NICKEL TITANIUM ROTARY INSTRUMENTATION IN THE CORONAL ROOT THIRD OF CURVED CANALS

by

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We accept this thesis as conforming
to the required standard

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Abstract

One of the desired outcomes of root canal instrumentation is to stay centered in the root canal and avoid stripping of the walls which could lead to perforation. Previous studies have shown that nickel titanium (NiTi) instruments stayed centered in the root canal system to a greater degree than stainless steel instruments. However, in cases such as mesial roots of mandibular molars, where root canals lie closer to the furcation side or the inner part of curved roots (danger zone), root canal instrumentation should be directed away from this region. This type of instrumentation, anticurvature filing technique, has not been reported utilizing rotary NiTi files to determine if removal of dentin during instrumentation can be directed away from the danger zone. It is of clinical significance to determine if rotary NiTi files can be directed away from the danger zone in order to avoid perforation and canal stripping which can lead to endodontic failure.

The aim of this study was to investigate whether rotary NiTi Orifice Shapers™ (Profile®, Tulsa Dental, Dentsply, USA) can be directed away from the danger zone, into the bulky or safety zone of the root dentin during instrumentation of the coronal portion of mesial canals of mandibular molars. For studying the anatomical morphology of root canals before and after instrumentation teeth were mounted in a modified muffle block. The modified muffle block allowed for removal and exact repositioning of the complete tooth block after tooth sectioning. Teeth modified muffle blocks were sectioned at 3 different levels, around furcation and orifice. The mesial canals were divided into 2 groups. Group A (Force group) where force was applied 90 degree to the long axis of the root while instrumenting with NiTi Orifice Shapers™ (Profile®). Group B (no force group)

functioned as control where no lateral force was applied during the instrumentation. Prior to instrumentation using NiTi rotary Orifice Shapers™ (Profile®), the canals in both groups were enlarged with K-files hand-instruments (Union Broach) up to size 25 as a pre-rotary instrumentation step. The first rotary instrumentation of canals was done using NiTi Orifice shapers™ (Profile®) according to the manufacturers suggested sequence sizes 30, 50, 40. The second rotary instrumentation of canals involved size 40 Orifice Shapers™ (Profile®) only. The third instrumentation of canals was done with Gates-Glidden bur #2 (Dentsply, Oklahoma, USA) as a positive control. The modified muffle block sections were scanned before and after each instrumentation. The images were superimposed in Corel Photopaint™ (Corel, Ottowa, CA) and transferred to Scion NIH image 1.62 (Scion Corp, Maryland, USA). Utilizing this software the X-Y centre point coordinates and the area of each canal space were computed. The X-Y centre point movement was calculated after the first rotary instrumentation, after the second rotary instrumentation and finally after Gates-Glidden instrumentation. The lateral force was applied 90 degrees to the long axis of the tooth, and was measured with an Instron Universal Testing Machine (Instron, Massachuset, USA), at all times.

No significant difference in canal centre movement was found between force and no force groups after first and second rotary instrumentation. However, a significant difference ($p=0.007$) was seen in canal centre movement between force and no force groups after Gates-Glidden instrumentation (positive control). It was concluded that with the amount of force (3-5.5N) and the time period (12-16sec) under which the force was applied, it is not possible to direct NiTi Orifice Shapers™ away from the danger area in the coronal root third of the mesial root of mandibular molars.

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1.Introduction

1.1– Background

It is well known by dental clinicians that inadvertent procedural errors can occasionally arise during the instrumentation of curved root canals. The misfortunes include ledge or zip formation, perforation of the canal, and separation or fracture of the instrument (Walia *et al.*, 1988). Although instrumentation technique may play a role, many of these procedural errors are caused by the stiffness of the stainless steel alloys used to manufacture root canal files. Because of their stiffness, files used within curved canals tend to transport out of, rather than remain in the centre of, the natural canal pathway. As a consequence, the root canal morphology is adversely altered, a violation of the basic principle that endodontic preparation is to retain the original shape of the canal (Walia *et al.*, 1988). Dental clinicians have adopted various methods to circumvent problems during the preparation of curved canals, such as pre-curving instruments and using different instrumentation techniques. Manufacturers have also marketed a number of instruments based on different cross-sectional shapes, design concepts, and fabrication procedures in a quest for improved cutting efficiency and flexibility (Rowan *et al.*, 1996).

In 1988, Walia *et al.* were the first investigators that used an entirely different metallurgical system, Nitinol nickel titanium orthodontic wire alloy, for the fabrication of endodontic files. The expectation was that nickel titanium alloy with a very low modulus of elasticity, superior flexibility in bending, and great resistance to torsional fracture was the ultimate answer to the problems associated with root canal instrumentation using stainless steel instruments.

Recently many different brands and designs of NiTi files have been marketed. Most commercially available nickel titanium instruments have design similarities with stainless steels counterparts. However, it is technically more complicated to manufacture or fabricate nickel titanium than stainless steel instruments resulting in more design limitations (Kazemi *et al.*, 1996).

1.2 – Characteristics of Nickel-Titanium Files

1.2.1 – Design

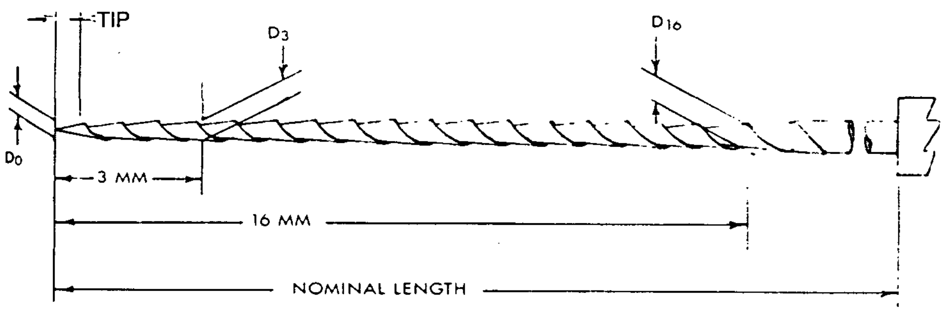

Figure 1 - Dimensional formula for H-type instruments.

(Ingle & Bakland, 1994)

Size	Diameter (Tolerance, ± 0.02 mm) D$_1$ mm	D$_2$ mm	D$_3$ mm	Handle Color Code
08	0.08	0.40	0.14	Gray
10	0.10	0.42	0.16	Purple
15	0.15	0.47	0.21	White
20	0.20	0.52	0.26	Yellow
25	0.25	0.57	0.31	Red
30	0.30	0.62	0.36	Blue
35	0.35	0.67	0.41	Green
40	0.40	0.72	0.46	Black
45	0.45	0.77	0.51	White
50	0.50	0.82	0.56	Yellow
55	0.55	0.87	0.61	Red
60	0.60	0.92	0.66	Blue
70	0.70	1.02	0.76	Green
80	0.80	1.12	0.86	Black
90	0.90	1.22	0.96	White
100	1.00	1.32	1.06	Yellow
110	1.10	1.42	1.16	Red
120	1.20	1.52	1.26	Blue
130	1.30	1.62	1.36	Green
140	1.40	1.72	1.46	Black
150	1.50	1.82	1.56	White

Table 1 - Dimensions in mm. Revision of ADA specification No.28.

(Ingle & Bakland, 1994)

In January 1976, the American standards Institute granted approval of ADA specification No. 28 for endodontic files and reamers. It established the requirements for diameter, length, resistance to fracture, stiffness, and resistance to corrosion. It also included specification for sampling inspection and test procedures (Ingle & Bakland, 1994). In the current ISO system the dimensional increase from one instrument to the next in a series of instruments when measured at D_0 is 0.02, 0.05, or 1mm (Table 1)(Fig 1). Initially manufacturers of endodontic instruments worldwide adhered rather closely to these specifications. Some variations have been noted, however, in size maintenance (diameter and taper), surface debris, cutting flute character, torsional properties, stiffness, cross-sectional shape, cutting tip design and type of metal. In 1992, a different concept of instrument sizing was introduced. Marketed as Profile^{R} series 29^{R} the instrument sizes progressed by a constant percentage increase (29%) in tip diameter from one instrument to the next, rather than by variable increases in tip diameter as seen in standardized ISO instruments (Ingle & Bakland, 1994).

Nickel titanium files are designed in K-type, H-type and U-type configurations. K-type instruments are usually produced by grinding graduated sizes of a round wire into either square or triangular configuration. A second grinding operation tapers these pieces. To give the instruments the spirals that provide the cutting edges, the square or triangular stock is then grasped by machine that twists it counter-clockwise a programmed number of times. All nickel titanium endodontic files are machined because it is impossible for a NiTi wire to undergo the inelastic deformation necessary to create the number of flutes of an endodontic instrument. The cutting blades that are produced are the sharp edges of either the square or triangular stock. These edges are known as the "rake" of the blade. For given direction of an instrument in use, the rake angle is the angle the cutting edge makes with the dentin surface. If this surface is turned in the same direction as the force applied, the rake angle is positive. On the other hand, if the blade performs a scraping action faced away from the direction of the force, the rake angle is said to be negative (Cohen & Burns, 1998). The more acute the angle of the rake, the sharper the blade (Ingle & Bakland, 1994). The tighter spiral of the file establishes a cutting angle (rake) that achieves its principal cutting action on withdrawal, although it will cut in a push motion as well. H-type files (Hedström files) are made by cutting the spiraling flutes into

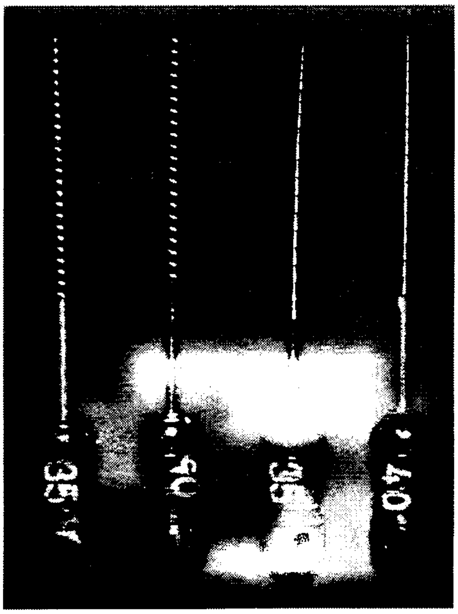

Figure 2 –From right to left, stainless steel Hedström files (hand files) 35, 40, stainless steel K-Files (hand files) 35, 40.

the shaft of a piece of round and tapered wire (Fig 2). H-type files cut in one direction only; on withdrawal. They have a positive rake angle of the flutes design (Ingle & Bakland, 1994). The new U-file's cross-sectional configuration is triangular, but with two 90-degree cutting edges at each point of the triangular blade (Ingle & Bakland, 1994). Since Walia introduced the first nickel titanium files (Walia *et al.*, 1988), different manufacturers have introduced different designs of nickel titanium files to improve the ability of these files to debride and instrument curved canals and limit complications such as zipping, ledging and perforation. Design variations of nickel titanium files include length of the cutting head, tip design, length of the shaft etc. The design of some of the most recent rotary nickel titanium files available in the market will be described in this chapter.

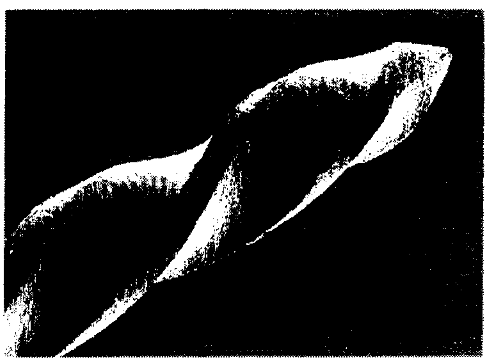

Figure 3- Profile^R 0.04 taper series 29^R (Electron microscope image X125), flutes with flat outer edge and bullet nosed tip.

(Thompson & Dummer, 1997, 2a)

Profile^R 0.4 taper series 29^R (Tulsa dental, Oklahoma, USA) are made by grinding three equally spaced, U-shaped grooves around the shaft of a tapered nickel titanium wire. These instruments have flutes with flat outer edges, known as radial lands that cut with a planning action (Fig 3). The radial lands allow greater accuracy of measurements in manufacturing, with a tolerance of ± 0.003 mm as opposed to the usual tolerance of ± 0.02 mm. The flats also allow the file to remain self-centered as it rotates through 360°. The Profiles^R have a `bullet nosed` tip with rounded transitional angle. The rate of increase between file tip sizes is a constant 29% so that although the size increase between the first two instruments is comparable to the ISO standards, there is a much greater incremental increase in size with the larger instruments (Thompson & Dummer, 1997 2a).

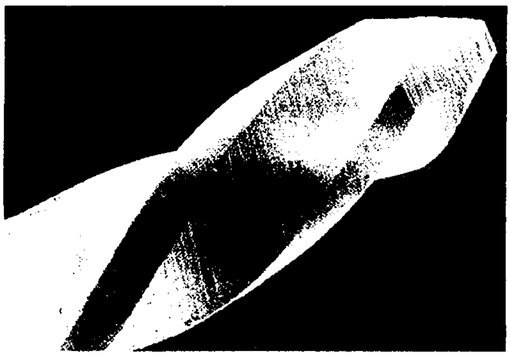

Figure 4 - Profile^R 0.04 taper (Electron microscope image X125). Flutes with flat outer edge. Bullet nosed tip with rounded transitional angle.

(Bryant *et al*, 1998)

Profile^R 0.04 tapers instruments (Tulsa dental, Oklahoma, USA) with ISO size tip have a similar design to the profile series 29^R with flutes that have flat outer edges, known as radial lands. The instrument is made by grinding three equally spaced, U-shaped grooves around the shaft of a tapered nickel titanium wire (Fig 4). The Profiles^R have a `bullet nosed` tip with rounded transitional angle. A portion of 56% Nickel, 44% Titanium is used in the production of the wire blank (Bryant *et al.*, 1998 1a)(Fig 5).

Profile^R Orifice Shapers^{TM} (Tulsa Dental, Oklahoma, USA) are rotary nickel titanium instruments designed to prepare the coronal portion of the root canal, before instrumentation with Profile^R 0.04 tapers files (Tulsa Dental, Oklahoma, USA). Orifice Shapers^{TM} files have a U-file radial-landed flute design. The total length of the file is

19mm, with a cutting area approximately 9mm. Orifice Shapers™ are available in six sizes; 20, 30, 50, 40, 60, 80. For standard root canal sizes the manufacturer recommends to prepare the canal in the sequence 30,50,40, with constant speed of 150 to 300 RPM (Fig 6) (Dentsply, Tulsa Dental products, information brochure).

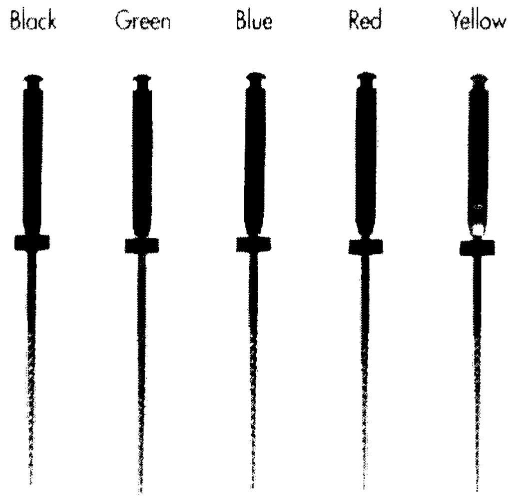

Figure 5 - Profile® 0.04 tapers instruments.

(Tulsa Dental Product, information brochure)

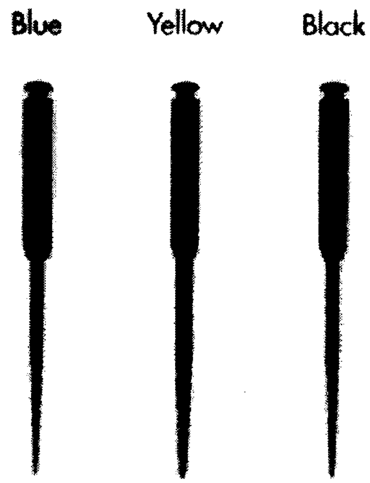

Figure 6 - From left to right, Profile® Orifice Shapers™ sizes 30,50,40.

(Tulsa Dental Product, information brochure)

There are other types of instruments used to prepare the root canal system including NT files, McXim files, Quantec series 2000 files, and Lightspeed instruments. The characteristics of each these file system is described below.

NT Engine driven files (NT company, Chattanooga, TN, USA) have a standard 0.02 taper and two different rotary instrument designs. Sizes 15-35 are H-type files with radial lands and are essentially Hedström files that have been manufactured by grinding a single L-shaped groove which spirals around the tapered round wire. A space has been left between each groove to create a 'land' or 'flat' (Fig 7). NT engine files sizes 37.5-60 have

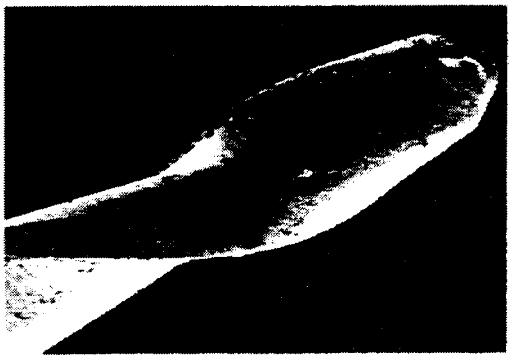

Figure 7- NT Engine driven files (Electron microscope image, X120).

(Thompson & Dummer, 1997, 3a)

a dissimilar helical design. The working surfaces of these instruments contain two or more blades that spiral around the shaft at different angles and rates (Thompson & Dummer, 1997 3a).

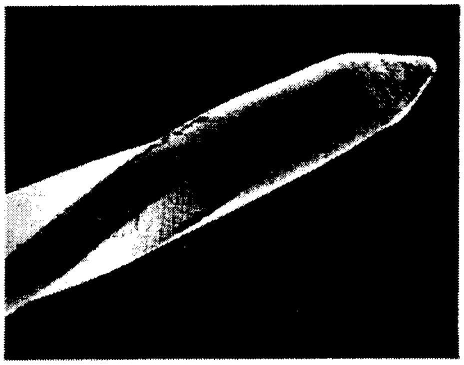

Figure 8 - McXim file with 0.055 taper and U-file design (Electron microscope image, X120).

(Thompson & Dummer, 1997, 3a)

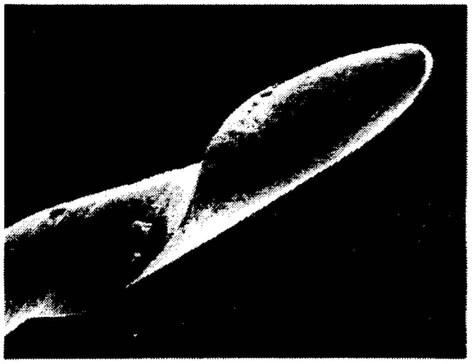

Figure 9 - McXim file with 0.05 taper and H-file design (Electron microscope image, X120).

(Thompson & Dummer, 1997, 3a)

McXim files (NT company, Chattanooga, TN, USA) supplement the NT engine files. They incorporate six tapers ranging from a combination 0.02 through 0.03, 0.04, 0.045, 0.05 to a 0.055 taper; all having an ISO size 25 tip. The McXim 0.03T, 0.045T, and 0.055T files have a U-file design with three equally spaced grooves ground into the file shaft (Fig 8). The 0.04T and 0.05T files incorporate the H-type design with radial land which are wider towards the instrument tip (Fig 9)(Thompson & Dummer, 1997 3a).

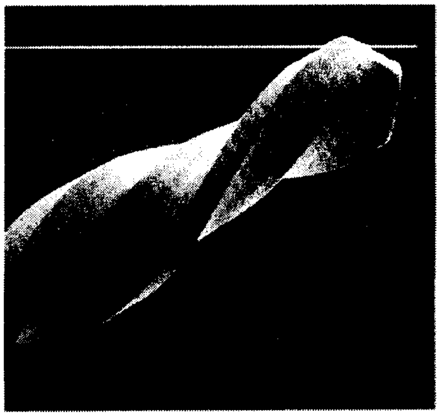

Figure 10 - Quantec series 2000 file with 0.06 taper and size 40 tip (Electron microscope image, X120).

(Thompson & Dummer, 1998, 4a)

Quantec series 2000 files (NT company, Chattanooga, TN, USA) have unequally spaced wide radial lands and a reduced peripheral surface ground around the shaft of nickel-titanium wires. The manufacturer claims that the instruments have blades with positive cutting edges that spiral around the shaft in 30• helix angle, helix angle is the angle between the axis of the instrument and the axis of the flutes (Cohen & Burns, 1994) (see fig 11). It varies with the type of instruments, the brand and the file size (Felt *et al.*, 1982). There are 10 Quantec instruments in the recommended series of files used for instrumentation. The first instrument in the series is an orifice enlarger which has a 0.06 taper (Fig 10), this is followed by three standard tapered instruments with ISO tip size 15, 20 and 25, four instruments which range in taper from 0.03 to 0.06 all with a size 25 tip and finally two standard 0.02 taper instruments with size 40 and 45 tips. The tip itself has four-facets which, as the cutting angle is positive, is claimed to allow maximum cutting efficiency to be achieved (Thompson & Dummer, 1998, 4a).

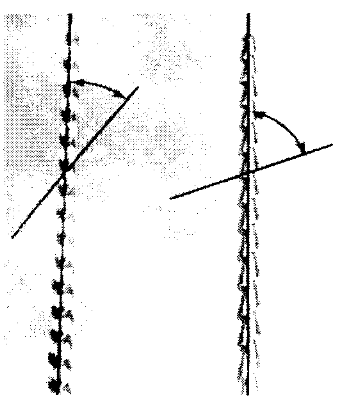

Figure 11 - Helical (Helix) angle of K- (left) and H-type file. Greater cutting efficiency is achieved in filing motion as the helical angle approaches 90° to the dentin surface.

(Cohen&Burns, 1994)

Lightspeed (Lightspeed technology, USA) instruments have a flexible non-tapered 16 mm shaft with a short cutting head with U-file blade design having a neutral rake angle and non-cutting tip. This is quite a unique instrument which only cuts at the head and has no cutting ability along the shaft. The complete set of 22 Lightspeed instruments are manufactured in sizes 20 to 100 with half sizes difference between 20 and 65. These files are improved version of the rotary Canal Master U (Knowles *et al.*, 1996) and were designed to prepare the entire root canal from the orifice to apical foramen.

Among the rotary instruments discussed, Profile^{R} Orifice Shapers^{TM} is the only instrument specifically designed for instrumenting and shaping coronal third of the root canal. Therefore this file was selected for the purpose of our study.

1.2.2 - Mechanical properties

The use of nickel titanium alloys in dental fields has been limited for years to orthodontic arch wires, where their low level of stiffness and their excellent springback property are useful (Camps *et al.*, 1995 b). However, there is a great discrepancy between the mechanical properties of the nickel titanium orthodontic arch wires available on the market (Yoneyama *et al.*, 1992). This might be partially due to the fact of variations in composition of nickel titanium alloys chosen by manufacturers.

Presently four different nickel titanium products are available: Nitinol (N for nickel, T for titanium and NOL for Naval Ordnance Laboratory; Lipshatz *et al.*, 1992), cobalt-substituted Nitinol (Andreasen & Hilleman, 1971), Chinese NiTi (Burston *et al.*, 1985) and Japanese NiTi (Miura *et al.*, 1986)(Camps & Pertot, 1995 a).

NiTi possess the properties of super-elasticity, shape memory, high corrosion resistance, and excellent biocompatibility. Super elasticity and shape memory are properties by which, upon force unloading, a material recovers the strain and subsequently reverts back to its original shape. These characteristics are conferred on NiTi by the transition from a parent austenitic structure to a martensitic one on loading. This is reversible on load cessation, and contrasts with stainless steel, which reacts to stress by conventional elastic behaviour and consequent permanent deformation (Haikel *et al.*, 1998 b).

Walia *et al.*, in 1988, were the first investigators to use Nitinol nickel titanium orthodontic wire alloy for the fabrication of endodontic files. The purpose of their study was to investigate the feasibility of manufacturing root canal files from Nitinol and to evaluate the bending and torsional properties of these instruments. Experimental Nitinol root canal files were fabricated in size 15 with triangular cross-sections, for comparison to size 15 stainless steel files with the same cross-sectional shape and manufactured by the same process. The Nitinol and stainless steel files were evaluated in the three mechanical testing modes of bending, clockwise torsion, and contour clockwise torsion. The Nitinol files were found to have two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture compared with size 15 stainless steel files. Their results suggested that because of these characteristics, Nitinol files might be promising for the instrumentation of curved canals (Walia *et al.*, 1988).

Several studies have been done on mechanical properties of nickel titanium files such as ductility, torsional fracture, stiffness and strength of this alloy. The ductility of an endodontic file is measured by the amount of rotation it can withstand before failure. Ductility can also be considered a safety factor (Seto *et al.*, 1990). Torsional moment and maximum angular deflection indicates the resistance to torsional fracture of an instrument. Maximum bending moment indicates the stiffness of the instrument and permanent angular deflection the strength of the base of alloy (Wolcott & Himel, 1997). The results of these studies will be discussed in this chapter. Many investigations have compared the properties of nickel titanium hand files with stainless steel hand files (Camps & Pertot, 1994) (Rowan *et al.*, 1996).

Camps & Pertot, in 1994, compared the stiffness and resistance to fracture of stainless steel (CMU-SS) and nickel titanium Canal Master U (CMU-NiTi) hand instruments. Instruments sizes 20 through 50 were tested according to ANSI/ADA specification No. 28 for bending moment. The American National Standards Institute (ANSA)/American dental association (ADA) has established maximum stiffness and resistance to fracture by twisting for different sizes of K-type files in specification No 28 (see table 2). A resistance to fracture was determined by twisting and measuring the maximum torque at failure in clockwise and counter clockwise rotation and the maximum angular defection at failure in clockwise and counter clockwise rotation. Stiffness was determined by measuring the maximum bending moment required to bend the instruments 45°. Stainless steel and nickel titanium Canal Master U and instruments satisfied and far exceeded specification standards for stiffness. They also satisfied and far exceeded the standards for angular deflection at the failure point. Angular deflection for CMU-SS (#30; 600°) was significantly lower (p=0.000) than CMU-NiTi (#30; 1900°) for sizes 20 and 30 but significantly higher for sizes 30 through 50 (CMU-SS #30; 900° vs CMU-NiTi #30; 800°). For CMU-NiTi the bending moment was at least seven times lower than stainless steel, in all sizes. The conclusion of their study was that the very low bending moment means that CMU-NiTi is very flexible which is clinically very desirable (Camps & Pertort, 1994).

File	Bending moment (g.cm)	Torsional moment (g.cm)	Angular deflection (degree)
Size	Max Iso value	Min Iso value	Min Iso value
25	120	30	360
30	150	45	360
35	190	65	360
40	250	100	360

Table 2 - ISO specification No. 28

In another study Camps & Pertot, in 1995, compared the stiffness and resistance to fracture of four brands of nickel titanium K-files: Brassler (Savanah, USA), JS Dental (JS

Dental Inc, USA), Mac Spadden (NT Co Inc, USA), Maillefer (Maillefer, Switzerland) with stainless steel K-file. Instruments sizes 20 through 50 were tested according to ANSI/ADA specification No. 28. Resistance to fracture was determined by twisting and measuring the maximum torque and angular deflection at failure. Stiffness was determined by measuring the moment required to bend the instruments 45°. Nickel titanium K-files satisfied and far exceeded specification standards for stiffness. They also satisfied and exceeded the standards for angular deflection at failure. NiTi files presented a bending moment five or six times lower than stainless steel K-files: they were five to six times more flexible. NiTi also met or exceeded the maximum torque at failure standards in all sizes. There was a significant difference among the torque at failure of the five types of files ($p<0.001$). The values for torque at failure for NiTi files were lower than stainless steel, which is a disadvantage, but their bending moment was so low that they were considered safer clinically. Nickel titanium K-files also presented a null permanent deformation angle (angle between the tip of the instrument and its cutting blade after the 45° bending ceased). On the contrary, stainless steel K-files presented a permanent deformation angle ranging from 9.94° to 18.14°. The stress generated by the rotation of an instrument in a curved canal is increased by the permanent deformation angle; its tip undergoes a stress equal to the canal curvature added to the permanent deformation angle (Camps & Pertot, 1995 a).

In 1996, Rowan *et al.* studied torsional properties of stainless steel and nickel titanium endodontic hand files (Quality dental products, TN). File sizes 15, 25, 35, 45, and 55 were subjected to torsional load in clockwise (CW) and counter clockwise (CCW) directions independently. Results showed that stainless steel files had significantly greater rotation to failure in the CW direction, whereas the NiTi files had a significantly greater rotation to failure in the CCW direction. Despite these differences in rotation to fracture, there was essentially no difference between the SS and NiTi instruments in the torque that it took to cause failure in both the CW and the CCW directions. Therefore, whereas the number of CW and CCW rotations to failure deferred for the two instruments, the actual force that it took to cause that failure was the same (Rowan *et al.*, 1996).

Canalda-Sahli *et al.*, in 1996, investigated torsional and bending properties of stainless steel and nickel titanium Canal Master U and Flexogate hand instruments. The bending moment, the torsional moment and angular deflection were measured according to ANSI/ADA specification No. 28. All endodontic instruments satisfied ANSI/ADA and ISO standards for flexibility. Stainless steel instruments presented a significantly ($p<0.05$) higher bending moment (Flexogate #30; 32.06 g cm) than those made of nickel titanium. Nickel titanium instruments were significantly more flexible than stainless steel files. With regard to the torsional moment, values obtained were below the standards in all sizes except stainless steel CMU sizes 25, 35 and 40, and nickel titanium CMU size 25. Nickel titanium instruments also showed the highest angular deflection values (Flexogate #30; 1068°) (Canalda-Sahli *et al.*, 1996 a). In another study Canalda-Sahli *et al.*, in 1996, compared bending and torsional properties of K-files with triangular cross-section manufactured with different metallic alloys. Five groups of K-type files were studied: Nitiflex (Maillefer, Switzerland), Naviflex (Brassler, Savanah, USA) both of which are nickel titanium files; Microtitane (MicroMega, Switzerland) a titanium file and two of stainless steel flexofile (Maillefer, Switzerland) versus Flex-R (Union Broach, USA). Ten instruments for each type from size 25 to 40 were tested according to ANSI/ADA specification No. 28. Files made of nickel titanium, especially Nitiflex, were the most flexible. Stainless steel instruments presented a higher bending moment (Flexofile #30, 63.30 g cm) than files made of nickel titanium (Nitiflex #30, 21.57g cm) and titanium (Microtitan #30, 48.03 g cm). Stainless steel files showed the highest torsional moment (Flexofile #30; 60.75gcm). With regard to resistance to fracture, measured by angular deflection at the failure point, all files satisfied or far exceeded the minimum standards according to ANSI/ADA and ISO specifications. Stainless steel files in all sizes were the most resistant (Flexofile #30; 1328°), with statistically significant ($p<0.05$) differences as compared with the remaining three types of files (Canalda-Sahli *et al.*, 1996 b).

In 1997, Wolcott & Himel compared and evaluated the torsional properties of stainless steel K-type .02 taper and nickel titanium U-type .02 and .04 taper (Quality Dental Products, TN) hand instruments. Torsion tests were performed on all three designs of instruments according to ANSI/ADA specification No.28. The three parameters measured were maximum torque, torque at failure, and angular deflection. All files met or exceeded specification standards for maximum torque. They also satisfied and far exceeded the standards for angular deflection at the failure point. The stainless steel instruments showed no significant difference between maximum torque (SS #35; 106.7) and torque at failure (SS #35; 103.7 g cm), whereas both of the nickel titanium instruments showed a significant difference ($p<0.05$) between maximum torque (NiTi 0.4taper; 139.7 g cm) and torque at failure (NiTi 0.4taper; 127.7 g cm). Rotation at failure decreased with increased instrument size in the stainless steel group. The results for the NiTi .02 tapered group were just the opposite (Wolcott & Himel, 1997).

In 1995, Camps *et al.* studied the relationship between file size and stiffness of nickel titanium hand instruments. Three groups of endodontic nickel titanium files with different cross-sections were tested: a triangular cross-section, a square cross-section and a modified triangular cross-section where facets of the triangular cross-section had been ground to create smaller cross-section area. The instruments were tested from size 15 to size 40 or 60 according to ANSI/ADA specification No. 28 for bending moment evaluation. There was a statistically significant difference between the three groups: the square cross-section K-files presented larger bending moment (#35; 46 g.cm) than triangular cross-section K-files (#35; 28 g.cm), which presented a larger bending moment than the modified cross-section K-files (#35; 28 g.cm). Like stainless steel instruments, there was an exponential relationship between file size and bending moment for the triangular and square cross section K-files, but a linear relationship between file size and bending moment for the files with the modified triangular cross-section (Camps *et al.*, 1995 b).

In summary, Nitinol alloy has a very low modulus of elasticity and bending moment. This indicates the outstanding elastic flexibility of the material (Walia *et al.*, 1988). There is a controversy around the resistance to fracture comparing nickel titanium files to stainless steel files. When Walia *et al.* investigated this property with size 15 NiTi files, they concluded that NiTi files had superior resistance to torsional fracture (Walia *et al.*, 1988). However, other investigators such as Camps & Pertot, in 1994, found that the torque at failure for NiTi files of different sizes was lower than stainless steel, but because their bending moment was very low they were considered to be safer clinically. Camps and Pertot (Camps & Pertot, 1994) also stated that nickel titanium undergoes less permanent deformation than stainless steel when subjected to the same amount of stress, which could be a very important clinical property. This favourable ductility characteristic would reduce instruments fracture if a cutting blade were locked in a canal.

1.2.3 – Comparison of Nickel Titanium and Stainless Steel Files in terms of canal transportation

One of the aims of root canal instrumentation is to create a continuously tapering root canal and keep the apical constricture small and in its original position. It can be difficult to attain these goals with traditional instrumentation techniques, especially in high curved root canals. Because stainless steel files tend to straighten, even if pre-curved, they can cause zipping, tearing of the apex of curved canals and create an elbow (Weine *et al.*, 1975). Apical zip is defined as an irregular widened area created near the end-point of preparation (Fig 12). Elbows can occur concurrently with an apical zip and form a narrower region, more coronally (Fig 13). Ledges are irregular areas of the dentin removed from the outer aspect of the curved portion of the canal, in a more coronal region of the canal (Fig 14). Attempts to re-establish canal length past the ledge can result in the file tip cutting straight through the root structure and into the periodontal ligament (Fig 15).

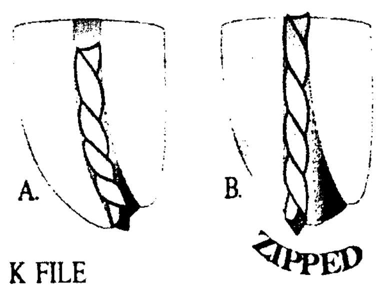

Figure 12 - Apical Zip
(Cohen&Burns, 1994)

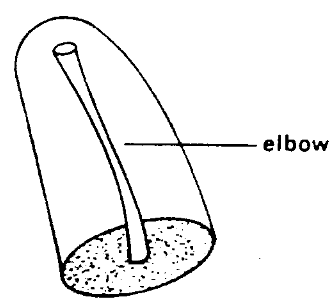

Figure 13 – Elbow
(Tidmarsh, 1982)

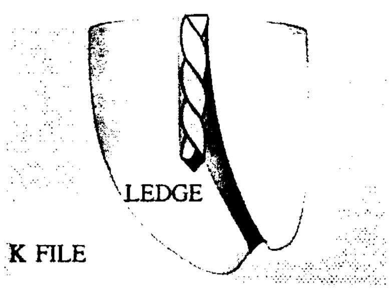

Figure 14 – Ledge
(Cohen&Burns, 1994)

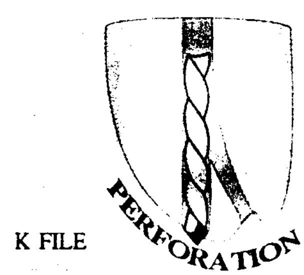

Figure 15 – Perforation
(Cohen&Burns, 1994)

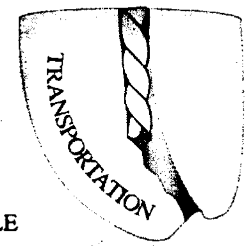

Figure 16 – Transportation
(Cohen&Burns, 1994)

Several investigators have compared the nickel titanium and stainless steel files for procedural canal aberrations and transportation after root canal instrumentation. Root canal transportation is defined as deviation form original canal position (Fig 16). Some of these studies will be discussed in this chapter.

Royal and Donnelly, in 1995, compared the ability of Flex-R, K-Flex and Brassler nickel titanium file to maintain roots canal curvature in curved root canals of extracted human mandibular molars using balanced force instrumentation. The canals were instrumented to working length up to size 45. The pre- and post-operative X-rays were projected and canal location traced to determine the canal curvature according to the method of Schneider. Results indicated statistically less reduction in canal curvature with nickel titanium files compared to stainless steel files (Royal & Donnelly, 1995).

Another study in 1995, by Esposito *et al.*, compared canal preparation with nickel titanium hand instruments (Mac), nickel titanium engine-driven (NiTi) files and stainless steel (K-Flex) files. Radiographs of pre- and post- instrumented canals were superimposed, images were digitized, and analyzed by NIH image software program. Nickel titanium hand and engine-driven instruments maintained the original canals path in all cases. The differences between nickel titanium groups and stainless steel became statistically significant ($P<0.05$) with instruments larger than size 30 (Esposito *et al.*, 1995).

Similar results were seen by other investigators. Himel *et al.*, in 1995, evaluated Nitinol and stainless steel hand files while instrumenting simulated curved canals in clear resin blocks. Overlay tracings were made of photographs taken before and after instrumentation of the blocks and differences between the tracings were measured along the canal walls. The canals instrumented with Nitinol files were shaped better than those instrumented with stainless steel files; as well, working length was maintained more often without ledging the canal walls and with less zipping of the apical foramen (Himel *et al.*, 1995).

In 1996, Tharuni *et al.* compared canal preparation using the stainless steel K-files and Lightspeed rotary instruments. Twenty-four resin blocks with simulated curved canals of 38 degrees were instrumented. The efficiency of canal preparation was evaluated at apical and mid-root levels, using magnified images of the radiographed blocks. The results showed that stainless steel K-files caused more widening at the apical level, with the higher incidence of transportation, zipping, and elbow formation (Tharuni *et al.*, 1996).

Lam *et al.*, in 1999, investigated the amount of apical and mid-curve transportation produced by a range of nickel titanium alloy (Mity H-File, Mity turbo), titanium file (Titane) and stainless steel files (H-file, K-file, Flexofile, safety H-file). Tests were carried out in simulated curved canals produced in resin blocks that were instrumented up to size 40. The results showed that there were substantial differences in amount and pattern of apical and mid-curve transportation produced. The amount of transportation increased with each subsequent size of file. Nickel titanium files produced significantly less transportation than stainless steel files. The least apical and mid-curve transportation was obtained with the NiTi Mity turbo (Lam *et al.*, 1999).

Pettiette *et al.*, in 1999, compared the effect of the type of instrument used by dental students on the extent of straightening and on the incidence of other endodontic procedural errors. Nickel titanium 0.02 taper hand files were compared with traditional stainless steel taper K-files. Sixty molars comprised of maxillary and mandibular first and second molars were treated. Pre and post-operative radiographs of each tooth were scanned, superimposed and analyzed. The degree of deviation of the apical third of the root canals from the original canal was measured. The presence of other errors such as strip perforation and instrument breakage was established by examining the radiographs. In curved canals instrumented by nickel titanium hand files, the deviation was significantly less. The incidence of other procedural errors was also significantly reduced by the use of nickel titanium hand files (Pettiette *et al.*, 1999).

In summary, nickel titanium endodontic instruments cause fewer procedural aberrations such as zipping, ledging and transportation compared to stainless steel files. This fact has clinical significance because a large part of success in endodontic therapy is to clean and shape the root canal system.

1.2.4- Shaping ability of rotary NiTi instruments

In order to facilitate obturation of the root canal system, adequate shaping of root canals is necessary. A continuously tapering funnel shape with the smallest diameter at the end-point and the largest at the orifice has seemed to be the most appropriate canal shape for filling with guta-percha and sealer (Schilder & Yee, 1984). Procedural misshapes such as zipped canals (Weine *et al.* 1975, Alodeh *et al.* 1989) and canal stripping (Abou-Rass *et al.* 1980, al-Omari *et al.* 1992a) have been shown to be created in curved canals following preparation with stainless steel hand files. Improvement in instrument design, particularly changes of tip configuration and cross-sectional shape (Roane *et al.*, 1985), has decreased the prevalence and severity of these procedural misshapes (al-Omari *et al.*, 1992 a&b). Unique characteristics of nickel titanium endodontic files such as increased flexibility and shape memory, allows shaping of curved and narrow root canals with less procedural misshapes.

Several investigators have studied the ability of different types of rotary nickel titanium instruments to prepare and shape the root canals. In 1997 and 1998, Thompson and Dummer published several studies on shaping ability of different types of NiTi rotary instruments. These studies were done in two parts. In part one they looked at the efficiency of the instrument in terms of preparation time, instrument failure, canal blockages, loss of canal length, and three-dimensional canal form (Thompson & Dummer, 1997 1a, 2a, 3a, 1998 4a). In the second part of their study they investigated the prevalence of canal aberrations, the amount and direction of canal transportation, and overall post-operative shape (Thompson & Dummer, 1997 1b, 2b, 3b, 1998 4b). They used 40 simulated canals with four different shapes in terms of angle and position of curvature, in each study. The canals prepared were 16mm long. The total length of the canal was investigated in terms of shape and aberrations.

In one study, Thompson and Dummer investigated shaping ability of Lightspeed ™ (Lightspeed technology, USA). Their results showed that when using Lightspeed ™ instruments canals were prepared quickly, and the time was not influenced by canals' shape. No fracture or deformation of the instruments occurred and none of the canals became blocked with debris. Seventeen canals retained their original working length, but 16 gained in length and seven lost length. Apical stops as judged from intra-canal impressions were present in 23 of the canals but they were all judged to be of poor quality. Most canals were smooth apically and coronally. On the other hand the Lightspeed ™ instrument produced canals with poor taper and poor flow characteristics (Thompson & Dummer, 1997 1a). Only one elbow was created with no ledges, perforations, or blockages being produced. Overall, the degree of absolute transportation was small with no significant differences between the canals shapes in the region apical to curve. The direction of canal transportation at the end point of preparation was most frequently towards the outer aspect of the curve. At the beginning of the curve, and half way to the orifice, transportation was reversed with the majority of canals being transported toward the inner aspect of the curve. They concluded that transportation was common. However, its magnitude was very small and was considered clinically insignificant as the original shape of the canal was largely maintained (Thompson & Dummer, 1997 1b).

Thompson and Dummer also investigated the shaping ability of Profile[R] 0.4 taper series 29[R] (Tulsa Dental, Oklahoma, USA). The results demonstrated that Profile[R] 0.4 taper series 29[R] prepared canals rapidly, and the time necessary for canal preparation was not influenced significantly by canal shape. None of the canals became blocked with debris and the average loss of working length distance was in 0.5 mm or less. Intracanal impressions of canal form demonstrated that most canals had defined apical stops, smooth canal walls and good flow and taper (Thompson & Dummer, 1997 2a). No zips or perforations were created although 24 specimens (60%) had ledges on the outer wall of the canal. The incidence of ledges differed significantly between the canals shapes. At specific points along the canal length there were highly significant differences in total canal width and in the amount of material removed from the inner and outer aspect of the curve between various canal shapes. Aberrations occurred more frequently in canals with short, acute curves (40°, 12 mm). At the apex of the curve, transportation was invariably towards the outer aspect of the curvature. At the beginning of the curve, transportation was more balanced between inner and outer. The absolute transportation, ignoring direction, was generally greater in 40° canals and those with the curve beginning 8 mm from the orifice. Of particular importance was a finding that excessive resin was removed from the outer aspect of the canal at the apex of the curve, which was often associated with irregular widened areas or ledges (Thompson & Dummer, 1997 2b).

In a subsequent study, Thompson and Dummer looked at shaping ability of McXim files (NT company, Chattanooga, TN, USA) and NT Engine files (NT company, Chattanooga, TN, USA). Overall, both instruments prepared canals rapidly, with canals shape having a significant effect on the speed of preparation. There were no blockages and minimal changes in working length were observed. The three-dimensional form of the canals demonstrated good flow and taper characteristics (Thompson & Dummer, 1997 3a). No zips, elbows or perforations were created during preparation. Forty-two percent of canals had ledges on the outer aspect of the curvature, the majority of which occurred in canals with short acute curves. There were significant differences between canals shapes in terms of the incidence of ledges. The direction of canal transportation at the end point of preparation was most frequently towards the outer aspect of the curve. At the beginning of the curve, transportation in the majority of canals was towards the inner aspect of the curve. Mean absolute transportation was less than 0.03 mm throughout the curve and towards the end point (Thompson & Dummer, 1997 3b).

In 1998, Thompson and Dummer investigated Quantec series 2000 files (NT company, Chattanooga, TN, USA). They found that these instruments prepared canals rapidly and that canal preparation time was significantly influenced by canal shape. The majority of canals maintained working length, however the mean change in length differed significantly between canal types. Examination of intracanal impressions revealed that preparation with Quantec series 2000 files produced canals with definite apical stops, smooth canal walls and good flow and taper. However, the quality of apical smoothness and flow was influenced significantly by canal shape with specimens having 40° canals displaying less desirable qualities (Thompson & Dummer, 1997 4a). Twenty-one zips and elbows, of 40 canals, were created during preparation with a significant difference between canal shapes in terms of the incidence of aberrations. Four perforations were created with significant differences between the canal shapes. Three ledges were also created. Significant differences were apparent between the canals shapes in total canal width at specific points along the canal length and the amount of resin removed from the inner and outer aspect of the curve. Canal transportation at the end point of preparation was most frequently directed towards the outer aspect of the curve. At the beginning of the curve, transportation became more evenly balanced between the inner and outer aspect of the curve, although predominated towards the outer. Transportation was generally directed towards the outer at the orifice (Thompson & Dummer, 1997 4b).

Canal instrumentation using Profile^{R} 0.04 tapers instruments (Tulsa Dental, Oklahoma, USA) sizes 15-35 were investigated in 1998, by Bryant *et al.* The same methods and criteria of investigation were used as Thompson's studies (Bryant *et al.*, 1998 a&b). They found that these instruments prepared canals rapidly and the time was not influenced by canal shape. None of the canals became blocked with the debris, and change in working distance was minimal. Intra-canal impressions of canal form demonstrated that most canals had apical stops and smooth canal walls whereas all canals had good flow and taper (Bryant *et al.*, 1998, 1a). Out of 37 completed specimens 9 zips and one ledge were created, but no perforations were found. There were significant differences between canal shapes for the incidence of zips and elbows. Canal shape influenced the incidence of zips and elbows but other aberrations had no effect. Overall, transportation was towards the outer aspect of the curve. They concluded that Profile^{R} 0.04 tapers instruments (Tulsa Dental, Oklahoma, USA) with ISO size tip produced a larger number of zips; however, the degree of zipping was limited and relatively minor (Bryant *et al.*, 1998, 1b).

In 1999, Bryant *et al.* investigated shaping ability of .04 and .06 taper Profile^{R} rotary nickel titanium instruments in 40 simulated root canals made of four different shapes in term of angle and position of the curvature. None of the canals became blocked with debris. Change in working distance was, on average, 0.063 mm with 33 canals retaining the correct length. Overall, five zips were created and 24 canals demonstrated widened areas on the outer aspect of the canal between the end point and the curve. Two perforations were created but no ledges were found. Between canals shapes there were highly significant differences for the incidence of zips and elbows but not for the other aberrations. Overall, transportation was towards the outer aspect of the canal except at the beginning of the curve (Bryant *et al.*, 1999)

From the results of these studies it can be summarized that nickel titanium rotary instruments in general prepared the simulated root canals more rapidly, without creating blockages, with only limited loss of length and with good taper and flow characteristics. In general, there were significant differences between the instruments for the incidence of a zips and elbows. Overall, transportation was towards the outer aspect of the curve, at the end point of preparation.

As authors of these studies mention, using simulated root canals in clear resin block has its advantages in terms of eliminating the variables encountered in the root canals in real canals which allows clear comparison between canal shapes. The disadvantage of using simulated root canals in resin blocks is that most manufacturers advise the use of mineral oil or a similar lubricant in the canal when instrumenting. Clearly a degree of caution should be exercised in the interpretation of the results and their extrapolation to the use of these instruments in a natural tooth (Thompson & Dummer, 1997 4a).

1.2.5- Cutting Efficiency

The cutting of dentin is an essential step during root canal treatment. It eliminates the infected dentin and provides an adequate funnel-shaped preparation. The speed of cutting depends not only on the motion used for endodontic instruments, but also on the helix-angle (Webber *et al.*, 1980), the cross-section (Camps & Pertot, 1990), the profile (Stenman & Spångberg, 1990) and probably the metal from which the instruments are made. The cross-sectional configuration determines how quickly the file wears out, the ability to remove the debris, the rake angle, and therefore, the efficiency and the motion of endodontic instruments (Wildey *et al.*, 1992).

Cutting efficiency is an important consideration in root canal instruments. However, there are no international standards for evaluation of cutting efficiency. To determine cutting efficiency of root canal instruments, two main aspects must be taken into account. First, studies require standardized conditions. Second, only those instruments that are primarily designed for the same working motion should be compared (Tepel *et al.*, 1995).

Camps and Pertot, in 1995, compared the machining efficiency of four brands of nickel – titanium K-files (Brassler, JS Dental, Mac Spadden, Maillefer) and two brands of stainless steel K-files (Colorinox and Flexofile). Each file had different cross-section. Instruments sizes 15 to 40 were tested in a linear motion simulating the clinical motion used to remove the file from the canal. The tips of the loaded files were in contact with a resin block. The load applied increased with file size. An indentation varnish caliper was used to measure the depth of the groove after 100 repetitions of back-and-forward motion. Their results showed that the cross-section of an instrument influences its machining ability and instruments with the triangular cross-section are more effective. Stainless steel instruments with a triangular cross-section were more efficient than the stainless steel instrument with the squared cross-section. The Maillefer (Maillefer, Switzerland) NiTi instruments, with triangular cross-section, and Flexofiles were the most efficient (Camps & Pertot, 1995c).

Tepel *et al.*, in 1995, investigated the cutting efficiency of Nitinol K-files, stainless steel reamers, K-files and flexible stainless steel files. With a computer-driven testing device, resin specimens with simulated canals were instrumented using a defined working motion simulating the clinical use of the instruments. Maximum penetration depth was the criterion for cutting efficiency. The results showed that Nitinol K-files had the least cutting efficiency. The stainless steel reamer and K-files showed better cutting efficiency than Nitinol K-files. Flexible stainless steel instruments displayed the best results (Tepel *et al.*, 1995).

Similar results were seen by other investigators. Brau-Aguadè *et al.*, in 1996, compared the cutting efficiency of different triangular cross-section K-files made of nickel titanium (Nitiflex, Naviflex), titanium (Microtitane), and stainless steel (Flexofile, FlexR). The cutting efficiency was assessed in a linear motion using an indentation caliper to measure the depth of grooves. The load applied was equal to the ISO file size. Each file was allowed to do 100 repetitive back-and-forward movements. Files made of stainless steel were the most effective, in particular Flexofile. There were statistically significant differences ($P<0.05$) between two types of stainless steel files in all sizes. In the group nickel titanium instruments, Nitiflex was significantly more efficient than Naviflex in all sizes. The cutting efficiency of titanium files was higher than that of Naviflex but lower than that of Nitiflex and stainless steel files (Brau-Aguadè *et al.*, 1996).

In 1997, Tepel *et al.* studied cutting efficiency of the different types of endodontic hand instruments: conventional stainless steel, flexible stainless steel, titanium-aluminium, and nickel titanium instruments used in rotary and linear motion. With regard to cutting efficiency in rotary motion, flexible stainless steel reamers and K-files clearly displayed best results and were superior to other files. With regard to cutting efficiency in linear motion, stainless steel Hedström files made by certain manufacturer were significantly superior to stainless steel, nickel titanium and titanium based Hedström files of other brands (Tepel *et al.*, 1997). Haïkel *et al.*, in 1998, compared the cutting efficiency of four brands of nickel titanium (NiTi) files (Brassler, JS Dental, Mac Spadden, Maillefer) and conventional stainless steel. The results showed that all NiTi files were less efficient than conventional stainless steel files (Haïkel *et al.*, 1998a).

In 1999, Schäfer *et al.* compared cutting efficiency and instrumentation of simulated curved canals with both stainless steel and nickel titanium Profile[R] 0.4 taper series 29[R] and stainless steel Flexoreamer. With respect to cutting efficiency in rotary motion, the Flexoreamer had significantly greater cutting efficiency than stainless steel Profiles[R] and nickel titanium Profiles[R] (Schäfer *et al.*, 1999).

In summary, nickel titanium hand files have lower cutting efficiency than stainless steel files. The triangular cross-section improves the cutting ability of NiTi files. However, it should be mentioned that all these studies have been done on plexi glass or resin block. Different results were seen when Kazemi *et al.*, in 1996, studied machining ability of eight different brand of NiTi hand instruments on dentin and compared the results with a previous study on stainless steel files (Kazemi *et al.*, 1995). The same methodology was used in both experiments. They concluded that NiTi instruments show great variation in machining efficiency and wear resistance within as well as among different brand and types. They also concluded that NiTi instruments are as aggressive as stainless steel files in removing dentin and more resistant to wear than their stainless steel counterpart (Kazemi *et al.*, 1996).

Recently, a variety of surface engineering techniques have brought about improvements of hardness and wear resistance by producing hard surface coatings, such as titanium nitride (Branding *et al.*, 1992). Rapisarda *et al*, in 2000, investigated the effect of surface treatments of nickel titanium files on wear and cutting efficiency of these files. They used 30 Profiles files (Maillefer Instruments SA, Switzerland). The instruments were divided into three groups. Group A was exposed to ionic implantation, group B was exposed to thermal nitridation processes performed for 480 minutes at 500°C and group C was not exposed to any processing. The chemical composition of the surface layers of each sample was determined by means of x-ray photoelectron spectroscopy. The cutting efficiency was tested at an "endotraining" block. The results showed that thermal nitridation and nitrogen-ionic implantation treatments of nickel titanium files produced a higher wear resistance and an increased cutting capacity (Rapisarda *et al.*, 2000).

1.2.6- Effect of Sterilization and Sodium Hypochlorite

Endodontic instruments must be able to endure the stresses and conditions imposed on them during canal instrumentation and by sterilization procedures. Torsional strength and rotational flexibility are important factors in determining when an instrument will break. Because root canal instruments are used in a rotating motion, fracture occurs when the resistance of dentin imparts a torsional force on the file that is greater than its torsional limit. If the torsional strength of the file is increased the incidence of breakage should decrease (Silvaggio & Hicks, 1997).

In 1997, Silvaggio and Hicks studied the effect of heat sterilization on the torsional properties of Profile^{R} 0.4 taper series 29^{R} rotary nickel titanium files (Tulsa Dental, Oklahoma, USA). Nine hundred files sizes 2 through 10 were divided into groups of 10 files each and sterilized 0, 1, 5, or 10 times in the steam autoclave, Statim^{R} autoclave, or dry heat sterilizer. Files were then subjected to torsional testing measured by a Torquemeter Memocouple. Complete data were collected for sizes 2 through 7, but not for sizes 8 through 10 because their torque resistance exceeded the testing limits of Torquemeter Memocouple. Dry heat produced the greatest increase of file torsional strength. Their conclusion was that sterilization of rotary nickel titanium files in dry heat, steam autoclave, or Statim^{R} autoclave sterilizer does not weaken the instruments. If any changes in torsional strength occur, it will most likely be an increase rather than a decrease in strength. Therefore, heat sterilization alone does not increase the likelihood of instrument fracture (Silvaggio & Hicks, 1997).

Canalda *et al.*, in 1998, investigated the effect of dry heat and autoclave sterilization on the resistance to fracture in torque and angular deflection and the resistance to bending of K-files manufactured with different metallic alloys. Ten K-files of each nickel titanium (NiTiflex, Naviflex), titanium (Microtitane), and stainless steel (Flexofile, Flex-R), for sizes 25 to 40, were tested according to ANSI/ADA specification No. 28. The results showed that sterilization with dry heat and autoclave slightly decreased the flexibility of files made of stainless steel and nickel titanium for most of the sizes, although the values obtained satisfied ISO specifications. The files made of titanium showed an increased flexibility after sterilization with autoclave and the dry heat. Resistance to fracture after dry heat and autoclave sterilization varied amongst the five groups of the files tested as follows: it decreased in some sizes of stainless steel instruments, decreased in all sizes of titanium files assessed by the torsional moments, and either increased or decreased in some sizes of nickel titanium files. All files tested however, satisfied the minimum standards for angular deflection after being subjected to autoclave or dry heat sterilization (Canalda *et al.*, 1998).

NiTi is a super-elastic alloy with shape memory characteristics. However, this alloy is susceptible to the effect of cyclic fatigue and under conditions of sufficient stress will fatigue fracture. A Martensite phase of the alloy is induced during NiTi fatigue stress and strain, as the instruments rotate in a curved canal. This phase of the alloy is suspected as the phase when fracture initiation and propagation begin. Heat treatment is known to reorient the crystals from the Martensite phase back to an Austenite phase that restores the elasticity of the alloy (Mize *et al.*, 1998). Depending on composition of nickel and titanium in the alloy, the transformation temperatures for the NiTi alloy might change.

Serene *et al.* have observed that sterilization procedures increased the hardness and may "rejuvenate" NiTi alloy (Serene *et al.*, 1995).

Mize *et al.*, in 1998, investigated the effect of sterilization on cyclic fatigue of Lightspeed rotary nickel titanium endodontic instruments (Lightspeed technology, USA). Instruments were cycled in artificial canals with angles of curvature of 30 degrees and either 2 or 5mm radii of curvature. Instruments were cycled to failure 25 % or 50% or 75% of the mean cycles-to-failure limit determined in a pilot study, then sterilized or not sterilized before being cycled to failure. No significant increases in cycles to failure were observed between groups for either experimental protocol when instruments were evaluated at the similar radius. Significant differences in cycles to failure were only observed when instruments were cycled to failure in artificial canals with 5 mm radius in which the sterilized instruments failed at less total cycles than the non-sterilized group. Scanning electron microscope photos showed crack initiation and propagation in all instruments that were cycled to a percentage of the predetermined cycles-to-failure limit. It was concluded that heat treatment as a result of autoclave sterilization does not extend the useful life of nickel titanium instruments. They have also mentioned that Lightspeed instruments have a composition of 55% nickel and 45% titanium which means that the transformation temperature from Martinsite phase to Austenite phase is much higher than the temperature used in their study (Mize *et al.*, 1998).

The effect of sterilization on cutting efficiency of NiTi files has also been investigated. Butti *et al.* found that after sterilization there was a slight deterioration in the cutting properties of the NiTi instruments. Deterioration was directly proportional to an increase in sterilization cycles (Butti *et al.*, 1995). Using spectroscope, Shabalovskaya and

Andregg examined NiTi alloy surface exposed to several sterilizations. They noticed that autoclaving at 120°C and 21 psi produced alternation in the concentration of nickel, titanium, oxygen and carbon on the alloy surface. The extent of changes was proportional to the time of treatment. A decrease in nickel concentration was also found on the surface of the instruments with increasing time of exposure (1-2 hours in the autoclave). Therefore, it was suspected that saturated steam in the autoclave causes oxidation on the files (Shabalovskaya & Anderegg, 1995).

In 1999, Rapisarda *et al.* investigated the effect of sterilization on the cutting efficiency of rotary nickel titanium endodontic files Profile (Maillefer instruments, Switzerland). Thirty-six files, 18 with the taper of 0.04 and 18 with the taper of 0.06, were exposed different sterilization cycles. Samples were divided into three groups; group A was exposed to 14 cycles of sterilization for 30 minutes, group B was exposed to 7 cycles of sterilization for 30 minutes, groups C was not sterilized and served as a control group. Chemical composition of the outer surface layers of samples of each group was determined by means of Auger spectroscopy. They observed that the instruments that underwent the greatest number of a sterilizations (group A) showed in depth distributions of chemical composition that were different from those seen in the control group; this was the result of greater amounts of titanium oxide on the surface of the sterilized instruments. The files of group A showed a decrease in cutting efficiency in comparison with those of the control group. They conclude that repeated sterilizations in an autoclave altered the superficial structure of nickel titanium files which plays a role in alternations of cutting efficiency (Rapisarda *et al.*, 1999)

During chemo-mechanical shaping and cleaning, canals are irrigated using variety of disinfecting and/or complexing agents. Sodium hypochlorite (NaOCL) is the typical irrigant used during endodontic instrumentation (Busslinger *et al.*, 1998). In addition to being a disinfecting agent, NaOCL also dissolves organic matter, which helps clean the root canals (Hand *et al.*1978, Koskinen *et al.*1980). The efficacy of NaOCL is concentration dependent. Generally, concentrations between 0.5% (Dakin solution) and 5-25% are used clinically during root canal instrumentation. The corrosion resistance of endodontic files to NaOCL is clinically significant. It has been demonstrated that the action of chloride on the fine NiTi in the alloys of orthodontic wires selectively removes nickel from the surface, leaving micropitting (Sarkar *et al.*, 1983). This is believed to lead to areas of stress collection and crack formation (Oshida *et al.*, 1992). In both these studies the immersion duration was 4 weeks in 1% NaOCL solution, much more exposure than would be expected during clinical use.

In 1998, Haïkel *et al.* investigated the effect of sodium hypochlorite on nickel titanium endodontic instruments. The endodontic files were divided into two groups subjected to NaOCL (2.5%) treatment for 12 and 48h respectively. Their mechanical properties were then tested according to ANSI/ADA specification No. 28. No effect of sodium hypochlorite was observed on mechanical properties of NiTi instruments. No pitting was observed on the post immersion test corrosion of NiTi endodontic files examined by SEM (Scanning electron microscope). They concluded that the results might be due to the NiTi alloy used for manufacturing endodontic files (46% Ti+ 54% Ni compared to Nitinol ortho wires 50%Ti+ 50% Ni). The duration for immersion might also play a role (Haïkel *et al.*, 1998b).

In 1998, Busslinger *et al.* investigated the corrosion of Lightspeed nickel titanium instrument (Lightspeed technology, USA) in 1% and 5% NaOCL solutions. The instruments were immersed in ultrasonicated NaOCL solutions for varying times up to 1h. Corrosion was determined by electro-thermal absorption spectrometry in 100µl aliquots of NaOCL. The results showed that NiTi was resistant to the corrosive action of NaOCL, at least up to a concentration of 5%. A statistically significant amount of titanium was detected from the Lightspeed (Lightspeed technology, USA) instruments after immersion times of 30 and 60 minutes in 5% NaOCL. Clinically such instruments do not have an *in-situ* time of 30 minutes, and this corrosion may be considered irrelevant clinically (Busslinger *et al.*, 1998).

1.3 –Centering Ability of Nickel Titanium Files

The inherent characteristic for endodontic files to straighten within curved canals has been referred to by Roane *et al.* (1985) as the "restoring force" of the instruments. It is postulated that this force is responsible for the deviation seen during canal preparation especially in the apical third. This restoring force or elastic memory has been related to the instrument's cross-section area and shape, as well as alloy stiffness (Cohen & Burns, 1994). It would be reasonable to predict that a more flexible file would conform better to the canal curvature with less movement of the canal centre during instrumentation.

Several *in-vitro* studies have investigated centering ability of NiTi files compared to stainless steel files. In this chapter these studies will be discussed. Some of these studies have compared NiTi hand instruments with stainless steel hand instruments. There is a controversy amongst the results of these studies which might be due to variables such as differences in the analysing methods, the type and design of the file that was investigated and the differences in the technique of instrumentation. Some of these studies indicate that nickel titanium hand files stay well centered in the canal. Zmener and Balbachan, in 1995, compared the effectiveness of NiTi hand files (Ultraflex) with conventional K-type stainless steel files (Kerr) during preparation of apical third of curved (30°) human maxillary incisors. In both groups, the files were used with an in-and-out linear movement in a circumferential motion. After the instrumentation the roots were ground longitudinally to half-thickness mesial-distal and examined under SEM (scanning electron microscope). Nickel titanium files demonstrated more centered and tapered preparation coincident with original root curvature (Zmener & Balbachan, 1995).

Coleman *et al.*, in 1996, compared instrumentation by NiTi K-files hand instrument (Mity) with stainless steel K-files. Forty canals in mesial roots of mandibular molars were embedded in resin and sectioned at apical, mid-root and coronal levels. All canals were instrumented using the Step-down technique. Direct digital computer images were recorded before and after instrumentation. Superimposition of the images combined with digital subtraction computer software was used to measure the area and distance of transportation. Results showed that NiTi files caused significantly less transportation and remained more centred at the apical and coronal level. No significant difference ($p<0.05$) in transportation could be observed at mid-root level (Coleman *et al.*, 1996). In another study in 1996, Gambill *et al.* compared nickel titanium (Mity) and stainless steel K-flex hand instruments using computed tomography. Thirty-six single rooted teeth of similar shape in canal size were divided into three groups. In group A root canals were instrumented with K-flex files (Kerr) using a quarter turn/pull technique. Group B was instrumented with Mity files using the same technique, and group C was instrumented with Mity files but using a reaming technique. Nickel titanium instruments used in a reaming technique caused significantly less canal transportation, and removed significantly less volume of dentin and produced more centered and rounder canal preparation than K-Flex stainless steel files (Gambill *et al.*, 1996).

Different results were shown by other investigators comparing hand NiTi with hand stainless steel files. Chan and Cheung, in 1996, compared instrumentation of curved canals, by stainless steel K-files (Mani) and nickel Titanium K-File (Mity). The degree of the curvature of the mesial roots of mandibular first molar was evaluated by Schneider method. All canals were instrumented using the Step-down technique. The cross sectional shape of the canals before and after instrumentation was computed at apical, mid-root and coronal levels, and analysed using image analyser software. The results showed that the two files removed similar amounts of dentin at all three levels, there was more tooth structure removed in the coronal >mid-root>apical section in each group yet the mean values were not statistically different. The nickel titanium files left a thicker layer of dentin on both the mesial and furcal aspects than stainless steel files. However, the difference was not significant ($p<0.05$). Their conclusion was that both types of files transported the centre of the canals but the nickel titanium files seemed to be safer because of reduced amount of transportation towards the danger zone (Chan & Cheung, 1996).

Harlan *et al.*, in 1996, compared centering ability of nickel titanium (Onyx) and stainless steel hand instruments (Flex-R) in preparing curved root canals. The roots were mounted and sectioned at apical and coronal levels. All canals were instrumented using the Step-down technique. Pre- and post-instrumented scanned images were superimposed and canal centre movement and areas were computed with NIH image version 1.52 (A public domain image of processing and analysis program). Coronally, stainless steel files demonstrated more movement of the canal centre. At the apical section, no significant difference in canal-centre movement or post-instrumentation area was observed (Harlan *et al.*, 1996).

Another study in 1996, by Samyn *et al.* compared NiTi instruments (NT files) to Stainless Steel files using forty curved mesial roots of mandibular molars, embedded and sectioned at the height of the curvature (mid-root) and apical third. The curvature of the canals was determined by the Schneider method (Schneider, 1971). All canals were instrumented using the Step-down technique. Utilizing NIH Image 1.52 software the X-Y centre point of the scanned pre- and post-instrumented images were computed and the distance between them measured. Result showed that there was no significant difference in canal centre movement between SS and NiTi files. All canal centres deviated towards the furcation at the height of the curvature and in the opposite direction in the apical section. The degree of the curvature had no correlation to the canal centre movement or canal area changes (Samyn *et al.*, 1996).

Other investigators have compared rotary nickel titanium instruments with stainless steel hand instruments. In 1995, Glosson *et al.* compared root canals prepared by nickel titanium hand instruments (Mity and CMU), NiTi engine-driven (Lightspeed and NT Sensor) and stainless steel hand instruments (K-Flex). Sixty mesial canals of mandibular molars were divided in 4 groups. In the groups instrumented with NiTi and stainless steel hand instruments, quarter turn/pull instrumentation technique was used to instrument the canals. Both the apical and mid-root levels were investigated. Digitized images of pre-instrumented canals in cross-section were compared with post-instrumented using a digital subtraction software program. Two evaluators performed images analysis of all sections. The results showed that engine-driven NiTi instruments (lightspeed and NT sensor file) and hand instrumentation with the CMU caused significantly less canal transportation, remained more centered in the canal, removed less dentin, and produced rounder canal preparations than K-Flex and Mity files at both apical and mid-root levels (Glosson *et al.*, 1995). Tharuni *et al.*, in 1996, compared the centering ability of Lightspeed instruments with stainless steel files using 24 resin blocks with simulated curved canals of 38 degrees. Their results showed that at apical and mid-root levels Lightspeed instruments stayed centered in the canals (Tharuni *et al.*, 1996).

In 1997, Kuhn *et al.* investigated the effect of the tip design of nickel titanium and stainless steel files on root preparations. Forty-eight mesial canals of mandibular molars were divided into groups and instrumented with OnyxR files (NiTi with non-cutting tip), Flex-R (SS with non-cutting tip), Mity file (NiTi with cutting tip) and stainless steel K-files. Apical and mid-root sections were evaluated. Pre- and post-instrumented sections were digitized and aligned. The extent and direction of canal transportation were determined by measuring the greatest distance between the edge of each instrumented canal and the corresponding edge of the un-instrumented canal. Results of this study showed that canals instrumented with NiTi files, regardless of tip design, remained significantly ($p<0.05$) more centered and demonstrated less apical transportation than size 25 stainless steel files. However during instrumentation to size 40, the combination of modified tip and nickel titanium alloy produced significantly more transportation and dentin removal, as well as greater deviation from the centre at the mid-root level than did other file design (Kuhn *et al.*, 1997). In another study in 1997, Short *et al.* used 15 pairs of mandibular molars to compare three engine driven NiTi instrument systems (McXIM Series, Lightspeed and Profile^{R} 0.04 Taper Series 29^{R}), with stainless steel hand files (Flex-R) for their ability to remain centered at the apical, mid-root and coronal portions of the canal. The roots were embedded in resin and sectioned according to Bramante methodology. The final images from each instrumentation phase were superimposed over the preoperative images. The amount and direction of canal transportation was measured on the transformed image by comparing the change in canal centres. The results showed that NiTi systems remained centered in the canal better than stainless steel hand files at all levels. There were no significant differences ($p<0.05$) among the NiTi systems at any level (Short *et al.*, 1997).

Shadid *et al.*, in 1998, compared Flex-R files with the Lightspeed nickel titanium file in respect to canal centre movement and final canal area after instrumentation. Thirty-eight root canals in extracted human molars, with the angle of curvature ranging from 20 to 35 degrees, were used. The roots were sectioned at apical and coronal levels and the photographic slides of each section were then scanned into a computer. All canals were instrumented using balanced-force technique. From these pre- and post-instrumentation images, the movement of the canal centre and the area of each canal were analyzed by NIH image version 1.57(A public domain image of processing and analysis program). Results showed significant differences ($p=0.04$) in the apical canal centre movement and post instrumentation area ($p=0.01$) with the Lightspeed yielding smaller values in both cases. Coronally, the Lightspeed instruments demonstrated no significant differences ($p=0.04$) in canal movements or area. No significant correlation was found between the angle of root curvature and canal movements or the angle of root curvature and post-instrumentation canal area (Shadid *et al.*, 1998). In 1999, Ottosen *et al.* compared changes in canal configuration resulting from instrumentation by Profile and Naviflex nickel titanium engine-driven rotary instruments. Forty mesial canals of extracted human molars were sectioned at the height of the curvature and at apical level, superimposed pre- and post-instrumented cross-sectional images were traced, scanned and analyzed by NIH image 1.52 software (A public domain image of processing and analysis program). The results showed that both files produced similar results with minimal transportation.

The degree of canal curvature had no effect on canal centre movement (Ottosen *et al.*, 1999)

In summary, results of all these studies reveal that NiTi rotary instruments stay more centered in the canal than stainless steel files, especially at the apical level. No significant correlation can be seen between the angle of root curvature and canal centre movement.

1.4 Proposed Study

1.4.1 –Significance

It has been shown that mesial roots of mandibular first molars have a concavity on the distal surface. In most instances, this concavity was greater than that of distal root (Bower, 1979). The mesiobuccal and mesiolingual root canals are closer to furcation than they appear on the radiograph. During root canal instrumentation there is a danger of perforation if the distal wall of these canals is flared too large (Ingle & Beveridge 1976, Weine 1975).

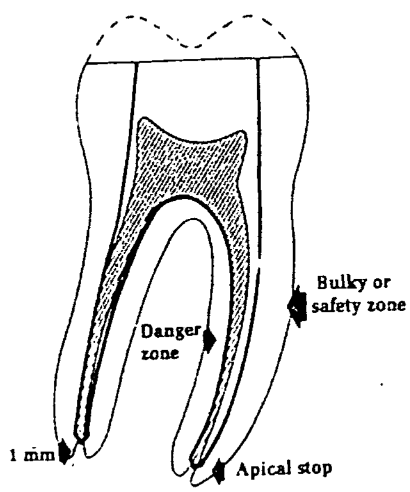

Figure 17 - Danger zone
(Abou-Rass *et al*, 1980)

In 1980, Abou-Rass *et al.* described a danger zone (Fig 17) where perforation is most likely to occur during root canal instrumentation. This zone lies on the inner or concave aspect of curved roots. He advocated a technique termed "anticurvature filing" for instrumentation of curved canals to avoid perforation. Tidmarsh (1982) and Goerig *et al.* (1982) supported the anticurvature filing concept and concurred that root canals in the mesial roots of mandibular molars lie closer to the furcation side or the inner part of curved roots. The greatest bulk of dentin lies on the buccal, lingual and proximal root surfaces opposite the furcation (safety zone), and they advocated that root canal instrumentation should be directed towards these regions. Kessler *et al.*, in 1983, also found the danger of creating thin dentin walls or perforation was much greater toward the bifurcation in the mesial roots of mandibular molars. With respect to average thickness of dentin remaining, hand instrumentation in an anticurvature filing manner left significantly thicker dentin toward the bifurcation compared to circumferential filing (Kessler *et al.*, 1983). Lim and Stock, in 1987, found that in mandibular molars the furcal wall of mesial canals was thinner than the mesial wall by approximately 20 percent for the 8mm level and 16 percent for the 5 mm level from the apex. They also found that anticurvature filing preserved greater thickness of the furcal wall and reduced the risk of perforation.

The anticurvature filing technique has never been investigated utilizing NiTi files, to determine if removal of dentin during instrumentation can be directed away from the danger zone. Many investigations of NiTi instrumentation have concentrated on centering ability of NiTi hand or rotary files versus stainless steel files. Due to flexibility of nickel titanium and the design of the file, NiTi instruments have been shown to stay centered in the root canal system (Tharuni *et al.* 1996, Glosson *et al.* 1995). It is of clinical significance to determine if rotary NiTi files can be directed away from the danger zone in order to avoid perforation and canal stripping which can lead to endodontic failure.

1.4.2 – Goals

The objective of this study was to investigate whether NiTi rotary file, Orifice Shapers ™ (Profile®), can be directed away from the danger zone, into the safety zone of the root dentin during instrumentation of the coronal portion of mesial canals of mandibular molars.

Our **null hypothesis** comprised:

Root canal instrumentation with rotary NiTi Orifice Shaper™ while directing an applied force 90 degrees to the long axis of the root, does not alter the coronal root canal centre-point.

2. Materials and Methods

2.1 – Specimen Selection

Twenty mesial roots of extracted human mandibular first and second molars were used in this study. The teeth were stored in saline. Sample selection criteria were: 1) no caries or fracture below the level of pulpal floor. 2) total canal length from pulpal floor to the apex between 12-13 mm. 3) root canal curvature between 20-35 degrees measured according to Schneider's Method (Schneider & Austin, 1971)(Fig 18, 19).

Figure 18 - Sample #12 from buccal side

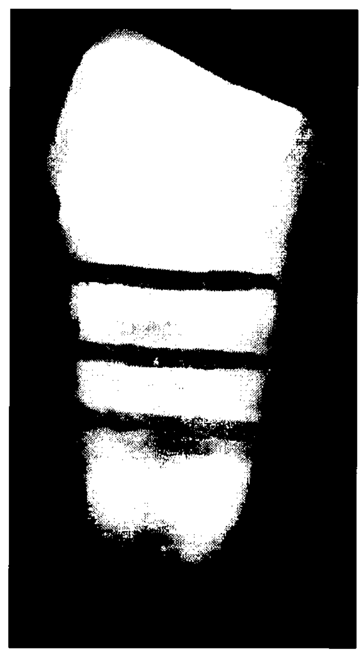

Figure 19 - Sample#12 from mesial side

Extracted teeth were radiographed in both the buccal-lingual and mesial-distal directions. Total canal length was measured on the radiograph using a millimeter ruler. Canal curvature was determined by projecting the radiographs onto a piece of paper at 18x magnification and tracing the root and canal outlines. A line was scribed parallel to the long axis of the mesial root and a second line from the apical foramen intersected the first line at the point where canal began to leave the long axis of the tooth (Figure 20). The acute angle made by the intersections was measured by means of a protractor (Schneider, 1971) and this value was recorded as the canal curvature.

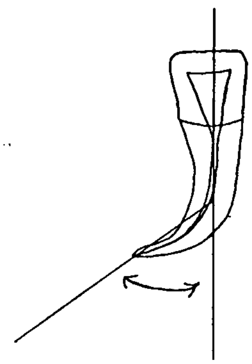

Figure 20 - Schneider method
(Schneider, 1971)

2.2 – Development of the modified muffle block

For studying the anatomical morphology of root canals before and after instrumentation a Teflon muffle block was constructed consisting of a U-shaped middle section and two lateral walls that were fixed together with three screws (Hülsman *et al.*, 1999) (Figure 21). Grooves in the walls of the muffle block allowed for removal and exact repositioning of the complete tooth block after tooth sectioning (Figure 22).

This block was a modification of the device once introduced by Bramante (Bramante *et al.*, 1987). Several prototypes of the muffle block were constructed. The first prototype was reduced in size to accommodate sample sectioning using a low speed saw (Isomet ^{TM}, Buehler ^{R}). A further modification of the width of the muffle block was necessary to position the muffle block on the load cell of the Instron Universal testing Machine (Instron, Massachuset, USA). Five identical modified muffle blocks were constructed for use in the experiment.

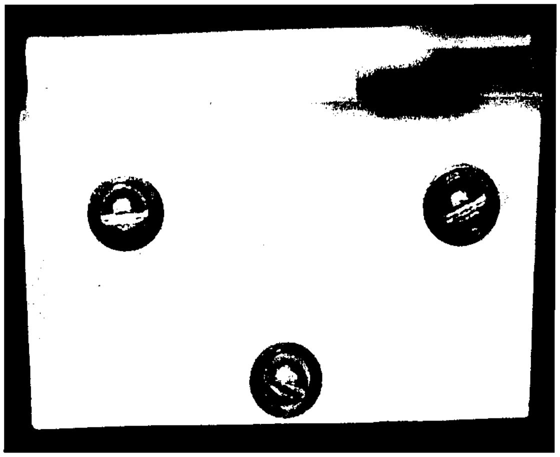

Figure 21 - Teflon Modified muffle block.

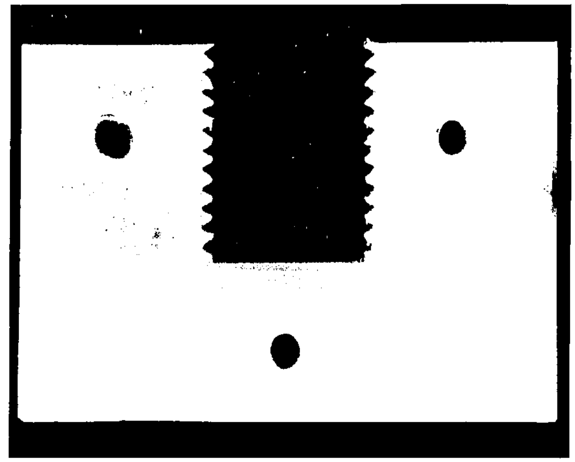

Figure 22 - U-shaped middle section of the modified muffle block showing grooves in the walls.

2.3 – Sample Preparation

Access openings were prepared on the selected teeth using a high speed dental handpiece equipped with carbide fissure burs. We investigated three levels of the cervical region of the root canals. These levels were identified by scribing three lines at different levels in the cervical region, on the buccal surface of the mesial roots. The first line was scribed 1mm below the level of the mesial canal orifice. The second line was drawn 1 mm below the height of the furcation while the third line was placed 2 mm below the second line (Figure 18, 19). The use of radiographs and a 15 K-file (Union Broach) placed in the access cavity helped to determine these external root levels.

Prior to embedding teeth in Ortho resin (Orthodontic resin, Dentsply) in the modified muffle block, Petroleum jelly was applied with a small brush to the grooves in the middle section of the modified muffle block, for easier separation of the resin mold from the muffle block. Wet cotton pellets were placed into the pulp chambers and the access cavity opening was covered by clear rope wax. Additionally, a small ball of utility wax strip (Heraeus, Kulzer, USA) was placed over the apical foramen to prevent resin penetration into the root canals. Individual teeth were embedded in clear polyester resin (Orthodontic resin, Dentsply) utilizing a three-piece plastic modified muffle block, described in the previous section. Following resin polymerization, the mold was disassembled and a specimen identification number was placed on the apical aspect of each resin block with the use of a #2 round bur and a high-speed. The marked levels on the cervical part of the teeth were duplicated with a pen on each block. Tooth blocks were then held in a low speed saw (Isomet™, Buehler®) to allow precise sectioning perpendicular to the root canal along previously scribed pen line. A 0.15 mm thick diamond wafering blade (Buhler LTD®) was used to section the embedded teeth.

Three indexes, in form of a dot and triangles were marked on the corner of each section for purpose of superimposition of the images. Tooth sections were then stored in saline before use.

2.4 – Instrumentation and Imaging technique

2.4.1 – Orifice Shapers™: First Instrumentation

Prior to root canal instrumentation, canals in all sections were filled with red bees wax. The wax was wiped in the canal with a small cement spatula. The sections scanned with a high resolution, 2400 dpi, Acer Scan (Prisma 620P), connected to an IBM computer (United computer 36X WTRP™) (Figure 23). A millimetre ruler was also scanned at the same resolution for measurement calibration.

Prior to reassembly of all sections for each tooth in the modified muffle block for canal instrumentation, wax was carefully removed from all canals using a size 20 K-file (Union Broach) to tease out the wax. Prior to instrumentation using NiTi Orifice Shapers^{TM} (Profile ^{R}), RC-prep (Premier, stone pharmaceutical USA) was applied into the canals as a lubricant and the canals in both groups were enlarged with K-files hand-instruments (Union Broach) up to size 25 (tip: 0.25 mm). The sections were disassembled; canals were filled with green bees wax and scanned as before (Fig 24).

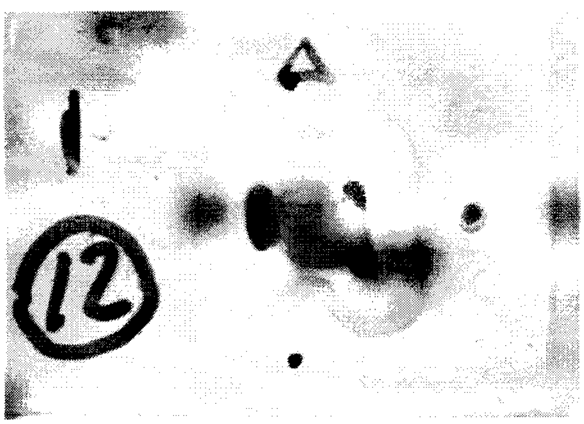

Figure 23 – Sample #12, section 1, Pre-instrumented

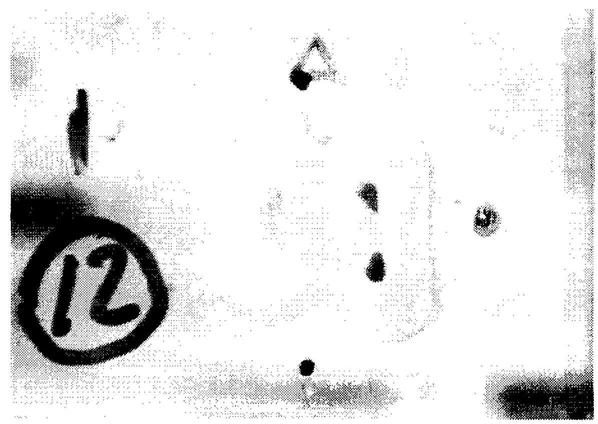

Figure 24 - Sample #12, section 1, hand-instrumented

Wax was removed from all canals using a size 20 K-file (Union Broach) to tease out the wax. Sections were again reassembled in the modified muffle block.

For each of the 20 teeth, mesiolingual and meisobuccal canals were randomly divided into instrumentation groups A and B. When a canal was assigned to be in one treatment group, the other mesial canal would automatically be designated in the other treatment group.

Group A canals were instrumented with NiTi Orifice Shapers™ (Profile®) according to the manufacturers suggested sequence: 30, 50, 40. Each rotary file was used to instrument the canals three times in an in-and-out motion without any horizontal force directed to the walls (control group).

Prior to instrumentation of group B, each tooth block was assembled on Instron Universal testing Machine 4301 (Instron, Massachussets, USA) for measuring the compressive (horizontally directed) force applied during instrumentation. For this purpose we had to modify the device by turning the load cell upside down. Each tooth block was then hooked by a C-clamp to the Platten, on the load cell (Figure 25, 26). A force calibration took place before instrumenting each tooth.

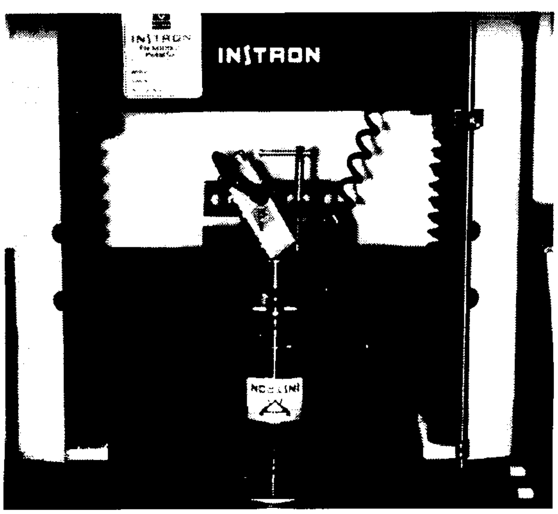

Figure 25 - Tooth block hooked by the C-clamp to the Instron device.

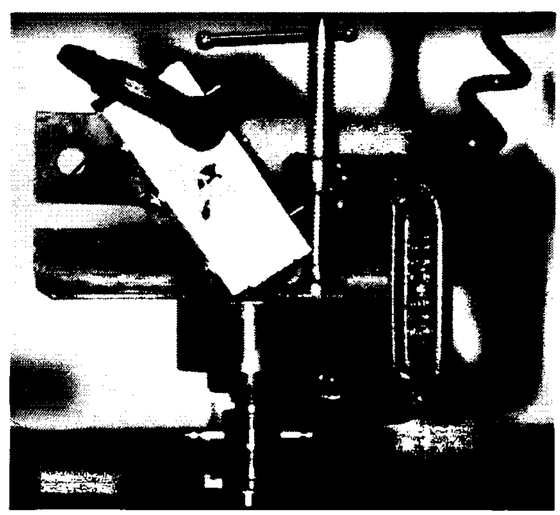

Figure 26 - Tooth block assembled on the Instron device.

Group B canals were instrumented with NiTi Orifice Shapers™ (Profile®) in the same sequence as Group A but with an additional horizontal force component directed away from the furcation, in an anticurvature filing manner. A rotary Nickel-Titanium file was first inserted into the root canal until resistance was felt. Then a horizontal force was applied when the rotary instrument was withdrawn from the canal. Each Orifice Shaper was used to instrument the canal three times in an in-and-out motion and a new rotary Ni-Ti file was used for each canal.

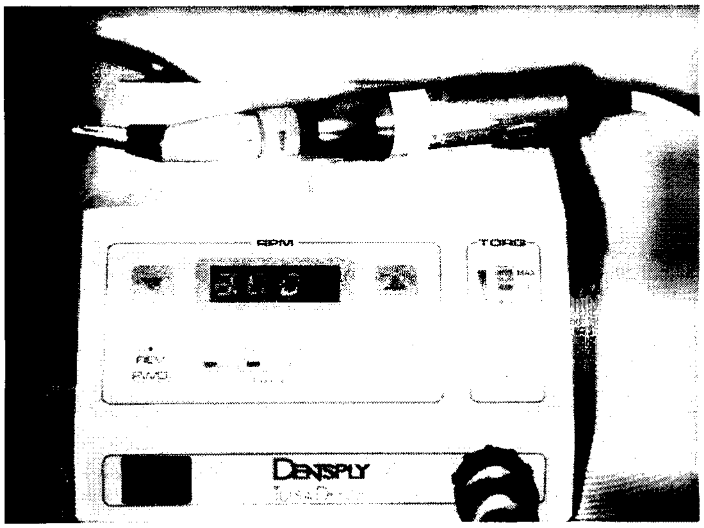

Figure 27 - Tulsa Dental electric hand-piece.

Rotary instrumentation was completed with Orifice Shapers™ (Profile ®) 30, 50, 40, utilizing an electric hand-piece (Tulsa Dental, Dentsply, Oklahoma, USA) at a constant speed of 300 rpm (Fig 27). RC-prep (Premier, stone pharmaceutical USA) was again used as a lubricant during root canal instrumentation. The force applied in Group B was directed towards either the mesiobuccal or mesiolingual wall of each canal depending on whether the canal was mesiobuccal or mesiolingual. The direction of the force was marked on each section. Following instrumentation, the modified muffle blocks were disassembled and the

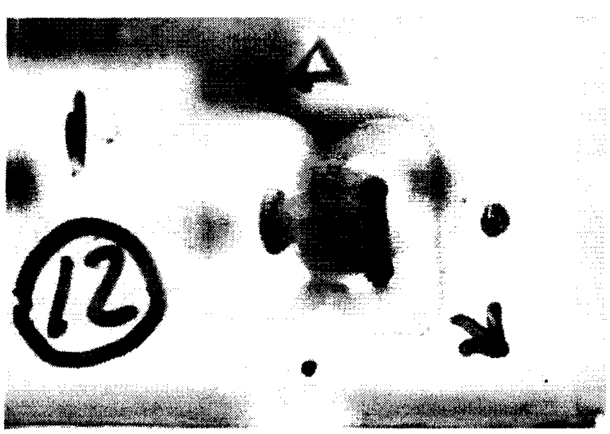

Figure 28 – Sample #12, section 1, after 1st rotary instrumentation.

canals were filled with blue bees wax prior to being scanned (Fig 28).

2.4.2 – Orifice shapers™ : Second Instrumentation

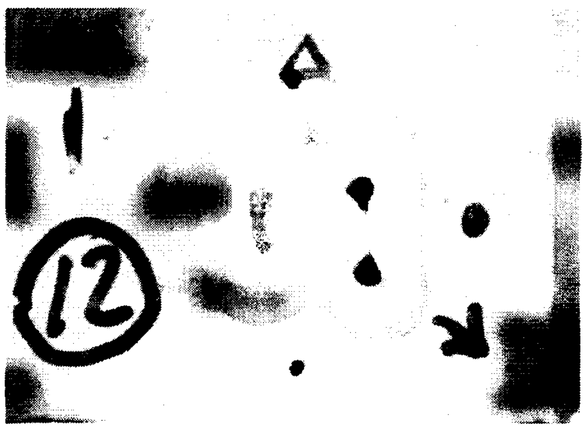

Figure 29 – Sample #12, section 1, after 2nd rotary instrumentation.

After removal of wax from the canals using a #20 K-file (Union Broach), sections of each tooth were reassembled in the modified muffle block. Prior to all instrumentation, RC-prep (Premier, stone pharmaceutical USA) was applied to all canals. This time canals in both groups A and B were instrumented 5 times with only file size 40 Orifice Shapers™ (Profile ®) in an in- and-out motion, using the electric hand-piece at a constant speed of 300rpm. In Group B, force was applied in the same direction as during the first instrumentation and measured by the Instron Universal testing Machine. The force was about 1N higher than with the first instrumentation. The modified muffle blocks were again disassembled and the canals were filled with green bees wax prior to being scanned (Figure 29).

2.4.3 – Gates-Glidden R: Third Instrumentation

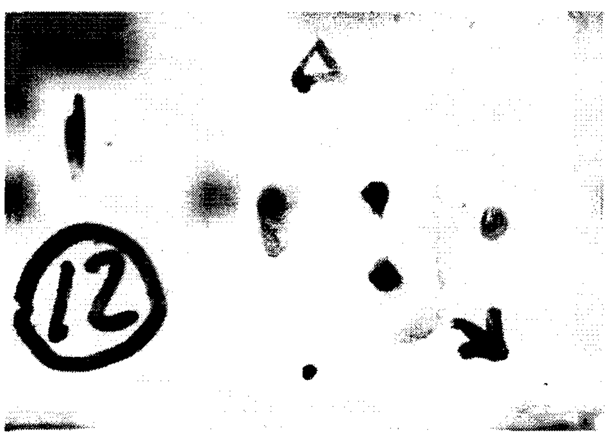

Figure 30 – Sample #12, section 1, after Gates - Glidden instrumentation.

After removal of wax from the canals using a size 20 K-file (Union Broach), sections of each tooth were reassembled in the modified muffle block. This time canals in both group A and B were instrumented with Gates-Glidden burs (Dentsply) size # 2. The rotational speed was 5000 rpm. The amount and direction of force in group B was the same as during the first instrumentation. The force was again calibrated and measured with the Instron Universal testing Machine. Sections were disassembled and the canals were filled with green bees wax prior to scanning (Fig 30). RC-prep (Premier, stone pharmaceutical USA) was used as lubricant prior to all instrumentations.

The same operator completed all canal instrumentations. New rotary NiTi files and Gates-Glidden burs were used for each canal. Sample sections were kept in saline at all times except during instrumentation and scanning.

2.4 - Observation and Measurement

After the first instrumentation, the images for each root section were superimposed over the pre-instrumented images in Corel Photopaint™ (version 9)(Corel, Ottowa, Canada) with help of indices marked on each section. Superimposed images were then converted to BMP (Windows Bitmap) format and cropped from size 2.5Mb to size 1.5Mb with the same resolution, 2400 dpi, and transferred to Scion NIH image 1.62 software (Scion Corp, Frederick, Maryland, USA, A public domain image of processing and analysis program, http;// rsb.info.nih.gov/nih-image/). Utilizing this software and utilizing 3X magnification, the X-Y centre point coordinates and the area of each canal space were computed 3 times for each tooth section. The mean values for centre point and canal area for each canal were calculated. The distance between the X-Y centre point coordinates of the pre-and post-instrumented canals determined the extent of the canal centre movement (Figure 31). This distance was documented between pairs of pre- and hand instrumentation, hand and first NiTi rotary instrumentation, first NiTi rotary and second NiTi rotary- instrumentation and finally between second NiTi rotary and Gates-Glidden

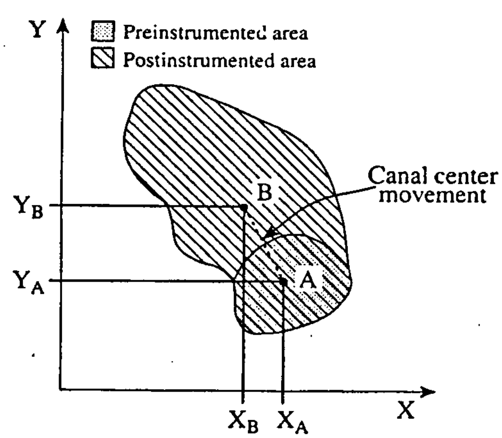

Fig 31: The amount of canal centre movement (C) was determined by formula:

$$C= SQR[(X_B-X_A)^2 + (Y_B-Y_A)^2]$$

(Samyn *et al.*, 1996)

bur instrumentation of the canals in the same section and instrumentation group.

The direction of canal centre movement was also evaluated. A paired t-test (Statview ™) was used to compare the canal centre movement between each instrumentation group. The horizontal force component applied during instrumentation in B group was measured using the Instron Universal testing Machine 4301 (Instron, Massachussets, USA). The sections reassembled in the modified muffle block were placed on the device and the compression force (horizontally directed force) applied 90 degree to the long axis of the root, was measured when the instrument was withdrawn from the canal. Force calibration on a sample tooth was done before each instrumentation. The values of applied force for each tooth were then printed out in graphic form. From each graph the total time which instrumentation took place and the mean value of the force applied was calculated (Fig 32).

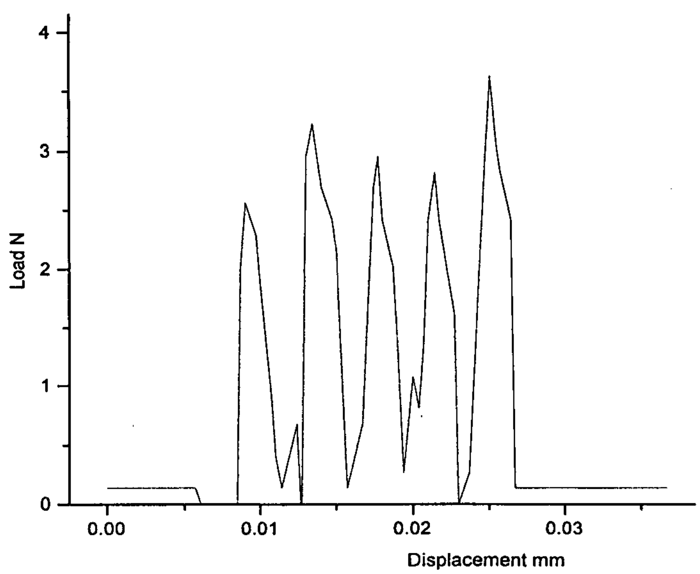

Figure 32 - Force applied during the instrumentation of tooth# 6 with Gates-Glidden bur. Force was applied 5 times with GG #2.

Displacement in X-axis represent the movement of the cross head of Instron Universal testing Machine. The time period under which the force was applied could be calculated knowing the speed of the cross head moving downwards.

Speed=0.01mm/s

Displacement could be measured from the x-axis.

Time= Displacement (mm)/ 0.01(mm/s)

3. Results

Area:

The canal area was measured before instrumentation, after hand and three rotary instrumentations utilizing Scion NIH image 1.62 software (Scion Corp, Frederick, Maryland, USA). The mean value for the canal area of all 20 paired canals, force and no force groups, are presented in Figure 33. The Graphic was created in Excel 2000, on Windows 98 platform. Each section, section 1 (1mm below the orifice), section 2 (1mm below the level of furcation) and section 3 (2mm bellow section 2) was evaluated separately. For all sections an increase in area was observed after each instrumentation.

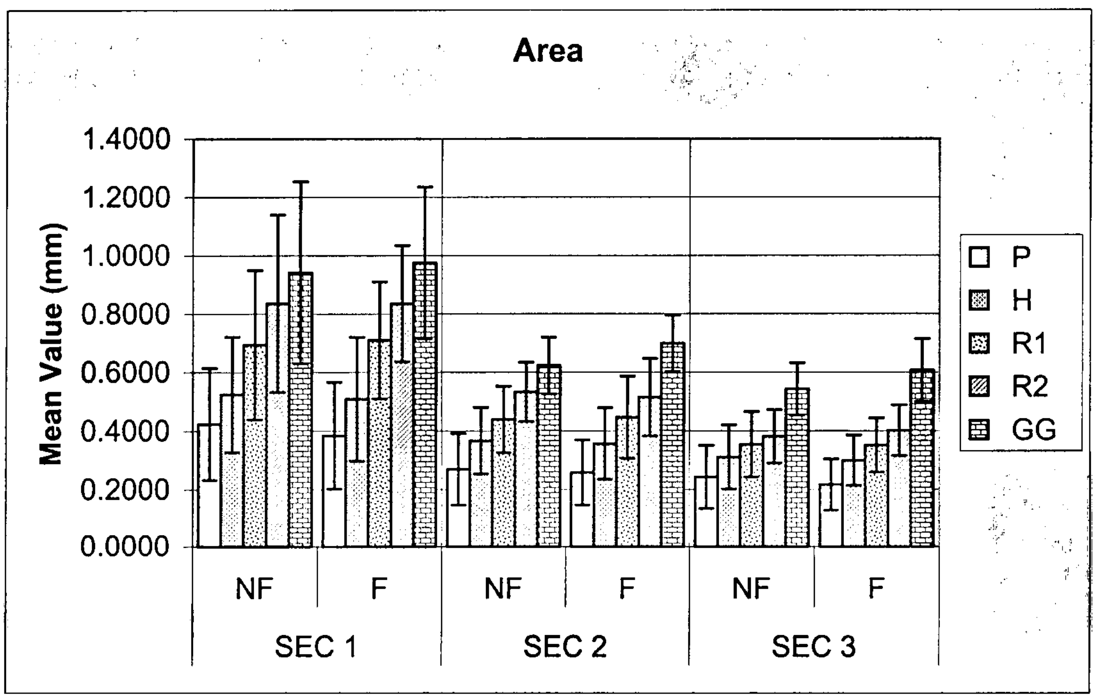

Figure 33 - Comparison of area between force (F) and no force (NF) group before instrumentation (P), after hand instrumentation (H), after 1st rotary instrumentation (R1), after 2nd rotary instrumentation (R2) and after instrumentation with Gates-Glidden (GG).

3.1 – First Instrumentation: Orifice Shapers™ 30/50/40, Force versus No force

The extent of the canal centre movement was measured between first NiTi rotary and hand instrumentation utilizing Scion NIH image 1.62 software (Scion Corp, Frederick, Maryland, USA). The mean value for canal centre movement of all 20 paired canals, force and no force groups, are presented in Figure 34. The Graphic was created in Excel 2000, on Windows 98 platform. Each section; section 1 (1mm below the orifice), section 2 (1mm below the level of furcation) and section 3 (2mm bellow section 2) was evaluated separately. No discernible difference was seen between the two groups at these canal levels.

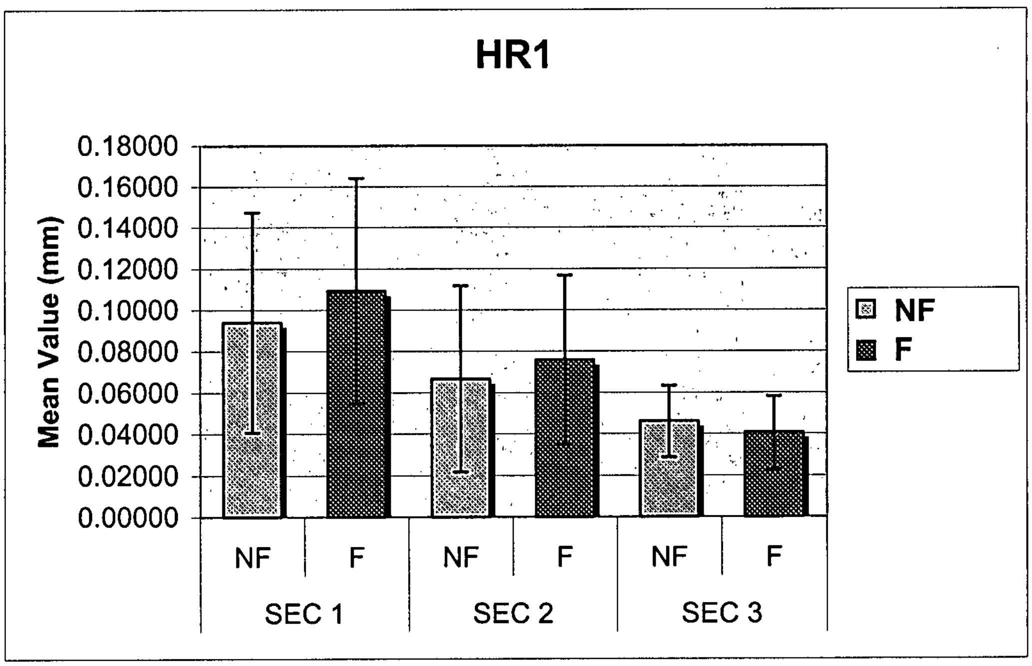

Figure 34 - Comparison of canal centre movement between hand instrumentation (H) and 1st rotary instrumentation (R1), emphasizing comparison of force (F) and no force group (NF), in each section.

Table 3 represents mean values of canal centre movement of 20 samples for each section, comparing hand and first rotary instrumentation.

		SEC 1		SEC 2		SEC 3	
		NF (mm)	**F** (mm)	**NF** (mm)	**F** (mm)	**NF** (mm)	**F** (mm)
HR1	MEAN	0.094	0.109	0.067	0.076	0.046	0.041
	STDEV	0.065	0.058	0.048	0.043	0.024	0.019

Table 3 - Mean and standard deviation of canal centre movement of 20 samples, comparing hand and first rotary instrumentation.

The results of paired t-test indicated that there was no significant difference between group A (no force) and group B (force) at these canal levels (sec 1; p=0.42, sec2; p=0.38, sec3; p=0.46) (Table 4).

	Paired t-value	Prob. (2-tail)
Sec 1	0.828	0.418
Sec 2	0.895	0.382
Sec 3	0.746	0.465

Table 4 - Paired t-test value for canal centre movement between hand and 1st rotary instrumentation comparing force and no force group. There is no significant difference between the force and no force group at any level.

The lateral (horizontally directed) force applied during the instrumentation with NiTi Orifice Shapers^{TM} (Profile ^{R}) was measured with Instron Universal testing Machine (Instron, Massachussets, USA). The average force applied during instrumentation of 20 canals in group B (Force group) was between 3.5 and 4 N. The average time under which the complete instrumentation took place was between 16 and 18 seconds. The average instrumentation time for each file size 30, 50, 40 was between 3 and 4 seconds. Figure 35 shows the graphic of the forces applied on sample #6 when instrumented with NiTi Orifice Shapers^{TM} (Profile ^{R}) sizes 30, 50, 40.

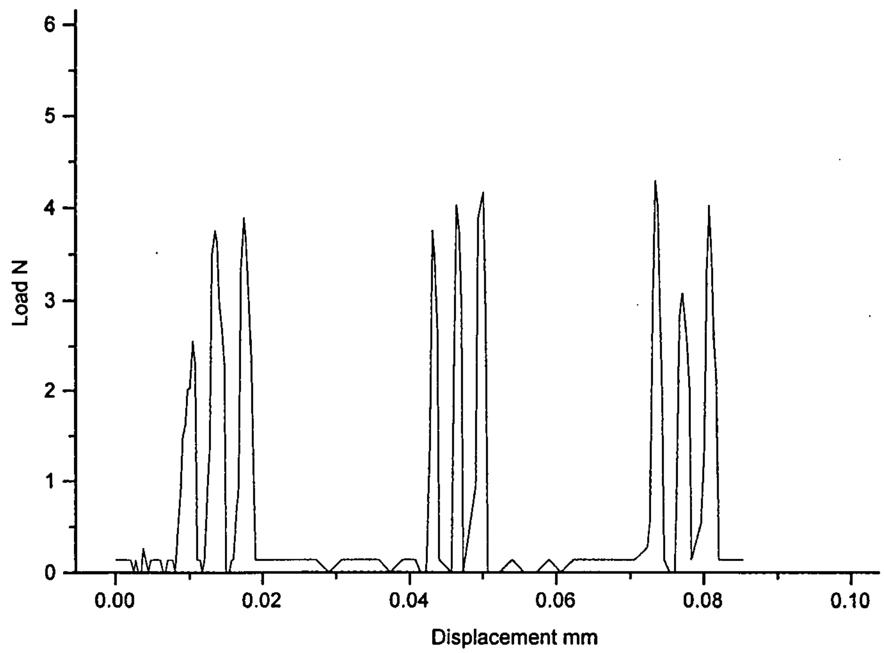

Figure 35 - Force applied during the instrumentation of sample# 6 with NiTi Orifice Shapers ™ (Profile ®) 30, 50, 40. Force was applied 3 times with each file 30 vs. 40 vs. 50.

3.2 – Second Instrumentation: Orifice Shapers™ 40, Force versus No force

Extent of the canal centre movement was measured between second NiTi rotary and first NiTi rotary instrumentation utilizing Scion NIH image 1.62 software (Scion Corp, Frederick, Maryland, USA). The mean value for canal centre movement of all 20 paired canals, force and no force groups, are presented in Figure 36. The Graphic was created in Excel 2000, on Windows 98 platform. As before each section was evaluated separately. No discernable difference can be seen between the two groups at these canal levels.

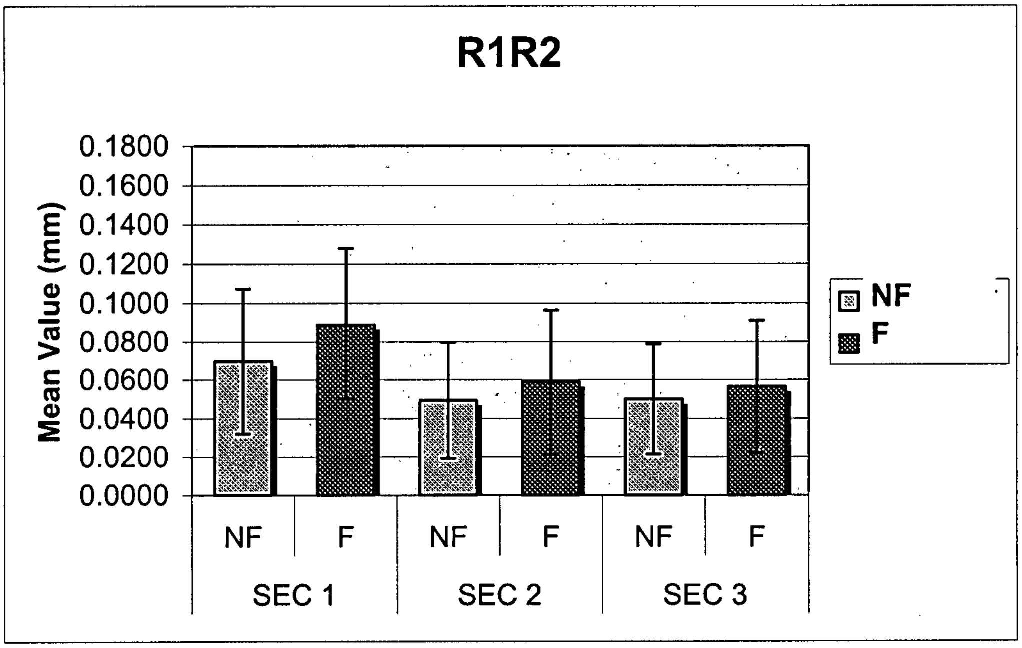

Figure 36 - Comparison of canal centre movement between 1st rotary instrumentation (R1) and 2nd rotary instrumentation (R2), emphasizing comparison of force (F) and no force group (NF), in each section.

Table 5 represents mean values of canal centre movement of 20 samples for each section, comparing first and second rotary instrumentation.

		SEC 1		SEC 2		SEC 3	
		NF (mm)	**F** (mm)	**NF** (mm)	**F** (mm)	**NF** (mm)	**F** (mm)
R1R2	MEAN	0.070	0.089	0.049	0.059	0.050	0.056
	STDEV	0.038	0.038	0.030	0.030	0.029	0.034

Table 5 - Mean and standard deviation of canal centre movement of 20 samples, comparing first and second rotary instrumentation.

The results of paired t-test indicated that there was no significant difference between group A (no force) and group B (force) at either canal level (sec 1; p=0.06, sec2; p=0.28, sec3; p=0.45) (Table 6).

	Paired t-value	Prob. (2-tail)
Sec 1	2.009	0.059
Sec 2	1.115	0.279
Sec 3	0.774	0.448

Table 6 - Paired t-test value for canal centre movement between 1st rotary and 2nd rotary instrumentation comparing force and no force group. There is no significant difference ($p<0.05$) between the force and no force group at any level.

The lateral (horizontally directed) force applied during the instrumentation with NiTi Orifice Shapers™ (Profile ®), was measured with Instron Universal testing Machine (Instron, Massachussets, USA). The average amount of force applied on all 20 canals in group B (Force group) was between 5 and 5.5N. The average instrumentation time was between 11 and 14 seconds. Figure 37 shows the graph of the forces applied on sample #6 when instrumented with NiTi Orifice Shapers™ (Profile ®) size 40.

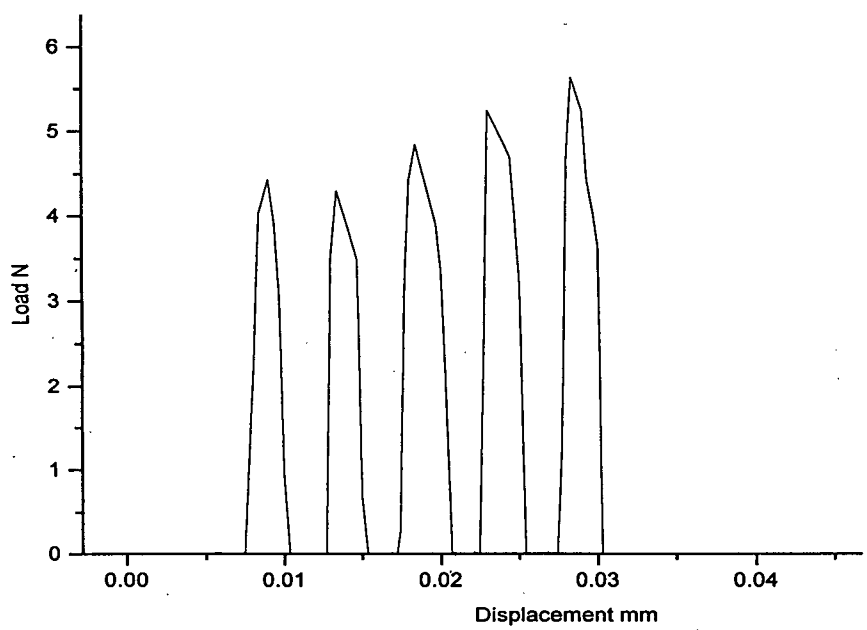

Figure 37 - Force applied during the instrumentation of sample# 6 with NiTi Orifice Shapers™ (Profile ®). Force was applied 5 times with size #40.

3.3 – Third Instrumentation: Gates-Glidden ^{R}, Force versus No force

Extent of the canal centre movement was measured between Gates-Glidden bur and second NiTi rotary instrumentation utilizing Scion NIH image 1.62 software (Scion Corp, Frederick, Maryland, USA). The mean value for canal centre movement of all 20 paired canals, force and no force groups, are presented in Figure 38. As before each section was evaluated separately. A discernible difference was seen between the two groups at all canal levels.

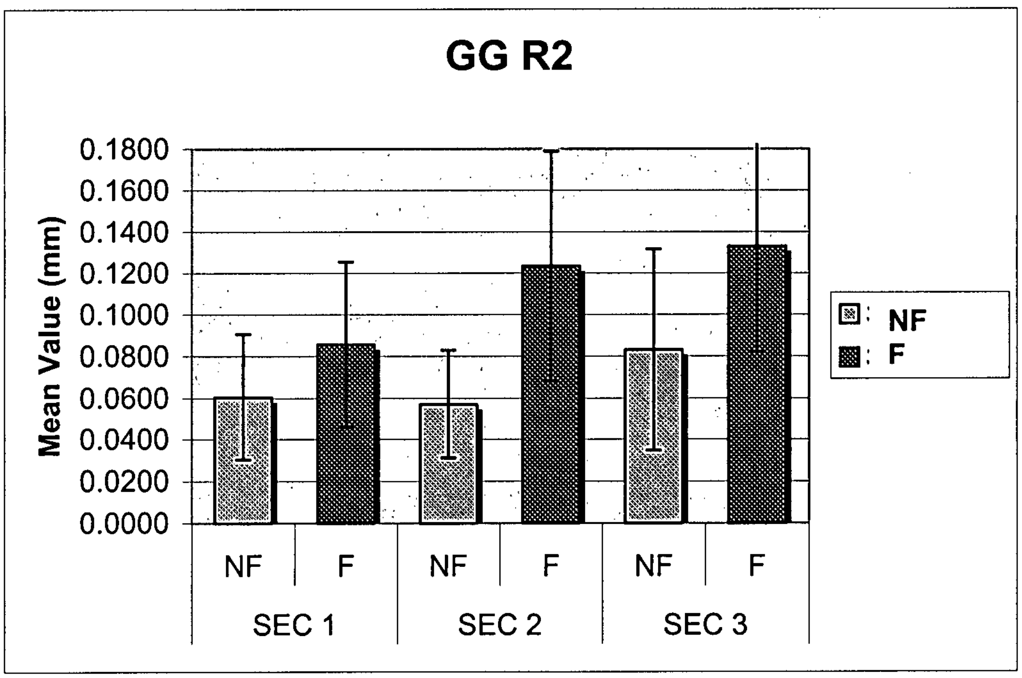

Figure 38 - Comparison of canal centre movement between Gates-Glidden bur (GG) and 2nd rotary instrumentation (R2), emphasizing comparison of force (F) and no force group (NF), in each section.

Table 7 represents mean values of canal centre movement of 20 samples for each section, comparing second and third rotary instrumentation.

		SEC 1		SEC 2		SEC 3	
		NF (mm)	F (mm)	NF (mm)	F (mm)	NF (mm)	F (mm)
R2GG	MEAN	0.060	0.086	0.057	0.123	0.083	0.133
	STDEV	0.030	0.040	0.026	0.055	0.048	0.051

Table 7 - Mean and standard deviation of canal centre movement of 20 samples, comparing second and third rotary instrumentation.

The results of paired t-test also indicated that there was a significant difference in canal centre movement between group A (no force) and group B (force) at all canal levels (sec 1; p=0.007, sec2; p=0.003, sec3; p=0.0001) (Table 8).

	Paired t-value	Prob. (2-tail)
Sec 1	4.435	0.0003
Sec 2	5.177	0.0001
Sec 3	6.415	0.0001

Table 8 - Paired t-test value for canal centre movement between Gates-Glidden bur and 2nd rotary instrumentation comparing force and no force group. There is a significant difference ($p<0.05$) between the force and no force group at all level.

The lateral (horizontally directed) force applied during the instrumentation with NiTi Orifice Shapers ^{TM} (Profile ^{R}), was measured with Instron Universal Testing Machine (Instron, Massachussets, USA). The average amount of force applied on all 20 canals in group B (Force group) was between 3 and 3.5N. The average instrumentation time was between 10 and 12 seconds. Figure 39 showed the graph of the forces applied on sample #6 when instrumented with Gate-Glidden burs.

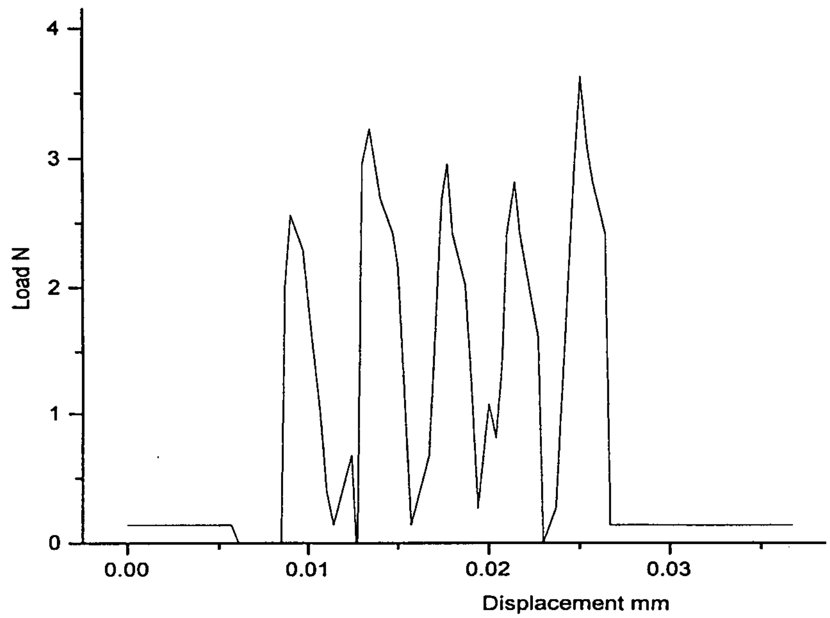

Figure 39 - Force applied during the instrumentation of tooth# 6 with Gate-Glidden. Force was applied 5 times with GG #2.

The direction of the canal centre movement was evaluated by the direction of movement of X and Y centre points comparing Gates-Glidden bur and second NiTi rotary instrumentation. The average centre point movement in sections 2 and 3 was towards the danger zone, while in section 1 the direction of the canal centre movement was towards the safety zone. After instrumentation with Gates-Glidden bur, the danger zone was violated at the levels of the canal where perforation can occur.

4. Discussion and Conclusion

This study evaluated the ability of NiTi rotary file, NiTi Orifice Shapers ™ (Profile ®), to be directed away from the danger zone of the root canal when flaring the coronal portion of mesial canals of mandibular molars. This directed root canal instrumentation in an anticurvature manner has been investigated earlier, using stainless steel files and Gates-Glidden burs (Lim & Stock, 1987), but there is no previous literature on anticurvature filing using rotary NiTi files.

The force applied during the anticurvature filing of root canals with rotary NiTi instrument and Gates-Glidden burs was controlled and measured in our study. There are no reported investigations on measurement and control of the force applied during anticurvature filing with rotary NiTi files. For measuring the force a modification of the Instron testing machine was necessary. The load cell of Instron machine was positioned upside down for measurement of the compressive force applied. This model functioned well for measurement of the horizontal force applied.

For studying the anatomical morphology of coronal third of mesial root of mandibular molars, before and after instrumentation, a modified muffle block was developed. Two prototypes were made in order to accommodate tooth sectioning device and Instron Testing Machine. This muffle block allowed exact repositioning of tooth sections in a predictable manner. The tooth sections investigated in our study were within the canal region that was considered to be a danger area in a study by Lim and Stock (1987); approximately 8 mm and 5 mm level from the apex. Mandibular molars were selected in our study because of their curved and flattened roots, where the middle section of the canal has been shown to lie much closer to the bifurcation side of the root (Tidmarsh, 1982). This represents the danger area. Mandibular molars were also used because the mesial root of mandibular molars has two very similar canals, whereby one canal could be used as experimental and the other as control.

It was concluded from the results of our study that with the amount force (3-5.5N) and the time period (12-16sec) under which the force was applied, it is not possible to direct rotary NiTi Orifice Shapers™ away from the danger area in the coronal root portion. This result supported our hypothesis. However, a trend of increased difference between force and no force groups could be detected at all sections when comparing first and second rotary instrumentation. This difference was most obvious in section 1, 1mm below the orifice. The amount of force and the period of time under which the force is applied were, therefore, considered to be important factors in determination of canal centre movement. In this study Gates-Glidden burs were used as positive control in order to verify our methodology. A significant difference ($p<0.05$) in canal centre movement was detected between force and no force groups after instrumentation with Gates-Glidden burs. The direction of canal centre movement was evaluated after instrumentation with Gates-Glidden bur. In the furcal area the average canal centre movement was towards the danger zone but towards the safety zone around the orifice. This supports the results from study done by Kessler *et al*, in 1983. They had concluded in their study that during anticurvature filing of the coronal portion of the root canal, round burs left greater average thickness of dentin toward the furcal area compared to Gates-Glidden bur (Kessler *et al.*, 1983). However, it should be mentioned that the amount of canal centre movement that was detected in our study, after instrumentation with Gates-Glidden burs, was minimal (less than 0.3mm). It could be argued that if a greater lateral force was applied, larger movement of the canal centre may possibly occur. The amount of force applied during instrumentation with Gates-Glidden bur (3-3.5N) was slightly less than the force used during instrumentation with Orifice Shapers™ (Profile ®) (3-5.5N). It was found that Gates-Glidden #2 bur would fracture if a force more than 3.5N was applied because of brittleness of Gates-Glidden #2 burs.

The centering ability of rotary NiTi instruments has been studied by many investigators. It can be concluded from the results of these studies that NiTi files stay centered in the root canal (Tharuni *et al.* 1996, Glosson *et al.* 1995, Short *et al.* 1997, Kuhn *et al.* 1997). The results of our study support this view. It can be discussed that because of centering ability of NiTi files, these files are more difficult to direct to a particular direction. Centering ability of an endodontic instrument during preparation of the root canals is usually a desired characteristic. But when instrumenting curved and furcated roots, it is significant to maintain the integrity of the canal walls at their thinner portion and reduce the possibility of perforation by directing the instrument away from the danger area. Continuing research is required to advance the successes already achieved thus far. Further investigations to examine larger amounts of force and longer time duration of instrumentation when directing the NiTi rotary instrument towards the safety zone of the root canal, are recommended.

Bibliography

Abou-Rass M. Frank AL. Glick DH. The anticurvature filing method to prepare the curved root canal. Journal of the American Dental Association. 101(5):792-4, 1980 Nov.

Alodeh MH. Doller R. Dummer PM. Shaping of simulated root canals in resin blocks using the step-back technique with K-files manipulated in a simple in/out filing motion. International Endodontic Journal. 22(3):107-17, 1989 May.

a) al-Omari MA. Dummer PM. Newcombe RG. Comparison of six files to prepare simulated root canals. 1. International Endodontic Journal. 25(2):57-66, 1992 Mar.

b) al-Omari MA. Dummer PM. Newcombe RG. Doller R. Comparison of six files to prepare simulated root canals. 2. International Endodontic Journal. 25(2):67-81, 1992 Mar.

Andreasen GF. Hilleman TB. An evaluation of 55 cobalt substituted Nitinol wire for use in orthodontics. Journal of the American Dental Association. 82(6):1373-5, 1971 Jun.

Bishop K. Dummer PM. A comparison of stainless steel Flexofiles and nickel-titanium NiTiFlex files during the shaping of simulated canals. International Endodontic Journal. 30(1):25-34, 1997 Jan.

Bower RC. Furcation morphology relative to periodontal treatment. Furcation root surface anatomy. Journal of Periodontology. 50(7):366-74, 1979 Jul.

Bramante CM. Berbert A. Borges RP. A methodology for evaluation of root canal instrumentation. Journal of Endodontics. 13(5):243-5, 1987 May.

Branding HJ, Morton Ph, Bell T, Earwarker LG. The structure and composition of plasma nitrided coatings on titanium. Nucl Instruments methods Phys Res 66:230-6, 1992.

Brau-Aguadé E. Canalda-Sahli C. Berastegui-Jimeno E. Cutting efficiency of K-files manufactured with different metallic alloys. Endodontics & Dental Traumatology. 12(6):286-8, 1996 Dec.

1a) Bryant ST. Thompson SA. al-Omari MA. Dummer PM. Shaping ability of Profile rotary nickel-titanium instruments with ISO sized tips in simulated root canals: Part 1. International Endodontic Journal. 31(4):275-81, 1998 Jul.

1b) Bryant ST. Thompson SA. al-Omari MA. Dummer PM. Shaping ability of ProFile rotary nickel-titanium instruments with ISO sized tips in simulated root canals: Part 2. International Endodontic Journal. 31(4):282-9, 1998 Jul.

Bryant ST. Dummer PM. Pitoni C. Bourba M. Moghal S. Shaping ability of .04 and .06 taper ProFile rotary nickel-titanium instruments in simulated root canals. International Endodontic Journal. 32(3):155-64, 1999 May.

Burston CJ, Qin B, Morton JY. Chinese Niti wire. A new Orthodontic alloy. American Journal of Orthodontics. 87: 445-52, 1985.

Busslinger A. Sener B. Barbakow F. Effects of sodium hypochlorite on nickel-titanium Lightspeed instruments. International Endodontic Journal. 31(4):290-4, 1998 Jul.

Butti A, Ferraroni M, Re D. Influenza delle tecniche di sterilizzazione rapida sulle proprietá meccaniche degli strumenti endodontici. Giornale Italiano di Endodnzia 9:144-50, 1995.

Camps JJ. Pertot WJ. Torsional properties of stainless steel Canal Master U and Flexogates. International Endodontic Journal. 27(6):334-8, 1994 Nov.

a) Camps JJ. Pertot WJ. Torsional and stiffness properties of nickel-titanium K files. International Endodontic Journal. 28(5):239-43, 1995 Sep.

b) Camps JJ. Pertot WJ. Levallois B. Relationship between file size and stiffness of nickel titanium instruments. Endodontics & Dental Traumatology. 11(6):270-3, 1995 Dec.

c) Camps JJ. Pertot WJ. Machining efficiency of nickel-titanium K-type files in a linear motion. International Endodontic Journal. 28(6):279-84, 1995 Nov.

a) Canalda-Sahli C. Brau-Aguade E. Berastegui-Jimeno E. Torsional and bending properties of stainless steel and nickel titanium Canal Master U and Flexogate instruments. Endodontics & Dental Traumatology. 12:141-5, 1996.

b) Canalda-Sahli C. Brau-Aguade E. Berastegui-Jimeno E. A comparison of bending and torsional properties of K-files manufactured with different metallic alloys. International Endodontic Journal. 29(3):185-9, 1996 May.

Canalda-Sahli C. Brau-Aguade E. Sentis-Vilalta J. The effect of sterilization on bending and torsional properties of K-files manufactured with different metallic alloys. International Endodontic Journal. 31(1):48-52, 1998 Jan.

Chan AW. Cheung GS. A comparison of stainless steel and nickel-titanium K-files in curved root canals. International Endodontic Journal. 29(6):370-5, 1996 Nov.

Cohen S, Burns R. Pathway of the pulp. 6th ed. St.Louis, MO:CV Mosby, 1994; 206-7

Cohen S, Burns R. Pathway of the pulp. 6th ed. St.Louis, MO:CV Mosby, 1998; 445-6

Coleman CL. Svec TA. Rieger MR. Suchina JA. Wang MM. Glickman GN. Analysis of nickel-titanium versus stainless steel instrumentation by means of direct digital imaging. Journal of Endodontics. 22(11):603-7, 1996 Nov.

Elliott LM. Curtis RV. Pitt Ford TR. Cutting pattern of nickel-titanium files using two preparation techniques. Endodontics & Dental Traumatology. 14(1):10-5, 1998 Feb.

Esposito PT. Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. Journal of Endodontics. 21(4):173-6, 1995 Apr.

Felt RA. Moser JB. Heuer MA. Flute design of endodontic instruments: its influence on cutting efficiency. Journal of Endodontics. 8(6):253-9, 1982 Jun.

Gambill JM. Alder M. del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. Journal of Endodontics. 22(7):369-75, 1996 Jul.

Goerig AC. Michelich RJ. Schultz HH. Instrumentation of root canals in molar using the step-down technique. Journal of Endodontics. 8(12):550-4, 1982 Dec.

Glosson CR. Haller RH. Dove SB. del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. Journal of Endodontics. 21(3):146-51, 1995 Mar.

a) Haïkel Y. Serfaty R. Wilson P. Speisser JM. Allemann C. Cutting efficiency of nickel-titanium endodontic instruments and the effect of sodium hypochlorite treatment. Journal of Endodontics. 24(11):736-9, 1998 Nov.

b) Haïkel Y. Serfaty R. Wilson P. Speisser JM. Allemann C. Mechanical properties of nickel-titanium endodontic instruments and the effect of sodium hypochlorite treatment. Journal of Endodontics. 24(11):731-5, 1998 Nov.

Hand RE. Smith ML. Harrison JW. Analysis of the effect of dilution on the necrotic tissue dissolution property of sodium hypochlorite. Journal of Endodontics. 4(2):60-4, 1978 Feb.

Harlan AL. Nicholls JI. Steiner JC. A comparison of curved canal instrumentation using nickel-titanium or stainless steel files with the balanced-force technique. Journal of Endodontics. 22(8):410-3, 1996 Aug.

Himel VT. Ahmed KM. Wood DM. Alhadainy HA. An evaluation of nitinol and stainless steel files used by dental students during a laboratory proficiency exam. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics. 79(2):232-7, 1995 Feb.

Hülsmann M. Gambal A. Bahr R. An improved technique for the evaluation of root canal preparation. Journal of Endodontics. 25(9):599-602, 1999 Sep.

Ingle JI, Beveridge EE. Endodontics. 2nd ed. Philadelphia; Lea& Febiger, 1976.

Ingle JI, Bakland LK. Endodontics. 4th ed. Philadelphia; Lea& Febiger, 1994.

Kazemi RB, Srtenman E, Spångberg LSW. The endodontic file is a disposable instrument. Journal of Endodontics. 21:451-5, 1995.

Kazemi RB, Srtenman E, Spnågberg LSW. Machining efficiency and wear resistance of nickel-titanium endodontic file. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics. 81:596-602, 1996.

Kessler JR. Peters DD. Lorton L. Comparison of the relative risk of molar root perforations using various endodontic instrumentation techniques. Journal of Endodontics. 9(10):439-47, 1983 Oct.

Knowles KI. Ibarrola JL. Christiansen RK. Assessing apical deformation and transportation following the use of LightSpeed root-canal instruments. International Endodontic Journal. 29(2):113-7, 1996 Mar.

Koskinen KP. Stenvall H. Uitto VJ. Dissolution of bovine pulp tissue by endodontic solutions. Scandinavian Journal of Dental Research. 88(5):406-11, 1980 Oct.

Kuhn WG. Carnes DL Jr. Clement DJ. Walker WA 3rd. Effect of tip design of nickel-titanium and stainless steel files on root canal preparation. Journal of Endodontics. 23(12):735-8, 1997 Dec.

Lam TV. Lewis DJ. Atkins DR. Macfarlane RH. Clarkson RM. Whitehead MG. Brockhurst PJ. Moule AJ. Changes in root canal morphology in simulated curved canals over-instrumented with a variety of stainless steel and nickel titanium files. Australian Dental Journal. 44(1):12-9, 1999 Mar.

Lim SS. Stock CJ. The risk of perforation in the curved canal: anticurvature filing compared with the stepback technique. International Endodontic Journal. 20(1):33-9, 1987 Jan.

Lipshatz J, Brockhurts PJ, West VC. Mechanical properties in bending of shape-memory wires. Australian Dental Journal. 37: 315-6, 1992.

Marsicovetere ES. Burgess JO. Clement DJ. del Rio CE. Torsional testing of the Lightspeed nickel-titanium instrument system. Journal of Endodontics. 22(12):681-4, 1996 Dec.

Miura F. Mogi M. Ohura Y. Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. American Journal of Orthodontics & Dentofacial Orthopedics. 90(1):1-10, 1986 Jul.

Mize SB. Clement DJ. Pruett JP. Carnes DL Jr. Effect of sterilization on cyclic fatigue of rotary nickel-titanium endodontic instruments. Journal of Endodontics. 24(12):843-7, 1998 Dec.

Oshida Y. Sachdeva RC. Miyazaki S. Microanalytical characterization and surface modification of NiTi orthodontic archwires. Bio-Medical Materials & Engineering. 2(2):51-69, 1992 Summer.

Ottosen SR. Nicholls JI. Steiner JC. A comparison of instrumentation using Naviflex and Profile nickel-titanium engine-driven rotary instruments. Journal of Endodontics. 25(6):457-60, 1999 Jun.

Pertot WJ. Camps J. Damiani MG. Transportation of curved canals prepared with canal master U, canal master U niti, and stainless steel K-type files. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics. 79(4):504-9, 1995 Apr.

Pettiette MT. Metzger Z. Phillips C. Trope M. Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel-titanium hand files. Journal of Endodontics. 25(4):230-34, 1999 Apr.

Portenier I. Lutz F. Barbakow F. Preparation of the apical part of the root canal by the Lightspeed and step-back techniques. International Endodontic Journal. 31(2):103-11, 1998 Mar.

Poulsen WB. Dove SB. del Rio CE. Effect of nickel-titanium engine-driven instrument rotational speed on root canal morphology. Journal of Endodontics. 21(12):609-12, 1995 Dec.

Pruett JP. Clement DJ. Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. Journal of Endodontics. 23(2):77-85, 1997 Feb.

Rapisarda E. Bonaccorso A. Tripi TR. Guido G. Effect of sterilization on the cutting efficiency of rotary nickel-titanium endodontic files. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics. 88(3):343-7, 1999 Sep.

Rapisarda E. Bonaccorso A. Tripi TR. Fragalk I. Condorelli GG. The effect of surface treatments of nickel-titanium files on wear and cutting efficiency. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics. 89(3):363-8, 2000 Mar.

Roane JB. Sabala CL. Duncanson MG Jr. The "balanced force" concept for instrumentation of curved canals. Journal of Endodontics. 11(5):203-11, 1985 May.

Roig-Cayon M. Basilio-Monne J. Abos-Herrandiz R. Brau-Aguade E. Canalda-Sahli C. A comparison of molar root canal preparations using six instruments and instrumentation techniques. Journal of Endodontics 23(6):383-6, 1997 Jun.

Rowan MB. Nicholls JI. Steiner J. Torsional properties of stainless steel and nickel-titanium endodontic files. Journal of Endodontics. 22(7):341-5, 1996 Jul

Royal JR. Donnelly JC. A comparison of maintenance of canal curvature using balanced-force instrumentation with three different file types. Journal of Endodontics. 21(6):300-4, 1995 Jun.

Samyn JA. Nicholls JI. Steiner JC. Comparison of stainless steel and nickel-titanium instruments in molar root canal preparation. Journal of Endodontics. 22(4):177-81, 1996 Apr.

Sarkar NK. Redmond W. Schwaninger B. Goldberg AJ. The chloride corrosion behaviour of four orthodontic wires. Journal of Oral Rehabilitation. 10(2):121-8, 1983 Mar.

Schäfer E. Tepel J. Hoppe W. Properties of endodontic hand instruments used in rotary motion. Part 2. Instrumentation of curved canals. Journal of Endodontics. 21(10):493-7, 1995 Oct.

Schäfer E. Lau R. Comparison of cutting efficiency and instrumentation of curved canals with nickel-titanium and stainless-steel instruments. Journal of Endodontics. 25(6):427-30, 1999 Jun.

Schilder H, Yee FS (1984) Canal debridement and disinfection. In COHEN S, BURNS RC, eds: Pathway of the pulp, 3rd edition. P 175. ST Louis: The CV Mosby Company

Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surgery, Oral Medicine, Oral Pathology. 32(2):271-5, 1971 Aug.

Serene TP, Adams JD, Saxena A. Nickel titanium instruments applications in endodontics. Chap.5. St. Louis: Ishiyaku EuroAmerica 1995.

Seto BG. Nicholls JI. Harrington GW. Torsional properties of twisted and machined endodontic files. Journal of Endodontics. 16(8):355-60, 1990 Aug.

Shadid DB. Nicholls JI. Steiner JC. A comparison of curved canal transportation with balanced force versus lightspeed. Journal of Endodontics. 24(10):651-4, 1998 Oct.

Shabalovskaya SA, Anderegg JW. Surface spectroscopic characterization of NiTi nearly equitamic shape memory alloys for implants. J Vac Sci Technolo 13:2624-32, 1995.

Short JA. Morgan LA. Baumgartner JC. A comparison of canal centering ability of four instrumentation techniques. Journal of Endodontics. 23(8):503-7, 1997 Aug.

Silvaggio J. Hicks ML. Effect of heat sterilization on the torsional properties of rotary nickel-titanium endodontic files. Journal of Endodontics. 23(12):731-4, 1997 Dec.

Stenman E. Spångberg LS. Machining efficiency of endodontic K files and Hedstrom files. Journal of Endodontics. 16(8):375-82, 1990 Aug.

Stokes OW. Fiore PM. Barss JT. Koerber A. Gilbert JL. Lautenschlager EP. Corrosion in stainless-steel and nickel-titanium files. Journal of Endodontics. 25(1):17-20, 1999 Jan

Svec TA. Powers JM. Effects of simulated clinical conditions on nickel-titanium rotary files. Journal of Endodontics. 25(11):759-60, 1999 Nov.

Tepel J. Schäfer E. Hoppe W. Properties of endodontic hand instruments used in rotary motion. Part 1. Cutting efficiency. Journal of Endodontics. 21(8):418-21, 1995 Aug

Tepel J. Schäfer E. Endodontic hand instruments: cutting efficiency, instrumentation of curved canals, bending and torsional properties. Endodontics & Dental Traumatology. 13(5):201-10, 1997 Oct.

Tharuni SL. Parameswaran A. Sukumaran VG. A comparison of canal preparation using the K-file and Lightspeed in resin blocks. Journal of Endodontics. 22(9):474-6, 1996 Sep.

1a) Thompson SA. Dummer PM. Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 1. Journal of Endodontics. 23(11):698-702, 1997 Nov.

1b) Thompson SA. Dummer PM. Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 2. Journal of Endodontics. 23(12):742-7, 1997 Dec.

2a) Thompson SA. Dummer PM. Shaping ability of ProFile.04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 1. International Endodontic Journal. 30(1):1-7, 1997 Jan.

2b) Thompson SA. Dummer PM. Shaping ability of ProFile.04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Part 2. International Endodontic Journal. 30(1):8-15, 1997 Jan.

3a) Thompson SA. Dummer PM. Shaping ability of NT Engine and McXim rotary nickel-titanium instruments in simulated root canals. Part 1. International Endodontic Journal. 30(4):262-9, 1997.

3b) Thompson SA. Dummer PM. Shaping ability of NT Engine and McXim rotary nickel-titanium instruments in simulated root canals. Part 2. International Endodontic Journal. 30(4):270-8, 1997.

4a) Thompson SA. Dummer PM. Shaping ability of Quantec Series 2000 rotary nickel-titanium instruments in simulated root canals: Part 1. International Endodontic Journal. 31(4):259-67, 1998 Jul.

4b) Thompson SA. Dummer PM. Shaping ability of Quantec Series 2000 rotary nickel-titanium instruments in simulated root canals: Part 2. International Endodontic Journal. 31(4):268-74, 1998 Jul.

Tidmarsh BG. Preparation of the root canal. International Endodontic Journal. 15(2):53-61, 1982 Apr.

Tulsa Dental Products brochure, Dentsply, Oklahoma, USA, 1996.]

Walia HM. Brantley WA. Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. Journal of Endodontics. 14(7):346-51, 1988 Jul.

Webber J. Moser JB. Heuer MA. A method to determine the cutting efficiency of root canal instruments in linear motion. Journal of Endodontics. 6(11):829-34, 1980 Nov.

Weine FS. Kelly RF. Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. Journal of Endodontics. 1(8):255-62, 1975 Aug.

Weine FS. Endodontic therapy. 2nd ed. Saint Louis: CV Mosby, 1976.

Wildey WL. Senia ES. Montgomery S. Another look at root canal instrumentation. Oral Surgery, Oral Medicine, Oral Pathology. 74(4):499-507, 1992 Oct.

Wolcott J. Himel VT. Torsional properties of nickel-titanium versus stainless steel endodontic files. Journal of Endodontics. 23(4):217-20, 1997 Apr.

Yoneyama T. Doi H. Hamanaka H. Influence of composition and purity on tensile properties of Ni-Ti alloy castings. Dental Materials Journal. 11(2):157-64, 1992 Dec.

Zmener O. Balbachan L. Effectiveness of nickel-titanium files for preparing curved root canals. Endodontics & Dental Traumatology. 11(3):121-3, 1995 Jun.

Appendix:

I. Area (mm)

Changes in area after each instrumentation of 20 samples. Mean and standard deviation of the samples before and after instrumentation.

II. Canal centre point movement (mm)

Changes in canal centre movement between pairs of pre- and hand instrumentation, hand and first NiTi rotary instrumentation, first NiTi rotary and second NiTi rotary- instrumentation and finally between second NiTi rotary and Gates-Glidden instrumentation, of 20 samples. Mean and standard deviation of the samples before and after instrumentation.

I. Area (mm)

Area (mm) of 20 samples, before instrumentation (P), comparing force (F) and no force group (NF) in each section.

		SEC 1		SEC 2		SEC 3	
	sample	**NF**	**F**	**NF**	**F**	**NF**	**F**
P	1	0.4333	0.4433	0.3300	0.1867	0.1800	0.1733
	2	0.2433	0.2367	0.1467	0.2467	0.2167	0.2667
	3	0.3533	0.1900	0.1400	0.1433	0.1933	0.1400
	4	0.4700	0.3200	0.3467	0.2433	0.2867	0.2033
	5	0.3967	0.3267	0.1733	0.1600	0.1533	0.0900
	6	0.0933	0.2933	0.1000	0.1367	0.1667	0.1667
	7	0.6367	0.4600	0.2433	0.1767	0.2200	0.1467
	8	0.3833	0.2733	0.2800	0.2500	0.2400	0.2600
	9	0.9100	0.8700	0.2067	0.2900	0.2400	0.2833
	10	0.6500	0.6867	0.3700	0.3467	0.3800	0.2833
	11	0.3767	0.2800	0.2133	0.3333	0.2567	0.3000
	12	0.7033	0.7000	0.5700	0.5167	0.5800	0.5000
	13	0.4633	0.4700	0.2467	0.2733	0.2500	0.2400
	14	0.5367	0.3667	0.2400	0.2033	0.1733	0.1633
	15	0.2367	0.2000	0.2400	0.1933	0.1600	0.1833
	16	0.4900	0.3833	0.0967	0.1400	0.0700	0.1133
	17	0.3233	0.4700	0.4700	0.4533	0.4133	0.2467
	18	0.3233	0.2633	0.2900	0.1867	0.1700	0.1500
	19	0.3100	0.3067	0.4633	0.4767	0.2633	0.2367
	20	0.1433	0.1433	0.2200	0.2033	0.2400	0.1833
	MEAN	*0.4238*	*0.3842*	*0.2693*	*0.2580*	*0.2427*	*0.2165*
	STDEV	*0.1911*	*0.1820*	*0.1226*	*0.1110*	*0.1078*	*0.0877*

Area (mm) of 20 samples, after hand instrumentation (H), comparing force (F) and no force group (NF) in each section.

		SEC 1		**SEC 2**		**SEC 3**	
	sample	**NF**	**F**	**NF**	**F**	**NF**	**F**
H	1	0.5933	0.5433	0.5400	0.5700	0.4733	0.3900
	2	0.3200	0.3933	0.3100	0.2967	0.2967	0.3200
	3	0.3967	0.3000	0.2133	0.2800	0.2733	0.3900
	4	0.5100	0.3200	0.3700	0.3300	0.3533	0.2567
	5	0.4100	0.3800	0.2267	0.2200	0.1933	0.2067
	6	0.2900	0.3733	0.1900	0.1467	0.3000	0.2667
	7	0.9067	0.6167	0.3467	0.2400	0.2367	0.1500
	8	0.4067	0.3500	0.4300	0.3800	0.3000	0.2933
	9	1.0467	1.1300	0.3533	0.4233	0.2700	0.3633
	10	0.7133	0.9100	0.4967	0.5533	0.3767	0.3400
	11	0.4233	0.3400	0.4233	0.3667	0.3867	0.4067
	12	0.7533	0.8433	0.5633	0.6000	0.5967	0.5133
	13	0.6600	0.5000	0.3767	0.3033	0.3100	0.3400
	14	0.5367	0.5567	0.2667	0.2267	0.1667	0.2000
	15	0.4000	0.3867	0.3900	0.3433	0.2300	0.2233
	16	0.5233	0.4200	0.2000	0.3000	0.1200	0.2567
	17	0.5067	0.4700	0.5000	0.4600	0.4733	0.2733
	18	0.3833	0.4267	0.4233	0.2933	0.2533	0.1867
	19	0.3833	0.5033	0.4633	0.4967	0.2767	0.3033
	20	0.3300	0.4233	0.2400	0.3000	0.3300	0.3200
	MEAN	*0.5247*	*0.5093*	*0.3662*	*0.3565*	*0.3108*	*0.3000*
	STDEV	*0.1967*	*0.2114*	*0.1131*	*0.1216*	*0.1090*	*0.0856*

Area (mm) of 20 samples, after first instrumentation (R1), comparing force (F) and no force group (NF) in each section.

R 1

sample	SEC 1 NF	SEC 1 F	SEC 2 NF	SEC 2 F	SEC 3 NF	SEC 3 F
1	0.7233	0.8200	0.6133	0.6033	0.5600	0.4133
2	0.4600	0.4500	0.3933	0.3367	0.2833	0.3267
3	0.5067	0.4833	0.3567	0.4733	0.3400	0.4000
4	0.7100	0.5233	0.3900	0.3667	0.3533	0.3600
5	0.6000	0.6567	0.2967	0.3033	0.2000	0.2133
6	0.4033	0.4800	0.2800	0.2367	0.3200	0.3633
7	0.9733	0.6733	0.4000	0.2967	0.2867	0.1900
8	0.5633	0.4967	0.4433	0.4133	0.3533	0.3967
9	1.6300	1.2900	0.5067	0.5167	0.2767	0.4433
10	0.7833	0.9833	0.6100	0.6733	0.4567	0.4433
11	0.6667	0.7067	0.4800	0.6133	0.4767	0.4400
12	0.9500	0.9067	0.6367	0.6800	0.6000	0.5467
13	0.6967	0.8133	0.3933	0.3967	0.3333	0.3667
14	0.5600	0.5567	0.4300	0.3400	0.2467	0.2333
15	0.5967	0.6267	0.4400	0.4833	0.3200	0.2667
16	0.6233	0.8500	0.2700	0.3000	0.1967	0.2767
17	0.6833	0.8400	0.5500	0.5567	0.5200	0.3667
18	0.6067	0.6400	0.4700	0.3567	0.2500	0.2000
19	0.5200	0.6900	0.5667	0.6667	0.3267	0.3733
20	0.6267	0.7133	0.2600	0.3200	0.3733	0.3967
MEAN	*0.6942*	*0.7100*	*0.4393*	*0.4467*	*0.3537*	*0.3508*
STDEV	*0.2554*	*0.2002*	*0.1131*	*0.1400*	*0.1110*	*0.0921*

Area (mm) of 20 samples, after second instrumentation (R2), comparing force (F) and no force group (NF) in each section.

R 2

	SEC 1		SEC 2		SEC 3	
sample	**NF**	**F**	**NF**	**F**	**NF**	**F**
1	0.8033	0.8867	0.7000	0.6867	0.5800	0.4300
2	0.4900	0.5200	0.5000	0.4300	0.3333	0.3300
3	0.5733	0.6367	0.4233	0.4900	0.3500	0.5000
4	0.7233	0.6400	0.5000	0.4067	0.3500	0.3700
5	0.7567	0.7300	0.4900	0.4900	0.3300	0.3133
6	0.6167	0.5700	0.4300	0.3800	0.3200	0.3600
7	1.2000	0.8700	0.4700	0.3900	0.3600	0.2700
8	0.6700	0.7433	0.5600	0.5900	0.3700	0.4600
9	1.9300	1.3000	0.6067	0.5900	0.3200	0.5267
10	0.8300	1.1500	0.6900	0.7200	0.4133	0.4900
11	0.7967	0.8767	0.5067	0.6200	0.4200	0.5133
12	1.0700	1.1367	0.7200	0.7433	0.6200	0.5567
13	0.7533	0.8900	0.4767	0.4667	0.3567	0.4133
14	0.7433	0.6300	0.5600	0.3500	0.3900	0.3067
15	0.6767	0.7633	0.4967	0.4700	0.3200	0.3100
16	0.8667	0.8900	0.3400	0.4367	0.2300	0.3300
17	1.0400	0.8967	0.6300	0.5167	0.5100	0.4300
18	0.6900	0.7000	0.5500	0.4400	0.3367	0.2767
19	0.5800	0.8433	0.6167	0.7700	0.3300	0.4500
20	0.9100	1.0400	0.3933	0.3167	0.3833	0.3967
MEAN	*0.8360*	*0.8357*	*0.5330*	*0.5152*	*0.3812*	*0.4017*
STDEV	*0.3038*	*0.1995*	*0.1009*	*0.1318*	*0.0901*	*0.0861*

Area (mm) of 20 samples, after third instrumentation (GG), comparing force (F) and no force group (NF) in each section.

		SEC 1		**SEC 2**		**SEC 3**	
	sample	**NF**	**F**	**NF**	**F**	**NF**	**F**
GG	1	0.9600	0.9900	0.8100	0.7567	0.6833	0.5033
	2	0.5467	0.6033	0.7500	0.6200	0.5067	0.5133
	3	0.7033	0.7233	0.6000	0.6133	0.5900	0.6400
	4	0.8100	0.6700	0.6167	0.7400	0.4933	0.6100
	5	0.8333	0.8900	0.5400	0.5600	0.4000	0.5400
	6	0.6700	0.7200	0.5267	0.5200	0.6300	0.5000
	7	1.5700	0.8900	0.5567	0.6867	0.5567	0.5400
	8	0.7800	0.7800	0.6133	0.8300	0.5300	0.6500
	9	1.9300	1.5600	0.6400	0.7400	0.5533	0.7100
	10	1.0467	1.3900	0.6900	0.7400	0.5333	0.5300
	11	0.8000	0.9000	0.6300	0.7700	0.5800	0.7100
	12	1.1033	1.3367	0.7800	0.8100	0.6400	0.6500
	13	0.8033	0.8867	0.5300	0.8233	0.5300	0.7500
	14	0.8200	0.6300	0.6100	0.6400	0.6800	0.6800
	15	0.7300	0.9233	0.5067	0.6000	0.4400	0.4867
	16	1.0367	1.1800	0.4600	0.6600	0.3800	0.4700
	17	1.1567	1.1900	0.7900	0.7500	0.6800	0.6333
	18	0.8500	0.9000	0.6700	0.5733	0.5300	0.5100
	19	0.7600	1.1600	0.6100	0.8700	0.5000	0.9067
	20	0.9300	1.1667	0.5333	0.6800	0.4133	0.6000
	MEAN	*0.9420*	*0.9745*	*0.6232*	*0.6992*	*0.5425*	*0.6067*
	STDEV	*0.3120*	*0.2605*	*0.0972*	*0.0965*	*0.0891*	*0.1074*

II. Canal centre point movement (mm)

Canal centre movement (mm) between hand instrumentation (H) and first rotary instrumentation (R1), comparing force (F) and no force group (NF), in each section.

HR1

		SEC 1		SEC 2		SEC 3	
	sample	NF	F	NF	F	NF	F
HR1	1	0.0047	0.1527	0.0537	0.0236	0.0359	0.0167
	2	0.0736	0.0994	0.0333	0.1086	0.0287	0.0464
	3	0.0316	0.0944	0.1255	0.0888	0.0105	0.0550
	4	0.0500	0.0801	0.1077	0.0640	0.0224	0.0333
	5	0.1001	0.1722	0.0582	0.0233	0.0380	0.0377
	6	0.0170	0.0915	0.0075	0.0547	0.0287	0.0368
	7	0.0267	0.0601	0.0236	0.0314	0.0550	0.0435
	8	0.0601	0.0920	0.0543	0.0583	0.0527	0.0435
	9	0.2191	0.0640	0.0667	0.0807	0.0407	0.0445
	10	0.0583	0.0641	0.0922	0.1128	0.0380	0.0867
	11	0.1314	0.1969	0.0407	0.1526	0.0967	0.0180
	12	0.0836	0.0120	0.0075	0.0390	0.0433	0.0180
	13	0.1687	0.0806	0.0433	0.1181	0.0075	0.0613
	14	0.0269	0.0801	0.1617	0.1202	0.0767	0.0596
	15	0.0943	0.1852	0.0527	0.0883	0.0285	0.0401
	16	0.1867	0.1814	0.1069	0.0752	0.0785	0.0377
	17	0.1603	0.0972	0.0335	0.0075	0.0389	0.0368
	18	0.2015	0.0438	0.1800	0.1414	0.0534	0.0033
	19	0.0590	0.1009	0.0644	0.1073	0.0865	0.0596
	20	0.1253	0.2382	0.0224	0.0224	0.0608	0.0328
	MEAN	*0.0939*	*0.1093*	*0.0668*	*0.0759*	*0.0461*	*0.0406*
	STDEV	*0.0653*	*0.0585*	*0.0482*	*0.0429*	*0.0242*	*0.0188*

Canal centre movement (mm) between first rotary instrumentation (R1) and second rotary instrumentation (R2), comparing force (F) and no force group (NF), in each section.

R1R2

	sample	SEC 1 NF	SEC 1 F	SEC 2 NF	SEC 2 F	SEC 3 NF	SEC 3 F
R1R2	1	0.1202	0.1721	0.1057	0.1156	0.1067	0.1443
	2	0.0137	0.0999	0.0994	0.0537	0.0777	0.0328
	3	0.0316	0.0732	0.0137	0.0401	0.0300	0.0407
	4	0.0568	0.1061	0.0447	0.0298	0.0000	0.0067
	5	0.0590	0.0354	0.0634	0.0939	0.0713	0.0477
	6	0.1114	0.0380	0.0910	0.0877	0.0047	0.0670
	7	0.0785	0.0300	0.0468	0.1037	0.0582	0.0760
	8	0.0105	0.0590	0.0707	0.1497	0.0567	0.0767
	9	0.1044	0.1245	0.0149	0.0075	0.0285	0.0298
	10	0.0367	0.0509	0.0566	0.0343	0.0474	0.0377
	11	0.0521	0.0823	0.0142	0.0361	0.0438	0.1076
	12	0.0657	0.1350	0.0269	0.0433	0.0447	0.0667
	13	0.0898	0.0770	0.0453	0.0632	0.0401	0.0527
	14	0.0718	0.0471	0.0354	0.0260	0.1059	0.0629
	15	0.0801	0.0841	0.0761	0.0328	0.0477	0.0105
	16	0.1157	0.1327	0.0167	0.1118	0.0680	0.0555
	17	0.1480	0.1182	0.0100	0.0340	0.0047	0.0412
	18	0.0283	0.0894	0.0504	0.0566	0.0460	0.0213
	19	0.0269	0.0828	0.0203	0.0167	0.0427	0.1184
	20	0.0939	0.1435	0.0881	0.0422	0.0773	0.0333
	MEAN	*0.0698*	*0.0891*	*0.0495*	*0.0589*	*0.0501*	*0.0565*
	STDEV	*0.0376*	*0.0387*	*0.0302*	*0.0374*	*0.0287*	*0.0345*

Canal centre movement (mm) between second rotary instrumentation (R2) and third rotary instrumentation (GG), comparing force (F) and no force group (NF), in each section.

GG R2

	SEC 1		SEC 2		SEC 3	
sample	NF	F	NF	F	NF	F
1	0.1470	0.1540	0.0574	0.0828	0.0696	0.0991
2	0.1076	0.1414	0.0601	0.1053	0.0852	0.1443
3	0.0275	0.0443	0.0447	0.1304	0.0713	0.0915
4	0.0594	0.0849	0.0543	0.2656	0.0314	0.1065
5	0.0348	0.0548	0.0236	0.0583	0.0939	0.1121
6	0.0825	0.0640	0.0567	0.0610	0.2126	0.2195
7	0.0949	0.1442	0.0889	0.1886	0.0307	0.1510
8	0.0412	0.0898	0.0662	0.1077	0.0632	0.1118
9	0.0700	0.1476	0.0359	0.0700	0.0707	0.1328
10	0.0664	0.0843	0.0367	0.1118	0.0120	0.0316
11	0.0433	0.0608	0.0527	0.0900	0.0721	0.1790
12	0.0137	0.0406	0.0283	0.0980	0.0510	0.0680
13	0.0604	0.0801	0.0120	0.2062	0.1221	0.2265
14	0.0555	0.0616	0.1110	0.1488	0.1554	0.2051
15	0.0438	0.1020	0.0485	0.1222	0.0361	0.1208
16	0.0659	0.1255	0.0728	0.0930	0.0686	0.0960
17	0.0785	0.1195	0.1200	0.1490	0.1342	0.1297
18	0.0447	0.0224	0.0500	0.0933	0.1297	0.1866
19	0.0403	0.0406	0.0534	0.0710	0.1195	0.1721
20	0.0316	0.0500	0.0674	0.2171	0.0337	0.0767
MEAN	*0.060*	*0.086*	*0.057*	*0.124*	*0.083*	*0.133*
STDEV	*0.030*	*0.040*	*0.026*	*0.055*	*0.049*	*0.051*