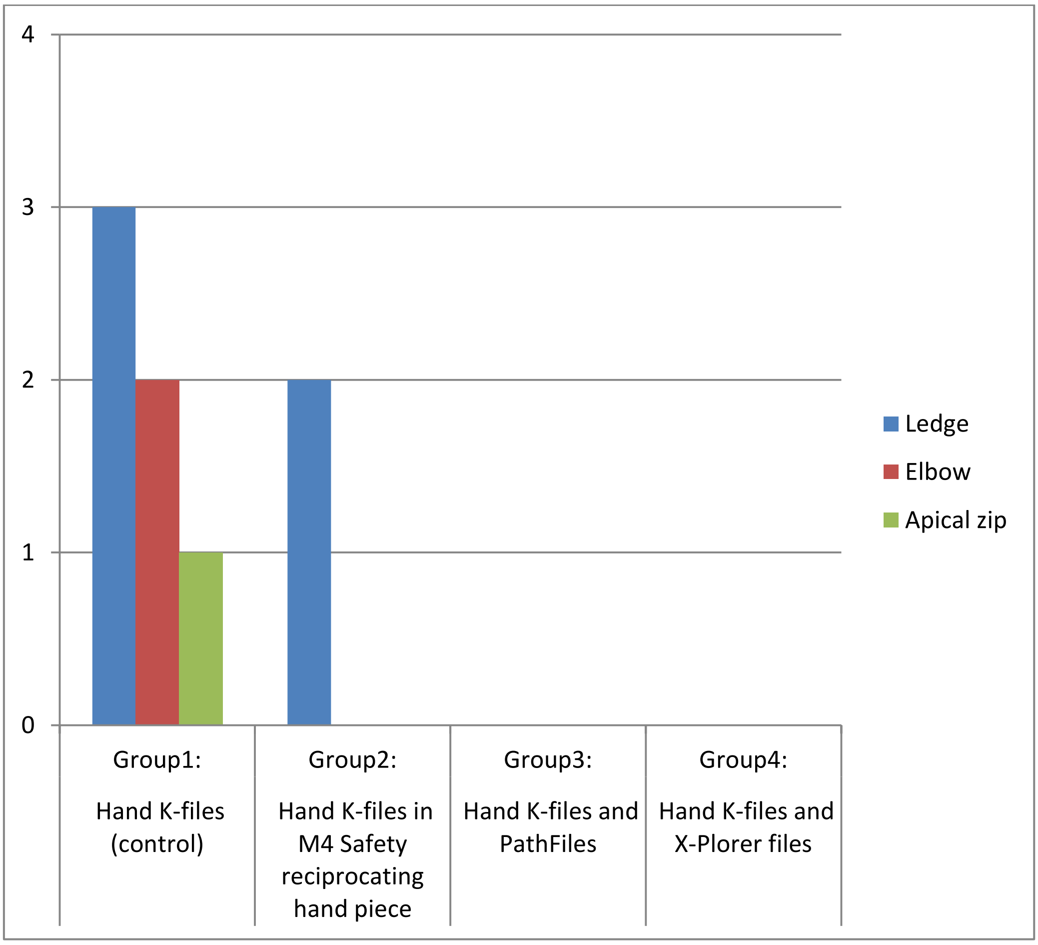

Figure 4.13: Graph showing the observed canal aberrations in the different groups

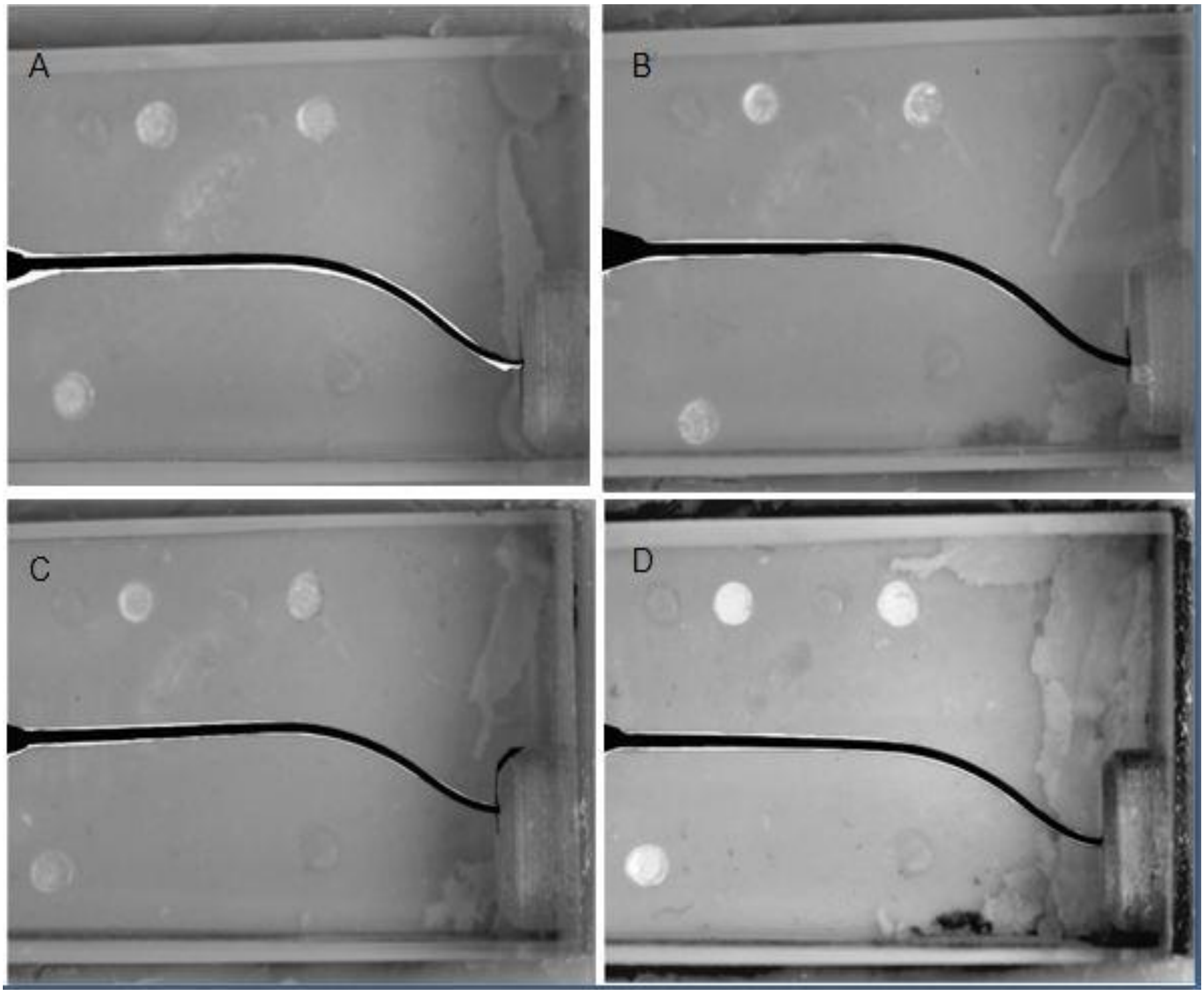

Figure 4.14: Representative super imposed pre-instrumentation and post-instrumentation images:

(A) Group 1: Hand K-files group, showing the presence of a ledge.

(B) Group 2: Hand K-files in the M4 Safety reciprocating hand piece - no visible canal aberration.

(C) Group 3: Hand K-files and PathFiles - no visible canal aberration.

(D) Group 4: Hand K-files and X-Plorer files - no visible canal aberration

Prepared (post-instrumentation) groups were compared with respect to the presence of aberrations using Fisher's exact test. Testing was done at the 0.05 level of significance.

Preparation groups were significantly different (p=0.005) with respect to the number of aberrations (Table 4). In particular, group 1 and group 2 did not differ statistically (p=0.254; 20% and 6.67%). However, clinically, the latter difference is regarded as relevant. Furthermore group 2 also did not differ significantly from group 3 and group 4 (p=0.326) (Table 4).

Table 1. **Coronal and Apical curves: Descriptive statistics of the radii of curvature (mm) and their change (%) after glide path preparation**

	Group 1. **Hand K-Files (control)**			**Group 2.** **Hand K-files in M4 Safety reciprocating hand piece**			**Group 3.** **Hand K-files and PathFiles**			**Group 4.** **Hand K-files and X-Plorer files**		
Group	Pre	Post	%Ch	Pre	Post	%Ch	Pre	Post	% Ch	Pre	Post	% Ch
Coronal												
Mean	74.26	87.04	17.28	77.7	85.49	10.11	76.63	81.33	6.16	73.27	77.5	5.81
SD	3.94	6.29	7.37	4.84	6.15	5.93	4.24	4.88	3.66	5.16	5.67	3.62
Median	74.41	87.94	17.01	78.6	84.49	8.42	76.77	80.75	5.64	73.06	77.4	5
Minimum	66.24	73.95	4.38	68.44	76.02	2.53	67.81	69.11	1.67	61.57	65.13	0.43
Maximum	81.74	98.23	30.3	88.37	97.2	22.97	85.62	95.08	14.84	84.32	89.11	13.5
95% CI	72.79-75.74	84.69-89.39	14.53-20.04	75.9-79.51	83.2-87.79	7.9-12.32	75.05-78.22	79.51-83.15	4.8-7.53	71.34-75.2	75.38-79.62	4.46-7.16
Apical												
Mean	36.86	54.06	47.05	37.78	44.44	17.77	37.56	40.33	7.31	38.08	40.99	7.72
SD	3.23	9.91	26.34	3.71	5.2	8.92	3.5	4.41	4.43	4.09	4.48	3.71
Median	36.86	55.66	50.02	37.9	43.83	16.4	37.27	40.76	6.57	37.75	40.15	7.49
Minimum	30.81	40.2	13.01	30.16	36.63	2.84	30.52	32.61	1.79	31.06	34.66	2.21
Maximum	43.14	74.24	97.73	46.97	57.64	36.85	45.05	50.42	18.46	45.35	53.42	17.79
95% CI	35.66-38.07	50.36-57.76	37.22-56.89	36.39-39.16	42.5-46.38	14.44-21.1	36.25-38.87	38.69-41.98	5.65-8.96	36.55-39.6	39.32-42.66	6.33-9.1

Pre, Pre-instrumentation; Post, Post-instrumentation; %Ch, Percentage change from pre-instrumentation {(Post-Pre)/Pre}*100%; SD, Standard deviation; CI, Confidence interval

Table2: Geometric means and 95% confidence interval for change to coronal radii by prepared groups

Prepared group	Geometric Mean	95% Confidence interval
Group 1: Hand K-files (control)	15.51	12.83 - 18.74
Group 2: Hand K-files in M4 Safety reciprocating hand piece	8.52	6.78 - 10.70
Group 3: Hand K-files and PathFiles	5.13	4.04 - 6.51
Group 4: Hand K-files and X-Plorer files	4.58	3.41 - 6.14

Table 3: Geometric means and 95% confidence interval for change to apical radii by prepared groups

Prepared group	Geometric Mean	95% Confidence interval
Group 1: Hand K-files (control)	39.46	31.2 - 49.92
Group 2: Hand K-files in M4 Safety reciprocating hand piece	15.24	12.11 - 19.19
Group 3: Hand K-files and PathFiles	6.10	4.82 - 7.72
Group 4: Hand K-files and X-Plorer files	6.84	5.65 - 8.3

Table 4: The statistical significance between the different groups using Fisher's exact test regarding the presence of canal aberrations is shown, where groups falling on the same line are not statistically different.

1 2 3 4
1 2 3 4

CHAPTER 5: DISCUSSION

The purpose of this *in vitro* study was to assess the curvature change to canal anatomy in simulated canals after glide path preparation using three different mechanical methods. The canals were also examined for the presence of ledges, elbows and apical transportation after instrumentation.

Maintenance of the multi-planar geometries of the original root canal anatomy facilitates the vectors needed for three-dimensional sealing of the root canal system which is a prerequisite for successful endodontic therapy (Schilder, 1974, 1967). In curved canals achieving a tapered preparation large enough for the exchange of irrigants, while maintaining the position of the apical foramen, can be precarious. The risk of creating ledges, perforations and zipping of the apex, as well as file separation, increases in curved canals. Since most teeth have root canals with single curves and some with multi-planar curves, the risk of iatrogenic errors is ever present during endodontic instrumentation (Vertucci, 2005). The risk is even higher during initial negotiation of the canals (Jafarzadeh and Abbott, 2007).

Though the introduction of NiTi instruments for shaping canals has reduced the risk of ledges, perforation and transportation, the risk of file fracture remains (Arens et al., 2003; Schäfer and Dammaschke, 2009; Peters and Paqué, 2010). The preparation of a glide path has been shown to reduce torsional stress on rotary NiTi instruments, prolong their lifespan, reduce the occurrence of canal aberrations, better maintain the original curvature of the canal and provide for better efficiency when canals are being shaped with NiTi instruments in reciprocating movement (Berutti et al., 2004; Patino et al., 2005; Berutti et al., 2012). Canal aberrations that may form during negotiation and glide path preparation could be further accentuated during progressive shaping of the root canal system (Ajuz et al., 2013).

The use of mounted extracted teeth set up in a mannequin is an experimental model that offers the best reproduction of the clinical situation. Variables exist in extracted teeth, such as: length, curvature and width of the canal; the hardness of the dentine; presence of calcifications and pulp stones; and the size and location of the apical foramen. Considering curvature of the root canal specifically, there are variations in the angle, radius, location, length and the multi-planar orientation of the curves (Hülsmann, Peters and Dummer, 2005).

Simulated canals in resin blocks can be used as an alternative experimental model. It must be noted that the hardness of resin blocks differs from dentine. The micro-hardness of dentine is estimated to be 35 to 40 kg/mm^2 near the pulp space, while the hardness of resin blocks with simulated canals is estimated to be 20 to 22 kg/mm^2 (Weine, Kelly and Bray, 1976; Eldeeb and Boraas, 1985). Twice the force has to be applied for the removal of natural dentine compared to that needed to remove resin (Lim and Webber, 1985). The size of resin chips and natural dentine chips may be not identical and could result in blockages of the apical root canal space and difficulty in removing the debris in resin canals (Weine, Kelly and Bray, 1976; Lim and Webber, 1985).

The experimental model using simulated canals in resin blocks guarantees a high degree of reproducibility and standardisation of the experimental design (Hülsman, Peters and Dummer, 2005). The advantages of simulated canals over extracted teeth are that they allow for standardisation of location, degree and radius of root canal curvature in three dimensions as well as for the hardness and the width of the root canals. Techniques using superimposition of post- on pre- instrumentation root canal outlines can easily be applied to these models and in this way facilitate measurement of deviations at any point of the root canals using computer-based software measurement or subtraction radiography. Simulated canals have been widely used to investigate instrumentation techniques and the shaping ability of endodontic instruments (Ding-ming et al., 2007; Berutti et al., 2009; Ounsi et al., 2010; Burroughs et al., 2012). Some authors have suggested that the results of studies using simulated canals may be transferred to human teeth (Lim and Webber, 1985; Ahmad, 1989).

Endo-training blocks with S-shaped simulated canals were used in the present study because of the inherent difficulty in shaping a canal with more than one curvature along its length without aberrations being caused (Allen, Glickman and Griggs, 2007; Berutti et al., 2009; Bonaccorso et al., 2009; Ajuz et al., 2013). This model also serves to highlight differences in the performance of instruments (Yoshimine, Ono and Akimine, 2005; Ding-ming et al., 2007; Burroughs et al., 2012).

The analysis of modifications to canal curvature post-instrumentation has been widely used to evaluate the tendency of a technique, the mechanical properties of an instrument, and the ability to maintain the original canal anatomy or to straighten the curves (Merret, Briant and Dummer, 2006; Berutti et al., 2009).

K-files were used as the control group in the present study because they have been recommended for initial negotiation of the root canal (Mounce, 2005). Several studies have compared NiTi files to stainless steel K-files for glide path preparation (Berutti et al., 2009; Pasqualini et al., 2012a; Alves et al., 2012; Ajuz et al., 2013). To date, no study has compared these methods to stainless steel hand files used in a reciprocating hand piece for glide path preparation, which has been suggested by some authors (Mounce, 2008; Kinsey and Mounce, 2008; Sleiman, 2011).

Most of the previous studies on equi-angular reciprocation have investigated and compared complete shaping of the canals in extracted teeth or simulated canals (Lloyd et al., 1997; Kosa, Marshall and Baumgartner, 1999; Hartman et al., 2007; Lopez et al., 2008; Rhodes et al., 2011; Çeyhanli et al., 2013). Lloyd et al. (1997) found that Safety Hedstrom files used in a M4 reciprocating hand piece created an hour-glass shape in simulated canals with increased curvature (40 degrees) and found ledges in 16 out of 40 samples. Kosa, Marshall and Baumgartner (1999) found no difference in canal transportation when they compared root canal preparation of extracted teeth using rotary NiTi files and NiTi shaping Hedstrom files in the M4 reciprocating hand piece. Hartmann et al. (2007) compared canal transportation between stainless steel K-files by hand, stainless steel K-files in a NSK reciprocating hand piece (TEP E-16R with 90 degree angle of reciprocation)(NSK, Nakanishi, Japan) and the ProTaper NiTi rotary system. The same authors found that the reciprocation method produced more transportation in extracted teeth while the stainless steel K-files by hand produced the least canal transportation.

In the present study the stainless steel K-files in the M4 safety reciprocating hand piece performed better in maintaining the canal curvature compared to their use by hand only. However, the NiTi rotary systems that were used for glide path preparation performed significantly better than both these groups. The improved performance of the stainless steel K-files in the reciprocating hand piece could be attributed to the smaller arc of reciprocation of the hand piece (30 degrees) compared to the quarter turn-and-pull motion employed during hand filing (90 degrees).

The findings of the present study were in agreement with previous studies that showed that NiTi glide path instruments caused less modification to canal curvature when compared to stainless steel hand instruments (Berutti et al., 2009; Pasqualini et al., 2012a, Ajuz et al., 2013). Since the flexibility of an endodontic file may influence its ability to shape curved canals (Lopes et al., 2013) the difference in curvature modification is probably due to the higher flexibility of NiTi files compared to stainless steel files. Camps and Pertot (1994) found that the bending moment of K-Flexofiles (Dentsply/Maillefer) was less than half of K-files (Kerr Company, Romulus, MI, USA) of the same size.

There is a difference in cutting efficiency of different files used in equi-angled reciprocation (Wan et al., 2010). Further research is needed with hand files that have greater flexibility for glide path preparation - especially in the M4 Safety reciprocating hand piece which could create less modification to canal curvature. In contrast, Alves et al. (2012) found no difference between stainless steel K-files and NiTi rotary files (PathFiles and the Mtwo 10.04, 15.05 and 20.06 files) in their study. This difference could be attributed to the difference in experimental models. Alves et al. (2012) used extracted teeth while resin blocks were used in the present study.

Two rotary NiTi glide path systems were tested in the present study. No study has been carried out on the performance of the X-Plorer file system. The design of the two file systems differs, in that the PathFiles have a tip angle of 50 degrees while the X-Plorer files have a tip angle of 70 degrees. The PathFiles all have a 2% taper and flutes up to D16 with ISO tip sizes of 13, 16 and 19 which represents a 33% increase in tip diameter from a size 10 K-file then 23% and 18.7% consecutively along the system. The X-Plorer files have cutting blades only up to D10, which decreases the lateral engagement of the files. The initial file in the X-Plorer file system has an ISO tip diameter of 15 and a 1% taper. The second file has an ISO tip diameter of 20 and 1% taper and the third file has an ISO tip diameter of 20 and a 2% taper. The increase in tip size from a size 10 K-file is 50% when using the first X-Plorer file, but the file only begins to fully engage the canal walls in the last 2mm as a result of the 1% taper and 10mm blade length. There is a 33% tip size increase with the second file but the taper remains the same (1%). The third file has a 2% taper but there is no increase in tip size, which results in a widening of the glide path with less engagement of the file tip.

No significant differences between the PathFiles and X-Plorer file system were observed with regard to the parameters tested in the present study, even though their design characteristics are different. Ajuz et al. (2013) compared PathFiles to Scout RaCe files for canal deviation during glide path preparation in simulated S-shaped canals. They found that the Scout RaCe files performed better than the PathFiles. These authors proposed that the contrast in performance was due to differences in flute design and the tip transition angle between the files.

With respect to aberrations, three ledges, two elbows and one zip of the apex were observed when the glide paths were completely prepared with stainless steel K-files by hand. Only two ledges were observed in the specimens where the glide path was prepared with hand K-files in the M4 safety reciprocating hand piece. No aberrations were noted when the glide paths were prepared by means of rotary NiTi glide path systems.

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 hand piece were located between the coronal and apical curves. This difference in position of ledges could be due to keeping the M4 safety hand piece 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. In contrast, with hand instrumentation there is a better tactile sense of the first curve, but beyond the first curve and as the tapered file progresses around the second curve, there is considerable lateral engagement of the instrument along the canal walls. This increased lateral engagement of the file reduces the tactile sense of the file tip which is a possible the reason that the ledges occurred closer to the foramen in this group and also the zipping of the apex and elbow formation as the file was withdrawn in the pulling motion. The increased lateral engagement of a constant tapered file as it progresses down a canal, lends credibility to the variable taper design of hand files such as Profinders (Dentsply/Maillefer) and C+ files (Dentsply/Maillefer) where the taper decreases from D4 towards the file handle. The decreased taper reduces lateral engagement of the file as it progresses down the canal and provides better tactile feedback from the file tip.

There were no statistically significant differences for aberrations between specimens in the M4 reciprocation group and all the other groups. However, the number of aberrations caused with stainless steel K-files by hand was statistically significant compared to the NiTi rotary groups. There is a difference between statistical and clinical significance (Barnett and Mathisen, 1997). While some procedures may differ statistically the difference may not have clinical relevance and vice versa. Procedures are evaluated to determine if they provide statistically significant results and clinically relevant benefits. If both are established, then the modality should be considered for implementation into treatment protocols (Ounsi et al., 2010). The findings of the present study were similar to those of Berutti et al. (2009) who found more aberrations when glide paths were prepared with stainless steel K-files only compared to PathFiles in simulated canals. However, Alves et al. (2012) found no aberrations in their study using extracted teeth when glide paths were prepared with stainless steel K-files by hand or NiTi rotary instruments (PathFiles and Mtwo 10.04, 15.05 and 20.06 files).

Our findings are in agreement with those of other authors (Berutti et al., 2009; Lopes et al., 2012; Ajuz et al., 2013) who have suggested the use of small stainless steel files followed by NiTi glide path preparation instruments. In this way the mechanical properties of both these alloys are utilised for safer subsequent root canal shaping.

CHAPTER 6: CONCLUSIONS

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

1. Rotary NiTi glide path preparation files (PathFiles and X-Plorer files) were statistically significantly better at maintaining the original canal curvature than the two methods using stainless steel K-files (P<0.001).

2. There were no statistically significant differences between the PathFiles and the X-Plorer files regarding maintenance of original canal curvature when these instruments were used for glide path preparation (P< 0.001).

3. Canals in which the glide paths were prepared with PathFiles and X-Plorer files exhibited no aberrations.

4. Stainless steel K-files in the M4 Safety reciprocating hand piece were better at maintaining the original canal curvature compared to stainless steel K-files used manually. However, this difference was not statistically significant (P<0.001) but may be regarded as clinically relevant.

5. There were more aberrations when glide paths were prepared with stainless steel K-files by hand compared to hand K-files in the M4 Safety reciprocating hand piece. However, this difference was not statistically significant (P=0.254) but this difference may be regarded as clinically relevant.

6. There were no statistically significant differences between the amount of aberrations when glide paths were prepared with hand K-files in the M4 Safety reciprocating hand piece compared to PathFiles and X-Plorer files (P=0.326).

The null hypothesis is therefore rejected.

Caution should be exercised when extrapolating *in vitro* findings to the clinical situation. Comparisons of the different methods of glide path preparation should be evaluated in extracted teeth or *in vivo* studies.

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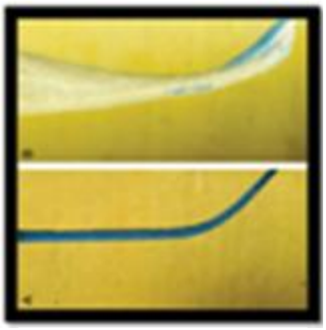
ADDENDUM A


LEDGE


ELBOW

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