Comparison of Time taken and Breakage of six different Endodontic Systems to prepare Molar Teeth

by

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A thesis submitted in partial fulfilment of the requirements for the degree of Magister Scientae Dentium in the Department of Restorative Dentistry, University of the Western Cape

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Keywords

HERO Shaper®

HERO Apical®

ENDOFLARE®

HERO System

K^3™ ®

PROTAPER®

AET™

FlexMaster®

PROFILE®

Rake angle

Helical angle

Tip design

Taper

Radial land

Abstract

Comparison of time taken and breakage of six different endodontic systems to prepare molar teeth.

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The purpose of this study was to determine duration time, breakage and apical displacement, whilst using six different endodontic filing systems to prepare molar teeth. A total of 96 molar teeth were used in the study, divided equally, ie 16 teeth per system selected randomly, totalling 48 canals per system. A standardised access cavity was prepared for all the teeth before selection.

The canals were filed according to the manufacturers' guidelines. The result showed that ***PROTAPER®***, ***K***^{3}**™** and the combination of: **HERO Shaper®**, **HERO Apical®** and **Endoflare®** (Referred from hereon as **HERO System** for convenience) were statistically faster than ***PROFILE***® and ***FlexMaster***®, which were in turn faster than ***AET***™. Although breakage did occur in ***K***^{3}**™** and **HERO System** this was not deemed statistically significant. Apical displacement occurred in the form of Type 1 in the ***AET***™, ***PROFILE***® and **HERO System**, but once again this was not statistically significant.

It was concluded that more aggressive cutting features such as a positive rake angle, pyramidal shaped tip, progressive taper and absence of radial lands, if present, could have enabled ***K***^{3}**™**, **HERO System** and ***PROTAPER***® to have faster times, and in addition these features did not compromise these systems with regard to apical foramina transportation and breakage.

March 2006

Declaration

I declare that "Comparison of time taken and breakage of six different endodontic systems to prepare molar teeth" is my own work, that it has not been submitted for any degree or examination at any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Roger Brittain **March 2006**

Signed:

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Chapter One

Introduction

Speed of treatment is important to dentists. Faster treatment can be equated to increased profits and decreased stress to the operator and patient. However, compromise in quality cannot be accepted for the sake of speed. With this in mind, it would be worthwhile to compare different endodontic systems, to investigate which system(s) is fastest in completing its assigned task (ie a properly shaped and cleaned canal ready for obturation). As a gauge in quality, breakage and apical canal transportation are included in this study. These topics are important because they can provide guidelines for dentists, when they choose the endodontic system(s) that they want to use in their practices. Studying the relevant literature, very little information was found regarding comparative time of completion using the different systems. However, it soon became apparent that each system exhibited different features, eg ***K***^{3}**™** Endo (radial lands with relief), ***PROFILE***® (radial lands) and ***PROTAPER***® (no radial lands), (Ankrum, Hartwell & Truitt, 2004). It is therefore necessary to investigate what roles these different features would play, to explain the results. Experimentation was used to determine which system would be the fastest. A logical hypothesis is that for a system to be superior in its cutting time it needs to have more aggressive cutting features (eg positive rake angles and cutting tips). However, this may result in more breakage and apical transportation. As to be expected, breakages and apical transportation will lead to higher cost, longer treatment times and lowering of treatment quality.

The main research questions the thesis hopes to answer, therefore, are:
Which system is the fastest?
Why is it faster than other systems?

Do factors that make it faster, also make it more likely to break or cause apical foramen transportation? This will also answer the stated hypothesis question.

Six different endodontic systems (**HERO System, *K3™***, ***PROTAPER®***, ***AET™***, ***PROFILE®*** and ***FlexMaster®***) will be compared, with regard to time, breakage and apical foramen transportation. Each system will be randomly assigned sixteen molar teeth (ie 48 canals), which will be shaped and cleaned, ready for obturation, according to the manufacturer's guidelines. The filing time, breakage and apical transportation will be noted and analysed.

Initially there will be a brief overview of pulpal anatomy. This is important, as it will shed some light on the complexity of the root canal system. Properties of nickel-titanium files, factors influencing transportation, time and breakage will then be explored. The research design, methodology and the results will be discussed prior to the conclusion.

1.1 Literature Review

1.1.1 Preamble

Although pulpal biology is included, it does not form the main emphasis of this thesis. In an attempt to make the review as relevant as possible, the main thrust of the work surrounds the key principles of the questions posed, namely the features of nickel-titanium files in different systems and how they may influence transportation, time and breakage.

Factors such as lubricants, irrigation and access cavities may also influence time taken, transportation and breakage.

1.1.2 Pulpal Biology and Dentine

A clear understanding of pulpal biology is important for successful root canal therapy. The main purpose of root canal therapy is to achieve a smooth, uninfected canal, which is shaped in such a way, that it can be obturated effectively (Bertrand, Lupi-Pégurier, Medioni, *et al*, 2001; Ponti, McDonald, Kuttler, *et al*, 2002; Fife, Gambarini, Britto, *et al*, 2004). This in turn will prevent re-infection and facilitate complete restoration (functional and aesthetic) of the tooth. Jansen van Rensburg (2001), describes the pulp as a neurovascular organ within a pulp chamber (coronal pulp) and a root canal (radicular pulp). Furthermore the root canal runs from the pulp chamber to communicate with the periodontal tissues, through an apical foramen. The root canals of teeth may be extremely complex, showing features such as accessory canals, lateral canals and apical deltas.

It is important to know what exactly dentine is, since this is the substance which surrounds the pulp chamber. Therefore, dentine is the substance that endodontic files cut in order to reach our treatment objectives. Dentine consists of mineralised tissue (chiefly hydroxyapite $Ca_{10}(PO_4)_6(OH)_2$). Extending through this mineralised tissue, are the odontoblastic tubules, which may be up to 61000 – 68000/mm^2 (Ankrum, Hartwell & Truitt, 2004). Dentine is composed of 70% inorganic material, 18% organic and 12% water. It is the second most mineralised substance in the body. Dentine may further be classified by subdividing it into primary dentine and secondary dentine. Although it is difficult to establish when exactly or why secondary dentine is formed, Jansen van Rensburg (1986) suggested in his article that the first dentine formed be referred to as primary dentine and any subsequent dentine formed, when or due to whatever reason, be referred to as secondary dentine. This is important as excessive deposits of secondary dentine may alter the original anatomy of the pulp and complicate treatment, ie narrower, calcified canals may be more difficult to root treat. Generally dentine is deposited throughout life and it may be noted that root canal treatment in older patients is more difficult.

1.1.3 Properties of Nickel-Titanium Root Canal Files

The definitions of the various terms used in association with NiTi files will be given below.

1.1.3.1 Rake Angle

This is the angle formed by the cutting edge and a cross section taken perpendicular to the long axis of the instrument. A rake angle is positive when the blade is in front of the perpendicular. A rake angle is negative when the blade is behind the perpendicular (Koch & Brave, 2003). A file with a positive rake angle will actively engage dentine. A file with a negative rake angle will not actively engage dentine, it removes dentine with a scraping action. Schäfer & Lau (1999) found that instruments with positive rake angles (eg **Flexoreamer®**) had a greater cutting efficiency than those with negative rake angles (***PROFILE®*)**.

1.1.3.2 Helical Angle

The helical angle is the angle that the cutting edge makes with the long axis of the file (Koch & Brave, 2003 and Schäfer & Lau, 1999). Some files have a constant helical angle along their entire length, whilst others have a variable helical angle.

1.1.3.3 Instrument Tip Design

Instrument tip design differs between the available files. There are files with a cutting tip (which actively engage dentine) and files with a non-cutting tip (rounded, do not actively engage dentine) (Koch & Brave, 2003). Schäfer & Lau (1999) support this statement and in addition found that non-active tips removed less material, caused less transportation and penetrated resin blocks less effectively.

1.1.3.4 Instrument Taper and Size

The cross-sectioned diameter at the first rake angle of any file is termed D_0, one millimeter coronal to D_0 is termed D_1, two millimeters coronal is called D_2 and so on. ISO files have a standard taper of 0.32mm over 16mm of cutting blades, therefore the taper is 0.02mm per millimeter (Cohen and Burns, 2002). Therefore, simply put, taper indicates the incremental enlargement of an instrument throughout its length. An enduring problem with ISO files is that the D_0 of no 10 and no 15 files shows an increase of 0.05mm (ie ISO no 15 shows a 50% difference in size compared to ISO no 10). ***PROFILE***® shows a constant percentage increment of 29% between different file sizes to overcome this problem of size differentiation between files (Shilder, 1993).

1.1.3.5 Radial Land

The radial land is the surface that projects axially from the central axis, between flutes as far as the cutting edge (Koch & Brave, 2003). Glickman (1997), describes the ***PROFILE***® (6% taper) as having flat radial lands using an electron micrograph as an example.

In endodontic treatments the risk with traditional stainless steel or carbon files, is plastic deformation and fracture. Other problems include over-instrumentation and hand fatigue. Nickel titanium (NiTi) instruments were introduced to address these problems. They possess pseudo-elastic properties (shape memory effect and super

elasticity). Unfortunately cyclic deformation during endodontic treatment changes the mechanical behaviour of NiTi alloys and finally leads to fatigue failure.
The super elasticity (SE) nature of NiTi has been attributed to a reversible austenite to martensite transformation. It is believed austenite is transformed to martensite during loading and reverts back to austenite when unloaded. The transformation is reversible during clinical use, because SE alloys have a transition temperature range (TTR) lower than mouth temperature.

The TTR of NiTi is affected by the chemical composition, method of fabrication, and heat treatment of the alloy. Sometimes the direct transformation from austenite to martensite NiTi includes an intermediate structure, called R-phase. It is important to have knowledge of relationships between austenite, R-phase and martensite transformation sequences on cooling and heating.

On cooling, we can observe: austenite - R-phase - martensite (direct transformation) and on heating: martensite - R-phase - austenite (reverse transformation).

However, due to the large differences between the hysteresis of the martensite and the R-phase transformation, in some cases, the transformation sequence on heating is martensite – austenite directly. The transformation A- R-phase shows the same properties (super elasticity and shape memory effect) because of the quasi-martensitic nature of this transformation. Young's Modulus of the R-phase is lower than that of martensite, and thus an instrument with the R-phase transformation would be more flexible (Koch & Brave, 2003).

In a study done by Kuhn & Jorden (2002), it was found that the R-phase may be missing in temperatures above 600ºC (thereafter decreasing flexibility). They also found that fracture/failure was more likely as stress increases.

Furthermore it was found that martensite transformation propagated in steel retarded crack growth, and it was proposed that this could result from internal compressive stresses induced by a positive volume change near the crack tip. However, in NiTi the volume change is small and negative and thus causes a negligible effect of stress induced martensite near a growing crack.

Some suggestions could be proposed to improve the lifespan of endodontic files, including:

i) Applying thermal treatments at approximately 400ºC (recovery) before machining to decrease the work hardening of the alloy;

ii) Choosing machining conditions adapted to this NiTi shape memory alloy, and electro polishing by the manufacturer to reduce the machining damage on the file surface;

iii) For an optimisation of the fatigue resistance in the specific range of reversible deformation, it is necessary to pay attention to the shape of the canal. Only a few cycles of use for very curved canals may be prudent, whilst following the manufacturers' advice for straight canals (Kuhn & Jordan, 2002);

iv) Enhance surface hardness by Boron implantation (Lee, Park, Saxena, *et al,* 1996).

Blum, Machtou, Ruddle, *et al* (2003), suggested that failure increased with increased torque, which is directly related to the increasing contact between the blades of the instrument and dentine as the file penetrates deeper into the canal. The term "working surface" contains the notion of both cutting and rubbing surfaces. They further recommended that mechanized files should be used only in canals that have been pre-negotiated with K-files, and in a brushing or stroking action engaging only one side of the canal. This should decrease the dangers of excessive torque development and dangerous taper-lock or screw-in effect, resulting in file failure.

1.1.3.6 Effect of Heat Sterilization on the Torsional Properties of Rotary Nickel-Titanium Endodontic Files

It is an obvious concern to practitioners whether sterilization causes any adverse affect, to the clinical performance of NiTi, ie does it weaken or strengthen it or have little effect.

In a study by Silvaggio & Hicks (1997), it was concluded that although sterilization did increase strength in some cases (14%) it does not guarantee a stronger rotary file. Conversely weakening was not considered a problem if files were used up to 10 times, but this does not mean that the files can be used safely up to 10 times.

1.1.3.7 Cyclic Fatigue

Metal fatigue (cyclic fatigue) leading to fracture and separation can occur below the elastic limit (bending limit) of the instrument (without permanent deformation) through known mechanisms called slip bands (microscopic fractures). Such fatigue mechanisms occur microscopically and are not visible to the eye. Cyclic fatigue is caused by repeated tensile-compressive stress. Rotation subjects an endodontic instrument to both tensile and compressive stress in the area of the curve. Instruments placed in curved canals deform, creating stress within the instrument. Half of the instrument shaft on the outside of the curve is in tension, (stretched outwards) and the half of the instrument shaft on the inside of the curve is in compression (pushed inwards). Each rotation within a curved canal causes an instrument to undergo one complete tension-compression stress cycle. This is the most destructive form of cyclic loading (Pruett, Clement & Carnes, 1997).

Considering the time taken for root canal instrumentation, it is obvious that great care should be taken to always operate with the most efficient instruments for the task to be undertaken. Kazeni, Stenman & Spangberg (1995), demonstrated that all files (in their study) rapidly deteriorated when machining dentine. They concluded that the decline in efficiency was significant but different within, as well as among, brands. It was suggested that endodontic files be disposable. Certainly single use may be more satisfactory, however, cost and convenience may prohibit single use.

Svec & Powers (2002), investigated the deterioration of rotary nickel-titanium files under controlled conditions. They examined rotary nickel-titanium files before and after each use while closely controlling the parameters of use. It was found that all the instruments used in their study, showed signs of deterioration after one use.

Distortion was accompanied by cracking of the metal (visible distortion), pitting or flaking (surface fatigue wear). Even small amounts of material lost, due to use, could make the instrument work-hardened and thus more prone to fracture. However, when measured in a torsiometer, it was found that this was not true. Therefore they concluded that instruments (NiTi) could be used multiple times without fear of fracture, unless there was a visible distortion of the instrument (Svec & Power, 2002).

In a more extensive study by Al-Fouzan (2003), it was found that cyclic fatigue does make an instrument more likely to fracture, ie instruments used for the second time are more likely to fracture than instruments used for the first time.

1.1.4 Transportation and Canal Centering Abilities of NiTi Files

Transportation is a term used in endodontics, to describe the filing away or deviation from the natural shape of the original root canal anatomy, resulting in ledging or zipping (Weine, Kelly & Leo, 1975).

Apical transportation may be broadly divided into:

Type I: Minor movement of the physiological foramen to a new position. Treatment is usually to gauge and tune canal.

Type II: Moderate movement of the physiological foramen to a new position. Treatment is usually to provide a barrier (eg M.T.A.) against which obturation can occur.

Type III: Severe movement of the physiological foramen to a new position. Treatment is extraction or corrective surgery (Cohen & Burns, 2002).

With this in mind, it will be useful to consider the different features which may cause (or prevent) transportation of root canals by endodontic files and the following proposals could be considered:

i) The geometry of the tip

A safe non-cutting tip or rounded tip is less likely to create ledges or transport the apical portion of the tooth. The idea behind this is that a rounded tip is more likely to follow the guide path set out before it, whereas sharp cutting tips will be more likely to actively engage dentine and create it's 'own' guide path (perforation) or transportation (deviations).

ii) Radial lands

Generous radial lands are thought to keep the files centred and the flat 'guiding' surface prevents excessive cutting (screwing in effect). Conversely files without radial lands may result in overactive engagement of dentine, resulting in transportation.

iii) Rake angle

Similarly negative rake angles may reduce the screwing in effect, versus positive rake angles which are more aggressive in their filing, which may predispose them to causing transportation.

iv) Instrument taper

Constant taper may make the file more flexible overall but less flexible at their tips. Therefore variably tapered files are possibly less likely to cause apical transportation, but more likely to cause middle to coronal third transportation.

v) Helical angle

Variable helical angled files are more efficient in removing debris. These files are therefore less likely to become 'clogged' or blocked, and in turn less likely to cause transportation. Maybe because of this feature (more efficient debris removal) canal patency is better, therefore the guide path is maintained.

vi) Canal anatomy

Due to the mechanical properties of NiTi files (tendency to straighten) it is proposed that: the more curved the canal is and the smaller its radius of curvature, the more likely transportation will occur.

Therefore, with these points set out, it may be investigated whether transportation is likely or not. Kosa, Marshall & Baumgartner (1999), investigated canal transportation in moderately curved canals using filing systems which displayed different geometric features. One system used had a U-shape cross-section (generous radial lands), non-cutting safety tip, a negative rake angle and consistent helical angle (flutes). Another system used had wide radial lands, cutting tip, positive rake angle and variable helical angle (progressive flutes).

It was found that there occurred statistically more transportation in the apical portion of the system with a 'cutting' tip. Considering that no transportation occurred further up the canal, (middle third, coronal third), a cutting tip may predispose a file to apical transportation.

An interesting finding in this study was that the direction of canal transportation was not predictable. It was expected that transportation towards the inner curvature would occur in the middle segment and the outer curvature in the apical segment. This was not found to occur. Transportation to the inner or outer curvature could not be predicted regardless of level or instrument system. This indicates that canal transportation may involve factors other than canal curvature.

This finding is supported by Luiten, Morgan, Baumgartner, *et al* (1995), who found that greater curvature did not result in an increase in transportation when compared with teeth instrumented with smaller curvatures. This contradicts the opinion (of the researcher, RB) that greater curvature will result in greater transportation. Kosa, Marshall & Baumgartner (1999), concluded that the role of flute design and taper in transportation remained unclear.

Iqbal, Fimi, Tulcan, *et al*, (2004), compared the apical transportation between two geometrically different models. One system (***PROFILE®***) used, had a u-shape cross-section (generous radial lands), non-cutting safety tip, a negative rake angle, a constant helical angle and constant taper. Another system (***PROTAPER®***) had a convex cross-section (no radial lands), partially active tip, a variable helical angle and a variable taper. They found that statistically, no differences were observed except at the D_4 level (4mm from the tip), where the ***PROFILE®*** performed worse. However, the degree of transportation exhibited by ***PROTAPER®*** was generally less. This supports the proposal investigated in this thesis that variable taper will result in less transportation, but contradicts the proposal that radial lands will reduce canal transportation.

Iqbal, Fimi, Tulcan, *et al* (2004), suggest that variable taper may dampen the screw-in effect of rotary instruments. This may explain why the effect of positive rake angle may be negated in this design.

Weigner, Bruickner, El Ayontia *et al* (2003), investigated canal transportation in extracted molar teeth. One system used, had a convex triangular cross-section, flattened non-cutting tips, no radial lands, variable taper in sequence (***FlexMaster®***) and negative cutting angle. The second system had a perfectly rounded cross-section, no taper (shaft smaller than tip), a non-cutting tip, but all the cutting is done near the tip. (***Lightspeed®***). They found that the two systems were comparable but the ***FlexMaster®*** was statistically more predisposed to apical transportation.

Hülsmann, Gressman & Schäfers (2003), compared two similar systems namely ***FlexMaster®*** and ***HERO 642®***, both have non-cutting tips. The main difference between the two systems is the number and sequence of instruments. They found no statistical differences with regard to maintaining canal anatomy (transportation) between the two systems.

This leads to the hypothesis that probably the most important feature in canal transportation, is the flexibility of the file, ie the more flexible the file is the less likely transportation will occur (Lim & Webber 1985). This is further complicated by Ponti, McDonald, Kuttler, *et al* (2002), that indicate that no statistical differences in canal-centering abilities could be found between ***PROTAPER®*** (partial active tip, negative rake angle and progressive taper) and ***ProFile®*** (inactive tip, negative rake angle and constant taper).

1.1.5 Factors Influencing Time taken to File the Root Canal

In this section we want to explore the factors that enable an endodontic filing system to reach its objectives, namely a tapered canal form with adequate deep shape to allow three-dimensional obturation (Schilder & Yee, 1984), the removal of debris and maintenance of the original canal curvature during enlargement (Schäfer & Lohmanns, 2002a & b), or to debride the pulp cavity completely of all debris and enlarge the root canal system for easy and fast obturation (Luiten, Morgan, Baumgartner, *et al*,1995).

Therefore manufacturers of filing systems have to design instruments which, when used in the correct fashion, can meet these above-mentioned objectives. Naturally, if the system cannot achieve these objectives, it will be considered a failure. So, within these constrictions, a secondary objective (time taken) becomes important. A decreased time will reduce operator fatigue (Iqbal, Fimi, Tulcan, *et al,* 2004), increase patient comfort and increase profitability.

One of the principle actions of instrumentation of root canals during endodontic treatment is the removal of dentine (Stenman & Spånberg, 1990). Factors that affect the ability of files to remove dentine and therefore time to reach objectives are:

i) Rotational speed

Most dentists have observed that the faster a bur rotates, the quicker dentine is removed. Therefore to decrease treatment time, rotational speed needs to be increased. Karagöz-Kücükay, Ersev, Engin-Akoca, *et al* (2003), reported no influence on canal curvature, working length or fracture when comparing **HERO 642®**, NiTi used at 300 versus 400 or 600 rpm. However, Gabel, Hoen, Steinman, *et al* (1999), reported that file distortion and/or separation is four times more likely to occur at 333 rpm versus 166.67 rpm. Therefore, procedural errors are more likely to occur at higher speeds. Even though transportation is not likely at a higher speed (Karagöz-Kücükay, Ersev, Engin-Akoca, *et al*, 2003), this (600 rpm) is still a relatively low speed and if say 2000 rpm was used, separation and transportation would possibly be more likely. Therefore, it would be fair to say that an increase of rotational speed would decrease working time but that this would be 'capped' by the mechanical limitations of the files used.

ii) Tip design and canal size

Tip design is possibly the most important factor when evaluating the cutting efficiency (the volume of hard tissue removed per unit of energy) (Miserendino, Moser, Heuer, *et al,* 1986), of instruments.

It may be hypothesized that certain characteristics of the tip of an endodontic file determine its cutting ability (cutting efficiency). It may be suggested that as the tip angle increases so the cutting efficiency will decrease. Furthermore, tips with triangular or square shapes will be more penetrative than those with cone or round geometries. It may also be suggested that files with very long tips may lose their cutting efficiency due to a flattening of their cutting features. In addition larger canals will be 'easier' to file due to the less restrictive nature of their anatomy.

This is partially supported by Miserendino, Moser, Heuer *et al* (1986), who used eighty-four #50 endodontic instruments, representing seven different designs of files and reamers that were compared for their ability to penetrate and enlarge artificial root canals. They found that: interestingly, files with tip angles of 60 – 69 degrees were more efficient than those with tip angles of 40 – 49 degrees in restricted canals, the reverse was found in larger canals. Pyramidal designs outperformed all other geometries. Furthermore, triangular shapes were better than square shapes, which in turn were better than conical shapes in constricted canals (0.33mm diameter). Interestingly, square shapes outperformed all other shapes in larger canals (0.40mm diameter). Importantly they were able to identify that the most important design feature (with regard to cutting efficiency) was the tip geometry, whilst the tip angle had hardly any influence on cutting efficiency of the files. Also of interest was that when they compared the flute and tip regions, it was found that the tip region played a greater role than the fluted region with regard to cutting efficiency.

This leads to the hypothesis that instruments with a pyramid tip with triangular or square cross-section will display a decrease in working time.

iii) Rake angle / sharpness of instruments

The sharper the instrument / file is the more efficient it will be at removing dentine, and therefore a decrease in time taken to reach the objectives. Therefore, it would be logical to make endodontic instruments as sharp as possible. However, this raises the concern of transportation, distortion and breakage.

Ankrum, Hartwell & Truitt (2004), compared three systems, namely ***PROTAPER***® (negative rake angle), ***K³™*** (positive rake angle) and ***ProFile***® (negative rake angle) and found no statistical difference with regard to breakage, but interestingly there was more distortion in the ***ProFile***® group when compared to the ***ProTaper***® group.

With regard to transportation Ayar & Love, (2004), compared ***ProFile***® (negative rake angle) and ***K³™*** Endo NiTi (positive rake angle) and found no significant difference between the two systems. Upon this evidence there is no reason why future endodontic designs will not employ a positive rake angle to improve speed and efficiency.

iv) Taper design of files

The greater the diameter of a file the greater the amount of dentine removed at that point of greater diameter (Usman, Baumgartner & Marshall, 2004). Therefore, to achieve the objectives previously described, (larger coronal shape, removal of debris) a progressive taper will be able to achieve this quicker (because its coronal segments will be larger than the coronal segments of the constant tapered shaft design).

A progressive taper may well be more efficient but it raises the concern of coronal transportation (due to increase diameter coronally), however, on the plus side the file is more flexible towards the middle and apical portions, with possibly less transportation here. In any event, coronal preflaring may offset this event (coronal transportation). This is supported by Bergmans, Van Cleyenbreugel, Wevers, *et al* (2003), who compared ***ProTaper®*** (progressive) versus ***K³™*** (constant tapered) and found that the ***ProTaper®*** instrument was less influenced by the mid-root curvature (increase flexibility) than the ***K³™*** design, however, ***ProTaper®*** tended to transport towards the furcation in the coronal region (decrease flexibility). With regard to smooth shafts versus tapered shafts they both perform adequately (Bergmans, Van Cleyenbreugel, Beullens, *et al,* 2002). But due to only the tip being active (in the smooth shaft design) this would increase the working time. Unfortunately an increase in taper may also result in an increase in torque (on the instrument) especially in narrow canals (Booth, Scheety, Lemons, *et al,* 2003). This may predispose the instrument to fracture.

v) Helical angle and radial lands

A variable helical angle, ie progressively greater angle, may facilitate coronal extrusion of debris. Greater spaces between the cutting edges may also enable the instruments to remove more debris / dentine before becoming 'clogged' up. Radial lands in themselves play no role in cutting dentine but are thought to aid in the canal centering ability of files (Shäfer & Lau, 1999). However, when compared to instruments without radial lands little difference could be found (Garala, Kuttler, Hardigan, *et al,* 2003).

vi) Other factors

a) Canal anatomy will influence time preparation. Straight wide canals require less dentine to be removed to achieve optimal shape than curved narrow canals (Martin, Zelada, Varela, *et al,* 2003).

b) Sequence and number of files. Complicated sequences and many files may take longer than simple sequences and few files.

c) Force applied by operator. The harder the operator pushes the faster the file will cut. But this is not recommended, as dangerous taper-lock will occur if more than light pressure is applied (Schrader, Ackermann & Barbakow, 1999).

d) The access cavity is the most important part to successful root canal therapy. It provides the 'gateway' to the root canals. An intimate knowledge of tooth anatomy is essential to facilitate the correct access cavity preparation.

The principles of Access cavity preparations:

i) The roof of the pulp chamber must be removed so that the pulpal remnants can be removed and the root canal orifices exposed. Then straight-line access to the first curve on the root canal, so that endodontic instruments are not impinged upon by coronal tissues (Levin, 1967).

ii) Damage to the pulpal floor must be avoided. This is achieved by using a safe-ended bur. At the same time, as much tooth substance as possible must be conserved, therefore the clinician must find the balance between proper access and tooth conservation (Cohen & Burns, 2002)

iii) Resistance form must be provided so that the temporary restoration remains intact until the final restoration is placed (Stock, Gulabivala, Walker, *et al*, 1995).

Therefore, to summarize, the access cavity should provide clear vision, not impinge on the operation of the files and preserve as much tooth substance as possible. Therefore a properly prepared access cavity will speed up treatment time, conversely as incorrect access cavity will slow down treatment time.

e) Endodontic Irrigants

Endodontic files in themselves do not clean the root canal, but they do provide the necessary shape so that the irrigant can ‘clean’ the canal and that once proper cleansing has occurred, three-dimensional sealing can be effectively done.

Ideally an irrigant should exhibit the following features: bacteriocidal, facilitate debris removal, non-toxic, dissolve necrotic tissue, eg sodium hypochlorite possesses this property, but is shown to have cytotoxic and irritant effects, whereas chlorhexidine is relatively non-toxic but is not proteolytic or does not dissolve necrotic tissue, but has antibacterial properties. Therefore, when searching for the ideal endodontic irrigant it is important to evaluate the advantages and disadvantages of each irrigant (Siquira, Batista, Fraga, *et al*, 1995). The irrigant must also be inexpensive and not detrimental to the endodontic files. Although sodium hypochlorite does not meet all these criteria it does meet most of them. In addition to this, sodium hypochlorite reduces the microhardness of dentine significantly (Slutzky-Goldberg, Liberman & Heling, 2002). Therefore, using the correct endodontic irrigant will speed up treatment time.

f) Chelating agents

The purpose of a chelator is for lubrication, emulsification and holding debris in suspension. ***RC-Prep®*** is used routinely in endodontic treatment due to its chelating, lubricating and effervescent properties (Heling, Irani, Karni, *et al*, 1999).

RC-Prep® contains:

i) Glycol acts as a lubricant which facilitates easier instrumentation, protects EDTA oxidation by urea peroxide. Glycol in combination with urea peroxide is a superior lubricant aiding flotation of dentinal particles (Rome, Doran & Walker, 1985).

ii) EDTA (ethylenediminetetractic acid) softens dentine and removes the smear layer (Yoshida, Shibata, Shinohara, *et al*, 1995). EDTA in itself is not considered bacteriocidal, however, it may affect bacterial cell membranes making them more susceptible to urea peroxide and sodium hypochlorite (Russel, 1991). Therefore, to summarize, it may be concluded that using a chelating agent such as RC-Prep would speed up treatment time.

1.1.6 Breakage of Instruments

There is a potential risk of rotary nickel-titanium instruments fracturing within the canals. This is obviously of concern, as it may jeopardize the success of the treatment (Martin, Zelada, Varela, *et al*, 2003). Depending where the instrument has fractured it may prevent the objectives of endodontic treatment being completed, namely cleaning, shaping and obturation. A fractured file may be difficult to remove and the structure of the tooth can be compromised whilst trying to remove it.

1.1.6.1 Speed of rotation of the file

Increased rotational speeds augment the rubbing of the file within the canal, and thus these files break more readily than those which are used at lower speeds. This statement is supported by a study done by (Martin, Zelada, Varela, *et al*, 2003). In their study it was found that files, which were used at 150 and 250 rpm, fractured less frequently than those used at 350 rpm.

1.1.6.2 Shape of the canal

Flexural / Cyclic fatigue

The fatigue of an instrument may be related to the degree of flexure that the instrument undergoes when placed in a curved root canal. When the curvature of canals is more pronounced, the cyclical fatigue that the instrument undergoes is greater, and thus its life expectancy is lower. This is supported by Martin, Zelada, Varela, *et al (*2003). In their study all instrument fractures occurred in canals with accentuated angles.

The radius of curvature was not found to be a factor. It was found that the resistance of files differs, depending on whether the canals are relatively straight or slightly curved, or conversely, whether the curvature of the canals is pronounced and acute. In the straight canal, it was possible to file at high speeds of at least 20 times higher without fear of fracture. In pronounced curved canals it was found that files should be used at minimum speed.

Ankrum, Hartwell & Truitt (2004), compared within three file systems the breakage and distortion in severely curved roots of molars. They found that all three systems demonstrated some file distortion. All three systems had at least one file break during instrumentation of these severely curved canals, but there were no significant differences when the three groups are compared statistically. They concluded that great care should be taken when instrumenting severely curved canals. This supports the notion that canal anatomy may predispose files to fracture.

Pruett, Clement & Carnes (1997), investigated the influence of canal radius and angle of canal curvature, on the lifespan of NiTi instruments. They define the radius of curvature (in millimetres) as the radius of a circle that coincides with the path taken by the canal in the area of the most abrupt curvature. A more abrupt curve corresponds to a smaller radius of curvature. The angle of curvature is the degrees of the arc formed between the points of deviation on the circle, or the angle formed between the perpendicular lines drawn from the tangents intersecting at the centre of the circle. The angle of curvature is independent of the radius. Thus two canals with the same degree of curvature can have radically different radii. They found that a decrease in the radius of curvature from 5mm to 2mm radius resulted in a significant decrease in the number of cycles (usage) to failure. They concluded therefore that as the radius of curvature decreases, instrument stress and strain increases and the lifespan of the instruments decreases.

Furthermore, radius curvature with its resultant increased stress on endodontic instruments may be a significant factor clinically contributing to instrument breakage and transportation. The 30-degree angle groups (smaller curvature angle) had significantly more cycles to failure, than the 45-60 degree angle groups (greater curvature angle). In addition to this they found that with a decrease in radius and an increase in angle (most stressed group), the decrease of cycle to fatigue was the most marked. This supports the hypothesis that with an increase in curvature and a decrease in radius, you will have an increase in file failure which is further supported by Best, Watson, Pilliar, *et al* (2004). They found that an increase in deviation angle (curvature) has an increase in likelihood of instrument fracture.

Torsional fractures occur when the apical portion of a rotating instrument is forced into narrow root canals. Friction increases at this point, high torque is required to rotate the instrument and the fragile instrument tip is subjected to excessive torque.

This effect is described as 'taper lock' since it might occur with similarly tapered instruments of varying tip diameters rather than with variably tapered instruments (Peters, Peters, Schönenberger, *et al*, 2003). Furthermore, Peters, Peters, Schönenberger, *et al* (2003), in their study (assessment of torque and force in relation to canal anatomy) found that torque is correlated not only to apically exerted force, but also to preoperative canal volume. Hence, preparation of narrow and constricted canals could subject rotary instruments to higher torsional loads. Under these conditions, the tip may lock, leading to large and rapid increases in torsional stress. The torque developed by the motor may then exceed a critical level, and the instrument immediately undergoes plastic deformation and failure.

1.1.6.3 Flexibility of nickel-titanium instruments

The relationship between stiffness and cross-sectional area of rotary nickel-titanium instruments.

Logically the larger the cross-sectional area of a file, the stiffer it would be. This in itself would suggest that thicker files (greater cross-sectional area) would be more resistant to fracture. However, with a reduced flexibility other complications may incur, namely, the transportation towards the outer aspect of the curvature in the apical region of root canals.

In a study done by Schäfer, Dzepina & Danesh (2003), they found low bend moments (small amount of force required to bend the nickel titanium) in all instruments tested. This is indicative that these files are extremely flexible, which is clinically very desirable. Because of their flexibility, the load on the cutting edges in a curved canal is reduced, which in turn reduces stress on the instrument and the possibility of fracture.

In addition, this superior flexibility reduces the risk of canal transportation during the enlargement of curved canals. However, it has been observed that some rotary nickel-titanium files created slight canal transportation especially in the apical region. This may be attributable to root canal preparation with instruments of greater taper, because these are considerably stiffer than those of 2% or 4% tapers (due to greater cross-sectional areas). Therefore, manufacturers should be aware of the bending properties of the different types of rotary nickel-titanium instruments when recommending an instrumentation sequence for the enlargement of severely curved canals.

Furthermore, Schäfer, Dzepina & Danesh (2003), found a highly significant correlation between stiffness and cross-sectional configuration. Their results indicate that the cross-sectional configuration seems to be the predominant factor affecting the bending properties of rotary nickel-titanium instruments.

1.1.6.4 The shape of the file

Progressive versus constant tapered shaft design using nickel-titanium instruments.

The following argument could be stated:
Constant tapered shaft design will provide a constant taper throughout the length of the file, ie smallest at the tip of the file and largest at the shank end of the file. The advantages theoretically would be a greater cross-sectional area throughout the length of the file. Unfortunately this design predisposes to a greater engagement of the file throughout its length, predisposing to dangerous taper-lock in the apical portion and therefore, fracture. Furthermore, this increased stiffness can result in excessive transportation in the outer curvature of the apical third in curved canals. Conversely, a progressive tapered design will result in less danger to taper-lock in the apical portion, and greater flexibility reducing transportation. This is because greater engagement is more likely to occur further up the file where it is

considerably thicker. The disadvantage of this scenario is that displacement is more likely to occur in the coronal third of the canal as the file will be fairly bulky here, due to progressive increase in taper.

This argument is supported by a study done by Bergmans, Van Cleyenbreugel, Wevers, *et al* (2003). They claimed that the progressive (increasing from tip to coronal) taper sequence of the shaping of files in the ***ProTaper®*** range enhances the flexibility in the middle to apical section, whereas the decreasing taper sequence of the finishing files enhances the strength of the files whilst making them rather stiff. Conversely the ***K3™*** system provided an asymmetrical constant tapered active file design with variable flute angle and variable core diameter, which may allow better debris removal, and a cutting rather than planing action. Their results indicated a centre displacement towards the furcation coronally was most pronounced for the ***ProTaper®*** group, whereas a centre displacement towards the outer side of the curvature more apically was only observed for the ***K3™*** group. The conclusion was that the progressive tapered shaft design of the ***ProTaper®*** instrument was less influenced by the mid-root curvature than the constant tapered design of the ***K3™*** instrument thereby providing a good centred apical preparation. However, ***ProTaper®*** instruments tended to transport toward the furcation in the coronal region (Bergmans, Van Cleyenbreugel, Wevers, *et al,* 2003).

1.1.6.4.1 Cross-section of files

For files to be successful, they must have two essential characteristics, namely, strength and flexibility. So how does the cross-section variables contribute to this? Simply put, the greater the core density of the file is, the stronger it will be, but unfortunately, with an increase in strength, you also have a trade-off, which is a decrease in flexibility. Therefore, if we compared two theoretical cross-sections, convex (eg ***ProTaper®***) and concave (eg ***ProFile®***), the convex model would be stronger and less flexible (given the diameters are equal) than the concave model, because of decreased surface area.

Berutti, Chiandussi, Garglio, *et al* (2003), did an analysis of torsional and bending stresses involving these two models. They found that the distribution of stresses in the model with the ***ProTaper***® cross-section is more regular and uniform. The model with the ***ProFile***® cross-section has marked stress peaks along the flutes and higher maximum stress values. The geometric characteristics of the ***ProFile***® model make it more elastic. This factor is enhanced by the fact that the ***ProFile***® model moves rapidly from the austenitic phase (see materials and characteristics of Nickel-Titanium) to the martensitic phase. The transformation phase is in this case short, and the change from the austenitic phase to the martensitic phase is very swift.

The behaviour of the ***ProTaper***® model is different, because the changeover from the austenitic phase to the martensitic phase is gentle and the transformation is longer. This means that, applied loads being equal, the ***ProTaper***® model works for a longer time in the super-elastic phase (transformation phase), which will give higher performance with less failure. On the contrary, the ***ProFile***® is more elastic but accumulates dangerous stress more rapidly, because the transformation phase is so short, this model (concave) frequently has to operate in the martensitic phase.

The durability of the ***ProTaper***® is supported by Fife, Gambarini, Britto, *et al* (2004). They found that ***ProTaper***® could instrument (12-16) canals without fracture.

1.1.6.4.2 Manual Preflaring and Torque on the failure rate of Rotary Instruments

Manual preflaring is recommended by manufacturers of NiTi rotary instruments. This is logical because it provides a guide path for the rotary instruments, and a decrease in the amount of work required by the rotary instruments.

The guide path is important because many rotary instruments have inactive or partially active tips. Therefore, they are incapable of creating or establishing their own pathway. Preflaring enables them to safely follow the anatomy of the root canal.

Preflaring also enables the file to negotiate the canal walls over a decreased surface area. This will decrease the stress that the file is put under (torsional stress is drastically reduced), because the canal width becomes at least equal to the diameter of the tip of the instrument used, therefore, decreasing the chance of file failure. Berutti, Negro, Lendini, *et al,* (2004), support this in their study where they compared the failure rate of preflared versus non-preflared groups. They found that if canals were preflared, files were up to six times more durable.

1.1.7 Operators' Proficiency and Torque Control Motors

The use of rotary instruments may also be influenced by the experience of the operator. Although manufacturers may set out strict guidelines, from personal experience the more a certain procedure is repeated, the better an operator gets at executing or applying that procedure. Diligence, perseverance and patience are a result of experience.

With experience comes clearer understanding and better results. So therefore, may it be said that rotary instruments in the hands of an experienced operator is less likely to fail, than in the hands of a novice? Well, yes and no is the answer. In newer models of torque control motors, as soon as too much stress is placed on the instrument, the motor sounds a warning (at approximately 75% of the breakage-threshold of the instrument). If any further stress is applied, the motor stops turning and starts rotating in the opposite direction. This would therefore 'protect' the inexperienced operator and increase the speed of the learning curve.

Conversely, with the use of a low torque controlled motor (eg endodontic hand piece attached to an airline), no such 'protection' exists, and here failure of the rotary instruments is more likely with the inexperienced operator. This hypothesis is supported by a study done by Yared, Dagher & Kulkarni (2003). In their study they compared two types of torque control motors: electric high torque control (Group 1) and low torque control (Group 2).

In the second part of the study, three operators with varying experience (coded as follows: experienced endodontist ≡ 1, semi-experienced ≡ 2 and inexperienced ≡ 3) were compared using the low torque control motors. They found that the experienced endodontist (1) could complete filing and shaping using both types of motors without failure.

Conversely, the inexperienced operator (3) fared the worst. The partially trained operator (2) fared better than the inexperienced endodontist (3), but worse than the experienced endodontist (1) when using the low torque controlled motors,

This confirms that experience (learning curve) is a crucial factor in the prevention of file failure. This is further supported by Bortnick, Steinman & Ruskin (2001), who found that no significant differences could be found with regard to file distortion when an experienced operator used an electric or an air-driven hand piece.

If a motor operates at a higher torque it would produce higher torsional stress on the rotary files, predisposing it to greater incidence of failure. This statement however, needs to be quantified. If an extremely high torque is set, the file would engage too actively and increases the risk of failure. Conversely, an extremely low torque would be ineffectual, as the file would be unable to turn or cut effectively. Another complication may be sudden stopping of rotation with low torque settings which may increase predisposition to fracture. Berutti, Negro, Lendini, *et al* (2003), support the notion of using higher torque. In their experiment they found that using higher torque, instruments shaped a significantly higher number of simulations before breaking, compared with groups in which the torque setting was lower. They attributed this to the endodontic motor frequently engaging auto-reverse at low torque, whereas at high torque, auto-reverse was never engaged. This was because anti-clockwise rotation (auto reverse) is engaged when a maximum torque value is reached, and this causes the instrument to perform work. This meant that the instrument builds up stress and hence its lifespan is reduced.

Furthermore they suggest that if low torque is to be used, the operator should be guided by the warning (acoustic sound) produced by the motor, and therefore remove the file before auto-reverse engages, thereby minimizing stress and ensuring instrument lifespan is solely consumed by cutting dentine.

1.1.8 Stainless Steel versus Nickel Titanium

This is of particular interest, because one of the newer systems (***AET***™ or Anatomical Endodontic Technology), employs stainless steel, instead of nickel titanium. With relevance to this study it is hypothesized that:

i) The stainless steel instruments will take longer to reach the required objectives, because all the work done is in an oscillating handpiece which is not as effective as a rotation motion;

ii) Stainless steel instruments are less flexible and therefore more likely to cause transportation. Due to the stiffness of the metal (stainless steel) more material (dentine) is removed which will increase transportation and preparation time;

iii) Stainless steel is less resistant to fracture, but on the plus side distortion is more visible in stainless steel than nickel titanium.

Gambill , Alder & Del Rio (1996), compared nickel titanium (Mity file) with stainless steel files (K-flex) and found that; Ni-Ti instruments used in a reaming technique caused significantly less canal transportation ($p<0.05$), removed significantly less volume of dentine ($p<0.05$), required less instrumentation time ($p<0.05$) and produced more centered and rounder canal preparations than K-flex stainless steel files used in a quarter turn / pull technique.

Furthermore, Walia, Brantley & Gerstein (1988), have shown that NiTi instruments are more flexible and have superior resistance to torsional fracture than stainless steel files. This is contradicted by Schäfer & Schlingermann (2003). They found no fracture in stainless steel ***Flexofiles***® but five fractures in ***K***^{3}™ files.

Davis, Marshall & Baumgartner (2002), supported the hypothesis that transportation is less with nickel-titanium instruments. This is further supported by Gluskin, Brown & Buchanan (2001), and in addition they also found less material removed in less time when using nickel-titanium. Ponti, McDonald, Kuttler, *et al* (2002), compared the canal centering ability of two rotary file systems and found that both nickel-titanium systems remained centered in the canal, with minimum deviation from the original canal path.

Since the ***AET***™ employs hand instrumentation for the apical third preparation this will also slow its instrumentation time. This observation is supported by Glosson, Haller, Dove, *et al* (1995), who found that rotary instrumentation was significantly faster than hand instrumentation.

1.1.9 Overview of Main Points Emerging from Literature Review

i) Canal anatomy

Detailed understanding of root canal anatomy is essential, without which effective root canal therapy is impossible. It is fair to say that the more complex the anatomy, the harder and longer it will take to reach the ideal objective.

ii) Breakage

It is dependent on canal anatomy (curvature and radius), operator's experience, speed of rotation, cross-section (distribution of stresses), cyclic and torsional fatigue.

iii) Speed of instrumentation

Tip design (pyramidal shape) and positive rake angle seem to be salient factors with regard to speed. Little evidence in the literature is provided for the effects of taper and helical angle and the time taken for each system. The aim is to shed some light on this in the experimental phase.

iv) Canal transportation

Increased flexibility seems to be the overriding factor with regard to canal transportation, ie the more flexible a file is, the less transportation will occur. This is logical because more flexible files are more likely to follow the guide path and less likely to straighten, thereby causing transportation.

v) Stainless steel system

It will be interesting to see if the new generation (***AET***™) stainless steel system would be slower, less fracture resistant and produce more canal transportation, when compared to the NiTi systems.

Chapter Two

Research Design and Methodology

2.1 Research Hypothesis

Certain instrument features will enable endodontic systems to cut dentine more efficiently and therefore reduce instrument-working time to reach the objective (root canal shaped to facilitate cleaning and obturation). It was hypothesized that these features are: tips that have pyramidal or square shaped geometry, active tip / partially active tip, progressive taper in individual files, positive rake angle, variable or multiple helical angles, absence of radial lands and simple sequences ie endodontic files that exhibit all these characteristics will be faster than files that have some or none of these features.

With regard to transportation, it was hypothesized that files that exhibit radial lands (keeps file centered in the canal), negative rake angles (cut in a scraping fashion rather than actively cutting), non-active tip (less likely to create its own guide path), progressive taper (more flexible in apical part) and variable helical angles (offsets the clogging of dentine debris) will produce less apical transportation than endodontic files that exhibit only some of these features.

Furthermore, it was hypothesized that endodontic instruments that exhibit an active tip (more likely to have taper-lock), positive rake angle (more cyclic strain placed on instrument), constant taper (more stress placed throughout the length of instrument), radial lands (more stress placed on instrument because of increased contact area) and constant helical angle (clogging of instrument providing more strain and decreasing flexibility) will result in a greater predisposition for the instrument to fracture.

2.2 Research Instruments

Endo IT Professional®

It was decided to use one motor for all endodontic systems compared, because this would eliminate the motor from becoming a factor in the experiment. The ***Endo IT Professional®*** was ideal because it was compatible with all the endodontic systems in the experiment. Although a specific presetting for the ***AET***™ system was not available, this was easily accommodated by selecting the Gates Glidden setting and increasing the speed to the required rpm. In addition this is one of the newer endodontic motors on the South African market and one I (RB) am familiar with. The motor used had the following model number: AELI-25VDW and serial number BW31403-00-75.

2.2.1 The Features of the *Endo IT Professional®* Motor

i) Advanced digital torque control technology with auto stop reverse (ASR) and it contains an integrated calibration system

ii) Extensive file library and the possibility to save user-defined file sequences

iii) Consists of a 30,000 rpm brushless micro motor and is sterilisable (eg in an Autoclave).

2.2.2 Intensity Features of the Endo IT Reaction Time

i) The ***Endo IT Professional***® checks the torque level 225 times a second (4,44ms).

ii) The decision to initiate an ASR (auto stop reverse) is statistically based on 9 consecutive readings (40ms total).

iii) The actual reversal time is affected by motor inertia, hand piece inertia, hand piece gear backlash, motor speed and a host of other possibilities (40ms at 300 rpm is 0.2 degrees travel).

iv) The reaction time of the "chip" is one millionth of a second.

v) Depending on system level used the torque settings vary from 75-90% of the maximum torque.

2.2.3 Endodontic Light Microscope (Zeiss)

Unique Dental provided an endodontic microscope, a Zeiss dental S100 standing model: Opmi Pico (Serial Number 360374). This was important to observe the apical foramen after instrumentation. The microscope optimally illuminated the apices of the teeth so that foramina could be visualized in fine detail. This enabled the degree of transportation to be accurately observed by the two other dentists.

2.3 Endodontic Systems

Selection of systems is motivated by availability, relevancy and popularity. All these systems are freely available in South Africa. These systems all exhibit design features which are relevant to the hypothesis, but each system differs in some way from each other. Some differences are subtle whilst others are radical or opposite. This provides the opportunity to compare them and thereby give pertinent conclusions, ie to single out single features in an endodontic file which explain different results. Because these systems are freely available they must be popular, therefore dentists would be interested in the findings of this study.

2.4 Manufacturers' Specifications and recommendations

2.4.1 System 1 — **HERO System**

i) **ENDOFLARE®** Lot 092302

ii) **HERO Shaper®** Lot 020204

iii) **HERO Apical®** Lot 121803

2.4.1.1 Manufacturer's Specifications

The combination of **ENDOFLARE®**, **HERO Shaper®** and **HERO Apical®** is a rotary NiTi system with 6% taper files (black rubber stop) and 4% taper files (grey rubber stop), further on referred to as **HERO System.**

System Features:

General features of the **HERO System**

On close examination and from manufacturers pamphlets the files exhibit the following features:

i) There is a constant taper throughout the length of the cutting blades.

ii) The cutting blades exhibit a partial radial land, a triple helix cross-section, showing a positive cutting angle, although no radial land relief is present. Furthermore, the cross-section exhibits convex sides with a triangular core.

iii) A variable helical angle is present and this is relative to the taper ie the greater the taper, the greater the pitch becomes.

iv) The tip is inactive and exhibits a triangular shape geometry.

v) The files are made of nickel titanium, have a variable taper in their sequence and have a shank length of approximately 11mm.

vi) The manufacturer recommends operation speeds of between 300 – 600 rpm.

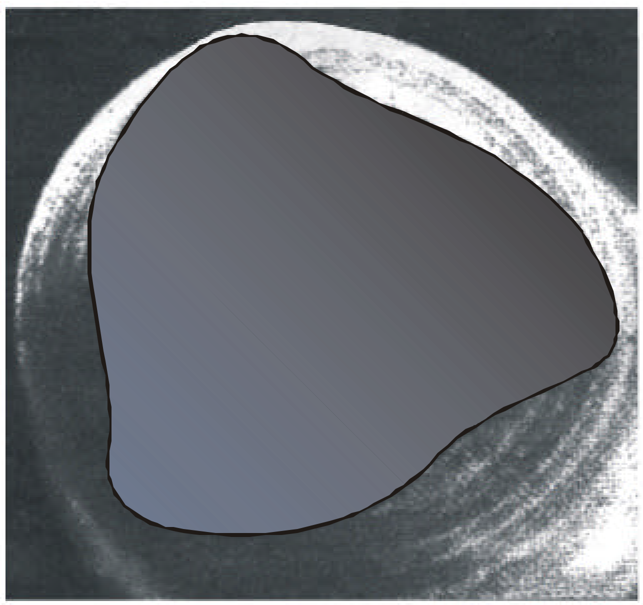

Figure 2.1:
Illustration of the cross section of the **HERO®** endodontic file

Technique sequence:

The **ENDOFLARE®** is used for coronal flaring, ie enlarging the coronal third of the canal. It consists of 15mm blade, 12% taper with a D_0 of 0.25mm.

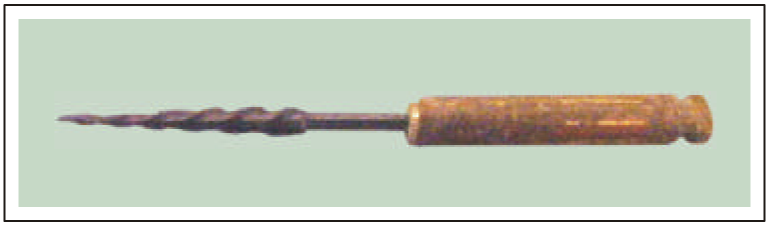

Figure 2.2
Illustration of the **ENDOFLARE®** file

The **HERO Shaper®** is used after the **ENDOFLARE®** (see protocol recommended by manufacturer page 31 of this thesis).

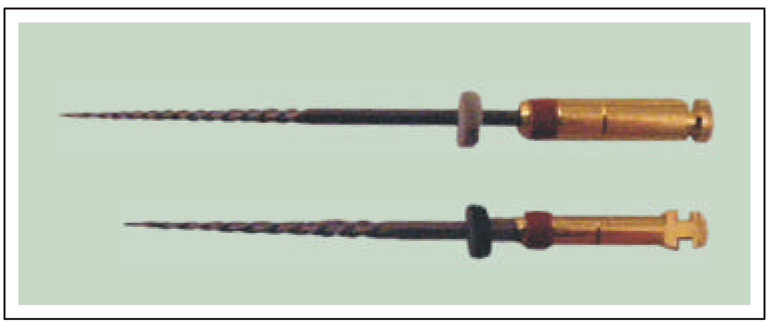

Figure 2.3
Illustration of two of the **HERO Shaper®** files

The **HERO Apical®** is used after the **HERO Shaper®** to provide final tuning and gauging of the apical third of the root canal. Two instruments are offered: 6% taper No 30 **HERO Apical®** black stop and 8% taper no 30 (red stop).

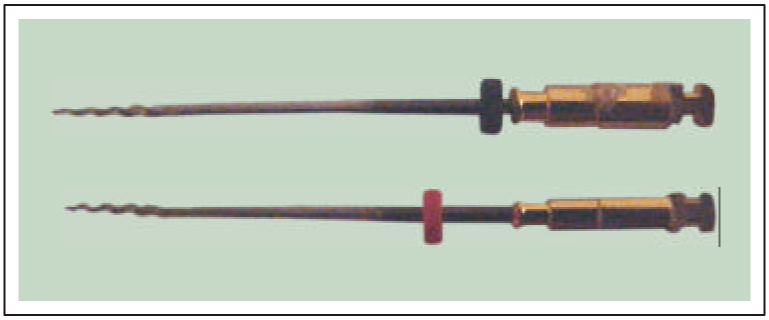

Figure 2.4
Illustration of the **HERO Apical®** files

The protocol may be divided as follows:

1. **Easy Cases** = Blue sequence (2 files)

   Low curvature, orifice and canal space large enough to allow a No 15 K-file to reach apex.

   - No 30 taper 6% (black stop) to 2/3 WL

     Determine WL
   - No 30 taper 4% (grey stop) to WL

2. **Medium Cases** = Red sequence (3 files)

   Canals of average difficulty, making the first penetration with ISO No 10 K-file hard to achieve

   - No 25 taper 6% to 2/3 WL (black stop). Determine WL
   - No 25 taper 4% to WL (grey stop)
   - No 30 taper 4% (grey stop)

3. **Difficult Cases** (Yellow sequence)

   Difficult canals, making first penetration difficult with No 6 K-files.

   - No 20 taper 6% to 2/3 WL. Determine WL
   - No 20 taper 4% to WL
   - No 25 taper 4% to WL
   - No 30 taper 4% to WL

2.4.2 System 2 — *K³*™ – 3rd generation rotary NiTi file

2.4.2.1 Manufacture Specifications

General features of the K³™

On close examination and from manufacturer's pamphlets the files exhibit the following features:

i) There is a constant taper throughout the length of the cutting blades.

ii) The cutting blades exhibit radial lands. The cross-section shows complex blades with a positive rake angle.

iii) A variable helical angle is present and this is relative to the taper ie the greater the taper the greater the helical angle.

iv) The tip is inactive and exhibits a triangular shape geometry.

v) The files are made of nickel-titanium, have a variable taper in their sequence and have a shank length of approximately 11mm.

vi) The manufacturer recommends operation speeds of between 150 – 350 rpm.

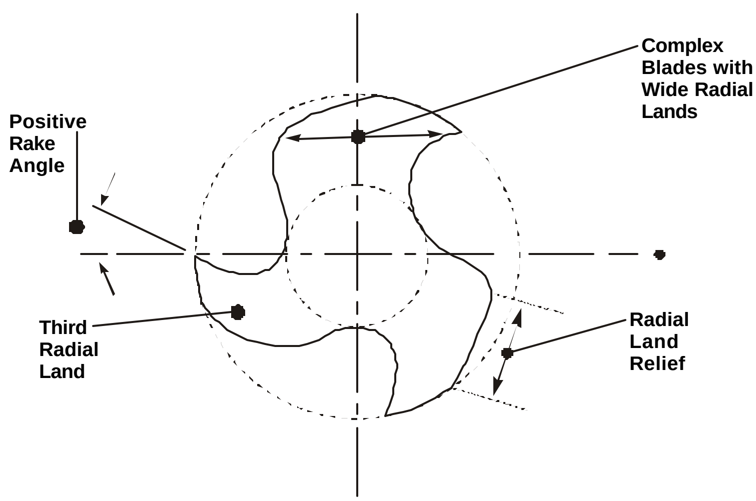

Figure 2.5
Illustration of the cross section of the *K³*™ endodontic file

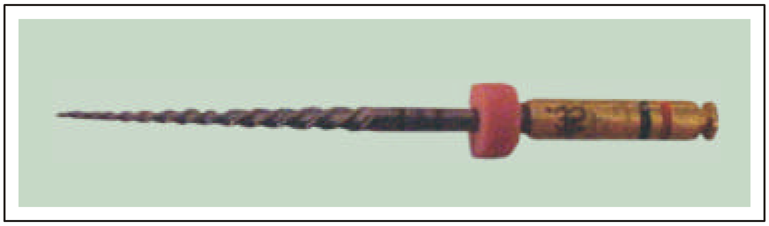

Figure 2.6
Illustration of ***K***[3]**™** endodontic file

File sequence

10%, 0.25mm → 8%, 0.25mm → 6% → 4%

Sequence K[3]**™**

→ Orifice opener 10% taper D_0 25 length 17mm, 10mm cutting blades

→ Orifice opener 8% taper D_0 25 length 17mm, 10mm cutting blades

File sequences in assorted pack:

Orange	6%, 40, 35, 30, 25, 20, 15	D_0 sizes
Green	4%, 40, 35, 30, 25, 20, 15	D_0 sizes

Filing technique

K file No 10, 15 to 2/3 working length

Orifice opener in crown technique ie 10% → to 3mm or first 1/3 followed by 8% → to coronal 2/3 followed by 6% D_0 40 following the orange sequence 35, 30, 25, 20, 15 up to full working length.

Green series is used when progression is not possible with orange series.
Green series is used when canals are thin and curved.

2.4.3 System 3 — *PROTAPER®* System

General features of the PROTAPER® system:

The files exhibit the following features:

i) There is a progressive taper in individual files ie unlike other files the taper varies in individual files.

ii) The cutting blades do not exhibit a radial land or a positive rake angle. The cross-section exhibits convex sides with a triangular core.

iii) A variable helical angle is present which is relative to the taper.

iv) The tip is partially active and exhibits a triangular shape geometry.

v) The files are made of nickel-titanium, have a variable taper in their sequence and have a shank length of approximately 11mm.

vi) The manufacturer recommends operational speeds of between 150 – 300 rpm.

Features:

1. Triangular cross section

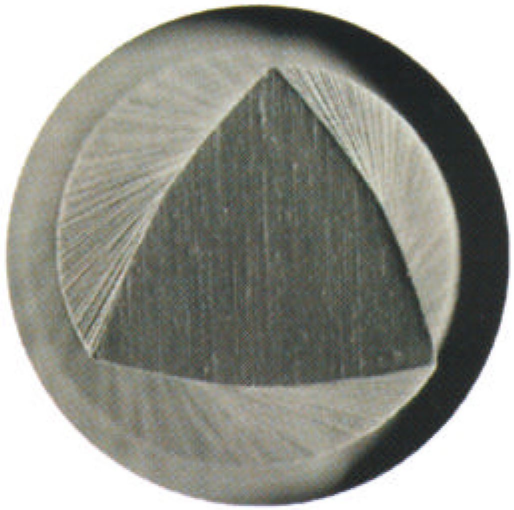

Figure 2.7

Illustration of the cross section of the ***PROTAPER***® endodontic file

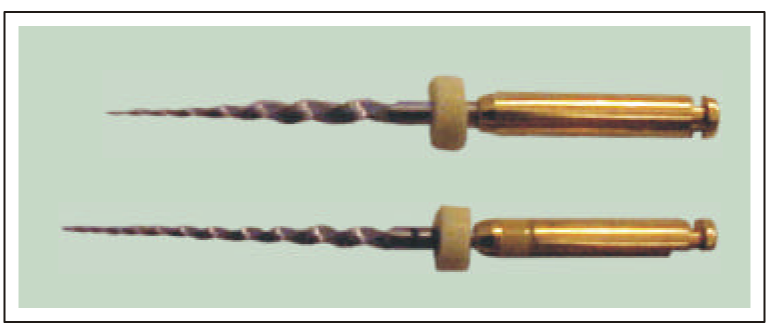

Figure 2.8
Illustration of two of the ***PROTAPER***® endodontic files

Further Features of *PROTAPER*®

The basic series comprises three "shaping" and three "finishing" instruments. The auxiliary shaping file (S_x-shaper) has an overall length of

19mm, Diameter zero (D_0) 0.19mm, partially active tip, 14mm of cutting blades and D_{14} diameter 1.2mm. It is used for optimally shaping canals in shorter roots, relocate canals away from the root concavities (anti-curvature technique) and produce more shape in coronal aspects of canals in longer roots.

Shaping files No 1 and 2 have D_0 0.175 and 0.20mm respectively, 14mm of cutting blades, partially active tips and their D_{14} diameters are 1.2 and 1.1mm. No 1 is used for the coronal third, No 2 for the middle third, although they do to some extent also enlarge the apical third.

The finishing instruments have D_0 diameters of 0.20, 0.25 and 0.30 and between D_0-D_3 they taper 0.076%, 0.08% and 0.096% respectively. From D_4—D_{16} each instrument has a decreasing taper which increases flexibility and reduces the potential for dangerous taper-lock, by engaging less dentine and thereby decreasing the chances of breakage.

Sequence recommendation: (also see chart sequence)

K files 10 and 15 or C files must first be used to establish a proper guide path.

- S1 used to prepare the coronal third of the canal
- SX used to shape the middle part of the canal

Then K files 10 and 15 or C files to determine Working Length (WL)

Then S1 and S2

***PROTAPER*®** **SX** is used to enlarge the coronal aspect.

F1

F2

F3

F2 and F3 are used to prepare the apical part of the canal and are usually used for large canals, otherwise only F1 is used. For most treatments only 3 instruments are needed.

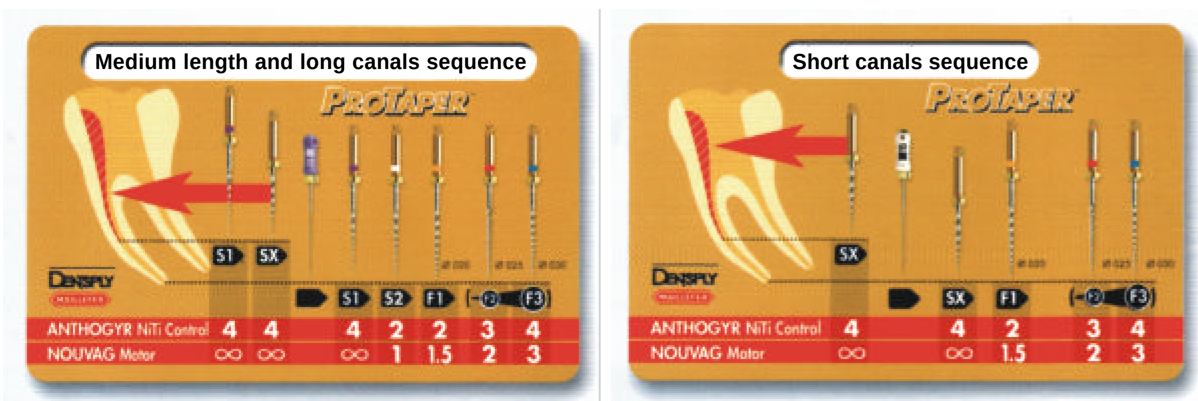

Figure 2.9
Illustration of canal sequences of short, medium and long canals

2.4.4 System 4 – ***AET***^{TM} – Endodontic System

2.4.4.1 *Manufacturer's Specifications*

The motivation behind this system is that canals found in human teeth are not perfectly round. They have a tendency to be more oblong or ribbon-shaped. This is especially true with regard to the coronal two-thirds of the canal. The manufacturer of ***AET***^{TM} equipment came up with a innovative design to address this non-uniform anatomical feature of root canals. Clinically X-rays may give the impression that canals are round in shape. But when the tooth is rotated by 90° the oblong shape is illustrated (see X-rays below).

Figure 2.10a
X-ray showing misleading two-dimensional clinical features (Clinical perception)

Figure 2.10(b)
X-ray showing oblong anatomical features (90 degrees reality)

The specially designed hand piece has a short oscillating action (30° from side to side) with a chuck that allows for length adjustment of files. This allows for complete preparation (removal of all infected pulp to facilitate cleaning and obturation). Furthermore, the apical third is usually round. This system provides a ‘back to basics’ concept using hand files in the step back technique to prepare this area.

General features of AET™ :

The files exhibit the following features:

i) There is a constant taper throughout the length of the cutting blades.

ii) The cutting blades exhibit no radial lands, they show a positive rake angle and a cross-section that is triangular.

iii) A variable helical angle is not present

iv) The tip is inactive and exhibits a square shape geometry.

v) The files are made of stainless steel, have a variable taper in their sequence and have a shank length of approximately 8mm or less (due to specially designed chuck).

vi) The manufacturer recommends speeds of between 300 – 600 rpm.

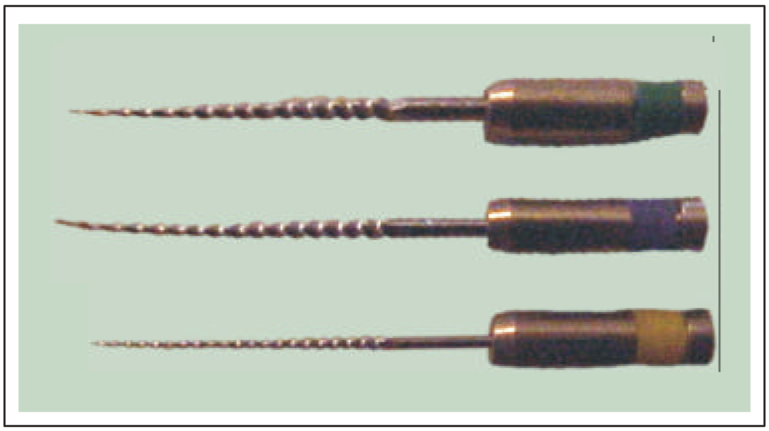

Figure 2.11
Illustration of three of the ***AET***^{TM} files

Shaping Files

- (yellow) 0.10mm Diameter zero (D_0)
- (blue) 0.13mm D_0
- (green) 0.13mm D_0

Apical Files

The ***ENDO – EZE®*** apical files are used in a manual twist-pull or gentle rotation motion and are designed to cut only in the apical portion of the canal.

- No 15
- No 20
- No 25
- No 30

I Coronal Third

Achieved using the Ritano access bur kit

i) Round tapered for initial access;

ii) Acom bur to remove pulpal roof;

iii) Enlarge access with safe end tapered diamond bur;

iv) Improve access with straight-line access diamond bur.

II Large middle third

Instrumentation of the large "Middle third" cleans and shapes most of the canal. This portion is completed before going to the small "apical third".

Step 1:

Measure parallel radiographic length with clear ***ENDO – EZE®*** scale;

Step 2:

Insert shaping file No 1 (yellow) by hand. Briefly manipulate file to find path. ***File-EZE®*** is recommended to facilitate initial file insertion into canal;

Step 3:

Insert shaping file No 2 (blue) into ***ENDO – EZE®*** hand piece and position file to previously determined radiographic length minus 3mm (average middle third length). Moving shaping file in a side-to-side motion, lifting slightly to facilitate removal of tissue coronally, while stroking along canal walls. Lean the file firmly, side-to-side, flexing the file. Repeat with shaping files No 2 (blue) and No 3 (green). Deliver ***File-EZE***® before each size of file is introduced. Irrigate copiously with sodium hypochlorite.

III Small "Apical Third"

Canals are usually round in cross-section in the apical 3mm.

Apical files consist of:

- No 15
- No 20
- No 25
- No 30

Measure file and set working length with rubber stop. X-ray verification is accomplished with shaping / and/or apical 15 or 20 files in canal. Prebending of file may be necessary, if resistance is felt.

The apical instrumentation occurs quickly with conventional twist-pull motion, starting with the No 15 file and ending with the No 30 file. If resistance is felt with the No 25 file, insert to full working length, stop there and move to obturation phase. If resistance to removal at full working length is not realized with the No 30 file, continue with larger apical (auxiliary file) or ISO file until resistance is felt, then move to obturation phase.

2.4.5 System 5 — *FlexMaster*®

2.4.5.1 Manufacturer's Specifications:

General features of the FlexMaster® system:

The files exhibit the following features:

i) There is a constant taper throughout the length of the cutting blades.

ii) The cutting blades exhibit no radial lands, no positive rake angle and their cross-section exhibits convex sides with a triangular core.

iii) A variable helical angle is present and this is relative to the taper.

iv) The tip is non-active and exhibits a round or cone-shaped geometry.

v) The files are made of nickel-titanium, have a variable taper in their sequence and have a handle length of approximately 15mm.

vi) The manufacturer recommends operation speeds of between 150 – 300 rpm.

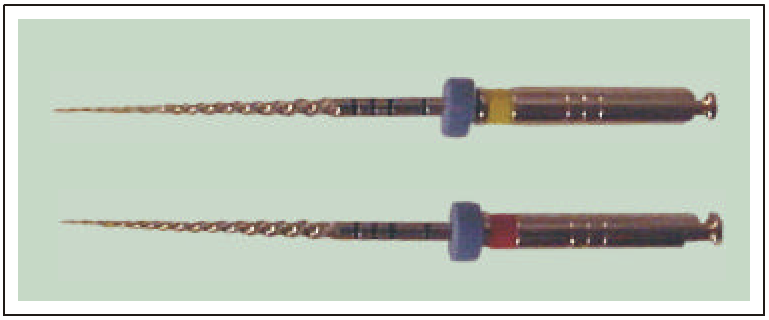

Figure 2.12
Illustration of two of the ***FlexMaster***® files

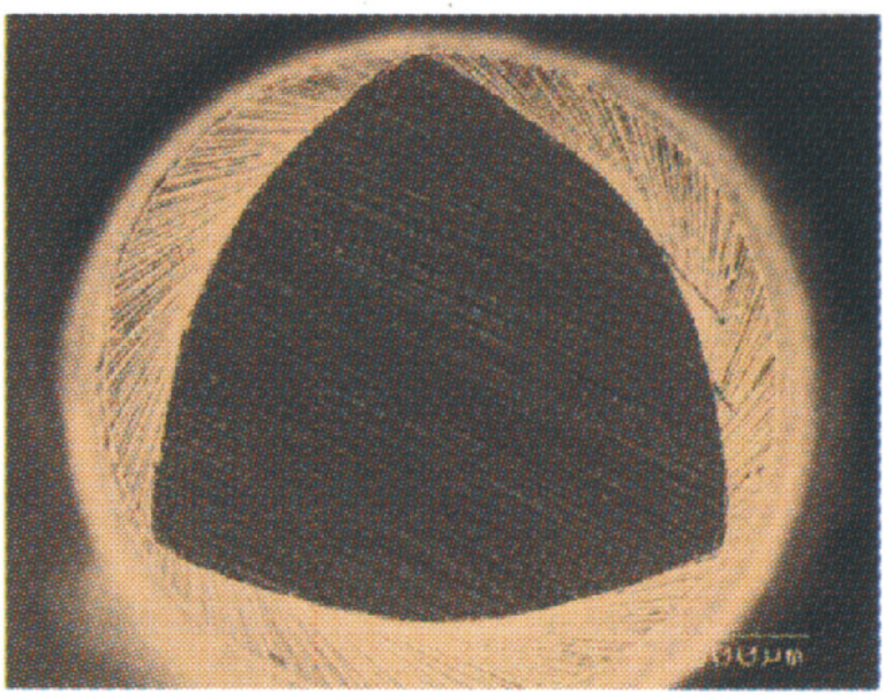

Figure 2.13
Illustration of the convex cross-section of ***FlexMaster***® instruments (500 x)

File Sequence: Taper labelling .02 = 1 ring, .04 = 2 rings, .06 = 3 rings.

Enlarge coronal 1/3 not more than 3mm with introfile.

STEP 1: Crown Down Phase

Three different instrument sequences

Large Canals

3 rings 06/30	?	
3 rings 06/25	?	Until WL – 3mm is reached
3 rings 06/20	?	
2 rings 04/30	?	

Medium Canals

3 rings 06/25	?	
3 rings 06/20	?	Until WL – 3mm is reached
2 rings 04/30	?	
2 rings 04/25	?	

Small/Narrow canals

3 rings 06/20	?	
2 rings 04/30	?	Until WL – 3mm is reached
2 rings 04/25	?	

2 rings 04/20 ?

NOTE:

WL = Estimated working length (from radiograph) – 3mm

STEP 2: Length determination

For exact working length determination use electronic apex locator or intra-oral x-ray with K-file inserted to exact working length.

STEP 3: Apical Preparation
In step back sequence

1 ring 02/20

1 ring 02/25

1 ring 02/30

1 ring 02/35

Only until resistance is felt; if no resistance felt at 02/35 it may be necessary to tune and gauge canals with ISO hand files.

2.4.6 System 6 — *PROFILE*® System

2.4.6.1 Manufacturer's Specifications

General features of the PROFILE® System:

The files exhibit the following features:

i) There is a constant taper throughout the length of the cutting blades.

ii) The cutting blades exhibit a radial land, a negative rake angle and cross-section exhibits a u-shape.

iii) The helical angle is constant throughout the blades.

iv) The tip is inactive and exhibits round or cone-shaped geometry.

v) The files are made of nickel-titanium, have a variable taper in their sequence and have a shank length of approximately 15mm.

vi) The manufacturer recommends operational speeds of between 150 – 350 rpm.

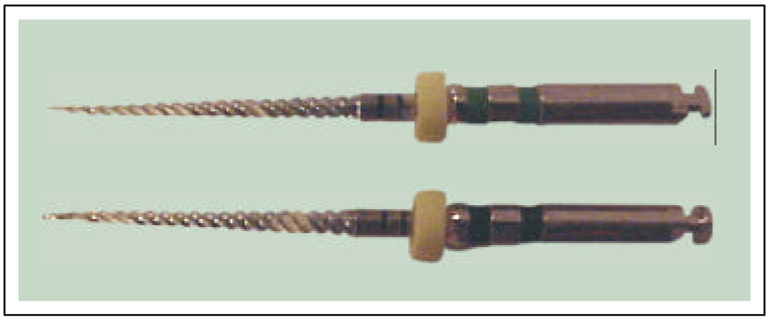

Figure 2.14
Illustration of two of the files in the ***PROFILE***® system

PROFILE® instruments have a U-shaped cross-section. A “Radial Land” is the ground in the zone of contact between the instrument and the canal wall.

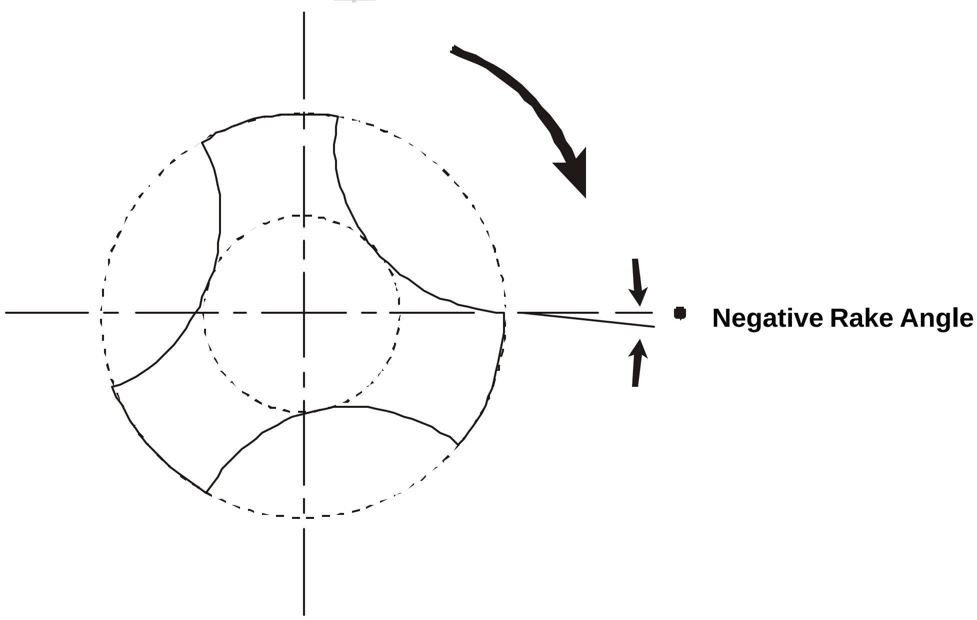

Figure 2.15
Illustration of the cross section of the ***PROFILE***® endodontic file

Operational sequence comprises of four phases:

i) Crown-down;

ii) Determination of the working length;

iii) Apical preparation;

iv) Final shaping.

i) Crown - down

Provisional working length is made on the basis of the pre-operative X-ray, eg 21mm. The first objective of the crown-down phase is to open up the root canal as far as the minimum estimated working length less 3mm (eg 21mm –3mm=18mm), the first depth-mark ring on ***PROFILE***® instruments is located at 18mm.

PROFILE® Orifice Shaper (O S) No 3 (06/40) 19mm. With the O S No 3 already rotating, insert it without excessive pressure and apply a slight in and out movement, for about 5 to 10 seconds. Do not think about working length at this stage, allow instrument to guide itself. When progression becomes difficult, withdraw instrument and go on to next.

PROFILE® O S No 2 (06/30) smaller diameter allows deeper penetration. When progression becomes difficult, withdraw instrument and go on to next.

PROFILE® 06/25 Smaller diameter allows deeper penetration. Use as previous instrument.

PROFILE® 04/25 Since this instrument has less pronounced taper it penetrates deeper. Use as before.

PROFILE® 04/20

Continue operations with this instrument up until the exact working length. This working length is determined as described below.

ii) Determination of the Working length

The exact working length is determined during the crown – down phase, by inserting a conventional No 010 or No 015 K-file (2% taper). K-files are used after the first ***PROFILE***® has reached the minimum estimated working length less 3mm (eg 21mm – 3mm = 18mm). The K-file's function is only that of a depth gauge, allowing exact working length to be determined with the help of and X-ray photo (or apex locator).

iii) Apical preparation up until the exact working length

PROFILE® 04/20

PROFILE® 04/25 or larger if necessary (eg 04/30, 04/35 etc.). Crown down as far as the exact working length is now complete.

iv) Final Flaring

PROFILE® 06/20 (or larger if necessary eg 06/25, 06/30) etc.

2.4.7 Summary of Important Features of the Six Instrument Systems

In the next table the most prominent features of the root canal treatment systems are summarised.

Table 2.1

Summary of Features of the six Root Canal Treatment Systems

	Taper	Hero System	K3	Pro Taper	AET	Flex Master	Profile
i)	Progressive taper in individual files	no	no	yes	no	no	no
ii)	Active tip	no	no	partial	no	no	no
iii)	Radial Land	partial	yes	no	no	no	yes
iv))	Positive rake angle	yes	yes	no	yes	no	no
v)	Variable helical angle	yes	yes	yes	no	yes	no
vi)	Radial Land relief	no	yes	no	no	no	no
vii)	Tip geometry	?	?	?	□	?	?
viii)	Cross-section	convex sides triangular core	Complex blades	convex sides triangular core	triangular core	convex sides triangular core	u-shape
ix)	Files with variable taper in sequence	yes	yes	yes	yes	yes	yes
x)	Rotational speeds (in rpm; recommended by manufacturer)	300-600	150-350	150-350	300-600	150-300	150-350
xi)	Material of file	NiTi	NiTi	NiTi	stainless steel	NiTi	NiTi
xii)	Shank length	11mm	11m	11mm	8mm or less	15mm	15mm
Xiii)	Number of files in sequence	7	7	4	7	11	5

2.5 Sample Design and Experimental Lay-out

The goal was to compare different endodontic systems with each other. Therefore, in an effort to make each system perform the same task, a standardized starting point was necessary. One hundred and fifty extracted molar teeth were sectioned at the amelo-cemental junction.

Figure 2.16a
Photograph illustrating sectioned tooth, superior view

Figure 2.16b
Photograph illustrating sectioned tooth, lateral view

This was done to ensure that no coronal interference played a role in instrumentation of the root canals (provide ideal access). A number 10#ISO K-file was inserted through the apical foramen and working length was recorded. The canal was further enlarged to a number 15#ISO K-file to ensure patency. This was successfully achieved in 110 molar teeth. The teeth (150) were stored in thymol solution and were kindly provided for by Dr Abdoll (working at a governmental clinic). The teeth were removed for periodontal or orthodontic reasons.

Tooth selection was done randomly in two stages, by two different people.

First selection

From 110 molar teeth, six containers were marked System One to Six. One tooth of the 110 went to each container until each container contained sixteen teeth. This was done so that teeth from the top of the container, middle and bottom of the container were evenly but randomly assigned to each system. It was judged that larger teeth may be at the top of the container and smaller teeth may be at the bottom of the container. This selection was done by Paleng Dithebe (chairside assistant, doing practical training at CBD Bloemfontein practice). It must be stressed that Paleng Dithebe knew absolutely nothing about root canal treatment at this stage of her course.

Second selection

Sixteen containers were assigned to each system (Systems One to Six). From the System One container (had sixteen teeth) the first tooth was selected and placed in container marked Number One, System One, then the second tooth was selected from the System One container and place into container marked Number Two, System One. This was repeated until all sixteen containers contained one tooth. This was repeated until all six systems had sixteen teeth in sixteen different containers numbered one to sixteen, system one to six. This selection was done by Maria Hlohlomi (domestic worker at Dr Brittain's house, Bloemfontein).

Each molar tooth selected had three canals, each with a patent apical foramina and was prefiled to working length with a number 15#ISO K-file. This means that each system would be required to instrument forty-eight canals, ie ninety-six teeth each with three canals, therefore, a total of two-hundred and eighty-eight canals for the entire experiment, ie forty-eight canals for each of the six systems tested.

This large sample size was selected to enable statistical analysis to be relevant. The sampling technique was used so that it was random and fair to each system.

2.5.1 Data Collection Process

i) Time measured

Only the actual time the file spent working was measured. Dr Barnard operated the stopwatch (Oregon – SL928D). As the file was introduced into the root canal 'start' was called out, and as it was disengaged 'stop' was called out. This was done to eliminate change-over time of files. Where breakage occurred that tooth's time was discarded. The time for each tooth was grouped together, to give a total time per tooth.

ii) Breakage

Where breakage occurred this was noted on the result sheet.

iii) Transportation of Apical Foramina

The apical foramina of all the teeth were examined by two dentists using a microscope (Dr Patrinos and Dr Boonzaaier). Transportation was noted on the result sheet. (Microscope used: **Zeiss®** Model Opmi Pico, Serial No 360374)

2.5.2 Measures used to Reduce Defects

a) The systems were evaluated on separate days, ie, the sixteen teeth used for System One on day one, System Two on day two, etc. This was to eliminate fatigue.

b) All filing was done by one operator (Dr Brittain).

c) Times were clearly marked on a result sheet, which contained the sequence of files to be used (to ensure correct use of files) and added by myself (RB) and Dr Barnard to correlate results.

d) Breakage was defined as file separation; this is a clear and undisputable event. (Unlike distortion which may be subjective).

e) Transportation evaluation was done by two dentists and was noted on a result sheet as: yes or no, slight (Type I), moderate (Type II) or severe (Type III). Only results that were the same were accepted. Those cases that the two dentists disagreed upon, were marked 'unable to measure'.

f) Sodium hypochlorite was used for irrigation. Irrigation was identical for each system. This followed the accepted protocol, namely: rinse with **Milton**® before and after usage of each file, ie copious and generous irrigation between each file and in addition always working in a moist environment. Sodium hypochlorite was used because of its long track record and evidence that it has no effect on the mechanical properties of nickel-titanium (Haikel, Serfaty, Wilson, *et al*, 1998). After the files were used, they were rinsed in a sodium hypochlorite solution, to remove debris and offset the effect of embedded dentine chips which may have an effect on breakage (Alapati, Brantley, Svec, *et al*, 2003).

g) Where breakage occurred, and the file was occluding the canal, the entire tooth was discarded, because it was noted that breakage always occurred in the narrower curved canals (eg mesio-buccal, mesio-lingual in mandibular molars and disto-buccal, mesio-buccal in maxillary molars) and never in the larger straight canals (palatal canals of maxillary molars and distal canals of mandibular molars). Therefore, to include the other two canals in a tooth with one occluded canal due to fracture would be bias towards that system ie one of the more 'difficult' canals would be omitted from the study.

h) In addition, basic principles of endodontics were applied namely a step-by-step approach; proper access, adequate guide path provided, copious irrigation, never force an instrument, when resistance was felt the instrument was immediately withdrawn. Furthermore, the manufacturer's guidelines were meticulously followed.

2.5.3 System Sequencing used in Experiment

1. **HERO System** **Endoflare®** Lot 092302

   HERO Shaper® Lot 020204

   HERO Apical® Lot 121803

Sequence:
1) Endoflare at 300 rpm, 500g/cm^3 (torque)
2) Red 06/25 at 300 rpm, 52g/cm^3
3) Length determination
4) Red 04/25 at 300 rpm, 200g/cm^3
5) Blue 04/30 at 300 rpm, 50g/cm^3
6) Apical flare black 06/30 at 300 rpm, 50g/cm^3
7) Apical flare red 08/30 at 300 rpm, 50g/cm^3

2. ***K^3™*** – NiTi sequence used in experiment: Lot 02M52M, Ref 825-0257

Sequence:
1) Orifice opener 10/25 17mm at 300 rpm, 156g/cm3 Pink/Red
2) 08/25 at 300 rpm, 135g/cm^3
3) Length determination
4) 06/40 at 300 rpm, 217g/cm^3
5) 06/35 at 300 rpm, 186/cm^3
6) 06/30 at 300 rpm, 115g/cm^3
7) 06/25 at 200 rpm, 62g/cm^3

3. ***PROTAPER®*** sequence used in experiment Ref A 040922190000

Sequence:
1) SX Short canal at 300rpm, 500g/cm^3
2) Length determination
3) F1 at 300 rpm, 88g/cm^3
4) SX Short canals at 300 rpm, 500g/cm^3

4. ***AET***™ sequence used in experiment Ref 156 Lot 5025

X-short 16 – 19mm sequence

Sequence: 1) Yellow no/shaping file at 600 rpm, 400g/cm^3

2) Blue No 2 shaping file at 600 rpm, 400g/cm^3

3) Green No 3 shaping file at 600 rpm, 400g/cm^3

4) Length determination

5) Handfile No 15

6) Handfile N 20

7) Handfile No 25

5. ***FlexMaster***® sequence used in experiment (as supplied by manufacturer)

File batch No (Lot) 6528620

Sequence: 1) Intro file at 280 rpm, 143g/cm^3

2) 06/30 at 280 rpm, 150g/cm^3

3) 06/25 at 280 rpm, 104g/cm^3

4) 06/20 at 280 rpm, 78g/cm^3

5) Length determination

6) 02/20 at 280 rpm, 21g/cm^3

7) 02/25 at 280 rpm, 45g/cm^3

8) 02/30 at 280 rpm, 61g/cm^3

9) Green 02/35 at 280 rpm, 88g/cm^3

10) Hand files ISO No 02/40 in some cases

11) Hand files ISO No 2/45 and ISO No 02/50 in one case

6. ***PROFILE***® sequence used in experiment (as supplied by manufacturer)

File batch No A0345 06 taper

File batch No A011N 04 taper

Sequence: 1)		06/40 at 200 rpm, 213g/cm^3
2)		06/35 at 300 rpm, 176g/cm^3
3)		Length determination
4)		Real 04/25 at 300 rpm, 51g/cm^3
5)		04/35 at 300 rpm, 120g/cm^3

2.5.4 Limitations in the Data Collected

Only the time actually engaging dentine was measured. This was thought useful to eliminate inconsistent changeover of files. This seems logical and useful, however, from a clinical perspective, systems that have a simple sequence and few files, are convenient to use and faster, because of less changeover time. However, this changeover time is difficult to measure objectively.

Although apical foramen transportation was first carefully described to the two dentists, this is to some extent a subjective analysis. Furthermore, this is an indication of the transportation in the apical third only; therefore, middle and coronal third transportation was not measured. This may favour some files that are more flexible in their apical third.

Chapter 3

Results of the Comparative Experiment

3.1 Sample Size and Characteristics

Each system was tested using sixteen teeth. Each tooth had three canals. Each canal had a patent apical foramen and was prefiled with a No 15 ISO K-file to working length ensuring patency. During the experimental phase canals were enlarged according to the manufacturer's specifications to reach a predetermined objective (properly shaped and cleaned canal, ready for obturation).

During the experiment some teeth were 'lost' as the file fractured in the root canal and blocked further instrumentation. In System One (**HERO System**) one file broke. The file, however, was mobile and the instrumentation of that tooth was possible, therefore, it was included in the final analysis. The remnant of this broken file was removed with a pair of college tweezers. In System Two (***K*³™**) three files broke in three separate canals in three different teeth. It was not possible to complete instrumentation of the three teeth in this group, leaving a sample size of thirteen teeth (39 canals).

In Systems Three (***PROTAPER***®), Four (***AET***™), Five (***FlexMaster***®) and Six (***PROFILE***®) no breakage occurred, leaving sixteen teeth (48 canals) per system, with regard to time and breakage measurement. However, apical transportation could not be measured in one tooth of the ***PROFILE***® systems (two dentists did not agree on their findings). The summarizing of all measurements was possible for Systems One, Three, Four and Five. System Two lost three teeth (leaving 13) and apical foramen transportation was not possible in one tooth for System Six (***PROFILE***®).

Table 3.1

Collected Data from the experimentation performed on approximately 16 teeth per root canal system (type)

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	HeroS	72	n	s (Type I)	1_Slight (TI)
2	HeroS	70	n	s (Type I)	1_Slight (TI)
3	HeroS	61	n	n	0_none
4	HeroS	61	n	n	0_none
5	HeroS	54	n	s (Type I)	1_Slight (TI)
6	HeroS	78	n	n	0_none
7	HeroS	67	n	n	0_none
8	HeroS	41	n	s (Type I)	1_Slight (TI)
9	HeroS	72	n	n	0_none
10	HeroS	66	n	n	0_none
11	HeroS	44	y	s (Type I)	1_Slight (TI)
12	HeroS	75	n	n	0_none
13	HeroS	67	n	n	0_none
14	HeroS	52	n	n	0_none
15	HeroS	96	n	n	0_none
16	HeroS	91	n	n	0_none

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	K3Niti	62	n	n	0_none
2	K3Niti	56	n	n	0_none
3	K3Niti	57	n	n	0_none
4	K3Niti	50	n	n	0_none
5	K3Niti	Unable F	y	n	0_none
6	K3Niti	40	n	n	0_none
7	K3Niti	55	n	n	0_none
8	K3Niti	63	n	n	0_none
9	K3Niti	82	n	n	0_none
10	K3Niti	50	n	n	0_none
11	K3Niti	52	n	n	0_none
12	K3Niti	Unable F	y	n	0_none
13	K3Niti	Unable F	y	n	0_none
14	K3Niti	39	n	n	0_none
15	K3Niti	105	n	n	0_none
16	K3Niti	96	n	n	0_none

Table 3.1 (Continued)

Collected Data from the experimentation performed on approximately 16 teeth per root canal system (type)

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	Protaper	52	n	n	0_none
2	Protaper	45	n	n	0_none
3	Protaper	47	n	n	0_none
4	Protaper	61	n	n	0_none
5	Protaper	52	n	n	0_none
6	Protaper	60	n	n	0_none
7	Protaper	82	n	n	0_none
8	Protaper	75	n	n	0_none
9	Protaper	74	n	n	0_none
10	Protaper	70	n	n	0_none
11	Protaper	84	n	n	0_none
12	Protaper	95	n	n	0_none
13	Protaper	96	n	n	0_none
14	Protaper	46	n	n	0_none
15	Protaper	64	n	n	0_none
16	Protaper	77	n	n	0_none

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	AET	81	n	n	0_none
2	AET	100	n	n	0_none
3	AET	117	n	n	0_none
4	AET	107	n	n	0_none
5	AET	106	n	n	0_none
6	AET	154	n	n	0_none
7	AET	87	n	n	0_none
8	AET	65	n	Slight (Type I)	1_Slight (TI)
9	AET	113	n	Slight (Type I)	1_Slight (TI)
10	AET	115	n	n	0_none
11	AET	75	n	n	0_none
12	AET	116	n	n	0_none
13	AET	163	n	n	0_none
14	AET	187	n	n	0_none
15	AET	212	n	Slight (Type I)	1_Slight (TI)
16	AET	156	n	n	0_none

Table 3.1 (Continued)

Collected Data from the experimentation performed on approximately 16 teeth per root canal system (type)

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	Flexmaster	102	n	n	0_none
2	Flexmaster	105	n	n	0_none
3	Flexmaster	94	n	n	0_none
4	Flexmaster	117	n	n	0_none
5	Flexmaster	87	n	n	0_none
6	Flexmaster	95	n	n	0_none
7	Flexmaster	93	n	n	0_none
8	Flexmaster	81	n	n	0_none
9	Flexmaster	85	n	n	0_none
10	Flexmaster	91	n	n	0_none
11	Flexmaster	91	n	n	0_none
12	Flexmaster	101	n	n	0_none
13	Flexmaster	105	n	n	0_none
14	Flexmaster	119	n	n	0_none
15	Flexmaster	118	n	n	0_none
16	Flexmaster	101	n	n	0_none

Tooth No	Type	Total Time	Breakage	Apical Displacement	Ordinal Scale of Displacement
1	Profile	95	n	n	0_none
2	Profile	84	n	n	0_none
3	Profile	93	n	n	0_none
4	Profile	86	n	n	0_none
5	Profile	123	n	n	0_none
6	Profile	91	n	Unable m	
7	Profile	82	n	n	0_none
8	Profile	89	n	n	0_none
9	Profile	117	n	n	0_none
10	Profile	37	n	Slight (Type I)	1_Slight (TI)
11	Profile	104	n	n	0_none
12	Profile	100	n	Slight (Type I)	1_Slight (TI)
13	Profile	46	n	n	0_none
14	Profile	44	n	n	0_none
15	Profile	139	n	Slight (Type I)	1_Slight (TI)
16	Profile	125	n	n	0_none

3.2 Duration Time of the Six Techniques

The Average of the total time per tooth (3 canals) and other descriptive statistics such as the Median, Standard Deviation, etc.

Table 3.2

Descriptive Statistics for Total Duration each of the six root canal systems

	Hero System	***K^3***	***Protaper***	***AET***	***Flexmaster***	***Profile***
Mean	66.7	62.1	67.5	122.1	99.1	90.9
Median	67	56	67	114	98	92
Standard Deviation	14.9	20.2	16.8	41.4	11.7	29.1
Range	55	66	51	147	38	102
Minimum	41	39	45	65	81	37
2nd Smallest	44	40	46	75	85	44
Median	67	56	67	114	98	92
2nd Largest	91	96	95	187	118	125
Maximum	96	105	96	212	119	139
Count	16	13 3 Missing	16	16	16	16

The data collected was summarised in Table 3.1 and shows whether breakages occurred (yes / no), apical displacement (yes / no) and classification of apical displacement (Type I, II or III). From Table 3.2 the following could be learnt:

Table 3.2 summarises the Duration Times measured. The mean time for ***K^3™*** was the fastest (62.1 seconds) closely followed by **HERO System** (66.7 seconds) and ***PROTAPER®*** (67.5 seconds). ***PROFILE®*** (90.9 seconds) and ***FlexMaster®*** (99.1

seconds) were considerably slower than Systems Two, One and Three. These in turn (Systems Five and Six) were considerably faster than System Four (***AET***™).

Range (difference between the minimum value and maximum value) was lower in System Five (***FlexMaster***®) (38). It was similar in Systems One, Two and Three (55, 66, 51 respectively) and higher in Systems Four and Six (147, 102).

Standard deviation therefore was lowest in System Five (11.7), similar in Systems One, Two and Three and higher in System Six (29.1) and extremely high in System Four (41.4). (See standard deviation result sheet 3). Result Sheet Four has a 'box-and-whisker plot' which illustrates the total mean time per system versus system type. This graphically illustrates the results described in Table 3.2.

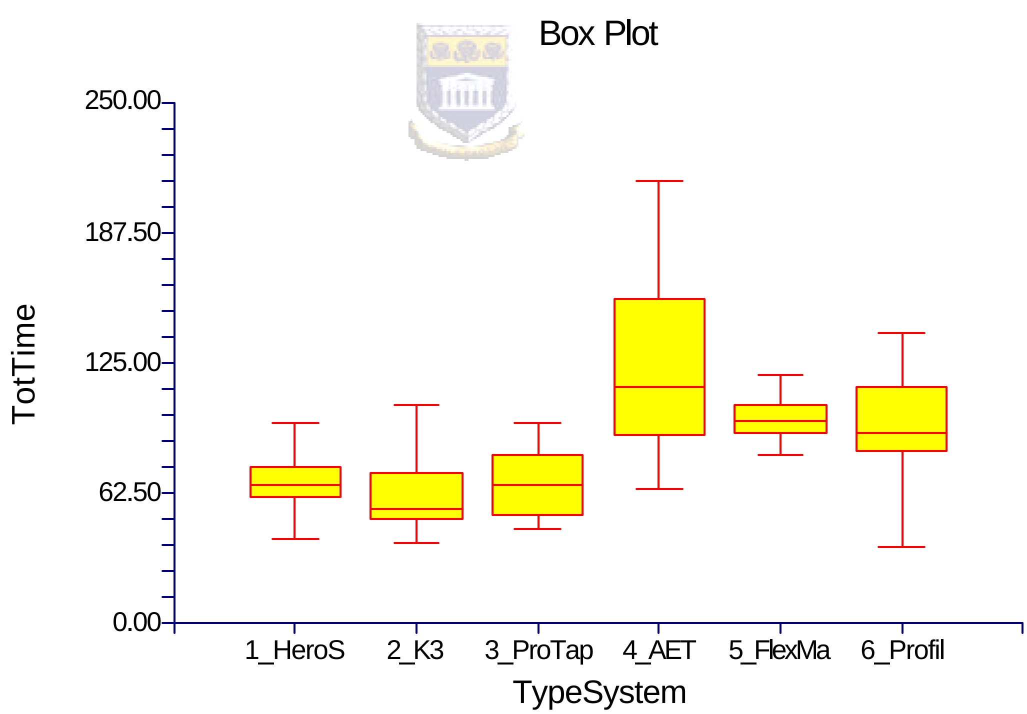

Figure 3.1
Side-by-Side Box Plot of the Total Time taken with respect to each of the six Systems

3.2.1 Statistical Analysis of Duration Time

The Kruskal-Wallis One-way ANOVA based on ranks was performed. It was hypothesised that all the Medians of the total duration were equal. However, some of the medians were different, $p<0.000001$. From the graphical display (Figure 3.1) it could be observed that the Total Duration of ***AET***™ and ***PROFILE***® were longer than most of the other Systems.

Table 3.3

Medians of the Total Duration and other rank statistics

Group	Count	Sum of Ranks	Mean Rank	Z-Value	Median
1_HeroS	15	458.50	30.57	-2.5261	67
2_K3	13	323.50	24.88	-3.1497	56
3_ProTaper	16	475.50	29.72	-2.7658	67
4_AET	16	1138.50	71.16	4.0638	114
5_FlexMaster	16	1027.50	64.22	2.9204	98
6_Profile	16	854.50	53.41	1.1383	92

The above table was used to order the Total Duration of the six procedures, from the shortest to the longest duration. This set or information was used to cluster these six procedures into a smaller number of similar sets (see Table 3.5) according to Multiple Comparison Principles.

Table 3.4

Kruskal-Wallis test for the Comparison of the Median duration
to implement each of the Six Systems

Kruskal-Wallis One-Way ANOVA on Ranks
Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	DF	Probability (H)	Chi-Square Level	Decision (0.05)
Not Corrected for Ties	5	41.94	0	Reject Ho
Corrected for Ties	5	41.96	0	Reject Ho

This implies that the differences for the duration of the six systems are highly significant (probability level 0.00001). Therefore, the findings indicate that Systems One (**HERO System**), Two (***K*³™**) and Three (***PROTAPER***®) have similar times, System Six (***PROFILE***®) is faster than System Five (***FlexMaster***®), which in turn is statistically faster than System Four (***AET***™).

Therefore, the respective groups can be ranked according to their medians to understand their relative position with respect to the Total Duration (see Table 3.3).

Table 3.5

Clustering of the Six Root Canal Treatment Systems with respect to the Total Duration

System	K^3	HeroS	Protaper	Profile	Flexmaster	AET
Median	56	67	67	92	98	114

Within this group the Medians did not differ significantly on the 5% level

Within this group the Medians did not differ significantly on the 5% level

However, the two groups form two separate clusters of which the components of Median times differ significantly

The six systems were classified into two main clusters namely those of shorter duration (***K^3™*, HERO System** and ***PROTAPER***®) and those of longer duration (***PROFILE***®, ***FlexMaster***® and ***AET***™**)**.

3.2.2 Analysis of Breakages

Breakage occurred in **HERO System** – (one breakage) and ***K^3™*** – (three breakages). No breakages occurred in ***PROTAPER***®, ***AET***™, ***FlexMaster***® and ***PROFILE***® (see Table 3.6 below).

Table 3.6

The occurrence of Breakages with respect to the Six Root Canal Treatment Systems

	Type						
Breakage	**Hero System**	**K^3**	**Protaper**	**AET**	**FlexMaster**	**Profile**	**Total**
No	15	13	16	16	16	16	92
Yes	1	3					4
Total	16	16	16	16	16	16	96

With respect to the breakages for the different types of files the number of teeth in each group was too low to identify (significant) differences.

3.2.3 Analysis of Apical Foramina Transportation

Apical foramina transportation was observed in System One (**HERO System**; Class I; four canals), Four (***AET***™; Class I; Three canals) and Six (***PROFILE***®; Class I; four canals). Only Class I (slight transportation) was observed. In Systems Two (***K³™***), Three (***PROTAPER***®) and Five (***FlexMaster***®) no transportation was observed (see Table 3.7).

Table 3.7

The occurrence of Apical Displacements with respect to the Six Root Canal Treatment Systems for those teeth where No Breakages occurred

	Type						
Apical Displacement	**Hero System**	**K³**	**Protaper**	**AET**	**FlexMaster**	**Profile**	**Total**
No	11	13	16	13	16	12	81
Slight (Type I)	4			3		4	11
Total	15	13	16	16	16	16	92

Twelve percent of the 92 experimental teeth showed slight apical displacement. There were some clustering of the displacement in **HERO System, *AET*™** and ***PROFILE***®;. The available teeth (approximately 96) were divided into six equal groups, however, the sixteen teeth (replicates) per group were too small to ensure reasonably accurate multiple comparisons of the six systems.

3.2.4 Discussion of Results

The purpose of this study was to compare the time taken by six endodontic systems to reach their objective (ie a canal which is shaped and cleaned ready for obturation). Also of interest was whether any of the files fractured and if apical foramen transportation took place.

3.2.4.1 Total Duration

One of the motivating factors for using nickel-titanium (NiTi) instruments is that they are able to prepare canals faster than stainless steel files (Gambill, Alder & Del Rio, 1996). Schäfer & Lohmanns, (2002a & b), found that ***FlexMaster***® was faster than stainless steel K-Flexo files. Results in this study indicate that all the nickel titanium systems (one, two, three, five and six) were significantly and statistically faster than the new stainless steel system (***AET***™). But of particular interest is why certain nickel-titanium systems were faster than others.

Tip geometry varied throughout the six systems. Literature evidence suggests that files with pyramidal tips would outperform other shapes (Miserendino, Moser, Heuer, *et al*, 1986). In this study Systems One (**HERO System**), Two (***K³™***) and Three (***PROTAPER***®) all had pyramidal shaped tips. They were statistically ($p<0.001$) faster than Systems Five (***FlexMaster***®) and Six (***PROFILE***®) that had round or flattened shaped tips. This finding is partially supported by Hülsmann, Gressman & Schäfers (2003). They found that **HERO 642**® was faster than ***FlexMaster***®.

Although System Four (***AET***™) has a square tip, the fact that it employs a 30° rotation in one direction followed by a 30° rotation in the opposite direction, ie no true rotary movement, and it is made from stainless steel, offsets any advantage of having a square shaped tip.

Only the ***PROTAPER***® had a partially active tip, yet it did not outperform the **HERO**® and ***K³™*** systems.

It is proposed (see hypothesis) that radial lands would slow down the instrumentation time. This was found to be correct with regard to ***PROFILE***® but totally contradicted by the performance of ***K³™***. This may be because the ***K³™*** has a radial relief which negates the negative effect of the radial land.

Progressive taper in individual files is only exhibited in the ***PROTAPER***® series. This is an important feature which may enable this particular file to have a faster time. Files that exhibit progressive taper in individual files are thicker coronally and therefore remove more dentine coronally (Usman, Baumgartner & Marshall, 2004), which results in less interference in working the apical third (supports the principles of the crown down technique).

Four of the systems had a variable helical angle, namely **HERO**®, ***K***^{3}™, ***PROTAPER***® and ***FlexMaster***®. ***PROFILE***® and ***AET***™ did not. With the exception of ***FlexMaster***®, the files with a variable helical angle exhibited faster times.

All six systems had files of different tapers in their sequences, therefore, this feature by nature of its universal use, cannot be a distinguishing characteristic.

3.2.4.2 File Cross-sections

PROTAPER®, **HERO System** and ***FlexMaster***® all had similar cross-sections (triangular with convex sides). ***PROFILE***® has a u-shape cross-section, ***K***^{3}™ has complex blades around a variable core (Iqbal, Fimi, Tulcan, *et al*, 2004; Ankrum, Hartwell & Truitt, 2004; Schäfer & Lohmanns, 2002a & b), and ***AET***™ a triangular cross-section. The triangular shape seems to produce better times than the u-shape. This is offset or complicated by the fact that ***FlexMaster***® was slower than the ***PROFILE***® system and the ***AET***™ time even slower.

3.2.4.3 Speed of Rotation

It was proposed that an increase in rotational speed would result in a decrease in instrumentation time. Unfortunately manufacturers' recommended speed for five systems was very similar, approximately 300 rpm – (see previous chapter). The (***AET***™) system recommended speed was twice as fast (600 rpm). However, since this system does not use true rotation, no conclusion regarding this can be drawn.

Similarly, with regard to variable taper in sequence (ie using 6% taper, 4% taper and 2% taper for one system) all systems used the same variation of this and therefore, no conclusion can be drawn.

Therefore, when considering all the features of the endodontic files, the following may be suggested:

i) Progressive taper in individual files does not necessarily produce a faster time. Although ***PROTAPER***® (only file exhibiting this feature) did have one of the fastest times.

ii) An active tip is not essential for a fast time. Although ***PROTAPER***® (only file exhibiting this feature) did have one of the fastest times.

iii) Radial lands did not definitively influence times. The fact that ***K³***™ and **HERO System** (the fastest files) and ***PROFILE***® (one of the slowest files) all exhibit radial lands, suggests that this is not an important feature with regard to time.

iv) Positive rake angles were exhibited in two of the faster systems (**HERO System** and ***K³***™) suggesting that this may be an important feature in speeding up time taken. The fact that ***PROTAPER***® doesn't exhibit this feature, but still has a fast time, may be explained by the fact that it exhibits other features (such as variable taper in individual files and active tip) which may speed up its performance.

v) Variable helical angle may be useful but since five of the six systems have this feature it is difficult to determine a conclusion here. Although it can be noted that the ***AET***™ did not exhibit this feature and had the slowest time.

vi) The tip geometry of the three fastest files is triangular in shape, suggesting this is an important feature, which enables endodontic files to have faster times. Although the ***AET***™ has a square tip geometry, other features probably compromise this advantage.

vii) Four systems (**HERO System**, ***PROTAPER***®, ***AET***™ and ***FlexMaster***®) show a triangular core cross-section, ***K***^{3}**™** has complex blades and ***PROFILE***® a **u**-shape. Since triangular cores are exhibited in the faster and slower sections of the results no definitive results can be drawn here. Although it may be suggested that the u-shape of ***PROFILE***® may compromise its time.

viii) Since all the files exhibited a variable taper in their sequence, no conclusion could be drawn here.

ix) Stainless steel files (***AET***™) produced the slowest time suggesting that files made from stainless steel and not employing true rotation, compromise time taken.

Therefore, with careful consideration the following features could influence a file to cut faster: Progressive taper in individual files, active tip, positive rake angles, variable helical angle, tip geometry, cross-section and material of the file.

3.2.4.4 File Breakage

No statistical evidence was found to suggest that breakage was more likely to occur in any particular system. Ankrum, Hartwell & Truitt (2004), in a similar experiment to this one (with regard to breakage and materials used) found as a percentage breakage ***K***^{3}**™** NiTi 2.1%, ***PROFILE***® 1.7% and ***PROTAPER***® 6.0%. They too could not find any statistical differences. Of interest and contrary to their findings, breakage was only observed in the ***K***^{3}**™** (three breakages out of 16) and **HERO System** (one breakage out of 16) groups. Could this possibly point to a trade-off situation, ie more aggressive faster cutting files are more likely to fracture? Interestingly, it is suggested in the literature of Yoshida, Shibata, Shinohara, *et al* (1995), that ***PROTAPER***®'s shape, because of its cross-section (more even distribution of stress) and its progressive taper (Fife, Gambarini, Britto, *et al*, 2004), (engages less dentine) will make it more resistant to fracture. However, neither the ***PROTAPER***® nor ***PROFILE***® fractured, suggesting that the u-shape, constant taper may also be resistant to fracture. Walia, Brantley & Gerstein (1988), suggested that stainless steel was less resistant to fracture than ***K³™***. However, no fractures were observed in the ***AET***™ group. Schäfer & Schlingemann (2003), found no fractures in the stainless steel group but five fractures in the ***K³™*** group, which is more in line with the results of this study.

3.2.4.5 Apical Foramen Transportation

Literature evidence suggests that stainless steel instruments may cause more transportation (Gambill, Alder & Del Rio, 1996; Bertrand, Lupi-Pégurier, Medioni, *et al*, 2001). Interestingly, this could not be proven in this study. Although transportation occurred in the ***AET***™ group (3) it also occurred in the **HERO System** (4) and ***PROFILE***® (4) groups. This suggests that the 'new way' of using stainless steel (***AET***™ system) may be an improvement on the traditional way. No transportation occurred in the ***FlexMaster***®, ***K³™*** and ***PROTAPER***® groups. When comparing the ***PROTAPER***® versus the ***PROFILE***® groups Iqbal, Fimi, Tulcan, *et al* (2004), found that ***PROFILE***® (constant taper in individual files) caused more transportation in the apical region than ***PROTAPER***® group (progressive taper in individual file). This is partially supported by results in (RB) experiment. But it must be stressed that no transportation was noted in the ***FlexMaster***®, ***K³™*** groups, (constant taper in individual files) which suggests that other features play a role in apical transportation. It was suggested in the hypothesis that apical foramen transportation was more likely to occur in systems with active tips. Surprisingly, it was found that this was not so; indeed in the ***PROTAPER***®

group (partially active tip) no transportation was observed. An interesting feature employed by the **HERO Apical®** files is a smooth flexible shaft which exhibits reverse taper. The idea is that there will be no coronal interference, and therefore facilitate better apical preparation. This feature however did not allow for statistically better results (with regard to transportation) than the other groups. This is supported by Bergmans, Van Cleyenbreugel, Beullens, *et al* (2002), who compared smooth versus active taper designs and could not find a statistical difference between them with regard to transportation.

Hübscher, Barbakow & Peters (2003), found that ***FlexMaster***® was able to shape maxillary molars without any significant shaping errors. This is confirmed in (RB) results, but frustratingly no single feature can be singled out which is exclusive to the ***FlexMaster***®, ***K³™*** and ***PROTAPER***® groups; suggesting that a combination of different features in each group resulted in the desired outcome. Furthermore, only a few files fractured and a small number of foramina were transported in this study. No statistical evidence was found to suggest that apical foramen transportation and file breakage were more likely to occur in any particular system.

3.3 Summary of Results

3.3.1 Positive and Negative Viewpoints

Of great encouragement is that all the systems were able to reach their objectives (properly shaped and cleaned canals ready for obturation) with minimal breakage and transportation. Indeed, there was no significant statistical evidence with regard to breakage and transportation between the six systems. Considering that 48 canals were prepared by each system this study proves that they are all remarkably strong (minimal breakages) and able to follow the canal anatomy (minimal apical foramen transportation). Some of the newer systems ***K^{3}™***, **HERO System** and ***PROTAPER***® were statistically faster than older systems such as the ***PROFILE***®, suggesting that manufacturers are striving to make newer systems faster. Disappointingly (with regard to time), the ***FlexMaster***® and ***AET***™ were slower than the ***PROFILE***® system. Although it must be stressed that no apical transportation was observed in the ***FlexMaster***® system, and that neither the ***AET***™ nor ***FlexMaster***® exhibited a single fracture.

3.3.2 Conclusions and Recommendations

This study statistically proves that ***K^{3}™***, **HERO System** and ***PROTAPER***® systems are faster than ***PROFILE***® and ***FlexMaster***® systems, which in turn are faster than the ***AET***™ system.

No statistical difference could be established between the six systems with regard to file breakage and apical foramen transportation. This confirms that all these six systems are very capable of reaching their objectives (properly shaped canals ready for obturation), and emphasizes the importance of proper access cavities, patent canals and provision of proper guide paths.

The research hypothesis suggested that files that exhibited pyramidal or square shaped tips, active/partially active tips, progressive taper in individual files, positive rake angles, variable or multiple helical angles, absence of radial lands and simple sequences would have faster times. Although no single feature seems to play a definitive role, it may be suggested that triangular tips are present in the faster groups. If the ***AET***™ system is excluded, triangular tip geometry seems to be an important feature. Furthermore, it may be suggested that a combination of features results in faster times. Therefore, it may be concluded within the boundaries of this study that more aggressive cutting features and simple filing sequences enabled the ***K*³™** , **HERO System** and ***PROTAPER***® groups to reach their objectives faster than files that have some or none of these features.

Surprisingly, systems that had radial lands, negative rake angles and non-active tips did not exhibit less transportation (no statistical difference). Also of interest was that breakage only occurred in the group that had the fastest time (**HERO System** and ***K*³™**) suggesting that more aggressive files may have a greater likelihood of fracture. However, it must be stressed that no statistical differences could be observed.

Furthermore, it may be concluded that features that enable certain systems to be faster, did not make them statistically more likely to fracture, or cause apical foramen transportation.

These findings have relevance to endodontic practice as they prove that all systems are remarkably adept in performing their assigned tasks. Newer designs are in the right direction, eg ***PROTAPER***® was able to complete its 'objectives' faster than older designs, eg ***PROFILE***® without a single fracture or apical foraminal transportation.

Of interest and an aspect that needs further research, is transportation: Only apical foramina transportation was measured. It would be interesting to see if transportation occurred at different sites along the canal pathway.

Were the objectives really reached by each system? Probably yes for shape, but were the canals really clean? A study regarding the cleanliness of each canal after instrumentation would be interesting.

Perhaps a study comparing the older systems – ***PROFILE***® versus ***PROTAPER***® – using a larger number of teeth could provide statistical power to the question whether the newer features of ***PROTAPER***® cause less or more transportation and if the new features enable a file to be more resistant to fracture or not. It is therefore necessary to compare the newer file systems to the older technology to see whether there is a real cost benefit to change to the newer systems.

References

Alapati SB, Brantley WA, Svec TA, Powers JM & Mitchell JC (2003). Scanning electron microscope observations of new and used nickel-titanium files. *Journal of Endodontics*; **29**: 667-669.

Al-Fouzan KS (2003). Incidence of rotary Profile instrument fracture and the potential for bypassing *in vivo. International Endodontic Journal;* **36**: 864-867.

Ankrum MT, Hartwell GR & Truitt JE (2004). K3Endo, ProTaper and Profile systems: Breakage and distortion in severely curved roots of molars. *Journal of Endodontics*; **30**: 234-237.

Ayar LR & Love RM (2004). Shaping ability of Profile and K3 rotary NiTi instruments when used in a variable tip sequence in simulated curved root canals. *International Endodontic Journal*; **37**: 593-601.

Bergmans L, Van Cleyenbreugel J, Beullens M, Wevers N, Van Meerbeek B & Lambrechts P (2002). Smooth flexible versus active tapered shaft design using NiTi rotary instruments. *International Endodontic Journal*; **35**: 820-828.

Bergmans L, Van Cleyenbreugel J, Wevers M, Van Meerbeek B & Lambrechts P (2003). Progressive versus constant tapered shaft design using NiTi rotary instruments. *International Endodontic Journal*; **36:** 288-295.

Bertrand M-L, Lupi-Pégurier L, Medioni E, Muller M & Bolla M (2001). Curved molar root canal preparations using Hero 642 rotary nickel-titanium instruments. *International Endodontic Journal*; **34**: 631-636.

Berutti E, Chiandussi G, Garglio I & Ibba A (2003). Comparative analysis of torsional and bending stresses in two mathematical models of nickel-titanium rotary instruments: ProTaper versus Profile. *Journal of Endodontics*; **29**: 15-19.

Berutti E, Negro AR, Lendini M & Pasqualini D (2004). Influence of manual Preflaring and Torque on the failure rate of ProTaper rotary instruments. *Journal of Endodontics;* **30**: 228-230.

Best S, Watson P, Pilliar R, Kulkarni GGK & Yared G (2004). Torsional fatigue and endurance limit of a size 30.06 Profile rotary instrument. *International Endodontic Journal*; **37**: 370-373.

Blum J-Y, Machtou P, Ruddle CJ & Micallef J-P (2003). Analysis of mechanical preparations in extracted teeth using ProTaper rotary instruments: Value of the safety quotient. *Journal of Endodontics*; **29**: 567-575.

Booth JR, Scheety JP, Lemons JE & Eleazer PD (2003). Comparison of torque required to fracture three different NiTi rotary instruments around curves of the same angle but of different radius when bound at the tip. *Journal of Endodontics*; **29**: 55-57.

Bortnick KL, Steinman HR & Ruskin A (2001). Comparison of nickel-titanium file distortion using electrical and air-driven handpieces. *Journal of Endodontics*; **27**: 57-59.

Cohen S & Burns RC (2002). Editors. Pathways of the Pulp, Eighth edition. The CV Mosby Company, St Louis. pp 914-917.

Davis RD, Marshall JG & Baumgartner JC (2002). Effect of early coronal flaring on working length change in curved canals using rotary nickel-titanium versus stainless steel instruments. *Journal of Endodontics*; **28**: 438-442.

Fife D, Gambarini G, Britto LR, Fla G & Sapienza L (2004). Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. *Oral Surg, Oral Med, Oral Pathol, OralRadiol Endod;* **97**: 251-256.

Gabel W, Hoen M, Steinman HR, Pink FE & Dietz R (1999). Effect of rotational speed on nickel-titanium file distortion. *Journal of Endodontics*; **25**: 752-754.

Gambill JM, Alder MA & Del Rio CE (1996). Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics*; **22**: 369-375.

Garala M, Kuttler S, Hardigan P, Steiner-Carmi R & Dorn S (2003). A comparison of the minimum canal wall thickness remaining following preparation using two nickel-titanium rotary systems. *International Endodontic Journal*; **36**: 636-642.

Glickman GN (1997). Nickel Titanium rotary instruments for root canal preparation: Are we there yet? *Alpha Omega;* **90**: 29-38.

Gluskin AH, Brown DC & Buchanan LS (2001). A reconstructed computerized tomographic comparison of NiTi rotary GT files versus traditional instruments in canals shaped by novice operators. *International Endodontic Journal*; **34**: 476-484.

Glosson CR, Haller RH, Dove SB & Del Rio CE (1995). A comparison of root canal preparations using NiTi hand, NiTi engine driven and K-flex endodontic instruments. *Journal of Endodontics*; **21**: 146-151.

Haikel Y, Serfaty R, Wilson P, Speisser JM & Allemann C (1998). Mechanical properties of nickel-titanium Endodontic instruments and the effect of sodium hypochlorite treatment. *Journal of Endodontics*; **24**: 731-735.

Heling I, Irani E Karni S & Steinberg D (1999). *In vitro* antimicrobial effect of RC-Prep within dentinal tubules. *Journal of Endodontics*; **25**: 782-785.

Hübscher W, Barbakow F & Peters OA (2003). Root canal preparations with FlexMaster: canal shapes analysed by micro-computed tomography. *International Endodontic Journal*; **36**: 740-747.

Hülsmann M, Gressman G & Schäfers F (2003). A comparative study of root canal preparation using FlexMaster and Hero 642 rotary NiTi instruments. *International Endodontic Journal;* **36**: 358-366.

Iqbal MK, Fimi S, Tulcan J, Karabucak B & Kim S (2004). Comparison of apical transportation between Profile and ProTaper, NiTi rotary instruments. *International Endodontic Journal*; **37**: 359-364.

Jansen van Rensburg BG, (1986). Classification of dentine – a morphological study. *Journal of the Dental Association of South Africa*; **41**: 689-695.

Jansen van Rensburg BG, (2001). Biology of the pulp. *South African Dental Journal*; **56**: (2) 87-90.

Karagöz-Kücükay I, Ersev H, Engin-Akoca E, Kücükay S & Gursoy T (2003). Effect of rotational speed on root canal preparation with Hero 642 rotary NiTi instruments. *Journal of Endodontics*; **29**: 447-449.

Kazeni RB, Stenman ES & Spangberg LSW (1995). The endodontic file is a disposable instrument. *Journal of Endodontics*; **21**: 451-455.

Koch K & Brave D (2003). Design of rotary files and how they affect clinical performances. *Oral Health*; **96**: 601-607.

Kosa DA, Marshall G & Baumgartner JC (1999). An analysis of canal centering using mechanical instrumentation techniques. *Journal of Endodontics*; **6**: 441-443.

Kuhn G & Jordan L (2002). Fatigue and mechanical properties of nickel-titanium endodontic instruments. *Journal of Endodontics*; **28**: 716-720.

Lee D, Park B, Saxena A & Serene TP (1996). Enhanced surface hardness by Boron implantation in Nitinol Alloy. *Journal of Endodontics*; **22**: 543-546.

Levin HJ (1967). Access cavities. *Dental clinics of North America;* **'1967':** 701-710.

Lim K & Webber J (1985). The effect of root canal preparation on the shape of the root canal. *International Endodontic Journal***; 18:** 233-239.

Luiten DJ, Morgan LA, Baumgartner JC & Marshall JG (1995). A comparison of four instrumentation techniques on apical canal transportation. *Journal of Endodontics*; **21**: 26-31.

Martin B, Zelada G, Vaiela P, Bahillo G, Magan F, Ahn S & Rodriquez C (2003). Factors influencing the fracture of nickel-titanium rotary instruments. *International Endodontic Journal*; **36**: 262-266.

Miserendino LJ, Moser JB, Heuer MA & Osetek EM (1986). Cutting efficiency of endodontic instruments. Part II: Analysis of tip design. *Journal of Endodontics*; **12**: 8-12.

Peters OA, Peters CI, Schönenberger K & Barakow F (2003). ProTaper rotary root canal preparations: assessment of torque and force in relation to canal anatomy. *International Endodontic Journal*; **36**: 93-99.

Ponti TM, McDonald NJ, Kuttler S, Strassler HE & Dumsha TC (2002). Canal centering ability of two rotary file systems. *Journal of Endodontics*; **28**: 283-286.

Pruett JP, Clement DJ & Carnes DL (1997). Cyclic fatigue testing of nickel-titanium endodontic instuments. *Journal of Endodontics*; **23**: 77-85.

Rome WJ, Doran JE & Walker WA III (1985). The effectiveness of glyoxide and sodiumhypochlorite in preventing smear layer formation. *Journal of Endodontics*; **11**: 281-288.

Russel AD (1991). Principles of antimicrobial activity. *In*: Block SS editor. Disinfection, sterilization and preservation. Lea and Febiger, Philadelphia, pp29-58.

Schäfer E, Dzepina A & Danesh G (2003). Bending properties of rotary nickel-titanium instruments. *Oral Surg, Oral Med, Oral Path, Oral Radiol Endod*; **96**: 757-763.

Schäfer E & Lau R (1999). Comparison of cutting efficiency and instrumentation of curved canals with nickel-titanium and stainless-steel instruments. *Journal of Endodontics;* **25**: 427-430

Schäfer E & Lohmanns D (2002a). Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile. Part 1: Shaping ability in simulated curved canals. *International Endodontic Journal*; **35**: 505-513.

Schäfer E & Lohmanns D (2002b). Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile. Part 2: Cleaning effectiveness and instrumentation results in severely curved root canals of extracted teeth. *International Endodontic Journal*; **35**: 514-521.

Schäfer E & Schlingemann R (2003). Efficiency of rotary nickel-titanium K3 instruments compared with stainless steel hand K-Flexofile. Part 2: Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. *International Endodontic Journal*; **36**: 208-217.

Schilder H (1993). Revolutionary new concepts in endodontic instruments sizing. *Journal of Endodontics;* **7**: 166-172.

Schilder H & Yee FS (1984). Canal debridement and disinfection. *In:* Cohen S, Burns RC, editors Pathways of the Pulp, Third edition, The CV Mosby company, St Louis, p175.

Schrader C, Ackermann M & Barbakow F (1999). Step-by-step description of a rotary root canal preparation technique. *International Endodontic Journal*; **32**: 312-320.

Silvaggio J & Hicks ML (1997). Effect of heat sterilization on the torsional properties of nickel-titanium files. *Journal of Endodontics*; **23**: 731-734.

Siquira JF, Batista M, Fraga RC & de Uzeda M (1998). Antibacterial effects of endodontic irrigants on black-pigmented gram-negative anaerobes and facultative bacteria. *Journal of Endodontics*; **24**: 390-395.

Slutzky-Goldberg I, Liberman R & Heling I (2002). The effect of instrumentation with two different file types, each with 25% NaOCl irrigation on the micro hardness of Root dentine. *Journal of Endodontics*; **28**: 311-312.

Stenman E & Spånberg LSW (1990). Machining Efficiency of Endodontic files: A new methodology. *Journal of Endodontics*; **16**: 151-157.

Stock CJR, Gulabivala K, Walker RT & Goodman JR (1995). Colour Atlas and Text of Endodontics Second edition Times Mirror International, Mosby-Wolfe Company, London, p1-5.

Svec TA & Powers JM (2002). The deterioration of rotary nickel-titanium files under controlled conditions. *Journal of Endodontics* ; **28**: 105-107.

Usman N, Baumgartner JC & Marshall JG (2004). Influence of instrument size on root canal debridement. *Journal of Endodontics*; **30**: 110-112.

Walia H, Brantley WA & Gerstein H (1988). An initial investigation of the bending and torsional properties of nitinol root canal files. *Journal of Endodontics*; **14**: 346-351.

Weigner R, Bruickner M, El Ayontia A & Löst C (2003). Preparation of curved root canals with rotary FlexMaster instruments compared to Lightspeed instruments and NiTi hand files. *International Endodontic Journal*; **36**: 483-490.

Weine FS, Kelly RF & Lio PF (1975). The effect of preparation procedures on original canal shape and on apical foramen shape. *Journal of Endodontics*; **1**: 255-262.

Yared G, Dagher FB & Kulkarni K (2003). Influence of torque control motors and operators' proficiency on ProTaper failure. *Oral Surg, Oral Med, Oral Pathol, Oral Radiol Endod*; **96**: 229-233.

Yoshida T, Shibata T, Shinohara T, Gomyo S & Sekine I (1995). Clinical evaluation of the efficacy of EDTA Solution as an endodontic irrigant. *Journal of Endodontics*; **21**: 592-593.