EVALUATION OF FRACTURE RESISTANCE OF ENDODONTIC ROTARY FILES: AN *IN VITRO* STUDY

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By

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DECLARATION BY THE CANDIDATE

I, hereby, declare that the work presented in this thesis, entitled **"EVALUATION OF FRACTURE RESISTANCE OF ENDODONTIC ROTARY FILES: AN *IN VITRO* STUDY"** in fulfillment of the requirements for the award of Degree of Doctor of Philosophy of Babu Banarasi Das University, Lucknow is an authentic record of my own research work carried out under the supervision of **Dr. B. Rajkumar.**

I also declare that the work embodied in the present thesis is my original work and has not been submitted by me for any other Degree or Diploma of any university or institution.

Date: **Dr. Akanksha Bhatt**

CERTIFICATE OF THE SUPERVISOR

This is to certify that the thesis, entitled **"EVALUATION OF FRACTURE RESISTANCE OF ENDODONTIC ROTARY FILES: AN *IN VITRO* STUDY"** submitted by **Dr. Akanksha Bhatt** for the award of Degree of Doctor Philosophy by Babu Banarasi Das University, Lucknow is a record of authentic work carried out by her under my supervision. To the best of my knowledge, the matter embodied in this thesis is the original work of the candidate and has not been submitted elsewhere for the award of any other degree or diploma.

Signature

Dr. B. Rajkumar
Guide

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Working alone might not be impossible but someone's guidance and support makes your day. Some helping hands for you and some pure souls to pray. Their stars shine to illumine your path and their blessings are showered upon to grace your way.

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PREFACE

Modern day endodontics is revolutionized with the use of nickel titanium endodontic files for a root canal therapy. Although the flexibility of these instruments is enhanced but fracture of endodontic file during instrumentation still remains an important challenge for the operator. This dissertation made a sincere attempt to enlighten about the file fracture caused during rotation in recently introduced rotary nickel titanium file systems. This will help the clinician to opt for the required file system according to the working condition present.

This dissertation is submitted for the degree of Doctor of Philosophy at Babu Banarasi Das University, Lucknow. The research described herein is an original, unpublished, and independent work by Dr. Akanksha Bhatt. This dissertation was conducted under the able guidance of Dr. B. Rajkumar. All of the work presented henceforth was conducted in the Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur and Indian Farmers Fertilizer Cooperative Limited Amla, Bareilly, U.P., India. All project and associated methods were approved by the Research Degree Committee, Babu Banarasi Das University, Lucknow.

The contents of this dissertation is divided into several chapters. Chapter 1 includes details about the endodontic instruments whether hand or rotary being used during root canal therapy, their standardization, parts of rotary instruments, components of rotary instruments, alloys used to manufacture these endodontic instruments, Motor required to engage these instruments though handpieces, and description of various types of handpieces. This section also includes manufacturing process of Nickel titanium alloy and post treatment fabrication, Metallurgy of Nickel titanium alloy, its properties and focusing mainly on property that is Cyclic Fatigue. The factors affecting cyclic fatigue and methods to improve cyclic fatigue resistance have been emphasized in this chapter. Chapter 2 deals with the review of literature regarding the cyclic fatigue resistance of the various endodontic instruments, the apparatus design, factors affecting cyclic fatigue etc. Chapter 3 describes the aim and objectives of the present in-vitro study. Chapter 4 describes the material profile of all the materials/ apparatus used in this study and Methodology used during this study. Chapter 5 provides observations and results obtained during the study. Chapter 6 focuses on the discussion whether pertaining to the methodology adopted, experimental files used for this study, apparatus design, results obtained in comparison to the other researches as well as intergroup in the present study. Chapter 7 deals with the present in-vitro study conclusion remarks. Chapter 8 provides the list of all the references consulted in the present study.

Part of work has been published in the following publications:

1. Dr. Akanksha Bhatt, Dr. B Rajkumar, Dr. Vishesh Gupta. A comparative evaluation of cyclic fatigue resistance of two recent rotary NiTi endodontic file systems: An In-Vitro Study. Journal of Clinical and Public Health Research 2016; 1(1):15-7.

2. Dr. Akanksha Bhatt, Dr. B Rajkumar, Dr. Vishesh Gupta. Evaluation of Cyclic Fatigue Resistance of Rotary Niti vs Controlled Memory Endodontic

File Systems: An *In-Vitro* Study. Medico Research Chronicles 2016, 3 (3), 278-82.

3. Dr. Akanksha Bhatt, Dr. B. Rajkumar, Dr.Vishesh Gupta. A comparative analysis of cyclic fatigue resistance of new rotary NiTi file systems (Hyflex CM and One Shape): An In-Vitro Study. Indian Journal of Basic and Applied Medical Research 2016; 6(1): 183-7.

4. Dr. Akanksha Bhatt, Dr. B. Rajkumar, Dr.Vishesh Gupta. A comparative evaluation of flexural fatigue resistance of Protaper Next and Profile Vortex: An In-Vitro Study. Journal of Biomedical and Pharmaceutical Research 2017; 6(1): 81-4.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS/ SYMBOLS	FULL FORM
Mm º	Millimeter Degree
NiTi	Nickel Titanium
ed.	Edition
et al.	and others
TM	Trade Mark
ADA	American Dental Association
JADA ISO	Journal of American Dental Association International Standards Organization
GA	Georgia
rpm	Revolutions Per Minute
#	Hash Tag
Co.	Corporation
KHZ	KiloHertz
M.O.A	Mechanism of Action
a.k.a	Also Known As
b/w	Between
%	Percentage
EP	ElectroPolished
gm/cm^2	Gram per centimeter cube
MN/m^2 ^oC	Mega Newton per meter square Degree Centigrade
LN	Long Neck
PTN	ProTaper Next
PV	Profile Vortex
VB	Vortex Blue
GT	Greater Taper
BCC	Body Centric Cubic
β phase	Beta Phase
A_f	Temperature at which transformation to Austenite finish.
M_S	Starting Temperature for transformation to Martensite
A_S	Starting Temperature for transformation to Austenite

M_f	Temperature at which transformation to Martensite finish.
SMA	Shape Memory Alloy
GPa	Giga Pascal
K	Kelvin
Pa ppm	Pascal Parts per million
M-Wire	Memory Wire
TTR	Transformation Temperature Range
RTTR	Reverse Transformation Temperature Range
Wt	Weight
N/cm^3	Newton per centimeter cube
>	Greater Then
<	Lesser Then
N-cm	Newton centimeter
IEJ	International Endodontic Journal
Vol	Volume
RC	Root Canal
Sec N	Seconds Newton
R.EDTA	EDTA with R-Lipoic acid
Ag/AgCl	Silver/ Silver Chloride
±	Standard Error
ϴ	Diameter
CF	Cyclic Fatigue
NCF	Number of cycles till fracture
SEM	Stereo Electron Microscope
%wt	Percentage by Weight
MTAD	Mineral Trioxide Aggregate Detergent
OH	Hydroxyl
H_2O	Water
Ti PFM	Titanium Porcelain Fused to Metal
CCW	Counter Clock wise
CW	Clock Wise
NiTiSMAS	Nickel Titanium Shaper Memory Alloys
TiO_2	Titanium Dioxide

CBCT	Cone Beam Computed Tomograpy
KOH	Potassium Hydroxide
LCF	Low Cyclic Fatigue
FE	Finite Element
R-Phase SE	Intermediate phase between Austenite & Martensite form. Super Elastic
DSC	Differential Scanning Calorimetery
wt	Weight
KV	Kilo Watt
CM Wire	Controlled Memory Wire
%wt	Percentage per weight
SMI	Structure Model Index
TF	Twisted Files
EDS	Energy Dispersive Spectrometric Analysis
NRT	Non Rotary
g	Gram
Ins	Insertions
3D NaOCl	Three Dimensional Sodium hypochlorite
i.e.	That is
PTU	ProTaper Universal
gm/cm^2	Gram per centimeter square
CT	Cryogenic Treatment
DCT	Di Cryogenic Treatment
FEA	Finite Element Analysis
ANOVA	Analysis Of Variance

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CHAPTER-1

INTRODUCTION

1.1 ENDODONTIC THERAPY

Endodontics has evolved and changed over the years like many other dental and medical specialties. Endodontic therapy involves the diagnosis of disease, removal of diseased tissue and filling of the root canal with an inert therapeutic material to obtain tight seal. Endodontic instruments play a major role in the success of endodontic treatment starting from the preparation of the access cavity to the final obturation of the root canal space. Refinement and modification of instruments enabled clinicians to enhance their skill in performing endodontic procedures. Earlier the technical demands and levels of precision required for successful performance of endodontic procedures was traditionally achieved by careful manipulation of hand instruments.

Among the difficulties encountered during endodontic therapy, are orifice access, its location, preparation of the canals without procedural errors, establishment and maintenance of working length. The risk of missing root canal anatomy was high because of the complexity of the root canal system. Calcifications, Lateral ramifications, irregular canal cross-sections and apical deltas of the root canal system were mostly inaccessible to mechanical instrumentation which increased the probability of leaving untreated spaces after root canal therapy. It has been found by Schilder (1974), Gupta *et al.* (2016) that the canal systems can have multiple geometric planes and curve significantly more than the roots that house them. Two-dimensional radiographs alone may not reveal these morphological variations of canals in spatial planes. According to Schilder (1974), the instrumentation of multiplanar curvatures can cause loss of length and ledging during hand file instrumentation. A recent aid in determining correct working length being apex locator has been regarded as one of the primary step to achieve endodontic success as concluded by Bhatt *et al.* (2015).

In earlier times, the instrumentation was aimed at facilitating the placement of medicaments in the root canal with little attempt to remove the organic contents from the root canal system. Later, the focus of instrumentation shifted to preparation of the root canal space to facilitate the placement of root canal fillings but the methods employed were mostly unrelated to the anatomy of the canal system given by Ingle in 1961 or the principles of the obturation laid by Schilder in 1974 and Bhatt *et al.* in 2015.

Considering the design objectives, most root canals were found curved as revealed by Schilder (1974). In contrast, endodontic instruments were manufactured from straight metal blanks and this led to uneven force distribution in areas where the file contacted the canal wall in curved canals. This was concluded by the finding of study done by Roane *et al.* (1985). The instrument finally tend to straighten itself in the canal. This resulted in wider canal shape to compensate for the presence of the curves. Historically 2% tapered stainless steel hand files were used to achieve a tapered preparation of the canal space with Gates-Glidden burs for coronal enlargement and taper. Technical protocols for shaping canals have evolved to achieve the objectives outlined by Schilder (1974). Schilder (1974) suggested serial instrumentation that involved usage of multiple curved hand files and reamers. The step-back technique involved preparation of the apical region of the root canal first, followed by coronal flaring to facilitate obturation. Mullaney (1979) was the inventor of this step back technique. On the other hand, crown-down preparation commenced with the use of larger instruments at the canal orifice proceeding down the root canal with progressively smaller files. A lot of researches by Goerig (1982), Michelich and Schultz (1982), Fava (1983) and Morgan and Montgomery (1984) have been done showing this technique.

Since the mid 1960's until the early 1990's, root canal therapy was done in large by traditional stainless steel hand instruments of various lengths, flute designs and methods of use. Although many geometric differences were present within this group of files, they shared many handling and mechanical characteristics. Some of these files have been used in a rotary or reciprocating action with the aid of motors. Stainless steel files were very adequate for straight root canals but presented ever mounting challenges when canal curvature increased or other anatomical anomaly (e.g. S-shaped canal) were encountered in a root canal. The stiffness of these instruments was an advantage when small diameter files were used for negotiating calcified canals, scouting for canal bifurcation below the canal orifice, trying to recapture the root canal anatomy after ledges, and when used to remove or bypass existing root canal filling (e.g. gutta-percha, silver points, Thermafill, etc.) or broken instruments.

As expected, the rigidity of stainless steel files increased as their tip size increased (and consequent overall bulk of the file). Adequate apical size and canal taper after root canal preparations was still a continuous source of debate within the field of endodontics. But when larger apical sizes were needed in a moderate to severe curved root canal or when difficult anatomy (e.g.: S-shape) was encountered, the use of stainless steel files was found more difficult and the possibility of creating an iatrogenic alteration of the canal was also increased. Pre-bending files which would match the root canal curvature was an important skill to master as failure to do so would created deviations from the root canal anatomy such as ledges, zips, perforations or even strip perforations. These root canal alterations would further pose potential clinical complications such as: underprepared or uncleaned root canal anatomy, difficulty in creating a proper seal with the root canal filling and sealer, communication of the root canal with the periodontal ligament space, etc. All of these could potentially lower down the prognosis of the root canal therapy and make any subsequent improvement more difficult or impossible.

Earlier the instruments used for endodontic therapy were made of carbon steel alloys that are now replaced by alloys of either stainless steel or nickel-titanium. Presently, the variety of rotary instruments for endodontic treatment is staggering. There has been a constant quest for quicker, safer and effective instrument for the treatment protocol. Each system was introduced with benefits which were apparent in their near perfection in preparing root canal. Mcspadden JT (2007) found that with the introduction of rotary nickel-titanium instruments there was promotion of single visit root canal therapy which earlier was a tedious procedure with conventional instruments.

The application of Nickel Titanium in field of endodontics was first reported by Walia *et al.* in 1988 who used NiTiNOL orthodontic wire to fabricate intracanal files. These were shown to have two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracturing when compared to similar size stainless steel endodontic files. Bergmans *et al.* (2001), Gergi *et al.* (2010) found that the use of NiTi as endodontic root canal instruments offered the advantages of less canal transportation during use whilst reducing treatment time. The morphology of the root canal system and the curvature of the roots varies as demonstrated by the finding of research conducted by Manning SA. (1990a, 1990b) and Cohen S and Burns RC (2002) and these factors provide great challenges for dentists. Because of the lower elastic modulus and wide elastic working range of the nickel-titanium (NiTi) alloy as compared with stainless steel, Nickel-titanium instruments were introduced into endodontic treatment in 1990's; with the first rotary instrument (ProFile® Tulsa Dental) marketed in 1993.

No doubt about it that endodontic treatment has benefited from the introduction of NiTi rotary root canal instruments. However, clinicians only concern remains still about their breakage while in use. Grossman stated that a dentist who has not separated an instrument has not done enough root canals (Grossman, 1969). Fracture is the most common procedural error that occurs during clinical use of rotary NiTi instruments (Spanaki *et al.* 2006). The fracture of stainless steel hand files usually occurs after a visible distortion or deformation of the instrument Zuolo and Walton (1997). Even though NiTi instruments are stronger and more flexible than their stainless steel counterparts Walia *et al.* (1988). These instruments can fracture within their elastic limit and without any visible signs of previous permanent deformation as concluded by the findings of Pruett (1997), Clement and Carnes (1997), Gambarini (2001) and without prior use as documented by the finding of Arens *et al.* (2003), Baumann (2004), Shen *et al.*(2009). Authors like Iqbal *et al.*2006 have reported that NiTi rotary instrument fracture was seven times more likely than hand instrument fracture in an endodontic residency programme.

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

It has been found by Bergmans *et al.* (2001), Kuhn *et al.* (2001), Parashos and Messer (2006) that the fear of instrument fracture is the biggest deterrent to clinical adoption of rotary NiTi instruments.

Although the actual prevalence of such breakages has been indicated to be low (about 5%) by Parashos & Messer (2004). NiTi rotary instruments may fracture as a result of shear or fatigue failure, with the latter being implicated in more than one-third of the instruments fractured clinically. This has been supported by various clinical researches conducted by Sattapan *et al.* (2000), Parashos *et al.*(2004), Peng *et al.*(2005) and Shen *et al.*(2006).

The word “Fatigue” is the appropriate term to use when referring to the fracture of materials submitted to cyclic stresses. Glossary of Prosthodontic Terms 8 defines Fatigue as the breaking or fracturing of a material caused by repeated cyclic or applied loads below the yield limit usually viewed initially as minute cracks followed by the tearing and rupture. Guiomar M (2005) considered fatigue resistance as one of the most important aspects to consider when using materials in appliances fitted with rotary parts. Many previous studies have shown that the fatigue life of various NiTi instruments is affected by various factors like the radius of curvature [Pruett *et al.* (1997), Mize *et al.*(1998), Haıkel *et al.* (1999)] and the instrument size [Yared *et al.*(1999), Gambarini (2001), Peters & Barbakow (2002)]. The instrument design also affects the magnitudes of stress and strain when it is subject to torsion or bending as shown by Berutti *et al.* (2003) and Xu *et al.* (2006). This, in turn, can influence the fatigue behaviour because the instrument design, and cross-sectional shape in particular, can predispose fatigue-crack initiation due to stress concentration. Hence, the clinician should have clear concept of his choice of instrument when planning the treatment plan in order to minimize the endodontic failure.

1.2 ENDODONTIC INSTRUMENTS

1.2.1 CLASSIFICATION

1.2.1.1 According to Louis I. Grossman

Root Canal instruments may be divided into four types according to their function:

1) **Exploring Instrument:** used to locate the canal orifice and to determine or assist in obtaining patency of the root canal.

Example- Smooth broach and Endodontic explorers like DG16.

2) **Debridement Instrument:** used to extirpate the pulp and to remove debris and other foreign material.

   Example- Barbed Broach.

3) **Shaping Instrument:** to shape the root canal laterally and apically.

   Example- Reamers and Files.

4) **Obturating Instrument:** used to cement and pack gutta percha into the root canal.

   Example- Pluggers, Spreaders and Lentulo spirals.

1.2.1.2 According to ISO - Federation Dentaire International

1) **Group I:** Hand use only— files:both K type (Kerr) and H type (Hedstroem); reamers: K type and U type and broaches,rasp, pluggers, and spreaders.
2) **Group II:** Engine-driven latch type— same design as Group I but made to be attached to a handpiece. e.g.instruments attached to reciprocating handpiece, Vertical stroke handpiece, ultrasonic and sonic handpiece.
3) **Group III:** Engine-driven latch type— drills or reamers such as Gates Glidden, Peeso reamers and Niti rotary file systems.
4) **Group IV:** Root canal points— gutta-percha, silver, paper.

1.2.1.3 According to S. Cohen - Endodontic instruments can be divided into three groups:

1) **Group-I:** Hand operated instruments such as Barbed broaches and K-type and H-type instruments

2) **Group-II:** Low- speed instruments on which the latch type of attachment is part of the working section such as Gates- Glidden (GG) burs and Peeso reamers.
3) **Group-III:** Engine- driven instruments similar to the hand and finger- operated instruments. However, the handle of these engine- driven instruments have been replaced with attachments of latch type of handpiece.

1.2.1.4 According to James L. Gutmann, Thorn C. Dumsha, Paul E. Lovdahl and Eric J. Hovland

Classification of instruments based on usage in the root canal system:

HAFI: Instruments used by hand that are passively placed in the canal until they bind; they are used in an inward or outward motion against the canal wall in a filling or scraping motion to both remove debris and enlarge the canal. Examples include stainless steel K-type files, Hedstrom- type files, and NiTi K- type files (many manufacturers).

HARI: Instruments used by hand that are actively applied in a rotary fashion into the canal with the purpose of boring into the canal walls; they are used apically to remove dentine and debris or used to bore through obstacles in the root canal space. Examples include stainless steel K-type reamers (many manufacturers).

PARI: instruments used on a power-driven air turbine or electically driven engine that primarily rotate in a crown-down manner within the root canal. Examples include ProFiles^{TM}, GT^{TM} files, K-3 , Hero^{TM}, Precision Endodontics System^{TM}, Liberator^{TM}, Hyflex CM^{TM}, Protaper Next, Hero Shaper, One Shape, Vortex.

1.2.1.5 According to John I. Ingle & Leif K. Bakland

Group I: Hand use only- files, both K type (Kerr) and H type (hedstroem), reamers, K type and U type; broaches, pluggers and spreaders.

Group II: Engine driven Latch type- same design as Group I but made to be attached to a hand piece. It also includes paste fillers.

Group III: Engine driven Latch type- drills (Gates-Glidden), Reamers (Peeso) and M type reamers.

Group IV: Root canal points – Gutta percha, silver points, absorbent paper point.

1.2.1.6 According to V.Gopikrishna

Group 1: Hand-operated endodontic instruments

- **A.** Barbed broaches and rasps
- **B.** K-Type reamers and files
- **C.** Hedsttoem files

Group II: Low-speed instruments with latch-type attachments

- **A.** Gates-Glidden drills
- **B.** Peeso reamers

Group III: Engine – Driven Instruments

- **A.** Rotary NiTi endodontic instruments
- **B.** Reciprocating instruments
- **C.** Self-adjusting file (SAF)

Group IV: Ultrasonic and Sonic instruments

Before the introduction of rotary endodontic instruments, engine driven instruments were popularly used and were classified

1.2.1.7 According to method of use

- **Instrument that enlarges root canal orifice/ coronal portion of the canal**

  - Gates Glidden drills

  -Peeso Reamers

  -Orifice Opener

- **Instrument that enlarges Radicular portion of the canal**

-K-Reamer (Engine Driven)

-Hedstroems (Engine Driven)

-NiTi Shaping Hedstroem files (Kerr Corp.)

1.2.2 ENDODONTIC HAND INSTRUMENTS

An endodontic hand instrument (reamer or file) is formed from round wire which is modified to form a tapered instrument with cutting edges. These are produced via two techniques:

1. By machining the instrument directly on the lathe. E.g. H-file and NiTi instrument are machined.
2. By first grinding and then twisting. Here the raw wire is ground into tapered geometric blanks i.e. square, triangular or rhombhoidal. These blanks are then twisted counterclockwise to produce cutting edges.

1.2.2.1 Reamers

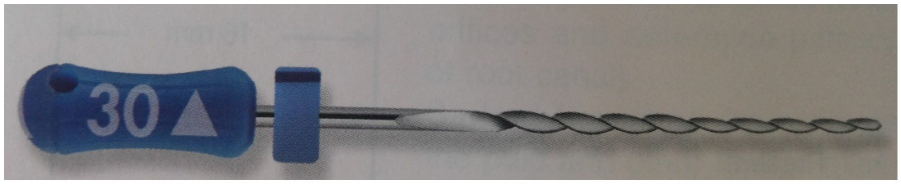


Figure 1.1: ISO size 30 Reamer

These are hand endodontic instruments. Reamers are made from triangular blanks. They are twisted to give the working end of the instrument a spiral form hence results in high resistance to torsional fracture. Reamers have upto 1 cutting blades per mm of their working end and thus have fewer cutting blades as compared to K File. The angle of the blades to the long axis of the reamer is about 10° to 30°, hence these instruments are primarily designed to be used in a rotational reaming motion. They cut by being inserted into the canal, twisted about one-quarter turn clockwise to engage their blades into the dentine, and then withdrawn.

The core diameter of any root canal instrument affects its flexibility as well as its resistance to fracture. Due to a well-balanced relation between core diameter and resulting area for debris removal, reamers have sufficient resistance to fracture and flexibility and at the same time sufficient cutting efficiency. Reamers are the only instruments that produce a round, tapered preparation, mainly in perfectly straight canals. Concerning the enlargement of curved canals, reamers may cause undesirable transportation or straightening of the canal, especially in canals with ovoid cross-sections.

1.2.2.2 K-Files

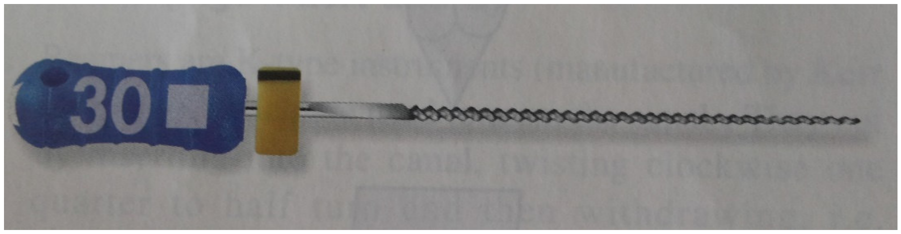


Figure 1.2: ISO Size 30 K File.

K-flles was first manufactured by Kerr Manufacturing Co. (Romulus, Michigan, USA) that is why it is called as K (Kerr) file. They have triangular or square or rhombhoidal cross section.

Moreover, K-files and reamers have a relatively high resistance to torsional fracture. Compared to reamers, K-flles show $1^{1/2}$ to $2^{1/2}$ cutting blades per mm of their working end. There are more spirals on a K-flle as compared to a reamer of a corresponding size.

The greater resistance to fracture of K-flles has a direct clinical impact. Under clinical conditions, the angular deflection gives some information about the risk that an instrument which bends at its tip will fracture if it is rotated any further. Hence, under clinical conditions the risk of torsional fracture is less for K-flles than for reamers.

The tighter spiral of a K-flle establishes a cutting angle, e. g. an angle of the flutes to the long axis of the K-flles, that is about 25° to 40°; thus these instruments are, like reamers, primarily designed to be used in a rotary reaming motion.

1.2.2.3 K-Flex file

In 1982 the Kerr Manufacturing Co. (Romulus, Michigan, USA) introduced a new instrument design, named the K-Flex file. This instrument was fabricated of V-4 steel and the cross section was rhombhoidal in shape to enhance fiexibility and cutting efficiency. The angle between the cutting flutes and the long axis was about 25° at the tip region and 50° at the end of the working part. Like K-files, the spirals of the K-Flex file were produced by twisting. Because of the rhombus-shaped cross-section "the cutting edges of the high flutes were formed by the two acute angles of the rhombus and presented increased sharpness and cutting efficiency.

The alternating low fiutes formed by the obtuse angle of the rhombus were meant to act as an auger, providing more area for increased debris removal. K-Flex files displayed higher cutting efficiency than conventional stainless steel reamers and K-files.

1.2.2.4 Hedstrom files

Figure 1.3: ISO Size 25 H File.

The cutting blades of Hedstrom files were machined into a round blank. Thus, the flutes of the Hedstrom file constituted a spiral like a screw.

Hedstrom files are characterized by an approximately circular cross-section ("teardrop cross-sectional shape") and the periphery bears spiral grooves. For

Hedstrom files, the angle between the cutting edge and the long axis of the instruments is about 60° to 65°; thus they are designed primarily for a linear, filing motion. Due to their positive rake angle they cut in one direction only, in a withdrawal stroke.

Since these instruments are machined from circular cross-sectioned blanks, they have sharp cutting edges. Used in linear motion, they are far more efficient than reamers or K files, cutting away more root canal dentin.

The helical angle of Hedstrom files appears closer to 90° . This can be an explanation for the better cutting efficiency of Hedstrom files in linear motion.

Hedstrom files are unsuitable for use in a rotary reaming motion because they have a low core diameter and are milled from blanks that show a higher risk of torsional fracture compared with reamers or K-files. That is why it is not recommended in narrow or curved canals due to an assumed higher risk of fracture.

In order to avoid undesirable shaping effects in curved root canals, such as straightening, ledging, zip and elbow formation, several manufacturers developed stainless steel alloys characterized by higher flexibility in bending compared with conventional stainless steel instruments.

These so-called flexible stainless steel instruments are similar in shape to conventional reamers and Kfiles.

1.2.2.5 Flexicut

In 1989, VDW Company, Munich, Germany presented the Flexicut instrument at the International Dental Show. These instruments were made of a chrome-nickel steel (SCS stainless steel). They had triangular cross-section and the working end showed 24 to 26 spirals, resulting in an angle of the cutting flutes to the long axis of 24° at the tip region and 45° at the end of the working part.

1.2.2.6 Flexoreamer

The Flexoreamer was produced by Maillefer (Ballaigues, Switzerland) since 1981 in ISO sizes 15 to 40. The cross-section of this twisted instrument was triangular. Independent of instrument size the working end had 16 spirals. Hence, the angle between the cutting fiutes and the long axis was 23° at the tip region and 32° at the end of the working part of the instrument. When used in rotary reaming motion, the Flexoreamer showed by far the highest cutting efficiency of all hand instruments.

1.2.3 ENDODONTIC ROTARY INSTRUMENTS:

Endodontic rotary instruments can be grouped into Bur & Endodontic File.

1.2.3.1 BUR:

It is defined as a cutting tool which revolves around its axis.

1.2.3.1.1 Caries excavation bur (Figure 1.4)

Eg. Mueller bur

Mueller burs are long-shaft, carbide-tipped burs used in a low-speed latch handpiece (Figure 1.4). They appear similar to Gates Glidden burs, but have a round carbide tip instead of the noncutting tip of the Gates Glidden bur.The long shaft is useful for working deep in the radicular portion of the tooth. In addition, it displaces the handpiece away from the occlusal surface, allowing the clinician to see the cutting tip in action. An added benefit of Mueller burs that is not well known even in the endodontic community is that unlike ultrasonics that leave a ragged, rough, dusty, debris-filled cut, Mueller burs leave a clean, shiny surface when used on intact dentin.

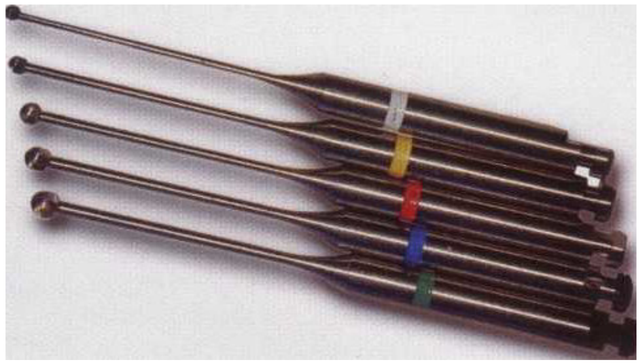


Figure 1.4: Mueller Bur

1. Endodontic Access Cavity Preparation bur.

- LA Axxess Bur (when access is through Tooth)

The LA Axxess Burs (Line-Angle Axxess) developed by Sybron Endo company are steel burs for the low speed handpiece designed by Dr. L.S. Buchanan specifically for the elimination of interferences in the pulp chamber and coronal one third of the canal. The LA Axxess are available in 3 diameters (Figure 1.5):

- Small with a minimum diameter of 0.20 mm
- Medium with minimum diameter of 0.35 mm and
- Large with a minimum diameter of 0.45 mm.

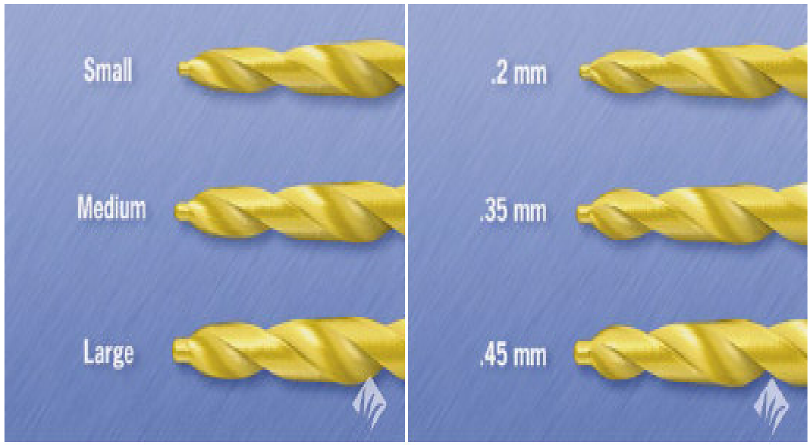


Figure 1.5: LA Axxess Burs with different diameters.

The LA Axxess have a rounded guiding tip and a 12 mm length of flutes (Figure 1.6) of which the first 3 mm has a parabolic increase, while the remaining 9 mm is characterized by a .06 taper.

Figure 1.6 : LA Axxess Burs showing flute design of 12 mm length.

The particular design of this bur favours the penetration of the coronal one third of the canal while the blade with its double cutting spiral rapidly removes the pulp chamber and coronal interferences. The recommended rotational speed for LA Axxess is about 5,000 rpm. Like the Gates and Largo drills, the LA Axxess must also be used with care, by pre-enlarging the canal with less aggressive endodontic instruments.

- Transmetal bur (Figure 1.7)

These metal cutting burs are highly practical adjuncts for gaining access through full nonprecious castings and nonprecious substructures like Porcelain fused to metal crowns.

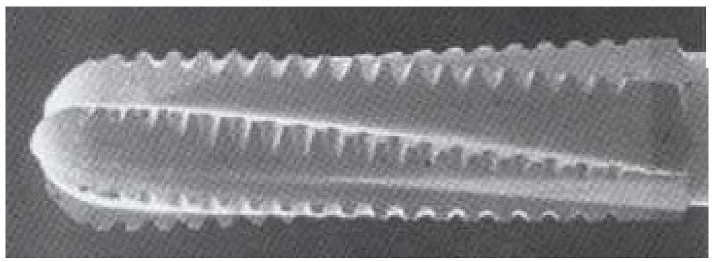


Figure 1.7: Transmetal bur.

The additional advantage of using these transmetal burs is time saving and reduced fatigue for operator as well as patient.

- Diamond point (when access is through Porcelain)

Round diamond points work predictably and quickly to cut through both porcelain fused-to-metal (PFM) crowns and all-porcelain crowns. (Figure 1.8)

Figure 1.8: Diamond Points of various diameters.

The clinician should use relatively new diamond points with abundant water and intermittent light pressure to avoid generating excessive heat. If dull diamond points are used, especially without water coolant, the clinician may be tempted to apply excessive pressure to accelerate the cutting process and thereby overheat the

crown. This can result in craze lines and fractures, which may chip off during instrumentation or after treatment completion. After removing the porcelain layer of the PFM, the clinician can then use a carbide fissure bur or a transmetal bur perforate the metal substructure and underlying foundation.

2. Access Refinement bur

Once the access to pulp chamber is gained, the refinement or shaping of chamber can be done by using Endo Z bur (Figure 1.9).

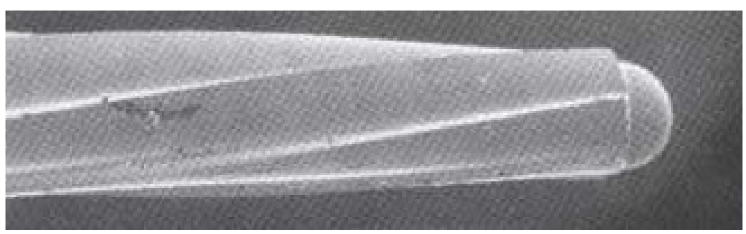


Figure 1.9: Endo Z bur

It is a carbide bur with a non cutting tip. It provides a clean shaved surface without danger of further deeping of the floor of pulp chamber.

3. Deep Exploration Burs / LN bur (Figure1.10)

Figure 1.10: LN Bur

This bur is tungsten steel bur manufactured by Dentsply Maillefer Company. This is also known as right angle bur. This unique, half-round bur with a long neck allows deep drilling alongside posts or broken instruments. The LN(Long Neck) Bur is used to break calcification to locate canals. The tip length is 8 mm; total length: 28 mm.

ENDODONTIC FILE: It is a instrument which is used for shaping and cleaning of the root canal during endodontic therapy.

Files can be classified according to Generations:

a) 1st generation: ProFile, Quantec, GT, Hero 642, Flex master.
b) 2nd generation: Race, ProTaper, K3, Hero Shaper, Revo-S.
c) 3rd generation: Profile Vortex, Twisted Files,Vortex Blue, Hyflex CM.
d) 4th generation: Wave One, Reciproc, Endosequence.
e) 5th generation: Protaper Next, One Shape.

➢ **First Generation**

To appreciate the evolution of Ni-Ti mechanical instruments, it is useful to know that in general, first generation Ni-Ti files have passive cutting radial lands and fixed tapers of 4% and 6% over the length of their active blades (Figure 1.11). This generation of technology required numerous files to achieve the preparation objectives. By the mid to late 1990s, GT files (Dentsply Tulsa Dental Specialties) became available, providing a fixed taper on a single file of 6%, 8%, 10%, and 12%. The single most important design feature of first generation Ni-Ti rotary file was passive radial lands, which encouraged a file to stay centered in canal curvatures during work.

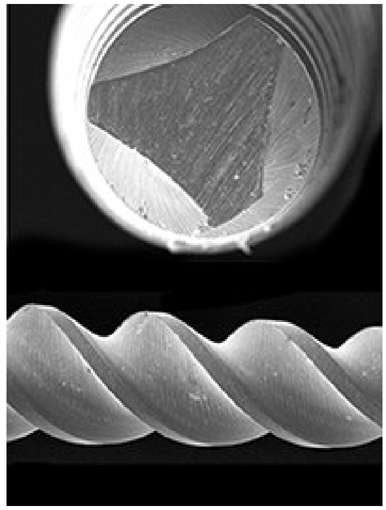


Figure 1.11. Scanning Electron Microscope (SEM) image reveals the cross-sectional and lateral view of a passively cutting radial-landed file.

- **Second Generation**

The second generation of Ni-Ti rotary files came to market in 2001. The critical distinction of this generation of instruments was that they have active cutting edges and require fewer instruments to fully prepare a canal (Figure 1.12). To discourage taper lock and the resultant screw effect associated with both passive and active fixed tapered Ni-Ti cutting instruments, EndoSequence (Brasseler USA) and BioRaCe (FKG Dentaire) provided file lines with alternating contact points. Although this feature was intended to mitigate taper lock, these file still had a fixed tapered design over their active portions. The clinical breakthrough occurred when ProTaper (Dentsply Tulsa Dental Specialties) came to market, utilizing multiple increasing or decreasing percentage tapers on a single file. This revolutionary, progressively tapered design limits the file's cutting action to a specific region of the canal and affords a shorter sequence of files to safely produce deep Schilderian shapes (Figure 1.13).

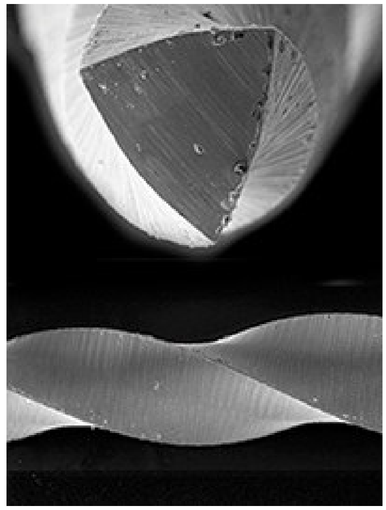


Figure 1.12. This SEM image reveals the cross-sectional and lateral view of an active file with sharp active cutting edge.

Figure1.13. ProTaper Shaping files (Dentsply Tulsa Dental Specialties) cut dominantly in their coronal and middle one thirds, whereas the Finishing files cut primarily in their apical one thirds.

During this period, manufacturers began to focus on other methods to increase the resistance to file separation. Some manufacturers electropolished their files to remove surface irregularities caused from the traditional grinding process. However, it has been clinically observed and scientifically reported that electropolishing dulls the sharp cutting edges. As such, the perceived advantages of electropolishing were offset by the more undesirable inward pressure required to advance a file to length. Excessive inward pressure, especially when utilizing fixed tapered files, invites taper lock, the screw effect, and excessive torque on a rotary file during work. To offset deficiencies in general, or inefficiencies resulting from electropolishing, more cross-sectional designs have become available and increased, yet more dangerous, rotational speeds are advocated.

- **Third Generation**

Improvements in Ni-Ti metallurgy became the hallmark of what may be identified as the third generation of mechanical shaping files. In 2007, manufacturers began to focus on utilizing heating and cooling methods to reduce cyclic fatigue and improve safety when rotary Ni-Ti instruments work in more curved canals. The desired phase transition point between martensite and austenite was identified to produce a more clinically optimal metal than Ni-Ti itself. This third generation of Ni-Ti instruments significantly reduced cyclic fatigue and, hence, the breakage of files. Examples of brand lines that offer heat treatment technology are Twisted File (Axis SybronEndo); HyFlex (Coltene); and GT, Profile Vortex, and WaveOne (Dentsply Tulsa Dental Specialties) (Figure 1.14).

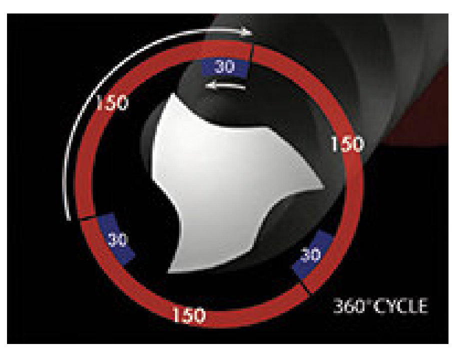


Figure 1.14. WaveOne reciprocating file utilizes unequal counter clockwise/clockwise angles to improve efficiency, inward progression, and augering debris out of the canal.

- **Fourth Generation**

Another advancement in canal preparation procedures utilized was reciprocation. It can be defined as any repetitive up-and-down or back-and-forth motion. Blanc, a French dentist, first introduced this technology in the late 1950s. Currently, the M4 (Axis SybronEndo), Endo-Express (Essential Dental Systems), and Endo-Eze (Ultradent Products) are examples of systems that use a movement where the clockwise (CW) and counterclockwise (CCW) degrees of rotation are absolutely equal. As compared to full rotation, a reciprocating file that utilizes an equal bidirectional movement requires more inward pressure to progress, will not cut as efficiently as a same-size rotary file, and is more limited in augering debris out of the canal.

From these earlier experiences, innovation in reciprocation technology led to a fourth generation of instruments for shaping canals. This generation of instruments and related technology has largely fulfilled the long hoped-for single-file technique. ReDent-Nova (Henry Schein) introduced the self-adjusting file (SAF). This file has a compressible open tube design that purported to exert uniform pressure on the dentinal walls, regardless of the cross-sectional configuration of the canal. The SAF being mechanically driven by a handpiece produced both a short 0.4 mm vertical amplitude stroke and vibrating movement with constant irrigation. By far, the most popular single-file concept was shown by WaveOne and Reciproc (VDW). WaveOne represents a convergence of the best design features from the second and third generation of files, coupled with a reciprocating motor that drives any given file in unequal bidirectional angles. The counter clock wise(CCW) engaging angle is 5 times the clock wise (CW) disengaging angle and is designed to be less than the elastic limit of the file. Strategically, after 3 CCW and CW cutting cycles, the file will have rotated 360°, or one circle (Figure 1.14). This novel reciprocating movement allows a file to more readily progress, efficiently cut, and effectively auger debris out of the canal.

- **Fifth Generation**

The fifth generation of shaping files has been designed such that the center of mass and/or the center of rotation are offset (Figure 1.15). In rotation, files that have an offset design produce a mechanical wave of motion that travels along the active length of the file. Like the progressively percentage tapered design of any given ProTaper file, this offset design served to further minimize the engagement between the file and dentin. In addition, an offset design enhanced augering debris out of a canal and improved flexibility along the active portion of a ProTaper Next (PTN) file (Dentsply Tulsa Dental Specialties).

Commercial examples of file brands that offer variations of this technology are Revo-S (Medidenta), One Shape(Micro Mega), and the PTN file system. Today, the safest, most efficient, and simplest file systems utilize the most proven design features from the past, coupled with the most recent technological advancements currently available.

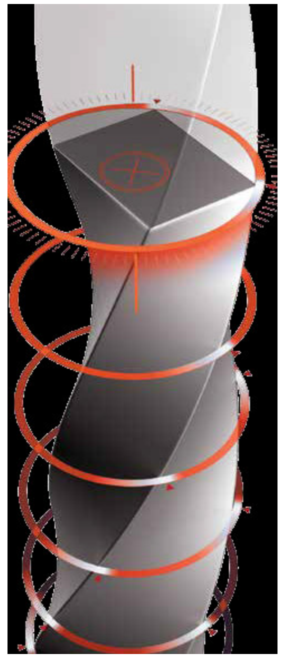


Figure 1.15. Protaper Next File design showing rectangular cross section and mass of rotation being offset.

1.2.3.3 Gates-Glidden Drills

Gates-Glidden (GG) drills are important instruments that have been used for more than 100 years. These instruments must only be used with the withdrawal motion to remove tooth structure at very slow speeds with irrigation. They create a funnel form shape.

Size and Lengths:

GG instruments are manufactured in a set and numbered 1 to 6 (with corresponding diameters of 0.5 to 1.5mm) (Table 1.1).The number of rings on the shank identifies the specific drill size. GG instruments are available in various lengths. (Figure 1.16)

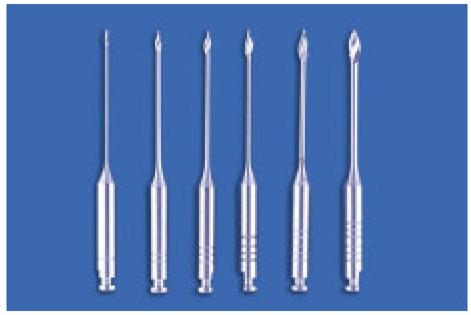


Figure 1.16. Gates Glidden Drills

Table 1.1: Size and Number of Gates Glidden Drills.

Gates Glidden Drill Number	Diameters (in mm)
1	0.50
2	0.70
3	0.90
4	1.1
5	1.3
6	1.5

They are available in standard (32 mm) and short (28 mm) length. Shorter 28 mm length is used for posterior teeth. The working portions of the drills are 18mm long, and the smaller size are slender from the handpiece portion to the bur end.

Cutting head (Figure 1.17):

GG has a bud shaped cutting point (short flame shaped head) mounted on a fine shaft attached to latch type shank. The bend is modified by having a blunt tip (non-cutting) which acts as a pathfinder in the root canal without damaging the walls or creating false pathways. The flame shaped head has side-cutting blades spiralling with a wide rake angle. The bur head for GG drill is triangular in shape. GG instruments should be used only in the straight portions of the canal, and they should be used serially and passively.

Figure 1.17. Cutting Head of Gates Glidden Drill.

Gates Glidden drills are designed to have a weak spot in the part of the shaft closest to the hand piece so that, if the instrument separate, the separated part can be easily removed from the canal. The fracture will be at the shaft and not at the tip of the instrument. Thus removal of fractured instruments is easy.

Procedural sequence:

Step-Down Technique, the clinician starts with a large drill and progresses to smaller ones, conversely, with the step-back technique, the clinician starts with a small drill and progresses to larger ones. With the step-down approach, the clinician must select a GG instrument with a diameter that allows introduction into the respective orifice and progression for about 1 mm. The subsequent smaller instruments progress deeper into the canal until the coronal third has been pre enlarged. This technique efficiently opens root canal orifices and works best when canals exit the access cavity without severe angulations. Opened orifices help to establish a smooth glide path from the access cavity into the root canal system.

With the step-back approach, a small GG instrument is introduced into the canal and dentin is removed on the outstroke. This process is repeated with the next larger GG instrument, which is again worked shorter than the preceding smaller one. In this way, the coronal third of the root canal is enlarged and dentin overhangs are removed.

Speed

Glidden drills may be used safely and to their fullest potential at 750 to 1500 rpm. GG drills work best when used in electric gear reduction hand pieces rather than with air motors.

Fracture (Figure 1.18)

High revolutions per minute (rpm), excessive pressure, an incorrect angle of insertion, and the use of GG instruments to aggressively drill into canals have resulted in mishaps, such as strip perforation. Also, GG instruments may fracture when used in curved canal areas because of cyclic fatigue, and the short cutting heads may fracture with high torsional loads. When misused, GG drills can dramatically reduce radicular wall thickness.

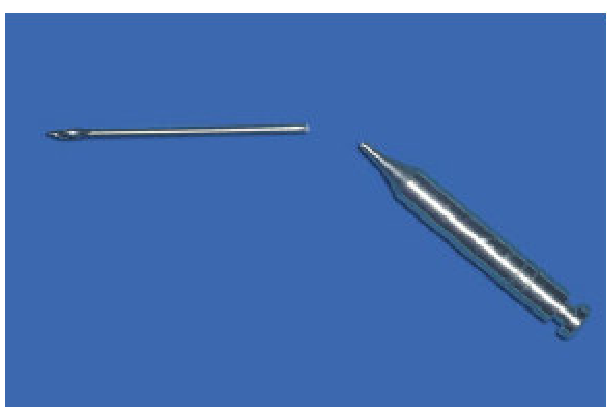


Figure 1.18. Fracture of Gates Glidden Drill

Uses

- Remove the lingual shoulder during access preparation of the anterior teeth.
- Enlarge root canal orifice.
- With step- down technique: start with larger drill and progress to smaller.
- With step – back technique: start with smaller drill and progress larger ones.

1.2.3.3.1 Modifications:

Flexogates (Dentsply /Maillefer; Tulsa, Olka.)

Also known as Handygates. A safe-tipped variation of the traditional Gates Glidden drill, the Flexogates is still to be tested clinically, although Briseno *et al.* compared Flexogates and Canal Master (Brasseler, Savannah, Ga.) in vitro found Flexogates less likely to cause apical transportation. (Figure 1.19)

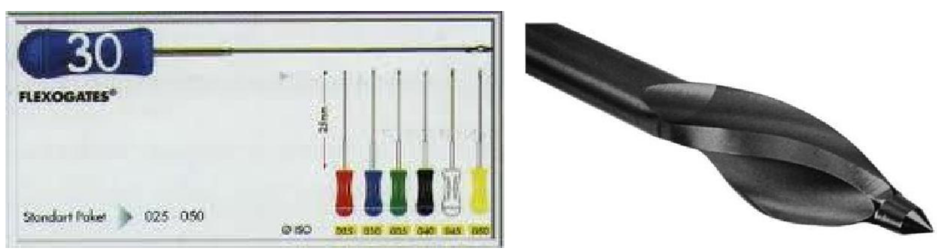


Figure 1.19: Flexogates

X-Gates

Combines Gates 1, 2, 3 and 4 in one single efficient instrument. Use the X-Gates with a brush cutting action at 800-1000rpm. Available in length 32 mm.

Figure 1.20: X-Gates

Advantages:

- Tip of Gates no.1 is easy insertion of the drill into the coronal third of the root canal.
- The shaft of Gates no.3 for improved strength.
- Maximum diameter of Gates no.4 is efficient re-localization of the root canal opening.

1.2.3.4 Peeso Reamers / Largo Drills

They are similar to gates glidden drills but have parallel cutting side ratherthan elliptical shape.

Figure 1.21: Peeso Reamers

Sizes:

They are available in sizes 1 to 6 (Table 1.2). These number represents the particular ISO size.

Table 1.2: Number and Size of Pesso Reamer Drills

Peeso Reamer Number	Diameters (in mm)
1	0.70
2	0.90
3	1.1
4	1.3
5	1.5
6	1.7

Tip:

The tip is a Safe ended one with the diameter ranging from 0.7 – 1.7

Motion:

Gently with apical directed pressure.

Use:

- Most often used in preparing post space when gutta percha has to be removed from the obturated root canal.
- They are also used in preparing the coronal portion of the root canal for post and core.

Advantages:

- If used too aggressively, with excessive pressure and incorrect angle can cause strip perforation.
- If misused can dramatically reduce radicular wall thickness.

1.2.3.5 Orifice Opener

Martin has developed an orifice opener used to flare and prepare the cervical and middle portions of the body of the canal. It comes in a pack of six with 3 tapers 0.08, 0.10, 0.12). It is used in a slow-speed latch type handpiece. It comes in ISO size 25-70.

Figure 1.22: Orifice Opener

The M-series Orifice Opener is more flexible than the Gates-Glidden. But it is still recommended only for straight portions of the canal (Figure 1.23).

Fgure 1.23: Mseries Orifice Opener

1.2.3.6 K-Reamer (Engine Driven)

The Maillefer K-Reamer provides flexibility, cutting ability and engine efficiency. K-type reamers are tapered and pointed metal instruments with spiral cutting edges, sometimes serrated. (Figure 1.24)

Figure 1.24: K Reamer (engine driven)

Size: Available in ISO sizes 10 – 120

Lengths: 18mm, 21mm & 25mm.

All Maillefer reamers are ISO sizes and color-coded. The standard sized handle fits all reciprocating hand pieces. It can also be used in a rotary hand piece.

Use: Enlarges root canals by a rotary cutting action.

1.2.3.7 Hedstroem (Engine Driven) (Figure 1.25)

The classic Hedstroem design is combined with the efficiency of engine driven instrumentation.

Figure 1.25: Hedstroem File (engine driven)

Sizes and lengths

Available on ISO sizes: 15-80.

Maillefer Hedstroems use ISO color identification and come in 21 mm, 23mm and 28mm lengths.

Design

H-type (Hedstroem) files are made by machine grinding the flutes of the file into the metal stock of the operating head of the instrument so as to form a series of intersecting cones successively larger from the tip towards the handle. The engine driven forms of H-type file have helical angles significantly less than 90 degrees.

Motion

These files are tapered and pointed, with spiral cutting edges arranged so the cutting occurs principally on the pulling stroke.

Use

They possess increased potential for cutting by rotary as well withdrawals movement.

1.2.3.8 NiTi Shaping Hedstroem files (Kerr Corp.)

This file features a non-cutting “safe” side that is thought to prevent stripping in the middle and coronal segments when placed against the inner curvature of the canal. Low flexibility and decrease torsion resistance seen in the terminal 4-5 flutes (2-3 mm) of each instrument. (Figure 1.26)

Figure 1.26: NiTi Shaping H File

Cross section: Round cross section ·

Engine Use: Rotary Speed 350rpm

Taper, Length, Size:

0.02 Taper, Length: 21mm, 25mm.

#ISO sizes: 15-40.

1.2.4 STANDARDIZATION OF ENDODONTIC INSTRUMENTS:

Before 1958, endodontic hand instruments were manufactured without benefit of any established criteria. There was little uniformity in quality control or manufacture, no uniformity existed in progression from one instrument to the next, and there was no co-relation of instruments and filling materials in terms of size and shape.

In 1959, guidelines of standardized instruments and filling material were introduced by Ingle and Levine. These included:

⇨ A formula for the diameter and taper in each size of instrument and filling material.

⇨ A formula for a graduated increment in size from one instrument to the next.

⇨ A instrument numbering system based on instrument metric diameter.

The guidelines were:

1. Instruments shall be numbered from 10 to 100, the numbers to advance by 5 units to size 60, then by 10 units to size 100 (Table 1.3).
2. Each number shall be representative of the diameter of the instrument in hundredths of a mm at the tip. e.g. No. 10 is 10/100 or 0.1mm at the tip.
3. The working blade (flutes) shall begin at the tip, designated site D_1, and shall extend exactly 16mm up the shaft, terminating at designated site D_2. (Figure 1.27)

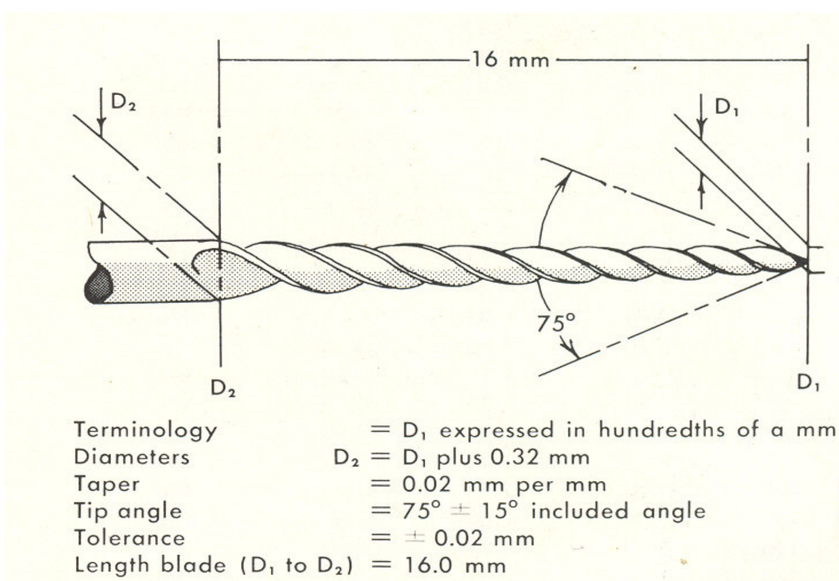


Figure 27: Standardization of a endodontic instrument.

The diameter of D_2 shall be 32/100 or 0.32mm > than that of D_1, for e.g. a no. 20 reamer has diameter 0.2 at D_1.Hence, Diameter at D_2 will be 0.2+ 0.32 = 0.52mm at D_2. This sizing ensures a constant increase in taper of 0.02mm per mm for every instrument regardless of the size. In addition, instruments handles have been colour coded for easier recognition (Table 1.3).

Table 1.3: ISO standardization (Color coding) of Endodontic Instrument

Color Code	New Number	Diameter (in mm)	
		D_0	D_{16}
Pink	6	0.06	0.38
Grey	8	0.08	0.40
Purple	10	0.10	0.42
White	15	0.15	0.47
Yellow	20	0.20	0.52
Red	25	0.25	0.57
Blue	30	0.30	0.62
Green	35	0.35	0.67
Black	40	0.40	0.72
White	45	0.45	0.77
Yellow	50	0.50	0.82
Red	55	0.55	0.87
Blue	60	0.60	0.92
Green	70	0.70	1.02
Black	80	0.80	1.12
White	90	0.90	1.22
Yellow	100	1.0	1.32
Red	110	1.10	1.42
Blue	120	1.20	1.52
Green	130	1.30	1.62
Black	140	1.40	1.72
White	150	1.50	1.82

- **The IS0 slightly modified Ingle's original standarization.**

1. Addition of Diameter measurement point (D_3) which is 3mm from the tip of cutting edge of the instrument at D_0 earlier designated as $D_{1.}$ Also D_2 is designated as D_{16}. (Figure 1.28 & 1.29)
2. Specifications for shapes of the tip → 75° tip ±15°.

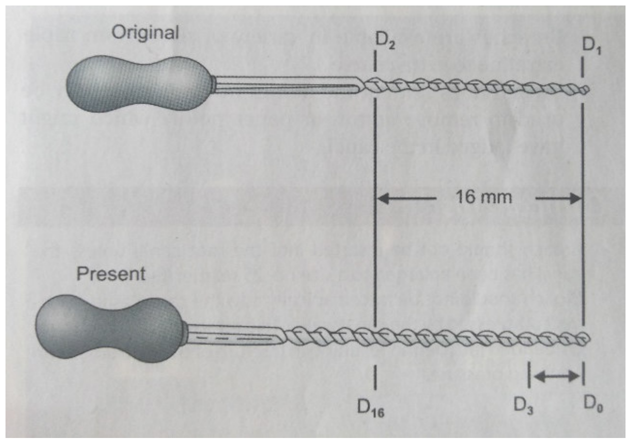


Figure 1.28: Original and Modified Standardization of Endodontic Hand Instrument.

- **ADA specification No. 28 was finally revised in March 1981.**

1. Instrument sizes 06 and 08 and 110 to 150 were added to the original standardization.
2. D_1 and D_2 were changed to D_0 and D_{16} respectively, to clarify in terms of mm from the tip.

D_0 → at the point of the tip. D_{16} → measured 16mm from the tip.

- **Instrument Length: Manufactured in four lengths:**

- Short– 21 mm (used in 2nd and 3rd molars or when patient has restricted mouth opening)

- Standard – 25 mm.(useful in anteriors)
- Long– 28 mm
- Extra long- 31 mm. (useful in canines)

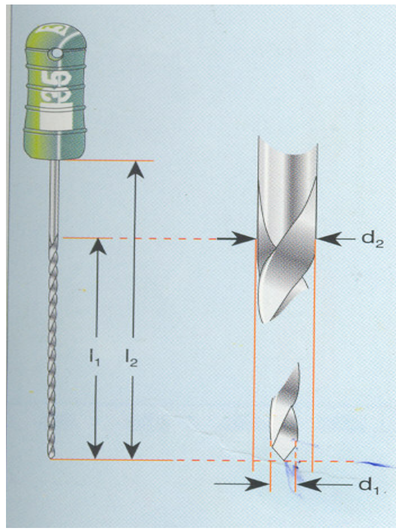


Figure 1.29 : Instrument Length

- Although instruments are available in various lengths, the working end of the instrument (length of the cutting segment, l_1) remains constant is 16 mm.
- Measured from the instrument tip to the end of the shank (l_2)
- Reamers are also available in 40 mm length for use in preparing root canals for endodontic implants.

Instruments with taper greater than the ISO standard of 0.02 mm/mm have become popular : 0.04, 0.06, 0.08, 0.10, and 0.12.

1.2.5 PARTS OF AN ENDODONTIC ROTARY INSTRUMENT

Each rotary instrument consists of 3 parts (Figure 1.30 & 1.31):

- Head

- Neck
- Shank

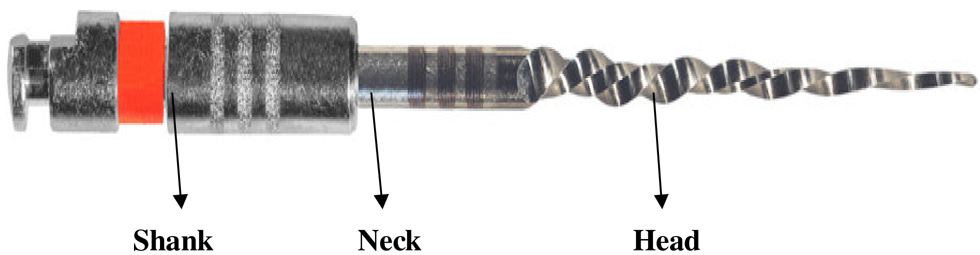


Figure 1.30: Part of an endodontic rotary instrument (File)

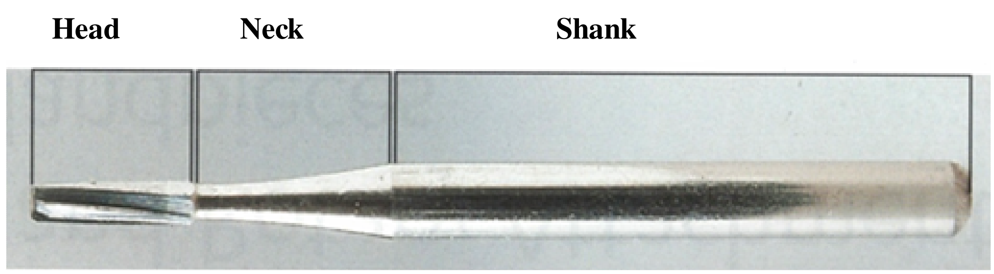


Figure 1.31: Parts of an endodontc rotary instrument (Bur).

Shank

It is the part that fits into the handpiece, accepts the rotary motion from the handpiece and provides a bearing surface to control the alignment and concentricity of the instrument.

ADA specification number 23, includes the following types of instrumental shanks types (Figure 1.32):

- Straight shank
- Latch type shank
- Friction grip shank

Figure 1.32: Types of Shanks.

Neck

It is the intermediate position of an instrument that connects the head to the shank.

The main function of the neck is to transmit rotational and translational force to the head. At the same time, it is desirable for the operator to have the greatest possible visibility of the cutting head and the greatest manipulative freedom.

For this reason, the neck, which gradually tapers from the shank to the head represents a compromise between the need for a large cross section to provide strength and a small cross-section to improve access and visibility.

Head

Head is the working part of the instrument, the cutting edges or points of which perform the desired shaping and cleaning of the tooth structure.

There are many characteristics of the heads of rotary instruments that could be used for classification. Most important among these is the division into Bladed instruments and Abrasive instruments. Material of construction, head size and head shape are other characteristics.

Advantages of Endodontic rotary instrument

- Easy to use
- Saves time
- Reduction in operator / patient fatigue
- Reduction in treatment time

Disadvantages of Endodontic rotary instrument

- Transportation, ledging and perforations error can occur.
- Hand instrumentation necessary before introducing rotary instrument in the canal.
- Apical packing of debris can occur.

1.2.6 COMPONENTS OF ENDODONTIC ROTARY INSTRUMENT (FILE)

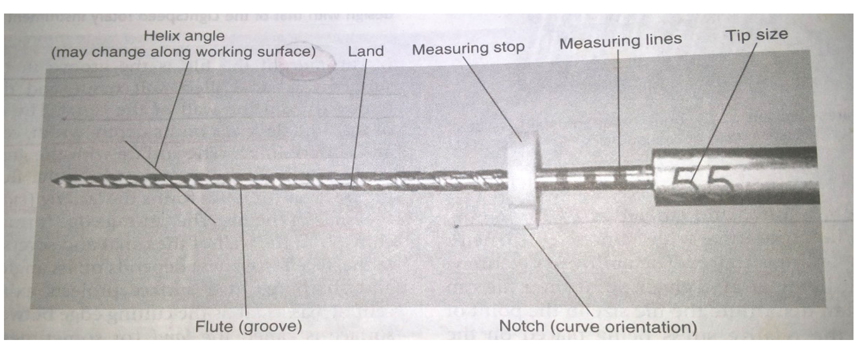


Figure 1.33: Component of a endodontic rotary file.

The following are the components of a endodontic rotary file (Figure 1.33):

- Taper of the file system.
- Cross-sectional design (symmetry or asymmetry, the presence of a positive or negative rake angle and/ or cutting angle, triangular and U shaped designs among others, etc.)
- Variability of the helical angle (flute width, flute depth, number of flutes along the working length of the file)
- File tip (cutting, non-cutting, or partially active)
- The presence or absence of radial lands and whether the radial lands are relieved.

1.2.6.1 TAPER (Figure 1.34 & 1.35):

- It is usually expressed as the amount the file diameter increases each millimeter along its working surface from the tip towards the file handle.
- E.g. a size 25 file with 0.02 taper would have a 0.27 mm diameter at 1 mm from tip, 0.29 mm at 2 mm and so on.
- Some manufacturers express the taper in terms of percentage. E.g. 0.02 taper is 2% taper.
- Historically, as an ISO standard, a file was fluted and tapered at 2% for 16 mm, but now files incorporate a wide variation of lengths and tapers of working surfaces.

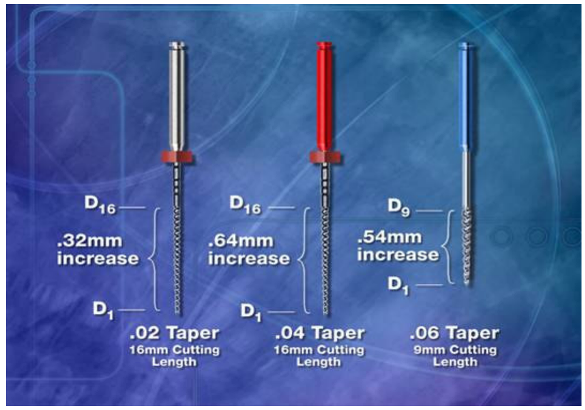


Figure 1.34: 2%, 4% and 6% taper rotary file.

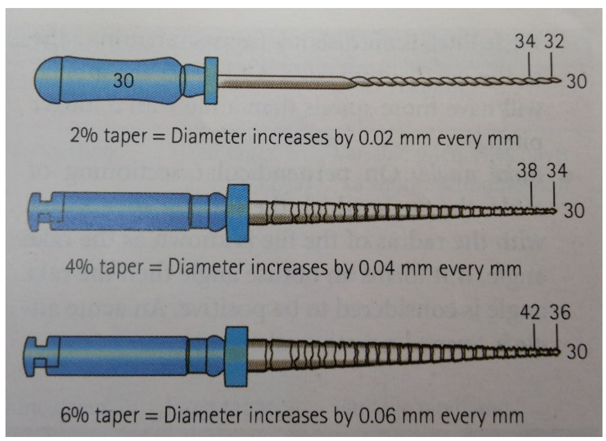


Figure 1.35: Schematic diagram showing 2% ,4 % & 6% taper in ISO no.30 rotary file.

- The ability to determine cross-sectional diameter at a given point on a file can help the clinician determine the file size in the point of curvature and the relative stress being placed on the instrument.

Rotary endodontics instruments are of two types:

1. Tapered
2. Non Tapered

Light speed file system are only Non Tapered Rotary System while rest of the rotary systems are tapered.

Tapers can be:

1. **Same/Fixed taper** → e.g. ProFile. They have a same taper throughout the file. For example 0.04% tapers for 40,35,30,25,20 no files.
2. **Graduating taper** → e.g. Quantec. These files have variable tapers with the same tip size. Quantec series with variable tapers ranges from 0.12 to 0.02 %, all have a tip size of 0.25 mm.
3. **Progressive taper** → e.g. ProTaper. These files have variable tapers at every cross section, with different tip sizes, for example ProTaper SX file a total increase ranging from D0 to D9 is defined with nine different tapers from 3.5% to 19%, a total increase S1 has an increasing taper from 2% on D1 to11% on D14 and the S2 file has an increasing taper from 4% on D1 to 11.5% on D14. (Metzger Z, 2011, Svec. TA, 2008)
4. **No taper** → e.g.Light speed. With no taper at all LightSpeed which is a taperless shaft followed by a short cutting head.
5. **Varying taper** → e.g. Greater Taper files

Advantages of variably tapered file concepts:

- Provide perfectly adequate coronal enlargement (eliminates the need for coronal enlargement burs).
- Confirmed full deep shape.
- Predictable apical resistance form.

- Standardized predefined tapers.
- Enhanced cleaning efficacy.
- Enhanced obturation efficacy.

1.2.6.2 FLUTE (Figure 1.36):

It is the groove in working surface used to collect soft tissue and dentin chips removed from the wall of root canal.

- The effectiveness of flute depends on its – depth, width, configuration and surface finish.
- The surface with the greatest diameter that follows the grooves as it rotates forms the leading (cutting) edge, or the blade of the file.

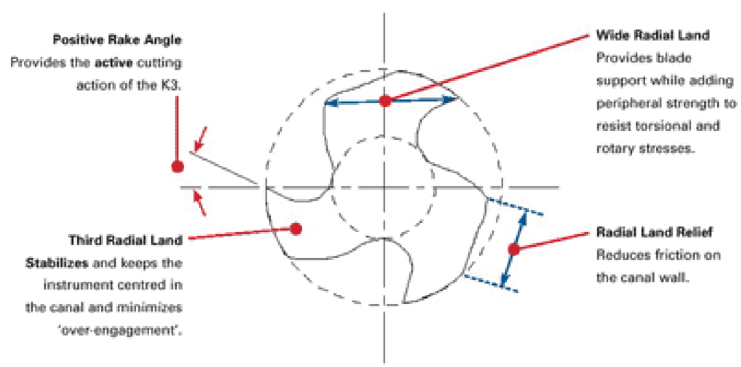


Figure 1.36: Component of a rotary NiTi file (crosssection view)

1.2.6.3 LAND (Figure 1.36 & 1.37)

- If a surface projects axially from the central axis as far as the cutting edge between the flutes, this surface is called as the land or marginal width.
- Its position relative to the opposing cutting edge and its width determines its effectiveness.

- To reduce frictional resistance, some of the surface area of the land that rotates against the canal wall may be reduced to form the relief.

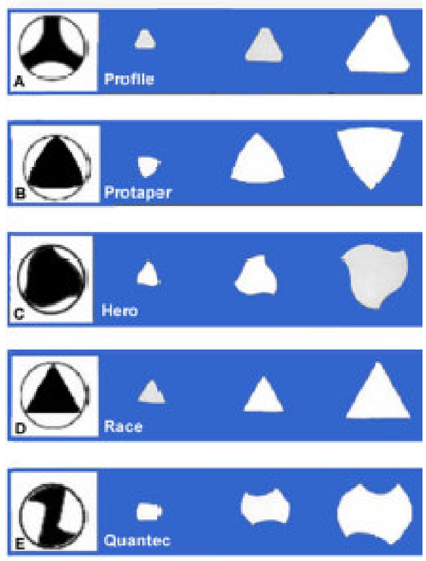


Figure 1.37: **Types of radial lands in A.Profile file. B.Protaper file. C.Hero file. D.Race file. E.Quantec File.**

Types of radial land:

1. Full radial land – ProFile, GT
2. Recessed land – Quantec
3. Modified radial land – K3
4. No radial land – Flexmaster, ProTaper, RaCe, HERO642, HeroShapers, Mtwo,Twisted, Endowave, LightSpeed.

Advantages:

The land reduces the tendency of the file to screw into the canal

1. Reduces transportation of the canal

2. Reduces the propagation of micro cracks on its circumference
3. Supports the cutting edge
4. Limits the depth of cut.
5. It also adds peripheral mass that adds to the strength of the instrument.

1.2.6.4 HELIX ANGLE (Figure 1.38):

- The angle formed by the cutting edge with the long axis of the file is called helix angle.
- It augers debris collected in the flute from the canal.
- It is important for determining which file technique to use.

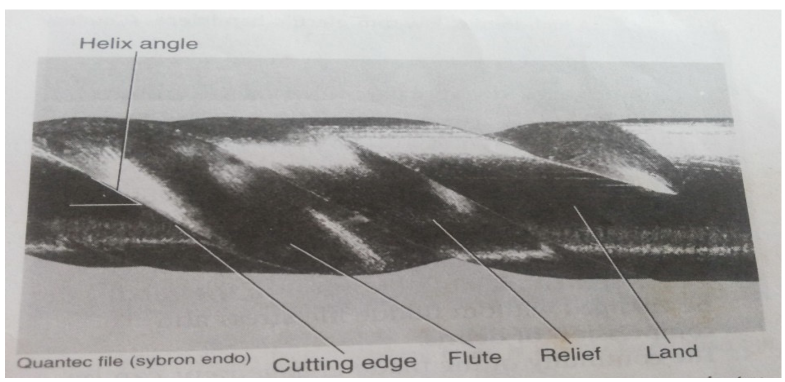


Figure 1.38: Helix angle shown in crosssection of a rotary file.

1.2.6.5 RAKE ANGLE (Figure 1.39):

- If a file is sectioned perpendicularly to its long axis, the angle formed by the leading edge and radius of the file is known as Rake angle
- If the angle formed by the leading edge and the surface to be cut (its tangent) is obtuse, the rake angle is said to be "positive" or "cutting".(Figure 1.39)
- If this angle is acute, it is said to be "negative" or "scraping". (Figure 1.39)

- However, the rake angle may not be the same as the cutting angle.
- The cutting angle or the effective rake angle, is a better indication of a file's cutting ability and is determined by measuring the angle formed by cutting edge and radius when the file is sectioned perpendicular to the cutting edge.
- If the flutes are symmetric, the rake angle and the cutting angle are essentially the same.
- Although cutting actions can be more efficient and require less force for enlarging a canal, a scraping action may have a smoother feel. e.g.
    1. Positive rake angle → K3 file.
    2. Negative rake angle → ProFile file.

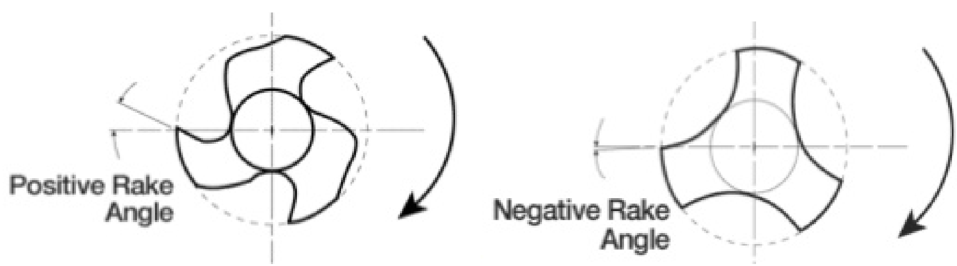


Figure 1.39. Positive rake angle results in a cutting action while Negative rake angle results in a "scraping" action.

1.2.6.6. PITCH (Figure 1.40)

- It is the distance between a point on the leading edge and the corresponding point on the adjacent leading edge, or, it may be the distance between corresponding points within which the pattern is not repeated.
- The smaller the pitch or shorter the distance between corresponding points, the more spirals the file has and greater the helix angle. Files with a variable pitch & helical angle are GT, RaCe, K3, ProTaper and constant pitch are ProFile.

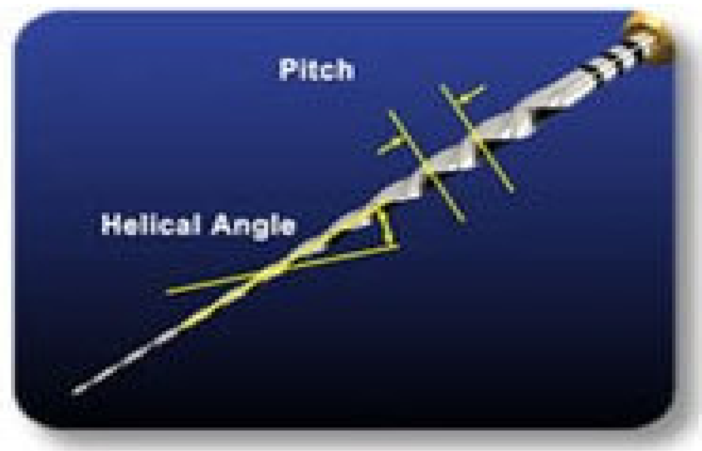


Figure 1.40: Showing Pitch in aRotary NiTi file

Most files have a variable pitch, one that changes along the working surface. Because the diameter increases from the file tip towards the file handle, the flute becomes proportionately deeper, resulting in a core taper that is different from the external taper.

Variable pitch (Figure 1.41)

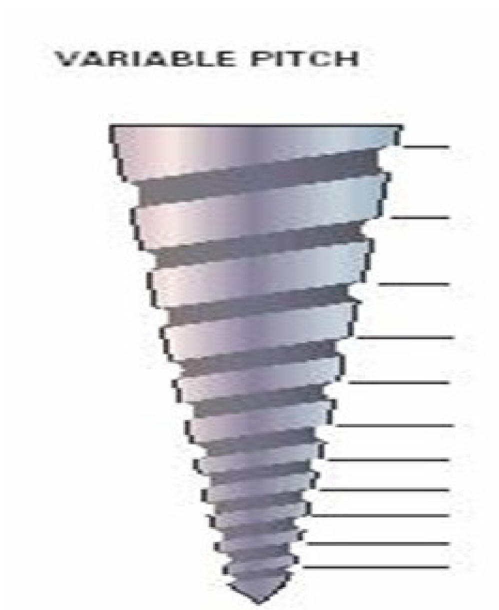


Figure 1.41: Variable pitch in a file preventing the screwing effect.

1. Improves cutting action,
2. Allows for better removal of debris out of the root canal.
3. Prevents the instrument from screwing into the canal**.**

1.2.6.7 CORE

The core is the cylindrical center part of the file having its circumference outlined and bordered by the depth of the flutes. The core taper and the total external taper may be different. Core taper may be less than the external taper in order to proportionately increase the instruments flexibility towards the handle. Lesser the cross-sectional mass more is the flexibility, hence more flexibility towards handle.

1.2.6.8 TIP

The tip design can effect file control, efficiency and outcome in the shaping of root canal system. The file can break if the clinician applies excessive torque while attemping to enlarge a canal with a smaller diameter than the noncutting portion of the file tip. Instrument tips have been described as cutting, noncutting and partially cutting.

Non cutting tip: Profile, Profile GT, Light speed, Protaper, Hero642,K3, Flexmaster, Race, Endowave, Mtwo,Twisted.

Cutting tip: Quantec SC.

Partially Cutting:- Endosequence

The instrument tip has two functions: to enlarge the canal and to guide the file through the canal. A clinicaian who is unfamiliar with the tip design of the particular instrument is apt to do either of the following:

1. Transport the canal.

2. Encounter excessive torsion and break the file.

Transportation of the original axis of the canal can occur by remaining too long in a curved canal with a tip that has efficient cutting ability. The angle and radius of its leading edge and the proximity of the flute to its actual tip end determine the cutting ability of file tip.

Tip Modification:

- It was reported by Rundquist BD "that the tips displayed better cutting efficiency than flutes" and that triangular pyramidal tips outperformed comical tips which were least effective.
- Powell SE, (1986) began modifying the tips of K files by "grinding to remove the transition angle" from tip to first blade .
- By 1988, Sabala *et al.* confirmed previous findings that the modified tip instruments exerted "less transportation and more inner curvature preparation.

Therefore "balance force" concept given by JB Roane in 1995 used during the canal preparation, with the introduction of the K-type file design, the Flex- R File, removed the transitions angles inherent to the tip of standard K file previously.

1.2.6.9 Variable Tip Diameter:

The variable tip diameters allow the files specific cutting action in defined areas of the canal, without stressing the instrument in other sections, e.g.– ProTaper.

A good beginner's rule is this : If the canal is smaller than the file tip , cutting tip should be more efficient. If the canal is larger than the tip , using a less effective cutting tip can help in preventing transportation.

The tips can also be classified according to the mode of contact:

- Active tip.
- Partially active.
- Passive tip.

Mostly all files have rounded like to act as guide with in the root canal. All modern day instruments tips are non aggressive they ride on the canal wall instead of gouging it.

1.2.6.10 Cutting Edge (Blade)

It is the working portion of the file and is the surface with greatest diameter that follows the flutes as it rotates. This is to prevent screwing of a file into the canal wall and gives more mass to the cutting edge. So the clinicians could do one of the following:

a) **Flatten the edges-** (Radial Land): Profile, system GT, lights speed

b) **Modify edge:** Quantec K3 (Flattered + sharp edge)

c) **Shortened cutting edge:** Race → 9-10mm, M file → 4-6.5mm, Light speed → 5 to 1.75 mm.

1.3 ROTARY HANDPIECES

Endodontic Rotary file system can be used in different types of hand pieces:

1.3.1 TYPES OF HANDPIECES:

→ A. Rotary

→ B. Reciprocating

→ C. Vertical Stroke

→ D. Random

→ E. Sonic

→ F. Ultrasonic

1.3.2 CLASSIFICATION OF HAND PIECES

1.3.2.1 According to Ingle

- Full rotary– latch/friction grip
- Reciprocating/Quarter turn
- Special – vertical and reciprocating
- Sonic and Ultrasonic

1.3.2.2 According to Stock

- Rotary
- Reciprocal
- Vertical

- Random

1.3.2.3 According to Cohen

- Contra angle Handpiece
    - Full rotary hand piece either latch type or friction grip.
    - Reduction gear handpiece
    - Reciprocating / quarter turn hand piece.
    - Vertical stroke hand piece
- Reduction Gear handpiece
- Reciprocating Handpiece
- Vertical Stroke handpiece
- Sonic and Ultrasonic Handpiece

1.3.3 CONTRA ANGLE HAND PIECE:

Contra-angle hand pieces are available as :

a) Rotary hand piece - latchtype or friction grip.

b) Reduction gear handpiece

c) Reciprocating / quarter turn hand piece.

d) Vertical stroke hand piece

Uses

a. Straight line drilling

b. To develop coronal access

c. Prepare post space channels

d. Widen the coronal two thirds of canal

e. With SS instruments used in straight canals only

a) **ROTARY HAND PIECE**:

- Specially designed hand pieces providing a mechanical action to a root canal cutting instrument have been available for 30 years.
- They are all designed to reduce the time spent in canal preparation.

Applications:

- Full rotary hand piece is used in straight-line drilling or side cutting.
- It is used to get coronal access to the canal orifice by using round or tapered burs or diamond points.
- It is used to funnel out the orifices for easier access to clean and shape canals with slow turning Ni-Ti reamer type instruments.
- It is used to prepare post channel for final restorations.

Draw backs:

- These hand pieces are used as straight time drilling, as instruments do not readily band and they should be limited to the straight canals only.
- They are often misdirected or forced beyond the limits and may cause perforations.
- Can be latch type / friction grip

Performs straight line drilling / side cutting.

- Includes – Air Turbines (Airotors), Micromotor Rotary System Hand Pieces

  In the past S. Steel instrument used with these rotary handpieces. But if misdirected or forced can lead to

  a. Perforations

  b. Separations in the hands of neophytes. Thus slower hand pieces were evolved.

1.3.4 REDUCTION GEAR HAND PIECE:

The full rotary have many from draw backs due to their speed and as a solution for these problems reduction gear hand piece with low speed has been introduced.

- These handpieces are specially designed to power the new Ni-Ti instruments in canal preparation.
- The speeds vary from 300 rpm to 2,000 rpm. 300 rpm is suggested for Ni-Ti profiles and 2000 rpm is suggested for light speed instruments.
- Newer hand pieces are available in reduction gear where both speed and torque can be controlled.
- Spin burs at speeds lower than the motor speed
- Torque Ratios ranging from 8:1(1/8th motor speed) to 27:1 (1/27th motor speed)

Only Speed Control Present :

- Medidenta / Micromega MM 324 Reduction Handpices
- Aseptico Electric Motor Hand piece
- Quantec ETM Electric Torque Control
- Moyco / Union Broach Sirint EDM (Electrical Digital Motor)

  Designed to power New Ni TI instruments speeds vary from 300-2000 rpm.

Newer Speed & Torque Control Handpieces

- Aseptico ITR Motor Hand Piece
- Nouvag TCM Endo Motor
- Endo ProElectric
- Protorq

Recent Hand piece

✓ **X Smart™**

The X-Smart™ is an endodontic micro-motor wih handpiece, specifically designed to drive NiTi rotary instruments. The X-Smart™ is a simple, compact and lightweight unit, adapted to the needs of an endodontic practice.

Technical features

- Operates on battery or electrical power
- Battery recharging time : approx. 5 hour
- Time of use on battery: approx. 2 hours

- Supplied with a 16:1 contra-angle
- Operates without a pedal (sold separately)

There is a clear LCD screen that is angled for easy visualisation during preparation. It indicates the various settings that have been chosen by the operator: speed, torque, gearing, direction of rotation, program (nine in total), auto reverse setting and gives a real-time read out of the load being applied to the instrument in the form of a graduated bar. There are also battery charge and audible warning indicators.

✓ **X Smart Plus**

This generation of the X-Smart endo motor is everything you like about the X-Smart with a plus:

No foot pedal: On / Off button on the motor handpiece

Excellent visibility & access: Due to the miniature contra-angle head

Simple & improved user interface:

- Large bright colour screen
- Dedicated button controls
- "Click and go" navigation
- New design with optimised screen & keyboard ergonomics.

Single file root canal shaping:

Reciprocating motion: Pre-programmed settings for WaveOne, Protaper® Universal, PROTAPER NEXT™ Pathfile™, Gates and reciproc™

- 8 free programs for individual settings

The X-Smart Plus is operated by a rechargeable battery and provides in continuous rotation, a speed range between 250 and 1,200 rpm and a torque range between 0.6 and 4.0Ncm. A warning sound helps you keep track of the file stress and the auto reverse rotation at the torque limit reduces the risk of file breakage. The X-Smart Plus endo motor comes with a 3 year warranty.

✓ **TRI AUTO ZX:**

Manufactured by J. Morita, Japan

- It is a cordless, battery powered, endodontic slow speed hand piece with built in apex locater
- It uses rotary Ni-Ti instrument held by a push button chuck.

Advantages:

- The hand piece automatically starts when the file enters the canal and stops when the file is removed.
- If more pressure is applied, the hand piece automatically stops and reverses the direction of rotation.
- It also automatically stops and reverses rotation when the file tip reaches the apical terminus as determined by the apex locater (built-in).

Applications of reduction gear hand piece:

- Used in slow speed latch type
- Gates Glidden drills, peaso reamers, rotary H type, K-type instruments can be used.

- Used to flare and prepare cervical and middle portions of the canal with orifice opener.
- Ni-Ti rotary and finishing files can be used.

✓ **TRI AUTO MINI** (Figure 1.42)

It is manufactured by J. Morita, Japan. It is a cordless, battery powered, endodontic hand piece. The mini head of this handpiece is refined, compact and the body is very small and lightweighted. With this handpiece, the dentist can experience the same tactile feedback as manual filing while various automatic controls reduce the risk of file jamming and breakage. Its slim design allows for easy access to posterior teeth with the ability to view both the canal openings and the pulpal floor during instrumentation. Another new and convenient feature is coordinated color change on the LCD display so that the user can easily recognize changes in speed, torque, file tip location, display type, etc. When connected to the Root ZX mini, the position of the file tip is monitored during the procedure, and many automatic functions such as Auto Apical Reverse can be activated. The technical specifications are as follows:

Figure 1.42: **Tri Auto mini endodontic handpiece**

Model: TR-CM

Display Type: LCD

Speed Range (no load) (rpm): 50±5-1,000±100

Power Supply (battery): DC 3.7 volts (lithium ion battery, rechargeable)

Weight (grams): 100 including contra angle and lithium batteries

Dimensions (mm): Motor Handpiece: Width 28 X Height 27 X Length 195, Head: Diameter 9 X Height 11.

1.3.5 RECIPROCATING HAND PIECE:

Specially designed hand pieces providing a mechanical action to root canal cutting instrument have been available for 30 years. They are all designed to reduce the time spent in canal preparation.

Also called as quarter turn handpiece.

Rotary – giromatic

- Also Known as ¼ Turn handpiece

e.g. Giromatic → Latch Type

¼ turn reciprocating

3000 times /rpm

e.g. Giro Pounters (16 mm long orifice opener)

Gior Broach

Giro File (H type)

Giro Reamer

Girofit with 3 cutting blade

M4 Safety Hand Piece

Reciprocating hand pieces are available as follows:

i) **Giromatic Hand Piece:**

- It is the first machined hand piece, now it is used little by the endodontists.
- In this device the quarter turn motion (90 degrees) is delivered 3,000 times per minute (Figure 1.43)

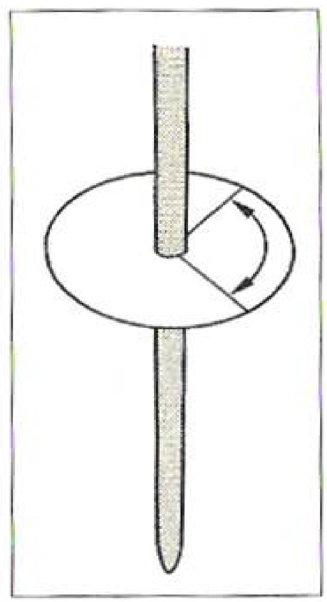


Figure 1.43: Reciprocating Giromatic handpiece motion

- It accepts only latch type instruments
- It accepts barded-broach-type files (Rispi) and three sided files (Heli files)
- The continuous rotation of the drives half in the hand piece is transformed into an alternating greater-turn movement of the file.

Draw backs:

- It leads to uneven canal preparations

- It was not able to accept all the instruments
- Lack of expertise

ii) **M4 SAFETY HAND PIECE** (Figure1. 44)

- It is marketed by Sybron-Kerr
- It has a 30 degree reciprocating motion

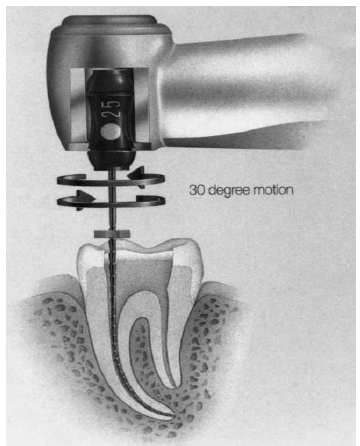


Figure 1.44: M4 Safety handpiece

- It has a simplified chuck mechanism activated by the thumb pressure to accommodate a plastic-handled root canal instrument.
- It has a 4:1 gear ratio, which even at full speed demonstrates minimal torquing.
- The Kerr Company recommended that their safety Hedstrom instrument be used with M4.

Method of use:

The hand piece lets the instrument glide along the walls of the canal by mimicking commonly used hand movements.

iii) **Endo Gripper Hand Piece (Figure 1.45)**

It is a Reciprocating Hand piece.

Figure 1.45: Endo Gripper

- It is marketed by Moyco/union broach.
- It is a similar hand piece with a 10:1 gear ratio with 45^0 turning motion
- Endo Gripper also uses regular hand instruments rather than the contra-angle instruments.
- Union broach recommends their flex-R files.

1.3.6 VERTICAL STROKE HANDPIECE

- These are the special hand pieces that imports a vertical stroke.
- With the added reciprocating quarter turns it cuts in when the instrument is stressed.
- Levy introduced a hand piece –Canal Finder (Figure 1.46), that is driven either by a air or electrically that delivers vertical strokes ranging from 0.3 to 1 mm.

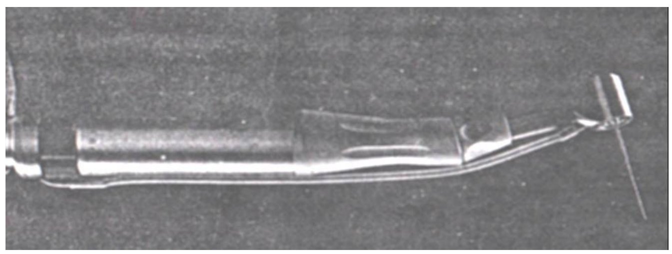


Figure 1.46: Canal finder system

- The more freely the instrument moves in the canal, the longer the stroke.

Mode of action:

- The hand piece with quarter turn reciprocating motion kicks in along with the vertical stroke, when the canal instrument is under bond in a tight canal.
- If it is too tight the motion ceases and the operator returns to a smaller file.
- Developed in France, the canal finder system uses the A file, cleaver variation of H-file.
- Driven by air / electricity
- Vertical stroke of 0.3 –1mm completed

- ¼ turn reciprocating motions.

Eg. Canal Finder System :1-3mm = uses the 'A' file pure vertical

Intra – Endo –3- LDSY : 0-4mm vertical movement with full rotary turn.

Canal Leader: 0.4-0.8mm positive 30^0 reciprocating turn

RACER

The racer contra angle hand piece uses a standard file and oscillates the file in the root canal.

The instrument length can be adjusted to the working length using this contra angle.

Disadvantage:

- A major disadvantage of this instrument is that debris may be forced ahead of the instrument, with resulting clogging of the canal or pushing of debris into periapical tissue.
- When engine driven instruments are used access to apical foramen must be made first by hand instrumentation.
- Ring found that root canals could not be enlarged with the RACER instrument in 13% of cases.

EXCALIBUR

- Runs at a speed of 20,000 – 25,000 rpm. can be attached to the air motor line in the dental unit and the water flow in the air motor line pass through the hand piece and irrigate root canal .

- This uses specially modified k type files and
- This hand pieces works rendering random vibratory movement laterally on endodontic files and is devoid of vertical movements.
- The oscillation frequency is about 1000-2000/ second and amplitude of movement is 1.5 –2 mm

Other examples include: Canal Leader

Intra Endo 3 LDSY

Endolift

1.3.7 ULTRASONIC HAND PIECE:

- Ultrasonic endodontics is based on a system in which sound as an energy source at (20-25 KHz) activates an endodontic file resulting in three dimensional activation of the file in the surrounding medium.
- Instruments used in the hand piece that move near or faster than the speed of sound range from standard K-type files to special broach like instruments.

Mode of action:

The main debriding action of ultrasonics was initially thought to be by cavitations, a process by which bubbles formed from the action of the file, become unstable, collapse and cause a vacuum like implosion. A combined shock, shear and vacuum results.

- Richman is credited with the first use of ultrasonics in endodontics in 1957.

- Martin and Cunningham were the first to develop a device, test it and see it marketed on 1976, and named it as Cavitron endodontic system.

Different ultrasonic devices available are :

- Cavitron endodontic system (Dentsply)
- Enac (Osado electric Co)
- Piezon master 400 (Eletro medical systems)

These instruments all delivered an irrigant which is usually sodium hypochlorite onto canal space while cleaning and shaping are carried out by a vibrating K-file.

Transient cavitation does not play a role in canal cleaning with cavi Endo unit; however acoustic streaming does appear to be main mechanism involved. Acoustic streaming depends on free displacement amplitude of file and that the vibrating file is dampened in its action by the restraining walls of canal.

Cavitron Endodontic System (Figure 1.47)

- Cunningham developed and marketed in 1976.
- It utilizes K, and K-flex.type files, diamond impregnated files.
- Modified cavitron having magneto stricture power source
- Its vibrations range around 25,000 KHz.
- It generates heat hence require cooling device.and- has special tube connections to pump irrigant from reservoir and supply point of compressed air.

Figure 1.47: Cavitron Endodontic system

Cavitron endo system was a disappointment in that it was so slow, blocked and ledged canals, and fractured files in severely curved canals.

Piezon Master 400 (Figure 1.48)

Advantages:

- Smaller files generated acoustic streaming and hence much cleaner canals.
- The K-flex is more efficient than the regular K-style files.

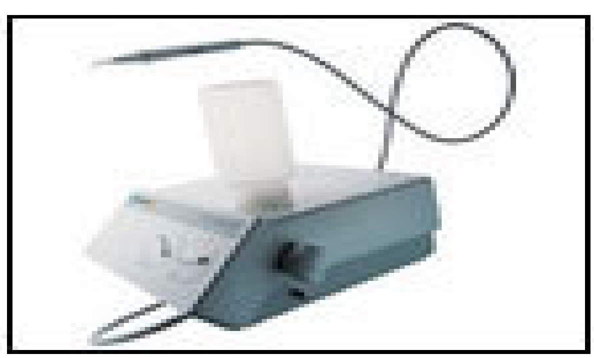


Figure 1.48: Piezon Master 400

Draw backs:

Greatest displacement amplitude occurs at the unconstricted tip and greatest resistance occurs when instrument is negotiating the apical third of a curved canal.

- Lack of freedom for the tip to move freely to either cut or cause acoustic steaming to cleanse
- Irrigant could not advance to the apex until the file could freely vibrate.
- K-files were precurved when used in the curved canals.
- Ultrasonics alone actually increased the viable counts of bacteria in simulated canals and it may be due to the lack of cavitation and dispersal effects of the bacteria by the acoustic streaming.

Table 1.4 : Comparison of Cavitron and Piezon Master endodontic system.

S. No.	**Cavitron endo**	**Piezon Master**
1.	Utilizes Magnetostrictive power sources	Utilizes piezo electric generator
2.	25,000 KHZ vibration	35,000 KHZ vibrations
3.	Generates heat, requires cooling device	No heat generated, hence no cooling device
4.	Long & Narrow	Short & white
5.	Has special tube connection to pump irrigant from reservoir to supply point of compressed air	Has built in pump Eg : Piezon Master 400 ENAC Neosonic, Neosonic Mini endo

Both utilize K-type files.

But K-Flex –more effective by ‘AHMED’

Diamond impregrenated file can be used in straight part of the canal.

1.3.8 SONIC HAND PIECES

- The principal sonic endodontic hand piece available today is the MICRO MEGA 1500 SONIC AIR ENDO SYSTEM (OR 1400). It is marketed by MEDIDENTA / MICRO MEGA (Figure 1.49).
- Like the air rotor hand piece, it attachés to the regular airline at a pressure of 0.4Mpa.
- The air pressure may be varied with an adjustable ring on the hand piece to gone on oscillatory range of 1,500 to 3,000 cycles /second.
- Tap water irrigant or coolant is delivered into the preparation from the hand piece.

Figure 1.49: Sonic handpiece by Micro Mega.

Mode of action (Figure 1.50):

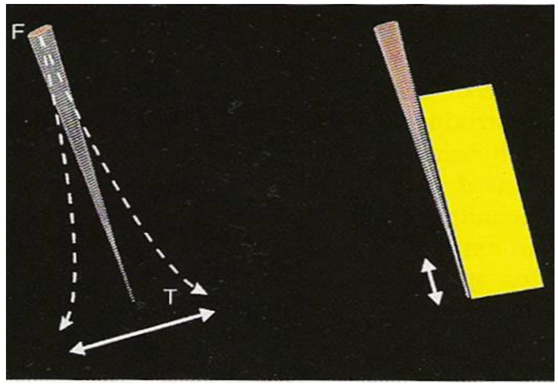


Figure 1.50: Elliptical motion of a sonic powered file.

- The sonically powered files in this hand piece oscillate in a large elliptical motion at the tip. When loaded into the canal oscillation motion changes into a longitudinal motion, up and down, a particularly efficient form of vibration for the preparation of root canals.
- The strength of micro mega sonic hand piece lies in the special canal instruments used and ability to control air pressure and hence the oscillatory pattern.

The files used in micro mega 1500 sonic handpiece are:

- Rispi sonic files (Figure 1.51)

- Shaper sonic files (Figure 1.51)

- Trio sonic files or Heliosonic or Tricut file (Figure 1.51)

Figure 1.51: Left: Rispisonic file, Middle: Shapersonic, Right: Heliosonic file.

Rispisonic File-

- Developed by Dr. Ritano spina in Italy.
- This file resembles old rat file.
- File has 8 Cutting blade.
- File has safe ended non cutting tip.
- Available as ISO sizes no.15 - 40.
- Used in Coronal $2/3^{rd}$ of root canal.

Shapersonic File

- Developed by Dr. J.M. Lauric chesse in France.
- File resembles husky barbed broach.
- File has 16 cutting blades.
- File has Safe ended non cutting tip.
- Available as ISO sizes no. 15 – 40.
- Used in the apical $1/3^{rd}$ of root canal.

Heliosonic File

- Also called as Triosonic or Triocut file.
- File resembles triple helix Hedstroem file.
- To use these files canal must be enlarged till (ISO no. 20).
- Cutting edges – (1.5-20mm) start from tip known as ‘Sonic Length.
- Available as ISO sizes no.15 - 40.

It was found by Dummer PMH(1989) that Rispisonic and Shapersonic files are more successful than Triosonic files.

Martin & Cunningham coined the term – ENDOSONICS

- **Endosonic system** – synergestic system where on canal preparation, cleaning, irrigation, disinfection packing and filling with same group of devices.

Endosonics as a ‘Debriding Device’

A) **Cavitation** (Figure 1.52)

Also called as ‘Implosion’

- Occurs when U.S. file vibrates is a liquid to produce alternate positive and negative pressure.
- Negative pressure will decrease local density of intracanal materials (pulp tissue, bacteria) causing an ‘implosion’ that pulls these cells apart leading to their destruction.

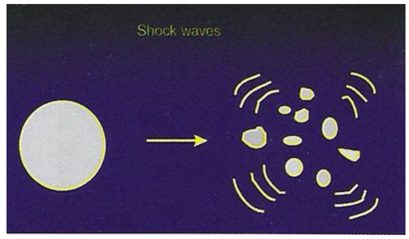


Figure 1.52: Caviation effect.

Ahmed from Guy's Hospital stated that very high power cutting is used to generate cavitations (1000 atmospheres) which cannot be produced in the small width of the root canal.

Also water is a pure liquid, thus force required to generally implosion will be much higher. Thus 'Naocl' is used as the irrigant of choice with ultrasonics.

Thus he suggested the principles of Acoustic streaming

B) **Acoustic Streaming (Figure 1.53)**

Vibrating files generates a stream of liquid to produce well intense circuular fluid movements known as 'eddies, this health hydrodynamic shear stress capable of dislodging lumps of materials but not sufficient to break the bacterial cell wall. No antimicrobial effect.

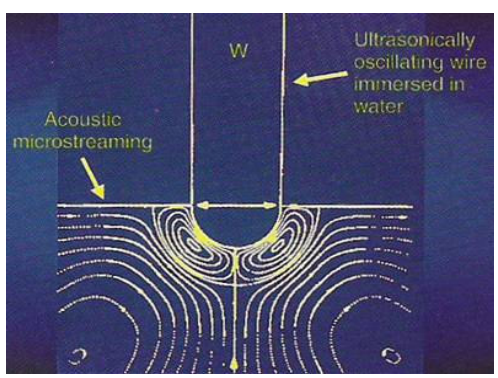


Figure 1.53: Acoustic streaming phenomenon.

- The cleansing ability is due to the capacity to move irrigant around the canal. To be effective file must be kept moving at all times.
- Synergistic relation b/w ultrasonic & Naocl occurs and further to increased temperature produced with increases the efficacy of Naocl.
- Thus this U.S. cleaning helps remove clumps of bacteria, smear layer and debris and looses aggregates of bacteria thus facilitating their mechanical removal.

Acoustic streaming causes clogging / corrosion but cleans 4 times better than sterile saline. It has been found that cleaning ability is better than hand, of these systems. There is better removal of smear layer but be careful not to touch the U.S. tip in the canal as it produces a new smear layer.

- Less extrusion of debris through apex during cleaning therefore fewer post operatives flare ups.
- Ultrasonic better than sonic in cleansing whereas the Sonic is better than ultrasonic in shaping.

1.4. MOTORS AND DEVICES FOR ROTARY INSTRUMENTS

Newer motors have been developed for rotary instruments since the simple electric motors of the first generation in the early 1990's. Electric motors with gear reduction are more suitable for rotary NiTi systems because they ensure constant rpm level; however, they also deliver torques much higher than those required to break tips.

Some authors believe that torque-controlled motors, which have been used for several years, increase operational safety. However, others have suggested that torque controlled motors may be useful and helpful mainly to inexperienced clinicians, these motors probably do not reduce the risk of fracture caused by cyclic fatigue; also, even if the torque is below the fracture load at D3, a fracture at the smaller diameter D1 is still possible.

To complicate matters further, an obvious differential exists between the torque at failure at D3 and the working torque needed to operate an instrument effectively. In many cases, the working torque is greater than the torque required to fracture the instrument's tip. However, the tip will not break if a passive glide path has been verified.

Instrument breakage with torsional load (MacSpadden factor) – for rotary instrument tips, susceptibility to breakage is governed by the quotient of torque needed to fracture divided by working torque. Simply put, the larger the value, the safer the file.

Examples of motors used with rotary NiTi endodontic instruments (Figure 1.54):

1. First-generation motor without torque control
2. Second-generation Fully electronically controlled motor with sensitive torque limiter
3. Third generation simple torque-controlled motor
4. Newest-generation motor with built-in apex locator and torque control.

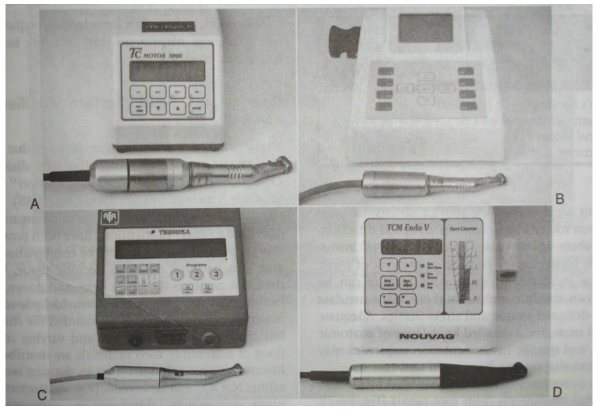


Figure 1.54: Examples of motors used with rotary NiTi endodontic instrument: A-First-generation motor without torque control. B-Fully electronically controlled second-generation motor with sensitive torque limiter. C-Frequently used simple torque-controlled motor. D-Newest generation motor with built-in apex locator and torque control.

Rationale for use of Low Torque Endodontic Motors:

Mechanical stress Ni Ti instrument - Motor Torque

If high torque motor used, the instrument– specific limit torque (fracture limit) is exceeded, the instrument can fracture. If torque is set at first become the limit of elasticity (E) for each instrument, then the risk of fracture reduces.

Ideally the motor should be stow speed, low-torque or right torque motors or each instrument has a set (right) torque.

Gambarini suggested low torque motion to reduced stress on Ni-Ti instrument Torque value for an instrument is set at Lower value than the limit of Elasticity

1.5 ALLOYS USED TO MANUFACTURE ENDODONTIC INSTRUMENTS.

Earlier the instruments used for endodontic therapy were made of alloys such as carbon steel alloys that are now replaced by alloys of either stainless steel or nickel-titanium (Table 1.5). Carbon steel instruments are rarely used because they cannot be re-sterilized due to their corrosive nature. Newer alloys like chrome-nickel steel and Vanadis 4 steel alloy have been introduced that provides good flexibility and produce better shaped root canal preparation than conventional instruments.

Table 1.5: Alloys Used For Various Endodontic Instruments

Type of Alloy	Endodontic Instrument
Carbon steel	Gates Glidden Drill, Peeso Reamer
Stainless steel	K Reamer, Hedstroems
NiTi	ProTaper, K3, Flexmaster, Liberator
R phase	Twisted file
M wire	GTX Series, Profile Vortex
CM wire	Typhoon CM, Hyflex CM

1.5.1 Types

1.5.1.1 Carbon steel:

This alloy is made by addition of small percentage of carbon (less than 2.1%) to iron. It is used for making blade and actual cutting edge of the instruments documented by Anusavice K *et al.* (2003). The advantage of carbon steel hand endodontic instruments includes high hardness than stainless steel. The disadvantages includes tendency to corrode and rust.

Example: Barbed Broach

1.5.1.2 Stainless Steel:

The Stainless steel hand endodontic instruments contains chromium (11.5%-18%), nickel (8-10%) and carbon (0-0.12%). There are three major types of stainless steel alloys. These are Ferritic, Martensitic, and Austenitic type. Austenitic type are the most corrosion resistant alloys and are used to manufacture endodontic instruments. The austenitic structure of stainless steel is achieved by the addition of nickel to the iron-chromium-carbon composition. They have following advantages: greater ductility and ability to undergo cold work without fracturing, substantial strengthening during cold working, greater ease for welding, ability to overcome sensitization and corrosion resistance. The disadvantages includes stiffness, prone to fracture and prone to distorsion. Example: K file, H file, Reamer.

Stainless steel instruments are manufactured by first grinding and then twisting. Raw wire is ground into various, tapered geometric blanks (Triangular, square, rhomboid etc. The blanks are then twisted counter clock-wise to produce helical cutting edges. The resistance to tarnish and corrosion is associated with the passivating effect of chromium which can be concluded by finding of Sattapan B *et al.* (2000). A very thin transparent adherent layer of chromium oxide is formed on the surface of the stainless steel when it is exposed to oxidizing atmosphere such as room air.

Stainless steel instruments have been used for root canal instrumentation. Craig *et al.*(1963,1968) demonstrated that stainless steel files were more resistant to cyclic fatigue and had similar or improved resistance to torsional failure when compared with carbon steel instruments. It has been found by Younis O. (1977) that this characteristic combined with the resistance of stainless steel to corrosion during sterilization procedures led to the adoption of stainless steel files as the primary type of endodontic file. However, stainless steel files have a tendency to introduce procedural errors which alter the natural canal anatomy in the form of perforations, zips or ledges of the canal. One reason for the difficulty in maintaining original canal shape with stainless steel files is that the files have limited flexibility, particularly when the file exceeds an ISO size #35.

1.5.1.3 Nickel Titanium Alloy

In the early 1960's, nickel titanium alloy was developed by William Buehler, a metallurgist investigating nonmagnetic, salt resistant, water proof alloys for the space program at the "Naval Ordinance Laboratory", in Silver Springs, Maryland. This alloy was named "Nitinol", an acronym for the elements from which the material was composed; Ni for Nickel, Ti for Titanium and NOL for the Naval Ordinance Laboratory. Nitinol is the name given to a family of intermetallic alloys of Ni and Ti which have been found to have unique properties of shape memory and super elasticity. It has been divided into two types on basis of composition: NiTinol 55 and NiTinol 60. Nitinol 60 (60% Ni; 40% Ti) was developed by Dr. William Buehler while working on non-corrosive, non-magnetic alloys. During research on these materials, one of the research team members accidentally discovered the memory capability of Nitinol 55 (55% Ni; 45% Ti), a sister alloy. Both Ni and Ti have several valencies like Ti_2Ni_3, Ti_2 Ni etc. Thereafter, the team devoted efforts toward Nitinol 55 development. Nitinol 60 was effectively abandoned in the late 1950's, when difficulties in machining and work-hardening were encountered.

Nitinol 55 is now a material of choice in the field of Endodontics.

There are two types of NiTi alloys:

- Conventional or Elastic
- Newer or Superelastic

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

Austenite nitinol is non-elastic and hard; in its martensite form, it is relatively soft and can be easily deformed; and super-elastic nitinol is highly elastic.

McSpadden (2007) highlighted that when external stress is applied, the austenite crystalline form of nickel titanium transforms into the stress induced martensite crystalline structure that can accommodate greater stress without increasing the strain. When the stress is removed without permanent deformation, the nitinol returns to its austenite structure (original shape) provided that the temperature remains within a specific range, this phenomenon is called a stress-induced thermo-elastic transformation.

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

The first investigation of nickel titanium in endodontics was reported in 1988 by Walia HM et. Al. using #15 files fabricated from nickel titanium orthodontic alloy. These files were shown to have 2-3 times the elastic flexibility in bending and torsion, as well as superior resistance to torsional fractures, compared with # 15 stainless steel files manufactured by the same process. The results showed that Nitinol files might be promising for the instrumentation of curved canals.

In 1992, Dr. McSpadden introduced the first rotary instrument for endodontic use but Dr. Johnson's Profile ISO (Dentsply Tulsa Dental Specialties) line of rotary files was a resounding commercial success and probably regarded as the prototype identifying the first generation of nickel-titanium rotary files. The main features of these files were the use of the more traditional "superelastic" nickel-titanium alloy, presence of radial lands, constant file taper and a negative rake angle resulting in a scrapping action of dentin instead of a cutting action. The Profile ISO files were the first to take advantage of the greater taper of file (4%) and were known for their canal centering ability as found by Haapasalo M (2013). At the turn of the new millennium, a second generation appeared on the market. The major differences with the previous generation involved mainly the lack or reduced use of radial lands, the positive rake angle resulting in an active cutting action and the use of multiple variable file tapers. The main file system belonging to this generation was Protaper (Dentsply Tulsa Dental Specialties) which still enjoys numerous loyal supporters. Year 2009 and 2010 brought forward an important development in metallurgical treatment of the nickel-titanium alloys. These closely guarded industry secrets have shrouded the way these metals were manipulated but the results got it on a paradigm shift on the potential use of these files. This third generation focused mainly on metallurgy and less on file geometry. Three major appellations arose from this period, namely: M-Wire (Dentsply Tulsa Dental Specialties), R-phase (SybronEndo) and CM Wire or Controlled-Memory Wire (DS Dental). These new forms of nickel-titanium alloys displayed greater superelastic qualities compared to the first two generations. Greater flexibility and increased number of cycles for cyclic fatigue failure proved to be the hallmark of these files. This was mainly due to the fact these files are maintained in their martensite phase at room/body temperature. The nickel-titanium alloy of first two generations of files operated mainly in the austenite phase at room/body temperature. Nickel-titanium alloys with greater proportion of martensite phase show more flexibility when compared to files with more austenite phase present. Profile Vortex (Dentsply Tulsa Dental Specialties) being good example of the third generation of file development (Figure 1.55). The file shares the same triangular cross-section, geometry, design and dimensions.It is made from M-Wire technology.

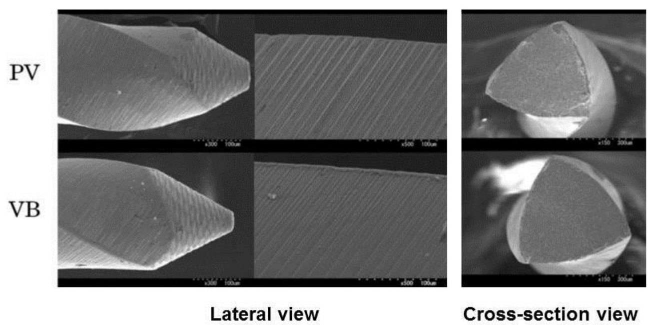


Figure 1.55. Lateral view (*left*) and cross-section (*right*) of Profile Vortex® under SEM.

The fourth generation of files is distinctive from the previous three generations because of its mode of action. Until this moment, engine-driven nickel-titanium files were used in a rotational manner, whereas the fourth generation files, in 2011, were used in a reciprocating movement. This constant clockwise-counterclockwise motion claimed to follow closely the original path of the root canal and lower down the prospect of file fracture by disengaging the tip of the file within the dentin substrate and prolonging the instrumentation time before failure of the file by way of cyclic fatigue failure. These files shared some geometric innovations of the second generation and the metallurgy improvements of the third generations. Examples of this generation files are WaveOne (Dentsply Tulsa Dental Specialties) and Reciproc (VDW). While one could be forgiven for thinking file development reached its peak with little room left for innovative designs, the final and fifth generation of files differentiate themselves with another twist on file geometry. This was accomplished by placing the center of mass of the file off the center of rotation. The "snake-like" motion of the file while in rotation reduces the overall contact of the file on dentin walls, thus reducing the torsional stresses on the file. The manufacturer claimed better dentin debris removal and less compaction of dentin mud against the root canal wall. ProTaper Next (Dentsply Tulsa Dental Specialties) and TRUShape (Dentsply Tulsa Dental Specialties) exemplify files of this latest generation. Illustrated below are the five generations of engine-driven nickel-titanium endodontic instruments (Figure 1.56)

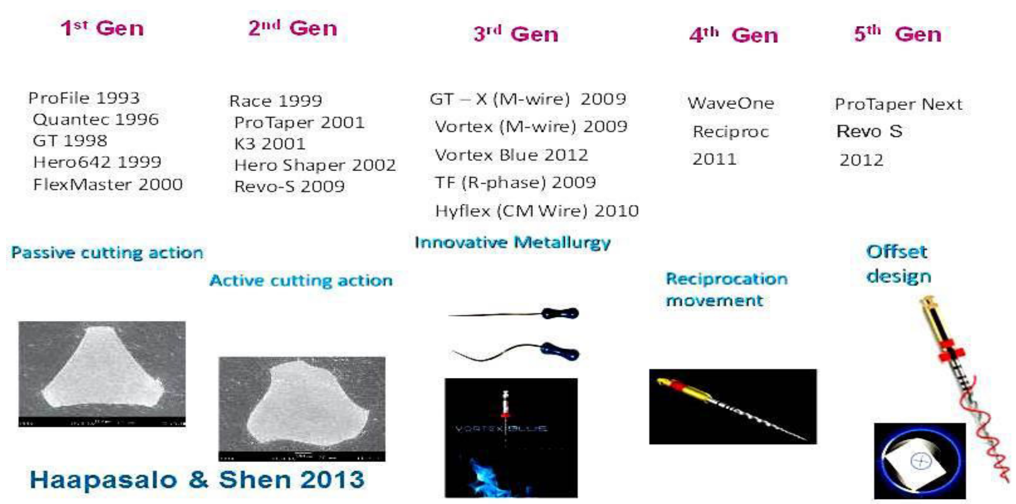


Figure 1.56 Generations of NiTi endodontic files.

A new type of nickel-titanium wire (named M-Wire) has been processed by an extensive thermomechanical procedure (Sports wire LLC) and this wire is reported to have superior laboratory fatigue performance compared to conventional NiTi superelastic (SE) wire used for the manufacture of rotary instruments. This new M-Wire has greatly enhanced fracture resistance compared with conventional superelastic wire, along with a higher ratio of tensile strength to upper superelastic plateau stress. The scanning transmission electron microscopy study done by Brantley *et al.*(2008) found presence of martensite and perhaps R-phase in the cross-sections of M-Wire, which is absent in the microstructure of conventional SE wire. Micro-X-ray diffraction analyses at room temperature suggest that M-Wire is a mixture of austenite, martensite and R–phase. This result is complementary to the temperature-modulated differential scanning calorimetry (TMDSC) analysis by Alapati *et al.* (2008). They found that the austenite-finish temperature of M-Wire (45°C – 50°C) is much higher than that for conventional superelastic wire (approximately 20°C or lower). The microstructural study by Buie *et al.* (2008) found the classic lenticular appearance of martensite in the microstructure of M-Wire. Energy dispersive spectrometric (EDS) analysis with the SEM have shown that the precipitates in M-Wire are Ti_2B Ni, indicating that this alloy is Ti-rich. It has been also found that the thermomechanical processing for M-Wire yields a different microstructure and phase transformation temperature range for this new M-Wire for rotary instruments compared to conventional SE wire.

Extensive studies of Shen Y(2013) and Thompson SA(2000) made evident that the nickel titanium alloys that are used to manufacture endodontic instruments are generally equiatomic mixtures of nickel (56% by weight) and titanium (44% by weight). NiTi can undergo solid phase transformations between three different crystalline structures: austenite (referred to as the parent phase), martensite, and R-phase. The changes between phases is classified as a diffusionless transformation, where atoms move in small coordinated ways to change the crystalline structure of the metal (Otsuka K,2005). This is different than normal phase transitions such as transitions between liquid, solid, and gaseous phases.

The austenite phase is a stable cubic crystalline structure which is considered the parent phase of the alloy because it can be recovered once the alloy is heated above a certain temperature (Thompson SA, 2000). The temperature at which transformation from martensite to austenite (or the reverse) is complete is called the finish temperature. Transition temperatures of NiTi can be thought of just like transition temperatures of other phase transitions such as ice changing to water and then changing to water vapor, or in the reverse direction. The ability of the metal to return to a parent phase once above the transition finish temperature is termed shape memory, one of the distinguishing features of NiTi (Torrisi L, 1999).

Another important property of NiTi is its superelasticity, and is a result of stress induced transformation from the austenite to martensite phase. Deformation of up to 8% strain occurs as a result of this phase change without plastic, or permanent, deformation. Where austenite is hard and strong, martensite has the ability to be deformed much easier. Otsuka K (2005) and Thompson SA (2003) found that the martensitic phase consists of a closely packed hexagonal lattice, which allows for the large recoverable strain without permanent deformation. Application of force results in the twinned martensite formation of the crystal structure to a de-twinned martensite configuration. A certain amount of de-twinning can take place upon the application of force before plastic deformation occurs. If this threshold is not exceeded, the crystal structure will revert back upon the removal of the applied forces. After enough deformation, the alloy will not even revert to the original shape when it is heated above the austenite finish temperature. The third major phase, R-phase, has a rhombohedral crystal structure. It can form under certain conditions as an intermediate transition between austenite and martensite phases. The R-phase occurs during a very narrow temperature range on the heating or cooling transitions between martensite and austenite. A proprietary method of twisting NiTi wire, which is only possible in R-phase, has been used by company to manufacture files as an alternative to the traditional grinding process. Through a series of studies like Gambarini G (2008) and Kuhn *et al.* (2001, 2002) postulated that heat treating NiTi used for endodontic instruments could alter the phase transformation temperatures, and thus what phases are present in a file at room temperature. This could ultimately alter the behavior characteristics of the instrument. Zinelis *et al.* (2007) investigated this idea by heat treating files at various temperatures before testing the resistance to cyclic fatigue failure. They found that heat treatment up to 430-440°C incrementally improved the properties of the file and treatment above those temperatures adversely affected the properties. Alapati *et al.*(2009) found that heat treatment of as received files could raise the A_f temperature to 45-50◦C. This meant that at room temperature, the file would potentially be a mixture of austenite with martensite and/or R-phase as opposed to austenite alone.

Companies have developed proprietary methods, called thermomechanical processing, which use a combination of heat treatments and hardening of the NiTi alloys to manufacture the next generation of NiTi instruments. In addition to the raw materials used, file design has an effect on the performance of endodontic instruments. Factors such as flute design, cutting efficiency, and amount of file contact with dentin are some of the variables considered in file design [Lloyd A.(2005),Schafer E(2008), Hsu YY(2004)]

Flexibility is another important characteristic of endodontic files, and was identified as of the biggest advantages of NiTi over stainless steel in the early work by Walia *et al.* (1988). Flexibility is tested according to the ANSI/ADA specification no. 28 (New American Dental Association Specification no. 28 for endodontic files and reamers). The torque experienced during a bend of 45 degrees is measured. A higher measured torque value indicates a less flexible instrument. Camps *et al.*(1995) found that the cross section of files played a significant role in determining file flexibility. In instruments made from superleastic NiTi, the files with a larger mass of metal in cross section were less flexible. A finite element analysis study by Lee MH *et al.*(2011) found that in their model the cross sectional design of the file had a more significant impact on the stress experienced during bending. Gao Y *et al.* (2012) studied the effect of the NiTi alloy on file flexibility and found that Blue Wire was more flexible than M-Wire which was more flexible than superelastic NiTi.

The multiple advantages of NiTi files over stainless steel files have allowed for rotary instrumentation to improve efficiency in shaping the canal. However, rotary instrumentation (typically carried out at a speed of 300-600 RPM) increases the risk for file separation by cyclic fatigue when compared to hand instrumentation. Pruett *et al.* (1997) studied cyclic fatigue in simulated curved canals and determined that larger file sizes, smaller radii of curvature and angles of curvature greater than 30 degrees all decreased the number of cycles before instrument separation occurred. The speed at which the files were rotated had no effect on the cycles before separation, and the separation always occurred at the portion of the file engaged at the midpoint of the curvature. These findings were confirmed in a later study by Haikel Y (1999).

Advantages and Disadvantages of Nickel Titanium over Stainless Steel

Advantages

- Nitinol files have 2-3 times more elastic flexibility than stainless steel
- Superior resistance to fracture in clockwise and counterclockwise tension owing to the ductility
- NiTi files can retain the shape of the curved canals and do not straighten like the stainless steel instrument (Weiger R, 2002)
- NiTi files are biocompatible as indicated by trace element studies and have excellent anticorrosive properties
- Post treatment pain is greatly reduced by NiTi due to fewer incidences of ledges and perforation during their use.
- During autoclaving or dry heating Ni Ti instruments for sterilization, rotation to breakage studies indicate a transformation of residual martensite to austenite to restore the hardness of the instrument.

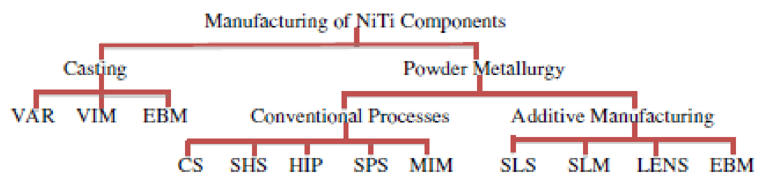
Disadvantages

- Cutting efficiency of Nitinol is only 60% than that of a matching stainless file.
- It does not give any indications before its fracture.
- Expensive when compared to stainless steel files.
- It cannot adapt to sudden variations in speed resulting in fracture of the instrument.

1.5.2 MANUFACTURING OF NITI ALLOY

Manufacturing of Ni-Ti (Flowchart 1.1)

The Manufacturing of NiTi alloys involves two methods: Casting method or Powder metallurgy method followed by other mechanical processes such as Hot or Cold Working, Surface Treatments and Heat-Treatments ,with the latter having an important role in the shape setting of the Nitinol.



Method	Description	Method	Description
VAR	Vacuum Arc Remelting	SHS	Self-propagating High Temperature Synthesis (combustion) Synthesis
VIM	Vacuum Induction Melting	HIP	Hot Isostatic Pressing
EBM	Electron Beam Melting	SPS	Spark Plasma Sintering
CS	Conventional Sintering	MIM	Metal Injection Molding
SLS	Selective Laser Sintering	LENS	Laser Engineered Net Shaping
SLM	Selective Laser Melting		

Flowchart 1.1: Manufacturing of NiTi alloy.

Furthermore, the manufacturing process of the specific SMA is critical and specifically affects composition homogeneity, ductility, machinability, biocompatibility as well as microstructure and the transformation temperatures all of which are important for the applications of the material.

1.5.2.1 Casting Method

The techniques that used for casting method includes Vacuum Arc Remelting (VAR), Vacuum Induction Melting (VIM) and Electron Beam Melting (EBM).

Production of Niti alloy components conventionally entails arc or induction melting followed by a hot working process and machining to the final shape. To minimize possibility of contamination during melting, an inert gas working atmosphere is used. It is stated by Elahinia HM *et al.* (2012) that pure raw materials are essential to achieve good mixing of the constituent elements for making alloys with homogeneity and uniformity in the properties.

1.5.2.1.1 Vacuum Induction Melting (VIM): This method involves the use of a graphite crucible, where pure raw Ni-pellets and Ti bars (or disks) melt in order to create the Ni-Ti alloy. The graphite is used as the crucible material as other materials have various problems such as a tendency for thermal cracking due to high temperatures and high costs. Additionaly, in terms of achieving homogeneity of the composition throught the material, the arrangement of the materials in the crucible is important. In order to increase the level of purity of the material, the contamination of the liquid alloy by carbon particles needs to minimized. This contamination by carbon consequently decreases the martensitic transformation temperatures. More specifically in order to avoid carbon contamination Titanium bars/disks are placed beetween the surface of the graphite crucible and the Ni-pelets (Figure 1.57).This way, as temperature rises for the melting phase, a TiC film is created which acts as barrier against diffusion of Carbon to Nickel. At high temperatures, the β- Ti is segrageted from the rest of the melt and forms, along with Carbon from the crucible, the TiC.

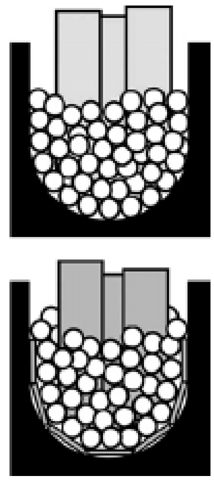


Figure 1.57: A schematic illustration of the crucible filling with Ni-pellets in contact with the graphite crucible; Below: crucible filling with Ti-disk cladding preventing direct contact between Ni and graphite.

One should note that, the phenomenon of interdiffusion of TiC is also present which means that as the film grows, Carbon is now diffused from TiC in the NiTi melt which is not acceptable. Thus, the only way of taking advantage of the TiC film's presence is to use crucibles that have already been used in the past for the same alloy production which means the film has already been created and consequently less Carbon will be diffused. Of course if no Ti is placed between the graphite crucible and the Ni-pellets in the beginning the content of Carbon will be much higher. Also the Carbon content in the molten Ni–Ti alloy largely depends on the melt temperature. If the melt temperature exceeds (939.4°C) 1723 K, the use of a graphite crucible is impractical. Fortunately, the melting point of the stoichiometric Ni–Ti alloy is (821.1°C) 1510 K so that the melting procedure can be carried out at relatively low temperatures. The carbon content in the ingot prepared under a pertinent operation lies between 200 and 500 ppm. Such a small amount of carbon does not affect the shape memory characteristics of the alloy. Another advantage of induction melting is the controllability of the chemical composition. If the operation proceeds carefully, the M_s temperature of the ingot can be controlled to within ± 5°C. Other crucible materials have problems such as sensitivity to thermal cracking, higher prices, and thermodynamic instability as for oxygen evolution.Furthermore, in order to take measures against undesirable chemical reactions between the components of the alloy and gasses such as Oxygen and Nitrogen, an inert gas environment is used.

1.5.2.1.2 Vacuum Arc Remelting (VAR): This method does not involve a crucible which leads to less contamination by carbon and as a result produces more pure, higher quality NiTi alloys although remelting procedures have to be used in order to achieve homogeneity.

This method is classified into two types with regard to heating system:

- **Using a non-consumable electrode :**

In this method, raw metals are installed on a copper mold and irradiated by the argon arc from an electrode made of a tungsten rod. When the alloy is melted down, its shape resembles a button due to the surface tension effect. The solidified button shaped ingot is turned over and remelted repeatedly to improve the homogeneity of the composition. A single arc-melting step is generally not sufficient to provide a homogeneous ingot, because only the upper section of the button melts, while a small layer of the lower section (in direct contact with the water-cooled Cu hearth) remains solid. To promote thorough mixing, remelting is required.

- **Using a consumable electrode constisting of the materials to be melted:**

The furnace uses a consumable electrode that consists of raw materials. The electrode has two roles: a heating source and a material source. The electrode is heated by the argon arc and the molten alloy drops down onto the mold and forms a cylindrical ingot. The productivity of the second method is higher than the first. Moreover, a disadvantage involves the easier formation of Ti_4Ni_2Ox or TiO_2 oxides if high vacuum pressure is not properly controled. This consequently leads to reduction of Ti in the matrix and the increase of Ni in the solid solution which means that equatomic composition homogeneity cannot be sustained throught the component. Additionaly, this increase in Ni, as stated before, depresses the transformation temperatures and this may not be acceptable for certain applications of the alloy. Furthermore, the fact that remelting is needed in order to achieve greater homogeneity of the alloy, increase the possibility of contamination.

1.5.2.1.3 Electron Beam Melting (EBM) (Figure1.58)

This method does not involve a crucible and the melting of the material is executed by an electron beam which creates a narrow melted zone via electron heating. In this process, carbon and oxygen contamination is minimized because melting is performed in a water-cooled copper crucible and under a high vacuum (pressure less than 10^{-3} Pa). The disadvantage of the EBM process in alloy production comes from the fact that during melting and remelting, it is difficult to control the nominal chemical composition due to the high vacuum operation and heating temperature. This causes some constituent element evaporation, thus changing the martensitic transformation temperatures. This effect is more pronounced on the nickel-rich side of the phase diagram. Meanwhile, composition homogeneity in the ingot is insufficient because the alloy solidifies uni-directionally from the bottom. In spite of these shortcomings, this method is used to prepare NiTi SMAs, which do not require precise control of the transformation temperature.

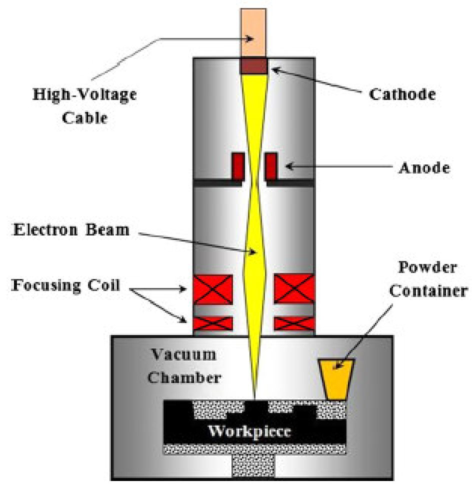


Figure 1.58: Schematic of an EBM apparatus

Furthermore, this method's superiority over the other mentioned before has to do with the minimization of contamination of the alloy from C and gases such as O and N. Firstly, since no crucible is used, there is no contamination from carbon at all and the content of carbon in the NiTi alloy solely depends on the purity of the raw materials. Secondly, because of the very high vaccum pressure used (which is usually about 10^{-3} Pa) oxygen contamination is also minimized consequently leading to the production of more pure NiTi alloys with even better fatigue properties. Nevertheless,despite the method's capability of producing high quality alloys with very small amount of impurities, two serious drawbacks should be mentioned. The first has to do with fact that due to high vaccum pressure during the melting, it is difficult to control nominal chemical composition because of some component evaporation and as a result a change in martensitic transformation temperatures occurs. The second disadvantage of this method is that small to medium sized materials are produced which makes it difficult to be used for large quantity production.

1.5.2.2 Powder Metallurgical Method

It is used to produce the NiTi alloy by using powders of Ni and Ti elements as the starting material. Powder can be made by various rapid solidification (RS) processes including gas atomization and rotating electrode to form particulates. Powder can also be made by non-RS processes such as chemical reactions including precipitation, or grinding and machining ingots.

Powdered method can be subdivided into : Conventional processes and Rapid Manufacturing processes.

- **Conventional processes**:

These processes basically include 6 methods in order to produce NiTi components from elementary or prealloyed powders. These are; Self ropagating High temperature Synthesis (SHS),Conventional Sintering (CS),Metal or Powder Injection Molding (MIM),Space Holder Technique (SHT), Hot Isostatic Pressing (HIP), Spark Plasma Sintering (SPS). In all methods described above,except for SHT, the precipitation of the intermetallics Ti_2Ni, $TiNi_3$,Ti_3Ni_4(titanium nitride) in more or less quantities, cannot be avoided. Unfortunately, the aforementioned phases are stable, do not possess pseudoelastic or shape memory effects and are very difficult to remove. Nevertheless, as far as biocompatibility is concerned, most of the methods can provide sufficient amount of porosity(between 40 and 60 %) along with acceptable mechanical properties.

- **Rapid (or Additive) Manufacturing processes**:

This method allows the abuse of stereolithography principles combined with the 3D computer aided design (3D CAD) in order to produce the desired-shaped material that may be of complex geometry and cannot be produced by conventional means. The common methods used to produce NiTi components via Additive metallurgy include; Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Laser Engineered Net Shaping (LENS) and Electron Beam Melting (EBM). Furthermore, rapid manufacturing processes poses as one of the methods for producing porous NiTi with great control over porosity's volumetric fraction and with acceptable mechanical properties such as corrosion and fatigue resistance that can be improved by properly controlling the operating conditions and particle size.

A serious drawback of powder metallurgical methods compared to vacuum melting methods is the greatest vulnerability of the alloy to impurities such as Oxygen. According to the content of oxygen may usually vary between 1500 and 3000 ppm, which is about 3 to 6 times more than that of the vacuum melting processes (worst case 500 ppm). This contamination can cause serious depletion of Ti from the matrix, forming oxides and consequently increase the grain size of the material. As a result, NiTi alloys fabricated this way tend to be more brittle which is generally unwanted. Additionaly, transformation temperatures are also affected by the precipitation of oxides and intermetallic phases.

1.5.3 POST-TREATMENTS

Thermal and mechanical treatments of fabricated NiTi's are very important in order to obtain desired properties suitable for a specific application. It is essential to have a combination of optimum mechanical properties and shape memory effect or pseudoelastic behaviour and for that the material is cold worked and heat treated. The amount of cold working and heat treatment conditions lead to different microstructures and consequently, in different properties. As cast microstructure and surface properties of NiTi products are not acceptable for medical applications and further processing is required. These post-processes includes hot working, cold working, machining, surface treatments, joining, and heat treatments. Hot working procedures include press forging, hot rolling, and rotary forging. Final product shapes such as wire, tubing, and sheet can be achieved via cold working. The average ductility of NiTi allows 30–50% of cold work. NiTi wires, the most widely available form of this material, are produced via drawing.

Surface treatments are useful in enhancing the biocompatibility of the alloy. Titanium is a biocompatible element; however excessive intake amount of nickel may cause local and systemic toxicity, carcinogenic effects, and immune responses. Nickel in NiTi is chemically joined to the titanium with a strong intermetallic bond, so the risk of reaction even in patients with nickel-sensitivity, is extremely low. One type of the surface treatments consists of a thermal oxidation, performed under low oxygen pressure to avoid Ni oxidation, which leads to the formation of a pure titanium dioxide (TiO_2) on NiTi surface. This TiO_2 oxide has been shown to efficiently protect the NiTi surface from release of Ni ions into the exterior medium.

Therefore, this new surface treatment was expected to improve NiTi cytocompatibility by decreasing the risks of toxic reactions associated to Ni. Also, TiO_2 oxide on NiTi surfaces has similar electrochemical corrosion resistance properties to native pure titanium oxide. This could be of paramount importance when applying the oxidization treatment to NiTi devices for biomedical applications. It is worth noting that pure titanium is a highly biocompatible metallic material widely used in medicine because of the appropriate properties of its surface oxide.

Moreover, nitrogen or oxygen plasma immersion ion implantation (PIII) leads to dramatically improved corrosion resistance and tribological properties such as surface hardness. The leaching of nearsurface Ni concentration in NiTi alloys has been significantly suppressed by implanting atoms on the surface (either with N or O) using PIII. The effects can be attributed to the formation of a barrier layer consisting of TiN and TiO_x, respectively. Carbon plasma immersion ion implantation and deposition (PIII&D) has been also proved to increase the corrosion resistance and other surface and biological properties of NiTi. The ion-mixed amorphous carbon coating produced via PIII&D or direct carbon PIII can improve the corrosion resistance and block the leakage of Ni and lead to enhanced surface mechanical and biomechanical properties.

1.5.4 METALLURGY OF NiTi ALLOY

The nickel titanium alloys used in root canal treatment contain approximately 56% wt. nickel and 44% wt. titanium. In some NiTi alloys a small percentage (2%) of nickel can be substituted by cobalt. Recently, Boron was added to improve the surface hardness. The resultant combination is one to one atomic ratio of the major components and as with other metallic systems; the alloy can exist in various crystallographic forms. The generic term for these alloys is 55 Nitinol; they have an inherent ability to alter their type of atomic bonding which causes unique and significant changes in their mechanical properties and crystallographic arrangement of the alloy. These changes occur as a function of temperature and stress.

According to Anusavice K, (2003) the two significant features that are of relevance to clinical dentistry occur as a result of the austenite to martensite transition with an intermediary phase(R phase) in the NiTi alloys are shape memory and super elasticity.(Figure 1.59)

- **Austenite:** Has a complex body-centered cubic structure. Exists at higher temperatures and lower stresses.
- **Martensitic:** Exists at lower temperature and higher stress. It has Monoclinical lattice.
- **R phase** : It's an Intermediary phase with a rhomboidal structure.

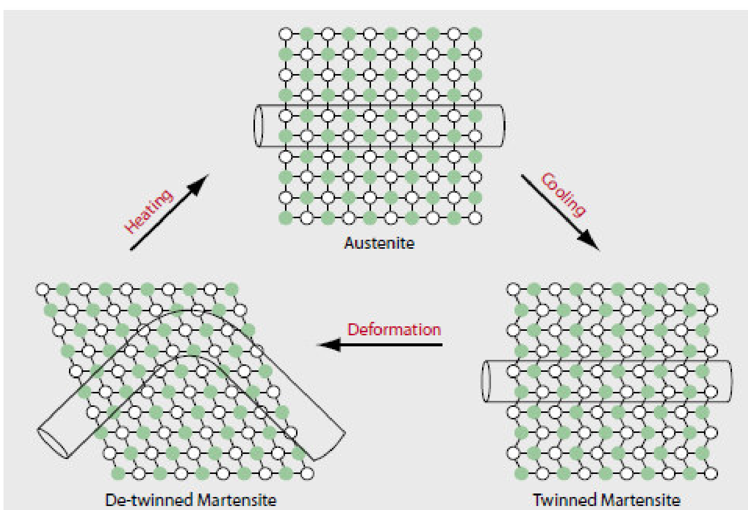


Figure 1.59: Diagramatic illustration of Martensitic transformation and shape memory effects of NiTi alloy.

Temperature Induced Phase Transformation (Figure 1.60 & 1.61,Graph 1)

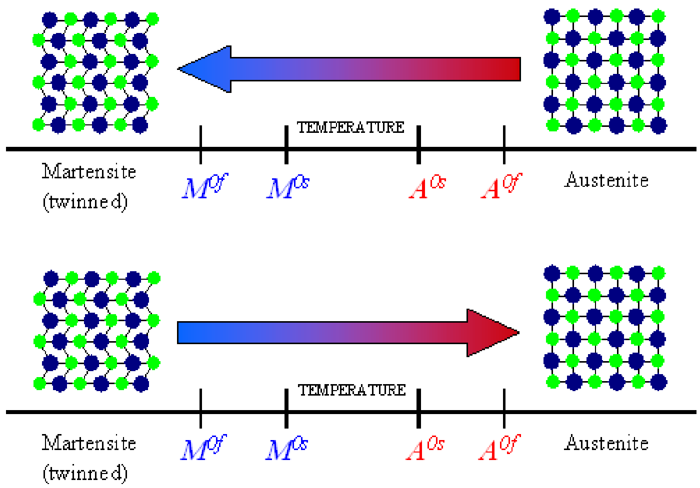


Figure 1.60: **Temperature-induced phase transformation without mechanical loading.**

The crystal structure of NiTi alloy at high temperature ranges (100^0 C) is stable, body centered cubic lattice which is referred to as the austenite phase or parent phase. Nitinol has the particular characteristic that when it is cooled through a critical transformation temperature range (TTR), the alloy shows dramatic changes in its modulus of elasticity (stiffness), yield strength and elastic resistivity as a result of changes in electron bonding. By reducing the temperature through this range, there is a change in the crystal structure which is known as the martensitic transformation. This phenomenon causes a change in the physical properties of the alloy and gives rise to shape memory characteristic. R phase is formed during forward transformation of martensite to austenite on heating and reverse transformation from austenite to martensite on cooling. (Figure 1.61)

Upon heating, martensite will start transforming to R phase at R_s temperature, and this transformation will be finished at the R_f temperature. With further heating, R phase starts transforming to austenite at the A_s temperature, and transformation is finished at A_f temperature. If heated above A_f temperature, it will be converted entirely to austenite. Then upon cooling to sufficiently lower temperature, the alloy starts transformation from austenite to R phase at the R_s temperature, and this transformation will be finished at the R_f temperature. By further cooling R phase starts transforming to martensite at M_s temperature and finished at M_f. The alloy has greater strength and a lower modulus of elasticity compared with stainless steel.

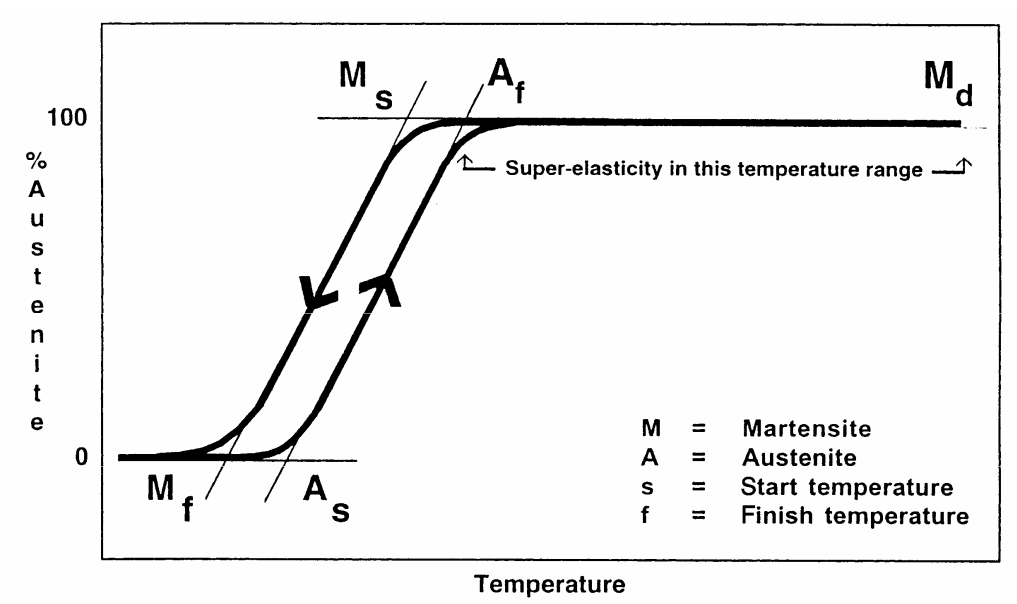
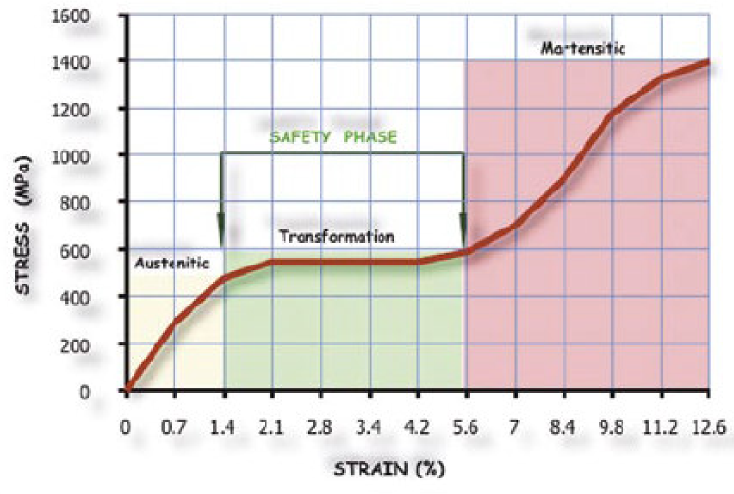


Figure 1.61: Temperature dependent transitions from austenite to martensite.



Graph 1.1: NiTi Phase transformation

Twinning (Figure 1.62)

It is a deformation that divides lattice into two symmetric parts at an angle. It is a mode of permanent deformation in metals. Small atomic movements occur on either side of a twinning plane that results in the atoms having a mirror relationship. It is the mechanism for reversible transformation between the austenitic and martensitic structures in NiTi.

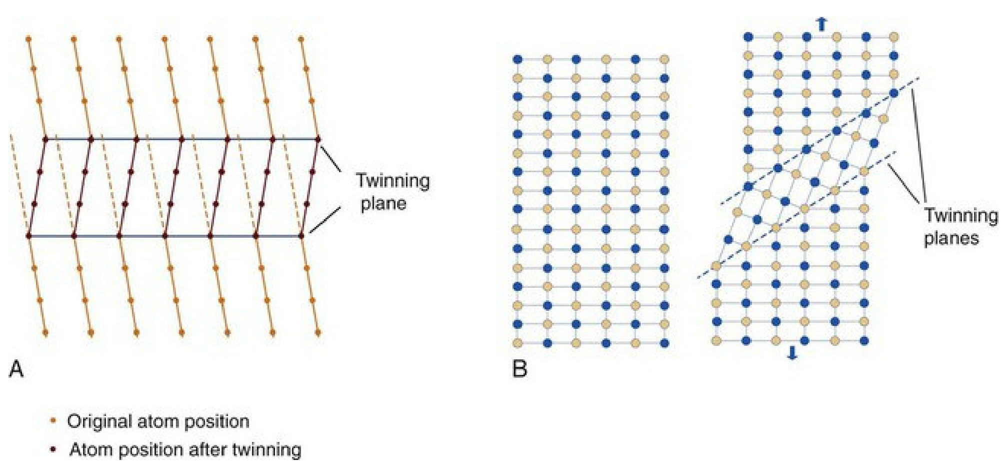


Figure 1.62: Schematic illustration of twinning in a metal. The atoms on either side of the twinning place have a mirror relationship

They return to their original shape before deformation The martensite shape, can be easily deformed to a single orientation by a process known as detwinning to detwinned martensite, when there is a flipping over type of shear. The NiTi alloy is more ductile in the martensitic phase than the austenite phase. (Figure 1.63)

The deformation can be reversed by heating the alloy above TTR (reverse transformation temperature range or RTTR) with the result that the properties of the of deformation can be reversed by heating the alloy above TTR (reverse transformation temperature range or RTTR) with the result that the properties of the NiTi alloy revert back to their previous high temperature values.

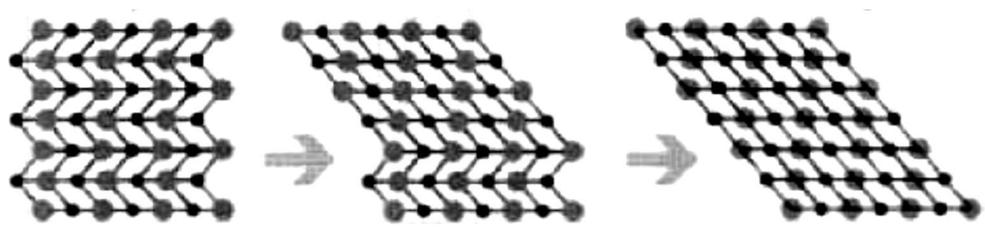


Figure 1.63. Martensitic deformation by Detwinning

This phenomenon is termed as shape memory and allows the alloy to return to its previous shape, by forming strong, directional and energetic electron bonds to pull back displaced atoms to their previous positions; the effect of the transformation is instantaneous.

Nowadays, nickel-titanium alloys are also known as martensitic-stabilized (Nitinol), austenitic active and martensitic active alloys. Austenitic active and martensitic active alloys present different rigidity depending on temperature or shape memory. For the martensitic-stabilized alloys, it is expected only good elasticity effect, thus having good springback. However, they can be deformed permanently, if a certain limit is exceeded or due to long time remaining in the mouth. Superelasticity or shape memory effect should not be expected. Austenitic active alloys presents the effect of superelasticity (also known as pseudoelasticity) which are not possible in martensitic-stabilized alloys. Many NiTi alloys are described as binary, in other words, they are characterized as presenting two phases, one NiTi matrix phase and a precipitation phase Ni_3 Ti_4. Martensitic alloys are characterized as ductile and plastically deformable, while Austenitic alloys are stiffer and not plastically deformable. In a more simplistic way, it might be stated that austenitic active alloys are more flexible and have good springback at room temperature; and if a certain tension (force) is applied upon them, small areas of martensitic crystalline structure might be formed, making them less stiff . In other words, little islands of crystalline martensitic structure are formed in a predominantly austenitic body. On the other hand, martensitic active wires show(at room temperature) very poor resistance to stress and discrete springback, so that they seem to accept a certain bend and, after removing it, the wire moves discretely toward the original shape, but without success because of the force decay. However, as they receive heat from the mouth, they initiate an austenitic crystalline alteration, becoming more resistant to stress and regaining their initial shape, confirming the shape memory effect. Once the heat is removed or the wire is cooled down, they present their initial characteristic, having predominantly a martensitic crystalline structure. In this alloy exist a mixed or rhombohedral phase “R” at room temperature that coexist with austenite and martensite structure.

M-wire

Developed in 2007 with the objective of producing superelastic NiTi wire blanks that contain substantial stable martensite under clinical conditions. Rotary instruments made of a new nickel-titanium (NiTi) alloy (M-Wire) have shown improved cyclic fatigue resistance and mechanical properties compared with those made of conventional superelastic NiTi wires. To improve fatigue resistance of rotary instruments is to optimize the microstructure of NiTi alloys through novel thermomechanical processing and showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products (GT series X and ProFile Vortex [Dentsply Tulsa Dental, Tulsa, OK]) in comparison with those made of conventional superelastic NiTi alloys. (Figure 1.64)

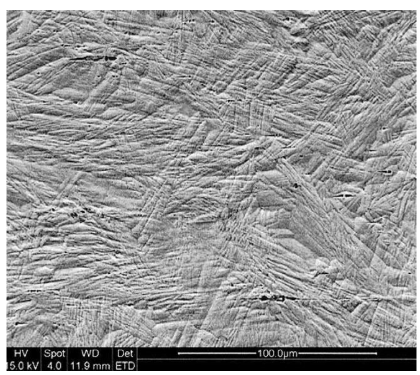


Figure 1.64. Image obtained with SEM of M-Wire, showing standard appearance of martensitic structures

According to the study by Alapati SB, (2009) on the metallurgical characterization of M-Wire contains all 3 crystalline phases including:

a) Deformed and microtwinned martensite,

b) R-phase

c) Austenite

The lower values of enthalpy (measure of the total energy of a thermodynamic system) changes for M-Wire, compared with values for superelastic orthodontic wires, suggest that these endodontic NiTi wire blanks contain substantial amounts of martensite that do not undergo transformation. This hypothesis is supported by the etched microstructures of M-Wire which have the standard appearance of martensitic structures. In (2012), Jia Ye *et al.* studied the characterize microstructural changes of M-Wire throughout the cyclic fatigue process under controlled strain amplitude and found out that endodontic instruments manufactured with M-Wire are expected to have higher strength and wear resistance than similar instruments made of conventional superelastic NiTi wires because of its unique nano-crystalline martensitic microstructure.

CM wire (Controlled Memory)

The NiTi files with thermal processing would be essentially in the martensite condition at body temperature. The martensitic phase of NiTi has some unique properties that have made it an ideal material for many applications like

- Excellent damping characteristics because of the energy absorption characteristic of it twinned phase structure.
- Remarkable fatigue resistance

The instruments of the martensitic phase can easily be deformed, yet they will recover their shape on heating above transformation temperature. The thermo-mechanical processing is a very promising way to increase the fatigue resistance of NiTi endodontic instruments.

The higher the A_f temperature (55°C), there is mixture of both austenitic and martensitic phase, observed at room temperature. It was found by Harty FJ (1974) that all NiTi instruments have a room temperature with martensitic microstructures consisting of colonies of lenticular features with substantial twinning.

1.5.5. STRESS INDUCED MARTENSITIC TRANSFORMATION

The transition from the austenite to martensite phase can also occur as a result of application of stresses, such as occurs during root canal preparation. In most metals, when an external force exceeds a given amount, mechanical slip is induced within the lattice, causing permanent deformation. However with the NiTi alloys, a stress induced martensite transformation occurs rather than slip. This causes a volumetric change associated with transition from one phase to the other and an orientation relation is developed between the phases. (Figure1.65)

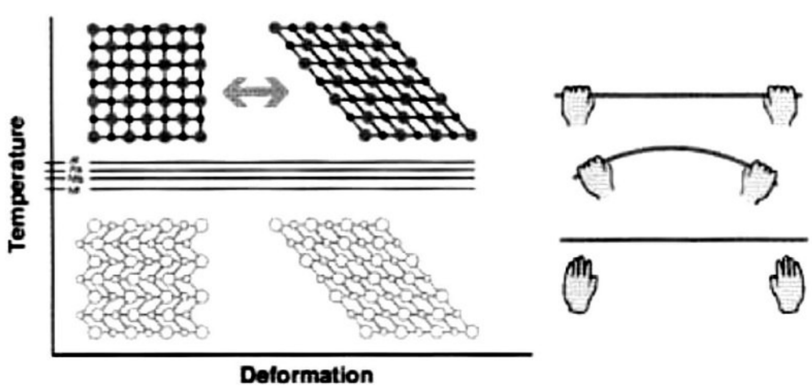


Figure 1.65: Stress induced Martensitic Transformation and Superelasticity.

The plastic deformation that occurs in NiTi alloys within or below the TTR is recoverable, within certain limits, on reverse transformation. It is this phenomenon of crystalline change which gives rise to the shape memory effect of the material and the superelastic behavior. The part of the RTTR, in which shape recovery occurs, is termed the shape recovery temperature range (SRTR).This has also been termed “mechanical memory”. This is unlike conventional metallic stress strain behavior, where elastic response in conventional alloys is recoverable, but is small in size, and where larger strains are associated with plastic deformation, that is not recoverable

The super elasticity of Nickel Titanium allows deformation of, as much as 8-10% strain to be fully recoverable, in comparison with a maximum of less than 1% with other alloys, such as stainless steel. Thompson SA (2000) reviewed and found that although other alloys such as copper-zinc, copper-aluminium, and gold-cadmium have been found to have super elastic properties, nickel titanium is the most biocompatible material and has excellent resistance to corrosion.

An alloy system is an aggregate of two or more metals which can occur in all possible combinations. As such, second groups of Nitinol alloys can be formed of the NiTi alloy contain more nickel and as this approaches 60% wt. nickel an alloy known as “60-Nitinol forms”. The shape memory of this alloy is lower, although its ability to be heat treated increases. Both 55 and 60 Nitinol are more resistant, tougher and have lower modulus of elasticity than other alloys such as stainless steel, Ni-Cr or Co-Cr. The super elastic behavior of NiTi occurs over a limited temperature window. This temperature window, in which super elastic behavior is observed, is dependent on the precise chemical composition of the alloy. Addition of iron to NiTi lowers the temperature window. In endodontic application, where it is desirable to have the greatest superelastic behavior in a temperature range of 23^0C to 36^0C, a composition consistency of 50 atomic percent Ni and 50 atomic percent Ti is ideal.

Properties of NiTi Alloy

To understand the properties of Nickel Titanium the following things should be known:

1. **Crystal**: A crystal has a definite geometry in which atoms are arranged in unit cells repeated again and again to form Lattice.

Cation- Anion arrangement → Increases the strength of crystals resist deformation

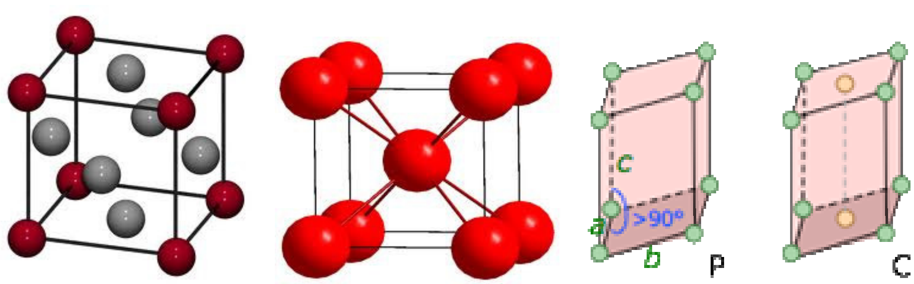
2. **Grain**

It is a microscopic single crystal in microstructure of a metallic material.

Crystal growth → Crystal penetrate each other → Grain Boundary:
Weaker, non-crystalline structure

3. **Lattices (figure 1.66)**

These are the three dimensional network of lines connecting the atoms in undistributed crystals.



Face Centred Cubic   Body Centred Cubic   Monoclinical Martensite (low-temperature phase, with a monoclinic B19 structure)

Figure 1.66: **Various types of Lattice.**

4. **Lattice Deformation**

Metals with BCC or FCC cells are densly packed.

Crystal deform → Lattice deform → Stresses atomic bond

↓

Increases resistance to further deformation

↓

Strain, work hardening or cold work

5. **Transition temperature**

Pure substances possess a definite melting point.

In NiTi alloys, the Martensitic transformation occurs with a set range of temperature called as transformation temperature range (TTR).

The desirable properties of nickel titanium instruments are:

1.5.5.1 Super elasticity:

It is also called as Pseudoelasticity. It allows it to return to its original shape upon unloading following substantial deformation. Anusavice K (2003) found that it exhibits 3 times the elastic flexibility in bending and torsion compared with stainless steel file. This happened to be due to lower modulus of elasticity as compared to stainless steel alloy file. Generally, NiTi exhibits superelasticity behaviour between 10 °C to 125°C.

To begin with, in the NiTi alloys, the effect can be triggered while the material is loaded and unloaded isothermaly, at temperatures above the A_f , thus the phenomenon is related to applying loads in the austenitic phase (in contrast with shape memory effect). More specifically, if external load is applied while the alloy is austenitic then the SIM transformation takes place transforming austenite to martensite via a reversible transformation, while at the same time the alloy is able to achieve large strains up to 10%. Even more ,due to the reversibility of the transformation ,after unloading the material is able to recover its original shape through an unloading plateau, which is different than the loading and a stress hysterisis is introduced.(Figure 1.67)

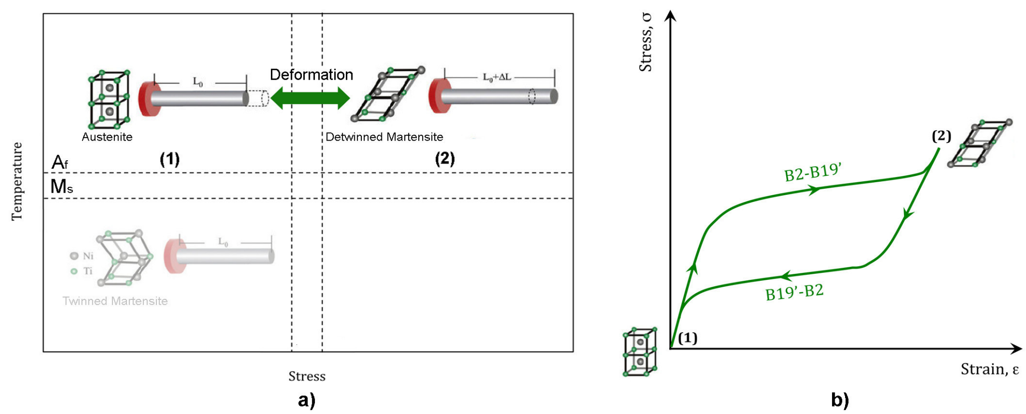


Figure 1.67: Pseudoelastic behaviour of NiTi instrument: a) The SIM transformation depicted above A_f b) A qualitative stress-strain diagram with the stress hysteris loop.

At this point, it is cruicial to mention that the pseudoelastic phenomenon of the NiTi alloys strongly depends, either directly or indirectly, on specific factors such as the composition of the alloy, manufacturing processes and the number of loading/ unloading cycles. For instance, pseudoelasticity appears to be more extended for near equatomic NiTi alloys. Widely used and with the desired thermoelastic properties are alloys with Nickel content between 49 and 51 %. Furthermore, the system is very sensitive to composition changes such that very small shifts of either of the components lead to major changes in transformation temperatures, phases precipitated and the reversibility of martensitic interfaces. Also, during the manufacturing process of the alloy, extra care is to be taken, since any impurities of other elements, such as oxygen and carbon, seriously affect the pseudoelastic behaviour of the NiTi alloy.

It has been found by Elahinia. H.M *et al.* (2012) that various tests have shown that, as the number of loading and unloading cycles increases the pseudoelastic recovery of the alloy decreases and this is brought about because of the permenant slip of some interfaces which gradually leads to some stable martenstic phase.

1.5.5.2 Shape memory:

It demonstrates an ability to return to previously defined shape or size when subjected to an appropriate thermal procedure, approximately 125 degree centigrad (Anusavice K, 2011). The discovery of the shape memory effects dates back to 1932 when a Swedish researcher Arne Olander first observed the property in Gold cadmium alloys. In this case, the reversible martensitic transformation is triggered not by induced strains but by changes in temperature.

Shape memory effect can be classified into

- One-Way Shape Memory Effect (OWSME)
- Two-Way Shape Memory Effect (TWSME)

One Way Shape Memory Effect

OWSME is the recovery of the original shape of an apparently plastically deformed material simply upon heating to a certain temperature. There are three key microstructure forms (Figure 1.68, 1.69 & 1.70):

- Austenite
- Twinned martensite and
- De-twinned martensite

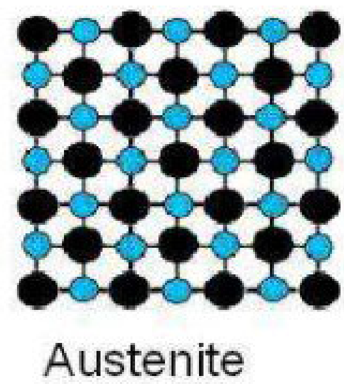


Figure 1.68: Austenitic atomic structure

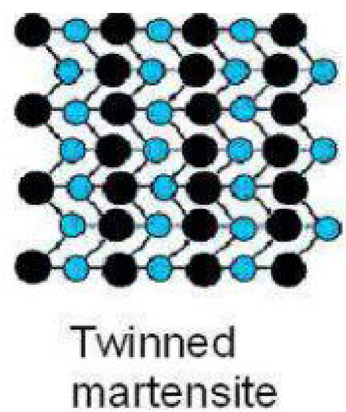


Figure 1.69: Twinned martensitic atomic structures

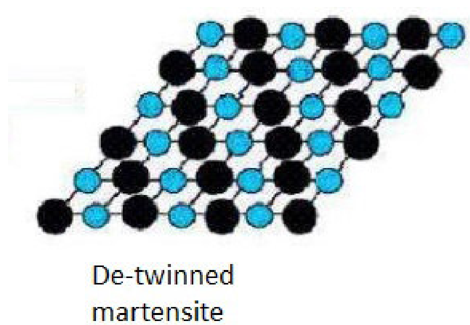


Figure 1.70: Detwinned martensitic atomic structure

At temperatures greater than A_f , the material is in austenite phase (Figure 1.68).

Upon cooling and once M_s temperature is reached, the forward martensitic transformation begins resulting in the formation of martensite. Such a transformation leads to the formation of several variants i.e. there are several alternative ways in which the austenite (high symmetry phase) can transform into martensite (low symmetry phase).These variants essentially correspond to the different orientations of the habit plane. Once the transformation is completed, the shape of the material remains the same due to the cancellation of the individual shape deformation by the variants. At temperatures lower than M_f , the material is in martensitic phase, also known as product or cold phase and the microstructure is consisted by twinned martensite (Figure 1.69). The material is easily deformed through de-twinning due to the existence of many highly mobile twinned boundaries. The detwinning results in the growth of favorably oriented variants in order to accommodate the strain, which most of the times leads in single variant (Figure 1.71a). The de-twinned martensite will be maintained in the microstructure even if the stress is completely removed.

Upon heating, the reverse phase transformation takes place which starts at A_s and finishes at A_f temperatures, respectively. Although, there are many ways in which the austenite can be transformed to martensite, there is only one manner in which the austenite is formed. Eventually, the original shape is recovered and upon cooling the above mechanism can be repeated (Figure 1.71 b).

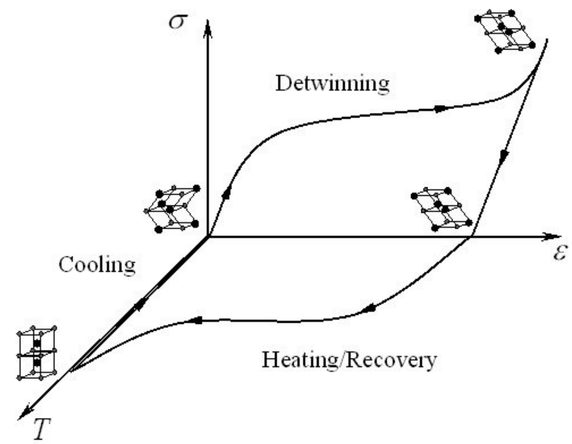


Figure 1.71 (a): **Detwinning Phenomenon**

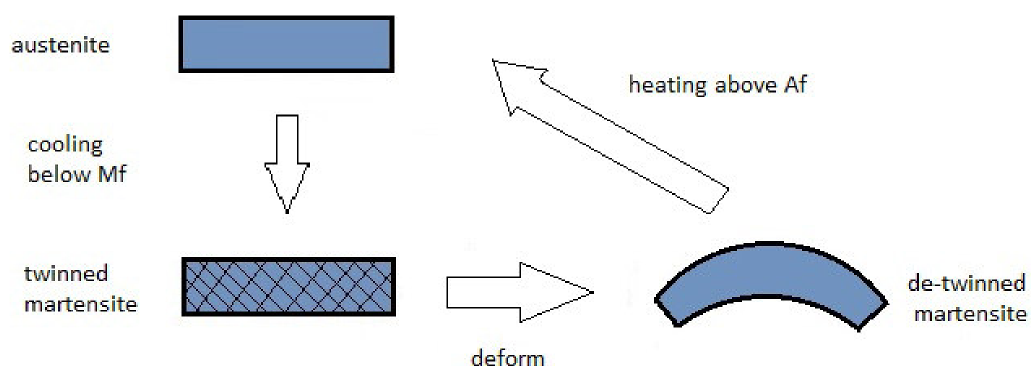


Figure 1.71 (b): Schematic depiction of OWSME

Two-Way Shape Memory Effect

As stated above,in the OWSME only the shape of the parent phase can be recovered but in TWSME property has the ability to remember both its parent and product phases and spontaneously change shapes upon heating and cooling. TWSME is not an inherent property in NiTi alloys but instead is a learned behavior. This can be accomplished by complicated thermo-mechanical procedures known as “Training”. The training involves repeated deformation and transformations between a favorable configuration of martensite and austenite. The substantial difference between the OWSME and the TWSME is that the shape change in the latter is generated even without external stresses.

At temperatures below M_f the material is in martensite phase. In contrast with the OWSME,an irreversible amount of deformation is introduced i.e. the martensite is deformed beyond its yield strength where slip occurs and dislocations are introduced.

Upon heating there is no 100% shape recovery due to the retardation of the martensitic transformation by the dislocations. Afterwards,upon cooling below M_f ,a specific configuration of martensite is formed resulting in a specific cold shape. This specific configuration of martensite is attributed to the anisotropic field that is introduced due to dislocations which are maintained in the parent phase and favor the formation of preferentially oriented martensite. Thus, spontaneous shape change between cold and hot shape occurs by cooling or heating respectively without external stresses.(Figure 1.72)

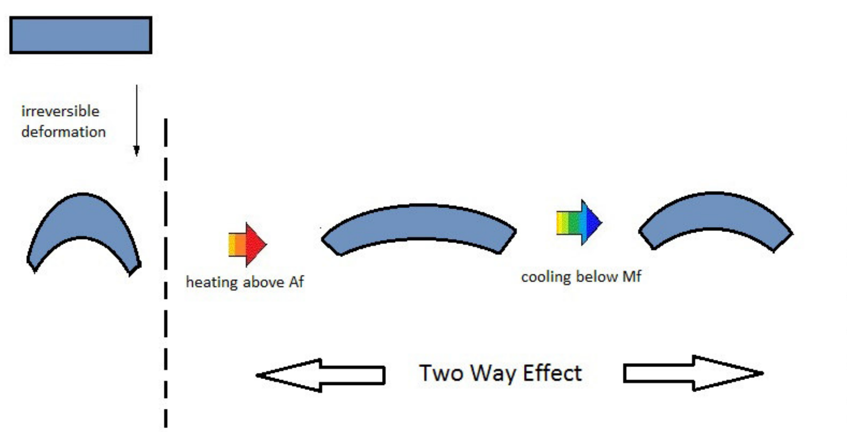


Figure 1.72: Schematic depiction of TWSME

The specific cold shape in which the material will revert back upon cooling can be obtained through particular thermo-mechanical treatments which are also known as training.

It is stated by Perkins J and Hodgson D (1990) that the TWSME is a weaker effect than the OWSME, since the first is due to the formation of preferentially oriented martensite variants, while in the latter there is a powerful reversibility between austenite and martensite. In particular, OWSME can recover large strains up to 8% whereas in TWSM only a 2% is recoverable. SMAs suffer both thermal and mechanical cycling. Alternating the temperatures between A_f and M_f result in functional fatigue. This is an additional fatigue that these alloys are subjected to, except for the usual fatigue in common metals that is associated with initiation and propagation of cracks and eventually the failure. More specifically, the functional fatigue in a SMA lead in loss of its shape memory effect over time i.e. loses its ability to undergo reversible phase transformations. Strong influence on the shape memory behavior and mechanical properties of SMAs are grain size, texture, transformation temperatures and transformation hysteresis which can be set through thermal and mechanical treatments.

Training Procedure

The One Way Shape Setting is analyzed which is the basic process for giving the desired parent phase shape. Furthermore the non-inherent TWSME is also described under this training process.

Whether the SMA is used for its superelastic property or its SME, a preferred shape suitable to the application must be obtained. This is done by a process known as Shape Setting. Shape Setting refers to a procedure used to form the desired shape that follows cold working. This is done in the following way: The sample is formed to the desired shape and is hold in that position tightly. Afterwards, the componet is heat treated to a certain temperature that is enough to obtain a uniform temperature on its entire mass. The heat treatment time depends on sample's size. It is quite essential that the sample remains still while being heat treated otherwise the required shape will not be set.Once at room temperature the alloy has transformed into the martensitic state and twinning has occurred to maintain the macroscopic shape.

SMA with the TWSME has the ability to remember and eventually recover both its hot (austenite) and cold (martensite) phase shapes simply upon heating and cooling, respectively. The TWSME is not an innate property of SMAs thus, particular thermo-mechanical treatments also known as training, must be followed before such a property is obtained. The training can be done with a variety of different ways and all are focused in optimizing the TWSME behavior. Most of the training procedures involve repetitive phase transformations between austenite and a preferred configuration of martensite. Furthermore, certain martensite variants are favored and grown upon cooling at the expense of others eventually leading in a specific cold shape. The preferentially oriented martensite is introduced either upon systematically loading / unloading cycles or by an over-deformation.

The following are the training procedures :

Shape memory training (Figure 1.73)

As indicated by its name, this training procedure is based on the SME. In particular, once the material is in martensite phase it is subjected to a deformation (which will be the same in the entire procedure) with a stress below the critical stress required for slip so the SME can be triggered upon heating. Once the A_f temperature is reached the material is in austenite phase and upon cooling it reverts back to martensite phase. The above procedure is continued with the material to be always deformed in a specific shape and after a sufficient number of cycles the TWSME is observed where the formation of martensite into variants of preferential orientation is favored. The final shape is related with the deformed shape in which the material was systematically deformed.

Stress-induced martensitic transformation training (Figure 1.73)

This training procedure is based on the other fundamental behavior of SMAs, the pseudoelasticity. The material is maintained above the A_f temperature but below the M_d temperature where stress-induced martensite is feasible. Upon loading, stress-induced martensite is introduced and the microstructure is consisted by de-twinned martensite. After that, the load is removed and the material gets back into its austenite phase. This procedure continues until the TWSME is observed. As with the Shape Memory Training, specific configuration of martensite variants is favored here as well resulting eventually in a macroscopic shape change upon cooling.

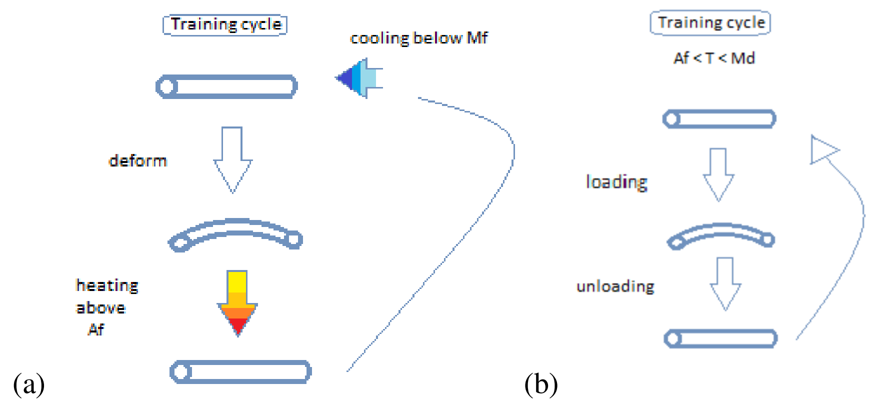


Figure 1.73: Schematic depiction of a) Shape memory training and b) Stress-induced martensitic transformation training.

Thermal cycle training under constant load (Figure 1.74a): This procedure is one of the most commonly used since it only involves temperature variations. More specifically, once the sample is below the M_f temperature, it is deformed resulting in detwinned martensite. Subsequently, it is maintained in the deformed state while heat is supplied until the A_f temperature is reached. The procedure is continued just by alternating the temperature between M_f and A_f with the sample to be always constrained in the original deformed shape until the training procedure is completed.

Over-deformation training (Figure 1.74b): Once the sample is in the martensite phase,a stress beyond the critical stress needed for slip is applied introducing irreversible slip and dislocations. Thus, heating the sample above the Af temperature will not allow it to recover its parent phase shape. The introduced dislocations favour the formation of preferentially oriented martensite at the expense of others upon cooling. Hence, upon cooling the material will impulsively move into the overdeformed shape.

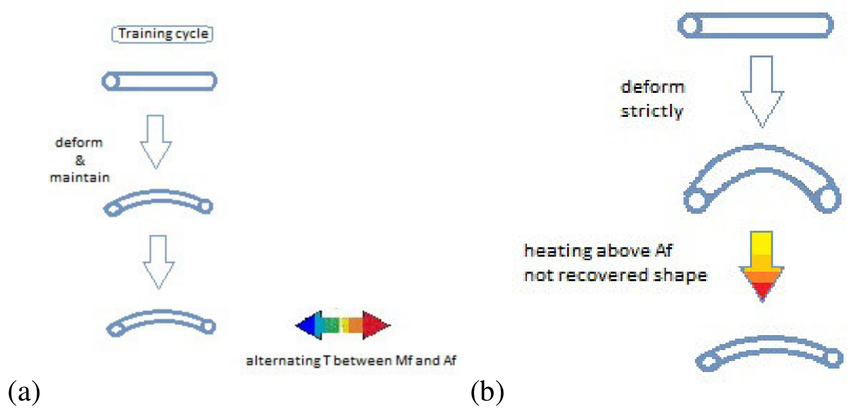


Figure 1.74: Schematic depiction of a) Thermal cycle training under constant load and b) Over-deformation training

1.5.5.3 Hardness and wear resistance

Grinding of Nickel based alloy is quite difficult because considerable wear of the milling head occurs within a short time. This leads to structural defects especially on the cutting edges of NiTi. Tripi TR (2003) found that the microhardness of Ni Ti is 303 to 362 VHN whereas that of stainless steel is 522 to 542 VHN. Due to these surface irregularities and low surface hardness cutting efficiency of Ni Ti files is less as compared to stainless steel. A variety of surface engineering techniques have been brought in the literature by Rapisarda E (2000) for gaining improvements in hardness and wear resistance by production of hard surface coatings. These are ion implantation of boron or N_2, Physical Vapor Deposition (PVD) and Electropolishing.

a. Ion Implantation of Boron or N_2

Tripi TR (2003) reviewed and stated Ionic implantation of N_2 creates a surface layer of titanium nitride which can significantly improve surface hardness, cutting efficiency and wear resistance.

Boron implantation into Nitinol has a potential for developing improved NiTi root canal instrument with excellent cutting properties, without affecting their superelastic mechanical properties with an implantation of 4.8×10^{17} boron/cm^2.Concentration of boron is incorporated into NiTi alloy by 110 eV boron ions at room temperature. There is formation of TiB_2. In the studies it has found that TiB_2 has better mechanical strength than titanium nitrogen.

b. Physical Vapor Deposition (PVD)

This was introduced by medical device industry in 1980s. PVD includes reactive magnetron sputtering, ion planting and arc evaporation.To achieve best possible adhesion of coating to the substrate, cathode arc evaporation is used, creating a hard coating including TiN, TiC, and TiCN and TiAIN. Schafer E (2002) demonstrated that using this technique it is possible to deposit a fine grained TiN film on the instrument at comparatively low temperature. Coating ranges from 1 to 7µm and it is possible to obtain surface hardness approximately 2200 Vickers unit. Tin coating enhances the properties and reduce the corrosion susceptibility of the NiTi instruments clinically this improvement is very useful to shorten instrumentation line and possibly to minimize the use of instrument separation during enlargement.

c. Electropolishing:

It is also called as reverse plating or passivation. It is a controlled electro chemical removal of surface roughness.

Process:

1. The metal part to be processed is connected to the positive electrode (anode) of a DC power supply.

2. The part is then immersed in a heated electrolyte bath that contains metal plates connected to the negative electrode (cathode).

3. The electrical reaction causes ionic conduction resulting in removal of metal particles from the anode.

4. During the process, the products of this anodic metal dissolution react with the electrolyte to form a surface film on the metal.

5. Electropolishing results in distinct improvement of the surface composition & properties of NiTi instrument and produces a surface layer free of organic & inorganic components.

Electropolishing dissolves existing natural oxide with all its imperfections and creates new more corrosion resistant oxide mainly in the form of rutile according to following reactions:

1. Dissolution and transfer of titanium ions into solution

$Ti = Ti_4+ + 4e^-$

2. Evolution of the oxygen from the anode surface

$4OH^- = O_2 + 2H_2O + 4e^-$

3. Formation of the passive film on the anode surface

$Ti + 2OH- = Ti_xO_y + 2H2O + 2e-$

The present investigation revealed that cracks can propagate along the straight line of machining marks in the Non-EP instruments, whilst for EP instruments this kind of propagation was not observed and surface cracks did not travel in straight lines. Therefore, the propagation of fatigue cracks along a tortuous path (in the absence of machining marks) could have retarded crack propagation.

NiTi alloys undergo a reversible solid state displacive crystalline phase transformation dominated by shear between a high symmetry parent phase (austenite in the form of ordered BCC superlattice β phase) and a low symmetry product phase (martensite in the form of monoclinic distortion of a B19 lattice). The deformation can also occur under martensite variant reorientation or detwinning of twins, where variants favorably oriented towards the applied load can form. There are 24 habit plane variants for stress induced martensitic transformation. This temperature and/or stress induced phase transformation (as opposed to conventional diffusion induced transformations) is the basis for the unique properties in NiTi alloys, namely shape memory effect and pseudoelasticity.

1.5.5.4 Thermoelastic Behaviour

i) Thermoelastic Martensitic Transformation (TMT)

It is a diffusionless reversible solid state phase transformation, a behavior that some alloys possess due to elastic shape deformation during the martensitic transformation. In the binary system of ,the Nickel-Titanium (Ni-Ti) system, a stable, at high temperature, Parent Phase (B2-Austenite) transforms into a low temperature stable phase (B19-Martensite) via Martensitic Transformation.

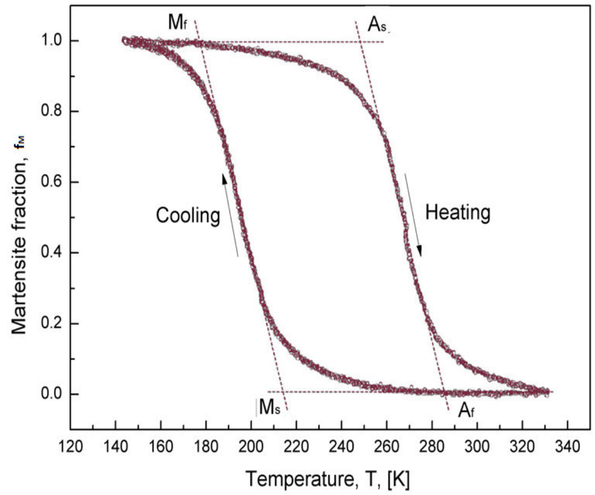
Furthermore, Martensitic Transformation can be either by a temperature variation (Thermaly Induced Martensite or TIM) or by the application of stresses which in turn result into strains (Strain Induced Martensite or SIM) and in any case equillibrium is sustained between chemical and mechanical forces.

ii) Thermaly Induced Martensitic Transformation

During the cooling from a hightemperature to a low temperature, austenite transforms into martensite below a critical temperature M_f through a non diffusive, displacive transformation also known as military transformation.

Additionally, following the reverse procedure i.e. heating the material above A_s temperature, results in reversing the transformation. Due to the displacive nature of the transformation, the movement of atoms is fully coordinated. Thus, the composition, the ordering of atomic structures and the number of crystallographic lattice defects are the same in the parent and the martensitic phase.

It is also of great importance to note (Graph 1.2) that a temperature hysteris loop occurs between the direct and reverse transformations due to the athermal kinetics that govern the transformation. Consequently, this implies that the transformation, although one can say it is crystallographicaly reversible (since the interfaces retain their reversibility), is not fully thermodynamically reversible, which in turn means that it does not proceed through thermodynamic equilibrium states.



Graph 1.2: Thermal Hysterisis Loop Between Direct and Reverse Transformation

M_s represent the temperatures where crystallographic martensitic alteration begins.

M_f represent the temperatures where crystallographic martensitic alteration ends.

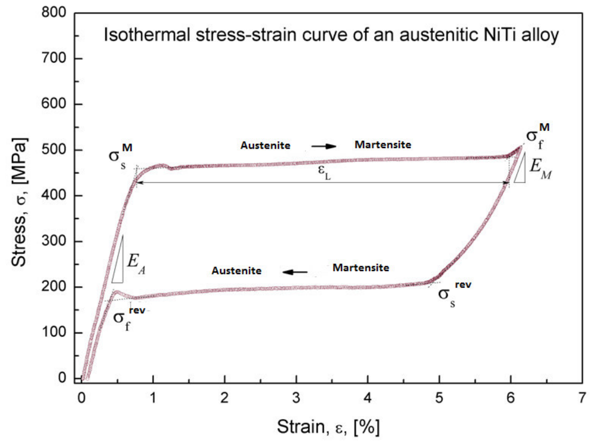
A_s represent where the austenitic alteration begins.

A_f represent where the austenitic alteration ends.

Stress Induced Martensitic Transformation

This transformation occurs when external load is applied to the austenitic parent phase which brings about the appearance of strains (due to stresses). After a critical strain-induced stress ($\sigma^M{}_S$) is applied martensitic transformation begins and is completed for a stress just bellow the yielding stress of the material($\sigma^M{}_f$) .

During the unloading,the reverse transformation occurs and, as illustrated in the Graph 1.3, a stress hysteresis loop is produced resulting in two stress plateau. Additionaly, it can be easly observed that large strains can be recovered due to the reversible character of the transformation.



Graph 1.3: Stress Hysterisis Loop Between Direct and Reverse Transformation. E_A and E_M correspond to the elastic modulus of Parent and Martensitic phases respectively.

Finally it should also be noted that the interefaces between the parent and martensitic phases are coherent and this due to the fact that the phase transition displacement field is continuous on the phase's interface.

Cyclic fatigue

Cyclic fatigue is synonymous with metal fatigue. It has been shown in various studies conducted by Bahi MG (2005), Pruett (1997), Haikel *et al.* (1999), Bahia and Buono (2005), Plotino *et al.* (2009) that when a file is rotating freely in a curved canal, resulting in alternating tension and compression cycles at the point of maximum flexure which is the midpoint of the curve until fracture occurs as a result of metal fatigue. The inner side of the curve and stretched on the outer side of the curve. With every 180^0 of rotation, the instrument flexes and stretches over and over again, resulting in cyclic fatigue and eventually fracture.

Flexural fatigue is influenced by the factors like radius and angle of the canal as shown in research conducted by Haikel *et al.* (1999), Li *et al.* (2002), Zelada *et al.*

(2002), Lopes *et al.* (2007) and Necchi *et al.* (2008), location of curvature as shown in research conducted by Necchi *et al.* (2008), Peters and Paque (2010), rotational speed as shown in research conducted by Zelada *et al.* (2002), Martin *et al.*(2003), Lopes *et al.* (2009), number of uses of instruments as shown in research conducted by Plotino *et al.* (2006), Ounsi *et al.* (2007), Viera *et al.* (2008) and taper and diameter of the files as shown in research conducted by Haikel *et al.* (1999).

In general, instruments used in rotary motion break in two distinct modes, torsional and flexural. Torsional fracture occurs when an instrument tip is locked in a canal while the shank continues to rotate, thereby exerting enough torque to fracture the tip. It was found by Schirrmeister JF (2006) that this also may occur when instrument rotation is sufficiently slowed in relation to the cross-sectional diameter

This problem precludes the manufacture of continuously rotating stainless steel endodontic instruments, because steel develops fatal fatigue after only a few cycles. NiTi instruments can withstand several hundred flexural cycles before they fracture.

Rotary nickel-titanium instruments with larger tapers and sizes consistently fractured after fewer rotations, and although the radius of the curves was halved, fatigue-life was reduced by 400%. The torque generated during canal preparation depends on a variety of factors, and an important one is the contact area. It was found by Dietz DB (2000). The size of the surface area contacted by an endodontic instrument is influenced by the instrumentation sequence or by the use of instruments with different tapers.

A crown-down approach is recommended to reduce torsional loads (and thus the risk of fracture) by preventing a large portion of the tapered rotating instrument from engaging root dentin (known as taper lock). The clinician can further modify torque by varying axial pressure, because these two factors are related. In fact, a light touch is recommended for all current NiTi instruments to avoid forcing the instrument into taper lock. The same effect might occur in certain anatomic situations, such as when canals merge, dilacerate, and divide. NiTi is unique in that it transforms from one phase to another (Austenite to Martensite) and then returns to its original phase. When this stress induced phase transformation takes place, however, the external shape cannot be detected visually. It is therefore important that the file should be carefully monitored for failure and fatigue.

Properties of Niti Alloy vs Stainless Steel :

Table 1.6. Properties of Stainless steel vs NiTi

Properties	NiTiNOL 55	Stainless Steel
Density (gm/cm^3)	6.45	7.9
Melting Temperature(^OC)	1310	1500-1550
Tensile strength (MPa)	690-1380 MPa	500-740 MPa
Vickers Hardness(VHN)	303-362 VHN	600-610VHN
Yield Strength(MPa)	379 MPa	140 MPa
Modulus of Elasticity (GPa)	33 GPa	193 GPa
Coeff. of Thermal Expansion	$11 \times 10^{-6}/^OC$	$17.3 \times 10^{-6}/^OC$
Biocompatibility	Good	Fair
Elongation	15.5%	2%

1.6 FACTORS AFFECTING CYCLIC FATIGUE

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

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

The factors that contributes to instrument fracture includes instrumentation Technique confirmed by the studies conducted by Blum *et al.*(2003), Walsch (2004), Schrader and Peters (2005), Boessler *et al.*(2007) ,accessibility of canals confirmed by the studies conducted by Cheung(2009), instrument surface condition confirmed by the studies conducted by Anderson *et al.*(2007), Condorelli *et al.*(2010), Lopes *et al.*(2010), instrument design confirmed by the studies conducted by Peters *et al.*(2003); Parashos *et al.*(2004), Xu *et al.*(2006), Ray *et al.*(2007), Yum *et al.*(2011), use of torque controlled motor confirmed by the studies conducted by Gambarini*et al.* (2000), Berutti *et al.*(2004), Cheung *et al.*(2009), sterilisation procedure confirmed by the studies conducted by O Hoy *et al.*(2003), Silvaggio and Hicks(1997), King *et al.*(2012) and operator proficiency confirmed by the studies conducted by Yared *et al.*(2001),Parashos *et al.* (2004).

1.6.1 OPERATOR PROFICIENCY

There is no doubt that both training and adequate skills are imperative for all dental procedures and particularly so in endodontics. Many guidelines have been suggested for the prevention of file fracture which are discussed in literature of Cheung GSP *et al.*(2009). Most are related to the operator, including:

- Instruments should be examined, before and after use, to make certain that blades are regularly aligned
- Instruments should not be used in dry canals
- Files should be used according to the manufacturer's instructions and excessive forces should be avoided.

There is a variety of protocols for root canal instrumentation. Zinelis S. *et al.* (2010) and Shen Ya *et al.* (2011) reported that the experience of file separation was found to differ not only between different dental practitioners, but also at different times for the same practitioner .Preclinical training for mastering instrumentation and improving operator competence through learning and experience are crucial for the avoidance of rotary file separation and reducing the incidence of instrument locking and deformation. A recent clinical study by O Connell DT(1975) comprising endodontists from four different countries showed that the most important influence on defect occurrence was the operator.This was attributed to their clinical skills or their decision either to use instruments for a specific number of times or until defects were evident.

1.6.2 ROOT CANAL ANATOMY

1.6.2.1 The angle of canal curvature: It is generally accepted that the more complicated the root canal morphology, the greater the risk of endodontic instrument breakage. A higher prevalence of separated endodontic file has been reported in molars by Iqbal *et al.* (2006) and Peng B *et al.* (2005) particularly in the mesial roots of mandibular molars.

Iqbal M K *et al.* (2006) stated that the risk of separated endodontic file in the apical third of the canal is found to be higher when compared with coronal and middle thirds .Files undergo greater fatigue as the curvature increases and the contact surface with the dentinal walls is greater since most curved canals are narrow. Clinically, fatigue of an instrument may be related to the degree of instrument flexure when placed in a curved root canal. When the curvature of canals is pronounced, the cyclical fatigue of the instrument is greater and thus its life expectancy is lower. This has been concluded by Pruett J P *et al.* (1997)

1.6.2.2 The radius of canal curvature: The parameters of the angle and the radius of curvature are independent in such a way that even if two canals have the same angle of curvature they may have different radii of curvature, which indicates that some curves are sharper than others.Thus, the radius of canal curvature is more important than the curvature angle itself. It has been reported by Patino PV *et al.* (2005) that the rate of file separation increases as the radius of curvature decreases. It has been shown by finding of the study conducted by Booth JR et (2003) that when several variables, including those related to root canal anatomy, are considered, the radius of curvature is the most signifi cant factor in rotary file failure.

1.6.3 METAL ALLOY

An understanding of the characteristics of endodontic file materials is important when failure is considered. The properties of endodontic instruments differ from each other depending, in particular, on their metallic composition. Also the manner and efficiency of cutting dentine are not the same. As a result, their resistance to defect formation and fracture differ. Stainless steel reamers and files were found to be preferable to carbon steel instruments in this respect. Kim S *et al.* (2004) reported that NiTi files have been found to be three times stronger, more flexible and have superior resistance to fracture compared with stainless steel files.

1.6.4 SIZE AND CROSS-SECTIONAL SHAPE

Cross-sectional shape determines the bulk of the file and the contact area between the file and dentinal walls, as well as its cutting efficiency. Study of Roulet JF (1983) demonstrate that the greater the area of file contacting the dentinal walls, the greater the quantity of cut dentine. Consequently there is greater friction and a fatigued file has a reduced life span. There are two types of endodontic file cross-section. While active instruments have active cutting blades, passive instruments have a radial land between the cutting edge and flute. The radial land contacts the canal wall on its entire surface. In general, active instruments cut more effectively and aggressively. Walsch H (2004) found that the passive instruments perform a scraping or burnishing rather than a real cutting action, and remove dentine more slowly. Adding to it, Wolcott S (2006) concluded that the size of the rotary file also determines how many times it should be used. As the diameter of the file increases, the force needed to unwind or fracture also increases. However, clinically large instruments that are used many times should be reused with great care or be discarded. Schafer E *et al.* (2001) reported that the instruments of a rhomboid-shaped cross sectional design were less resistant to bending force compared with those of square cross-section. Also, S shaped files and H-type cross-section were less resistant to failure, compared with those of a triangular cross-sectional shape. Although this was explained by the flexibility and bulk point of view, the contact surface should be considered especially in clinical cases, as some cross-sectional shapes have greater areas of contact than others. It has been found clinically by Gambarini G (2001),Wolcott J *et al.* (1997), Haikel Y *et al.*(1999) that greater the file taper, the greater the contact surface with dentine, and the less resistance to fracture. Recently, the mechanical properties of endodontic files have been mathematically studied using the finite element analysis method by Xu *et al.* (2006). It has been shown that as the area of the inner core of the crosssection increased, the model was more torque-resistant. Berutti *et al.* compared torsional and bending stresses between ProTaper and ProFile rotary systems. They concluded that :

- ProTaper, being stronger and less elastic, may be more appropriate for use in narrow and curved canals during the initial phase of shaping
- The ProFile system, being elastic but not as strong, may be more appropriate for wide and curved canals in the fi nal phase of shaping.

1.6.5 FREQUENCY OF USE

There is no agreement in the literature regarding the number of times of use related to fracture. Seperated enddontic file is a complex multi-factorial clinical problem, thus one cannot expect or recommend how many cases or even canals may be prepared by a file. Parashos P *et al.* (2004) recommended small hand instruments not to be used more than twice.However, even the smallest instruments cannot be used many times without fear of fracture specially where there is visible distortion. Svec T A *et al.* (2002) and Yared *et al* .(1999) found that Profile instruments could be used up to ten times in simulated canals without fracture. In a follow-up study, these instruments were pronounced safe in up to four molars. It is clear that the frequency of use in simulated canals is different compared to that in extracted teeth. A recent clinical study by Wolcotts S *et al.* (2006) has indicated that ProTaper rotary files may be safely reused at least four times. Nevertheless, it is still very diffi cult clinically to recommend a specific number of times of use. Individual canals are not anatomically the same as well as all other factors that infl uence file separation. It is difficult to predict when an instrument will fracture. Consequently, single use has been recommended for absolute safety by Arens F C *et al.* (2003). They examined a total of 786 clinically single used rotary file. Fourteen percent of instruments showed various defects and seven files (0.9 %) fractured. It was concluded that for absolute safety a single-use approach should be followed. However, it was obvious that even with single use, endodontic files still undergo defects. Moreover, files were inspected at X16 magnification, which is not suffi cient to show all microstructural defects that may be observed by SEM. These defects are stress-concentration points at which microcracks can initiate and later propagate resulting in file separation.Peng B *et al.* (2005) and Cheung GSP *et al.* (2005) found that when using SEM to study separated endodontic files, the question of the clinical usability of rotary NiTi files remains unanswered. It is almost that endodontic files fractures not because of how many times they are used, but rather how they are used.

1.6.6 STERILIZATION

It is well accepted that thermo-cycling may result in metal fatigue. However, there is no consensus in the literature regarding the effects of the specifi c type of thermo-cycling during sterilisation of endodontic instruments. Studies conducted by Hilt BR *et al.* (2000), Silvaggio J *et al.* (1997) have shown that sterilisation does not adversely affect endodontic instruments. Although others reported slight or signifi cant adverse effects of sterilisation, it was confirmed that these adverse effects are not of clinical importance. On the other hand, study by Viana AC *et al.* (2006) have reported increased resistance to failure after endodontic files are subjected to sterilisation procedures. However, most studies did not simulate the clinical situation. Thus, the impact of multiple usages of endodontic files should be considered. Nevertheless, it has been recommended that only single use should be opted for endodontic files. This is due to the concern that effective disinfection is not possible with respect to prion disease.

1.6.7 TORQUE

Sattapan B *et al.* (2000) studied and found that during instrumentation, files tip or flutes may engage a portion of the canal smaller than their diameter. Hence, instruments tend to lock or screw into the canal walls and the torque rises rapidly leading the file to be subjected to high levels of stress. The torque generated during instrumentation of small canals is higher than that in large canals.

Also, as the file diameter increases, the torque (force) needed to begin unwinding or to fracture also increases.

It has been stated by Gambarini G. *et al.* (2001) that if the torque reaches a critical level, the instrument undergoes structural failure resulting in separation. When a high torque is used, the instrument is very active and the incidence of instrument locking and consequent deformation and separation tends to increase

Sometimes instruments become less active and the operator may force the instrument into the canal, leading to deformation and separation. With respect to root canal curvature, smaller files fail at less torque, as do files in more acutely curved canal. It has been reported that instruments used with low-torque motors (<1 N/cm) are more resistant to fracture than those results have been reported regarding used with high-torque motors (>3 N/ cm). Therefore, practitioners should use electric motors set at low torque levels during root canal preparation.

1.6.8 SPEED OF ROTATION

Most manufacturers suggest using rotary files at speeds ranging from 150 to 350 rpm. A higher rate of file separation was reported by Li UM *et al.* (2002) when found rotating at high speeds (300-350 rpm). Martin B *et al.* (2003) found that the time for rotary instruments till failure significantly decreases as rotation increases.

On the other hand, Karagoz *et al.* (2003) showed no effect of different rotation speeds on the incidence of rotary file fracture. However, it should be noted that file fracture was considered as a main criterion for failure of instruments.

Different methodologies were used, which may explain the different conclusions reported. However, it is imperative that clinicians always adhere to the speed recommended by the manufacturer for each rotary system and sometimes for each specific file.

1.6.9 MANUFACTURING PROCEDURE

Endodontic instruments may fracture even after a single use. Kuhn G *et al.* (2001) reported the existence of manufacturing defects on the surface of new endodontic instruments. Hence, visual examination before inserting files into canals is required. Cold work and heat treatments are important manufacturing procedures that should be controlled during file manufacture.

Marending M *et al.* (1998) emphasized that the debris of metal origin which causes stress-concentration should be taken into consideration. A high incidence of machining defects on the surface of NiTi files was shown by SEM observations in the study by Alapati S B *et al.* (2005). These defects caused microcrack formation, which in turn propagates during instrumentation and eventually the file failed in fatigue mode. Oxide particles served as nucleating sites for micro-voids, leading to dimpled ruptures.

Consequently, high metallurgical quality of NiTi alloy, to avoid initiating of micro-cracks, and innovative manufacturing strategies are essential. The lifetime of endodontic files may be increased by different procedures.Thompson SA *et al.* (1997) found that the application of thermal treatments (recovery) before machining decreased the work-hardening of the alloy. Electro-polishing was reommended to reduce machining damage on the file surface by Kuhn G *et al.* (2001) and Alapati S B *et al.* (2005). Considerable care is necessary to avoid degrading the cutting efficiency of fluted regions. Nevertheless, a promising approach is the use of ion implantation to modify surface properties of NiTi instruments.

1.6.10 INSTRUMENTATION PROCEDURES

A. Pre-flaring

It is accepted that provision of a glide path should facilitate the work of subsequent instruments which can smoothly clean and shape root canals. Preflaring of root canal with hand files was reported by Berutti E *et al.* (2004) which allowed a significantly greater number of uses of rotary files before fracture occurred.

There are two main advantages when initial manual preflaring is established. Firstly, torsional stress is drastically reduced because the canal width becomes at least equal to the diameter of the tip of the instrument is used. Secondly, preflaring creates an understanding of the root canal anatomy and allows a glide path for the instrument tip.

B. Instrumentation sequence

It is essential that the instrumentation sequence of a specific technique is not neglected. A sequence including various tapers is safer compared to a single taper use. Although it requires a greater number of instruments to prepare canals, each file will undergo less stress and consequently a greater life span. The concept of hybrid instrumentation has been recently introduced. It is believed that a combination of files of different systems and the use of different instrumentation techniques to manage individual clinical situations can reduce the risk of file separation.

1.6.11 IRRIGATION AND IRRIGANTS USED

Lubrication, in general**,** decreases friction between solid objects so few defects occur. In endodontics it is imperative to use files in wet canals to facilitate cleaning and shaping as advocated by Grossman LI(1969).

It is important to stress that most studies have shown different degrees of corrosion on the surface of instruments. These can be considered as weak areas at which further defects, such as microcracks, may be initiated. Clinically, sodium hypochlorite (NaOCl) is one of the most commonly used irrigants and its effect on endodontic files has been widely investigated. The integration of this irrigant with other factors may result in magnitude metal fatigue and later in file separation. A study by Berutti E *et al.* (2006) showed that files immersed in 5.25 % of sodium hypochlorite had significantly less resistance to fracture when they underwent cyclic fatigue.

1.6.12 DENTINAL DEBRIS

The possible effect of dentine chips embedded in the microstructure of failed endodontic instruments should be considered. Alapati S B *et al.* (2004) studied and showed that dentinal debris was wedged mostly in narrow radial, land-type regions and less on the convex flute surfaces of used ProTaper files. For used ProFile instruments, dentinal debris was wedged mostly in the metal rollover and on concave flute surfaces. These dentinal chips can cause concentration of stresses that contributes to the clinical failure of NiTi rotary instruments. It was hypothesised that clinical fracture of nickel-titanium rotary instruments is largely caused by a single overload incident during instrumentation, rather than the result of significant alloy fatigue. Such overloading can be caused by local embedment of dentinal chips in machining grooves.

1.6.13 TYPE OF HANDPIECES

Air-driven and electric handpieces are both currently available for use with rotary nickel-titanium files. As indicated above, usage of electric hand pieces enable clinicians to control the torque applied on endodontic files in individual situations.

1.7 METHODS TO IMPROVE FATIGUE RESISTANCE

Several strategies have been employed to improve the fatigue resistance of NiTi endodontic instruments. These strategies include electropolishing, ion implantation, surface coatings and heat treatment. Ion implantation of NiTi instruments was first introduced by Lee *et al.* (1996), and proved to be an effective method to increase surface hardness and wear resistance, resulting in better cutting efficiency of the rotary instruments. Rapisarda E *et al.*(2000) advocated that Thermal nitridation and nitrogen-ion implantation treatment of NiTi files yielded a higher NiTi ratio and increased cutting ability. Physical vapor deposition was employed by Schafer (2002) increased the fatigue resistance of NiTi instruments and the cutting efficiency of surface-coated NiTi files by 26.2% compared to uncoated instruments. Although these surface treatments have obvious advantages for improving fatigue resistance and cutting efficiency of NiTi rotary instruments, their high costs limit wide usage among manufacturers.

Electropolishing has been used by some manufacturers to improve the surface finish. Studies including Walia *et al.*(1988), Eggert *et al.* (1999), Kuhn *et al.*(2001), Lausmaa *et al.* (2001), Tripi *et al.*(2006) have reported that it is an effective way to increase instrument fatigue resistance by reducing the presence of microcracks and machining damage, which was previously suggested to play a role in instrument stress concentration and crack propagation. However, another study by Cheung GSP *et al.* (2007) found that the low fatigue life of rotary instruments was not affected by the surface electropolishing procedure. Similar results were found in a study by Barbosa *et al.* (2008); there was no effect of electrochemical polishing on the fracture resistance of K3 (SybronEndo) rotary instruments.

The clinically relevant properties of NiTi biomedical alloys depend on the thermomechanical processing history used by the manufacturer.

Previous studies conducted by Miura *et al.*(1986) and Khier *et al.*(1991) on NiTi wires have shown that the effect of heat treatment depends on both temperature range and heating time. For example, the bending properties of superelastic NiTi orthodontic wires are not affected by heat treatment at 400°C, whereas the superelastic behavior would be lost after heat treatment at 600°C. For heat treatment at 500°C, the average superelastic bending moment for NiTi orthodontic wires would be decreased by prolonged heat treatment (for example, 2 hours), compared with minimal effect on the cantilever bending plots for a heat treatment time of 10 minutes.

The effect of heat treatment on the mechanical properties of NiTi rotary instruments was examined by Kuhn *et al.*(2001,2002). Annealing at temperatures around 400°C was found to yield a superior microstructure, resulting in increased instrument flexibility and lower brittleness. However, increased brittleness of instruments was observed after the annealing temperature was increased higher than 600°C. Similar results were reported by Zinelis *et al.* (2007), who found that the fatigue resistance of a commercial rotary NiTi file was steadily increased from the asreceived state with increasing heat treatment temperature to 440°C, and then decreased with further increase in the heat treatment temperature to 550°C. These latter investigators suggested that heat treatment at temperatures higher than 600°C would cause recrystallization of the microstructure, which should be avoided for rotary instruments. Interestingly, decreased surface hardness of the heat-treated instruments was observed, which was attributed to elimination of work hardening. In general, thermomechanical processing seems to be a very promising way to increase the fatigue resistance of NiTi endodontic files. Alapati *et al.*(2006) reported the results from an extensive study of the effects of heat treatment on phase transformations in NiTi rotary instruments. He found that heat treatments at 400°C, 500°C and 600°C raised the A_f B temperature of ProFileB GTP to 45°C – 50°C, however, heat treatment at 850°C caused drastic changes in transformation behaviour, the DSC curves were very complex with irregular peaks. He suggested that high temperature induced the change in NiTi file microstructure. Similar results were found in studies by other investigators, who suggested that heat treatment at temperatures higher than 600°C would cause recrystallization of the microstructure, which should be avoided for rotary instruments.

CHAPTER-2

REVIEW OF LITERATURE

Ingle JI (1961) found that the endodontic instruments were manufactured from straight metal blanks and this led to uneven force distribution in areas where the file contacted the root canal wall in the cases of curved root canals. The instrument itself had a tendency to straighten itself in the canal. This resulted in a wider canal shapes to compensate for the presence of the curves.

Schilder H (1967) reviewed the various obturation techniques and their advantages as well as disadvantages. He advocated that vertical condensation of warm gutta percha produced consistently dense , three dimensionally stable root canal filling as compared to the lateral condensation obturation technique.

Grossman LI (1969) found that stainless steel reamers and files were preferable to carbon steel instruments because while they bent under excessive torque, they had minimal chance of breakage. He emphasized that the root canal instruments must be examined both before and after use to make sure that the blades are regularly aligned. Too little or too much space between the blades indicated that the instrument has been under strain and may break any moment. It was also observed that the smaller sizes of reamers and files (Nos. 10 to 30) should not be used more than twice (that is, instrumentation for more than two root canals). Dull instruments gets clogged by debris and instead of cutting it promoted the chance of breakage. The instruments should be used in sequence of sizes, without ever skipping a size because of the slight difference in diameter between a reamer or a file there occurred a stepwise increments in width that led to breakage of instruments. It has postulated that all the root canal instruments should be used in a wet canal, preferably one which has been flooded with sodium hypochlorite, to facilitate cutting and thereby prevent its breakage. In the cases where an instrument has been broken in the root canal, the prognosis was found more favorable if an area of rarefaction was not present at the time of the accident.

Schneider SW (1971) conducted an *in-vitro* study on twenty nine human single rooted permanent teeth to determine the frequency with which round root canal preparations could be produced using hand files and the degree of root curvature. The root canals were classified on the basis of degree of root curvature into three groups: straight, moderate, and severe. The canals were enlarged by hand instrumentation. Cross sections were made at 1 and 5 mm. from the apical foramen. The specimens were then evaluated under a dissecting microscope to determine whether the preparations were round or irregular. They concluded that round preparation were obtained 51% of the time at the 1 mm level, as compared to 17% at the 5 mm level.

Schilder H (1974) observed that canal systems have multiple geometric planes and curve significantly more than the roots that house them. Alone two-dimensional radiographs may not reveal these morphological variations of canals in spatial planes. It was also found that initially, instrumentation was aimed at facilitating the placement of medicaments in the root canal with little attempt to remove the organic contents from the root canal system. They proposed serial instrumentation involving using multiple series of hand files and reamers in a curved canal. Later the focus of instrumentation shifted to preparing the root canal space to facilitate the placement of root canal fillings but the methods employed were mostly unrelated to Ingle's anatomy of the canal system or the properties of the obturation materials.

Mullaney TP (1979) emphasized that no single method of enlargement of root canal is better than another in finely curved canals. Also no single filling material is better than another but rather all materials and methods should be considered when endodontic therapy is performed. It was concluded that the step-back method enlargement technique was probably the best technique for enlarging finely curved canals, provided careful procedures of instrumentation and cleansing are followed.

Goerig AC, Michelich RJ, Schultz HH (1982) laid down and advocated the concept of crown down technique. Crown-down technique commenced preparation with the use of larger instruments at the canal orifice and then proceeding down the root canal with progressively smaller files. This technique utilised rotary instrumentation.

Roane JB, Sabala CL, Duncanson MG (1985) advocated the "balanced force concept," to overcome the curved canal during instrumentation. The concept used force magnitude in order to create control over undesirable cutting associated with canal curvature. Rotation was promoted as the means for maintaining magnitude as a control and counter clockwise direction of rotation provided finite operator control. Diagrammatic evaluations, mathematical calculations, bending moments, test canals, sectioned teeth, and clinical radiographs were presented to document each step of the concept. The concept came with the introduction of a new K-type file design.

Dederich DN and Zakariasen KL (1986) analyzed the effects of cyclical axial motion on instrument failure by testing endodontic files, sizes 15 to 45, with and without cyclical axial motion. A thick-walled Pyrex capillary tube with a 1 mm diameter lumen was heated and bent to a curvature representative of a moderately curved root canal. The tips of eighteen new instruments of each size (126 files in all) were carefully ground under a light microscope to eliminate the cutting edges on the apical tips of the files. This was intended to minimize abrasion of the lumen of the capillary tube, thus maintaining a consistently shaped curvature throughout testing as well as eliminating axial torqueing of the instruments, which could occur if the instruments' cutting edges were to engage any abraded areas. The capillary tube was mounted on a adjustable miniature lathe, and its lumen was filled with lubricating oil. The oil was used to minimize friction and to mimic the heat-sinking properties of sodium hypochlorite on the flexing file in vivo. Nine files of each size were mounted on the lathe and turned at 1650 rpm in the lumen of the capillary tube until failure occurred. The depth of penetration into the lumen was such that a moderate curve of the file was obtained. This curvature was kept consistent throughout the study. The break time was recorded, and the oil was replaced for each instrument. The experiment was then repeated for nine new files of each size with cyclical axial motion. The capillary tube was moved in a cyclical axial motion of 2 mm/second for 8 mm coronally and then 8 mm apically on the calibrated movable stage of the lathe for the duration of the run. It was concluded that the cyclical axial motion could significantly extend the life span of rotary engine files. Furthermore, there appeared a trend toward for an instrument life span that was inversely proportional to instrument size.

Mayhew MJ and Kusy RP (1988) studied the effects of sterilization on the mechanical properties and the surface topography using 0.017 x 0.025-inch Nitinol and Titanal wires. Three approved heat sterilization methods were used dry heat, formaldehyde-alcohol vapor, and steam autoclave. Elastic moduli were obtained on 1-inch segments in 3-point bending. Laser scans of flatwise wire surfaces were conducted to detect surface alterations whether caused by tarnish, corrosion, or pitting. Tensile properties were determined on 7-inch lengths: the 0.1% yield strength, the ultimate tensile strength, and the percent elongation at break. The results showed that no detrimental changes were observed for either the selected mechanical properties or the surface topography. When the mean values of the two products were compared, Nitinol was less compliant but stronger than Titanal. Laser spectroscopy showed that Titanal possessed at least three times more specular reflectivity than Nitinol.

Walia H, Brantley WA and Gerstein H. (1988) conducted a study evaluating the NiTiNOL files properties. Root canal files in size #15 and triagular cross-sections were fabricated from 0.020-inch diameter arch wires of Nitinol, a nickel-titanium orthodontic alloy with a very low modulus of elasticity. A unique manufacturing process was used in which the fluted structure of a K-type file was machined directly on the starting wire blanks. 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 manufactured by the same process. The fracture surfaces for clockwise and counterclockwise torsion were observed with the scanning electron microscope and exhibited a largely flat morphology for files of both alloy types and torsional testing modes. It was possible to permanently precurve the Nitinol files in the manner often used by clinicians with stainless steel files. These results suggest that the Nitinol files may be promising for the instrumentation of curved canals, and evaluations of mechanical properties and in vitro cutting efficiency are in progress for size #35 instruments.

Wildey WL, Senia ES, Montgomery S (1992) postulated various factors that must be considered in an analysis of instrumentation of the root canal system. The factors included the quality of dentin that was cut; the technique used to cut it; the design of the instruments; the material and manufacturing process used to make the instruments; the irrigant used during the procedure; and the anatomic configuration of the root canal system. An analysis of these factors clearly indicated that existing root canal instruments and techniques were less than ideal and, in fact, do not accomplished what is expected of them. The Flex-R and Canal Master instruments were developed to address some of the shortcomings of previously existing instruments and techniques.

Kapila S, Haugen JN, Watanabe LG (1992) investigation determined the effects of in vivo recycling interposed by dry heat sterilization (together referred to as clinical recycling, CR) on the load-deflection characteristics of nickel-titanium alloy wires. To differentiate the effects of dry heat sterilization (DHS) from those of CR on the behavior of these wires, a series of wires were also subjected to DHS only.

Two types of nickel-titanium wires, namely Nitinol and NiTi were subjected to a three-point bending test in an as-received condition (T_0), after one cycle (T_1), and two cycles (T_2) of DHS or CR. Ten wires comprised each subsample. Both DHS alone, as well as CR, produced significant changes in the loading and unloading characteristics of Nitinol and NiTi wires. It was observed that the force levels during loading and unloading were substantially increased for both types of wires after CR. Most of these changes in load-deflection characteristics occurred between T_0 and T_1. They concluded that, clinical recycling appears to reduce the "pseudoplasticity" and "pseudoelasticity" of NiTi wires and increases the stiffness of both NiTi and Nitinol wires. (Load-deflection characteristics of nickel-titanium alloy wires after clinical recycling and dry heat sterilization.

Camps JJ, Pertot WJ, Levallois B. (1995) evaluated the relationship existing between file size and stiffness for three endodontic files made of Nickel Titanium Alloy. The three group of instrument tested were of different cross section which were triangular, square and modified triangular cross sections. There was a statistically significant difference between three groups tested. The results showed that the square cross section file presented a larger bending moment than triangular cross section file, followed by modified triangular cross section file.

Ennio B, Enzo S, Principi G, Schiffini L (1996) evaluated the number of revolutions till separation and maximum torque at failure of NiTi Light Speed intruments. Two hundred and sixteen Lightspeed NiTi instruments were evaluated microscopically for the presence of corrosion, surface debris, and alloy defects. The instruments were assessed morphometrically for consistency of physical design and dimensions by measuring and analyzing eight parameters of the instrument pilot tips, heads, and shafts. Results from visual inspection showed that none of the instruments were corroded; 23 presented surface porosities, and 17 had sharp strips of alloy. Data obtained by morphometric analysis indicated the mean diameter of the head of only 7 of 18 sizes met the +/- 0.02 mm allowable tolerance set forth by the American Dental Association (ADA) Specification No. 28. Observation analysis indicated that instruments of the same size adhere to the same basic design, but morphometric variations did existed. The Scanning Electron microscopy of the fractured instrument showed two distinct areas. There was a striated concentric area in the periphery of the fracture site characteristic of a brittle or cleavage fracture and a corrugated area in the centre of the fractured site which was a characteristic of ductile fracture.

Pruett JP, Clement DJ, Carnes DL (1997) evaluated the cyclic fatigue of nickel-titanium, engine-driven instruments by determining the effect of canal curvature and operating speed on the breakage of that NiTi rotary instrument. Also a new method of canal curvature evaluation that addressed both angle and abruptness of curvature was introduced. In their study, canal curvature was simulated using curved stainless-steel guide tubes with angles of curvature of 30, 45, or 60 degrees and radii of curvature of 2 and 5 mm. Instruments were able to rotate freely in the test apparatus at speeds of 750, 1300, or 2000 rpm until separation occurred. Number of cycles till failure were determined. Cycles to failure were not affected by rpm. Instruments did not separate at the head, but rather at the point of maximum flexure of the shaft, corresponding to the midpoint of curvature within the guide tube. The instruments with larger diameter shafts, #40, failed after significantly fewer cycles than did #30 instruments under identical test conditions. Multivariable analysis of variance indicated that cycles to failure significantly decreased as the radius of curvature decreased from 5 mm to 2 mm and as the angle of curvature increased greater than 30 degrees ($p < 0.05$, power = 0.9). The results found showed that, for nickel-titanium, engine-driven rotary instruments, the radius of curvature, angle of curvature and instrument size are more important than operating speed for predicting separation. The results suggested that the effect of the radius of curvature as an independent variable should be considered when evaluating the cyclic fatigue resistance.

Schafer E. (1997) subdivided root canal instruments on the basis of different alloys used for manufacturing (stainless steel, nickel-titanium and nickel-aluminium) and different geometric forms (e. g., instruments with short cutting segments). In summary, flexible stainless steel instruments with noncutting tips seem to be a decisive improvement in the development of an ideal root canal instrument. They are superior to titanium-based instruments in both cutting efficiency and instrumentation of curved root canals.

Zuolo ML and Walton RE (1997) stated that nickel-titanium instruments allegedly resist deformation and loss of sharpness better than do stainless steel instruments but may be more susceptible to breakage. The processes of wear and breakage of nickel-titanium and stainless steel instruments were examined. Sixty files of five types (12 each) and three manufacturers were used. All were used repeatedly in curved canals until failure or for a maximum of 22 minutes. Each instrument was examined with scanning electron microscopy both new (control) and at spaced intervals for evidence of wear and fatigue. All new instruments were of good quality. Stainless steel instrument tended to wear the most rapidly, and next were nickel-titanium rotary instruments; the most resistant to wear were nickel-titanium hand instruments. There were few instrument separations. In general, nickel-titanium (particularly hand) instruments resisted deterioration better than did stainless steel. Nickel-titanium rotary instruments (2 of 12) had the most breakage.

Busslinger A, Sener B, Barbakow F (1998) investigated the effect of sodium hypochlorite used as irrigant on NiTi instrumentes. They evaluated corrosion effect on NiTi LightSpeed instruments using 1% and 5% sodium hypochlorite as irrigant during shaping and cleaning of canal. The instruments were immersed in ultrasonicated sodium hypochlorite solution for varying times up to 1 hour. Corrosion was determined by electrothermal absorption spectrometry in 100 μL aliquots of sodium hypochlorite solution. Background contamination of nickel in the 1% and 5% sodium hypochlorite solution used was low, but high enough to interfere in detecting any increases in nickel after immersing the instruments. The amounts of titanium recorded in the 1% sodium hypochlorite solution was insignificant. However, a statistically significant amount of titanium was detected from the Lightspeed instruments after immersion times of 30 and 60 minutes in 5% sodium hypochlorite solution. Clinically such instruments do not have an 'in situ' time of 30 min, and this corrosion may be considered irrelevant.

Baumann MA and Roth A (1999) compared inexperienced third year dental students and experienced dentists with respect to their ability to use rotary NiTi files specifically with respect to root canal shape and instrument fracture. A total 102 simulated endodontic plastic blocks were used. Twelve untrained dental students and

12 practitioners prepared 3 blocks each, and an endodontist and a trained student completed 15 blocks each. Before preparation images and after preparation images were then superimposed. The results showed 16 out of 170 blocks had undergone instrument fracture (9.4%). [OOO 1999 december vol.88 (6):pg 714-18].

Haikel Y, Serfaty R, Bateman G, Senger B, Allemann C. (1999) investigated the cyclic fatigue life of NiTi endodontic instruments (Profile, Hero and Quantec) and assessed the times for dynamic fracture in relation to the radius of curvature to which the instruments were subjected during preparation, with the instrument diameter determined by size and taper and the mode by which the fracture occurred. From 600 instruments, Ten instruments were randomly selected representing each size and taper for each group and for each radius of curvature. The instruments were rotated at 350 rpm and introduced into a tempered steel curve that simulated a canal. Two radii of curvature 5 mm and 10 mm of simulated canals were used. Time at fracture was noted for all files and the fracture faces of each file were analysed with scanning electron microscopy. Radius of curvature was found to be the most significant factor in determining the fatigue resistance of the files. As radius of curvature decreased, fracture time decreased. Taper of files was found to be significant in determining fracture time. As diameter increased, fracture time decreased. In all cases, fracture was found to be of a ductile nature, thus implicating cyclic fatigue as a major cause of failure and necessitating further analyses and setting of standards in this area.

Boardman B (2000) evaluated the effect of multiple cycles of sterilization on endodontic stainless-steel and nickel-titanium files on fatigue resistance of the file.

One hundred stainless-steel and one hundred nickel-titanium #30 K-type files were chosen and divided into 20 groups comprising of 10 files. They were sterilized in increments of 10 cycles, using a full cycle and a fast cycle autoclave. These files were tested by twisting each of them in a clockwise direction until fracture (torque g-cm). Samples of the fractured files were embedded in an epoxy resin and polished for Knoop hardness tests. In addition, the samples were chemically etched to reveal changes in microstructure. The results of this study indicated that neither the number of sterilization cycles nor the type of autoclave sterilization used affected the torsional properties, hardness, and microstructure of stainless-steel and nickel-titanium files.

Sattapan B, Nervo GJ, Palamara JEA, Messer HH (2000) analysed the type and frequency of defects in nickel-titanium rotary endodontic files after routine clinical use. All of the files (total: 378, Quantec Series 2000) discarded after normal use from a specialist endodontic practice over 6 months were analyzed. The files were discarded because of perceived decrease in cutting efficiency. Almost 50% of the files showed some visible defect; 21% were fractured and 28% showed other defects without fracture. Fractured files could be divided into two groups according to the characteristics of the defects observed. Torsional fracture occurred in 55.7% of all fractured files whereas flexural fatigue occurred in 44.3%. The results indicated that flexural failure, could be caused due to file overuse. The factors important for governing flexural fatigue behaviour were radius of curvature of the canal, angle of curvature and the instrument size to be used in the canal.

Daniel Y (2000) evaluated Nickel titanium rotary files of 0.04 taper for breakage at different rotational speeds in semicircular bovine bone simulated root canals of identical size and radius. The bovine bone simulated root canals had a radius of curvature of 5 mm and a canal width equivalent to the D1 diameter of the file plus 0.04 mm. Endodontic Rotary Profile instrument #3, #4, and #5 were tested at 150, 250, and 350 rpm. A contra-angle electric handpiece was mounted on an Instron machine that was set to deliver a constant downward speed of 5 mm/min. The electric handpiece and Instron machine were activated until the files broke. The amount of file tip penetration into the semicircular bovine bone canal was measured in degrees with a protractor from a radiographic image taken of the file inside the bone model. Greater degrees of tip penetration indicated greater resistance to breakage. The results found indicated that there was a significant difference for all file sizes in the extent of file tip penetration before breakage. In the rotation range between 150 and 350 rpm the greatest extent of penetration occurred at 150 rpm. The study concluded that 0.04 taper nickel-titanium rotary file breakage was minimal when the files were rotated at lower speed.

Rapisarda E, bonaccorso A, Tripi TR, Fragak I, Condorelli GG. (2000) observed the effect of nitridation treatment of the cutting surfaces on wear resistance of NiTi endodontic files. Total 30 NiTi rotary files (15 ProFiles 0.06 taper and 15 Profiles 0.04 taper) were selected for the study. The instruments were divided into 3 groups of 10 instruments each; each group included 5 instruments of each type mentioned. First group files were exposed to ionic implantation by using 150 keV of nitrogen ions and doses of 1 × 1017 ions per cm^2. Second group files were exposed to thermal nitridation processes performed for 480 minutes at 500°C temperature.

Third or Control group files were not exposed to any process. The chemical composition of the surface layers of each sample was determined by means of x-ray photoelectron spectroscopy. The cutting efficiency was tested on an endotraining bloc. The experimental instruments showed in-depth distributions of chemical composition that were different from those seen in the control group. The thermal-nitridated instruments demonstrated a surface ratio of nickel to titanium of 0.5. Implanted samples had a higher Ni/Ti ratio (1.2). This ratio was due to the presence of a layer of titanium nitride. Samples in the experimental groups showed an increase in cutting ability as compared with the controls. It was concluded that the thermal nitridation and nitrogen-ionic implantation treatment of nickel-titanium files produced a higher wear resistance and an increased cutting capacity.

Thompson SA (2000) reviewed the nickel titanium alloys. It has been shown that Nitinol has been used in the manufacture of endodontic instruments in recent years. Nitinol alloys possessed greater strength and a lower modulus of elasticity as compared to stainless steel alloys. It was told that the super elastic behaviour of Nitinol wires mean that on unloading they returned to their original shape following deformation. These properties were of interest in the field of Endodontology as they allowed construction of root canal instruments that utilized these favourable characteristics to provide an advantage when preparing curved canals. This review aimed to provide an overview of Nitinol alloys used in dentistry in order for its unique characteristics to be appreciated. The review attempted to highlight the various uses of NiTi alloy in dentistry and previous research findings that had relevance to endodontology. It was observed that NiTi root canal instruments were more flexible than stainless steel files and had the ability to prepare canals quickly and without undue aberrations. There are important considerations such as their increased cost, the potential decrease in cutting ability due to wear and the ability to machine instruments with various designs and dimensions to a consistent size. These issues needed attention of clinician so that the Endodontist can embrace the use of instruments constructed from this new alloy with confidence. Clearly, the effects of sterilization and corrosion during clinical use on NiTi alloys were appreciated. A further need for examination together with the enhancement of the files hardness by ion implantation method was suggested.

Turpin YL, Tallec A, Le Menn AC (2000) compared the torsional and bending behaviours of two cross sections bearing endodontic instruments commonly encountered during routine clinical endodontic procedures, a triple U and triple helix design. The result of this study found that under working conditions, the stress generated in case of triple helix instruments were much distributed as compared to triple U design instruments. This led to low fatigue resistance of Triple U instruments as compared to triple helix instruments.

Yared GM, Dagher FEB, Machtou P (2000) evaluated cyclic fatigue of .06 ProFile Ni-Ti rotary instruments after clinical use in molar teeth. In group 1, instruments size 40–15 were used in a crown-down technique using 2.5% NaOCl as an irrigant. Fifty-two molars were included and 13 sets of Profile Ni-Ti rotary instruments were used. Each set of instruments was used in four molars, and was steam autoclaved before each use. Group 2 (10 sets of new ProFile Ni-Ti rotary instruments) was the control group. Cyclic fatigue was tested by rotating the instruments in a 908 metallic tube until they broke. One-way analysis of variance did not show any statistically significant differences amongst the files from both groups regarding cyclic fatigue. They concluded that sterilization and clinical use in the presence of sodium hypochlorite did not led to decrease in the number of rotations to breakage of the files.

Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P (2001) reviewed the various NiTi rotary file systems in terms of their rationale, performance and safety status. The file systems studied were GT Rotary file, Hero 642, K3, Light speed, McXIM/NT files, Mity Roto 360°, Naviflex, ProFile, ProTaper, Quantec. They suggested that to improve NiTinol instruments via the boron or nitrogen implantation method that in turn effected bulk mechanical properties of NiTi file system. The article also mentioned about the negative effects of sterilization on NiTi files. It was shown that repeated cycles of sterilization under autoclave decreases the cutting efficiency by altering the superficial structure of Niti files. It was found that the phenomenon of repeated cyclic metal fatigue was the most important factor in instrument separation. When instruments were placed in curved canals, they deformed and stress occured within the instrument. The half of the instrument shaft on the outside of the curve was in tension and the half on the inside was in compression. Consequently, each rotation caused the instrument to undergo one complete tension-compression cycle. The stress levels were the greatest in the area of curvature. More severe bends created greater stress and larger and stiffer instruments experienced greater stress than smaller instruments when confined to the same curved canal shape. It was emphasized that considering cycle fatigue as a contributor to instrument fatigue followed by failure or fracture, the larger instruments were not considered safer or stronger during clinical usage. Moreover, it was shown that NiTi alloy due to its wide range of elastic deformation could be strained much further than stainless steel files before it gets permanently deformed. Resistance to fracture was lower for the NiTi instruments. The phase changes along with the stress-induced transformation was slow thermoelastic or burst type of martensite. During the crystal changes, the instrument was very prone to fracture. This was of special concern when used for rotary instruments. Upon rotation, abruptly changed stress levels caused movement of dislocation defects and break anatomic bonds within the matrix, leading to crack initiation and propagation.The article also mentioned that the direction of use of instrument should be considered when instrument separate during rotation. Both the stainless steel and NiTi files demonstrated greater rotation to failure in the clockwise direction than in the counter-clockwise direction for the same file size chosen. The reason postulated was that during clockwise rotation, the cutting spirals unravel. After a while, the outer portion of these spirals began to experience longitudinal compression as the twist direction started to reverse. After the spirals had reversed direction, tension was created leading to the tightening of the winding and finally file fracture occurred.

Gambarini G. (2001) investigated the cyclic fatigue resistance of used nickel-titanium rotary instruments clinically operated by a traditional high-torque motor and a new low-torque electric motor. Fifty NiTi rotary instruments (ProFile) each of the following sizes were used: .06-25, .06-20, and .04-25. They were divided into three groups: A = 10 new instruments (control), B = 20 used instruments operated by a high-torque motor, and C = 20 used instruments operated by a low-torque motor. Each instrument was used in 10 clinical cases (at least six molars). Cyclic fatigue testing of new and used instruments was performed with a device that allowed the instruments to rotate freely inside a stainless-steel artificial canal at 350 rpm. The results showed that group A instruments exhibited significantly higher values of rotation-to-breakage cycles when compared with groups B and C, respectively. Statistically higher resistance to cyclic fatigue was noted for group C in all sizes compared with group B showing that the use of endodontic motor with lower torque values reduced cyclic fatigue of nickel-titanium rotary instruments.

Kuttler S, Garala M, Perez R, Dorn SO (2001) extensively redesigned muffle system is presented incorporating improved design features, i.e. endodontic cube which is a rigid external fixation and machined internal indexing to enable a more accurate, clinically relevant, and reproducible evaluation of root canal anatomy before and after preparation. Given the ability to directly observe and quantify changes in the root canal system, the information obtained using this design is comprehensive. In each tooth pre-treatment evaluation provides the ideal control, reinforcing the suitability of this technique.

Revathi M Rao CVN and Lakshminarayanan L (2001) discussed the behavioural properties of NiTi files made up from NiTi alloy and its mode of application. The article discussed the metallurgy of NiTi alloy, the parameters affecting the cyclic fatigue resistance, importance of speed and torque during cleaning and shaping procedure and role of endodontic handpiece during preparation. It was concluded that the angle of curvature and radius of curvature were the two most important factors affecting cyclic fatigue resistance of a NiTi file. It was observed that as the radius of curvature decreases the instrument stress and strain increases and the fatigue life decreases which contributes to instrument breakage in clinical situations. It was emphasized that a low speed torque controlled endodontic handpiece and motor used during canal preparation was better in terms of reducing instrument fracture during canal preparation which further lead to safe and successful treatment.

TR Tripi, Bonaccorso A, Tripi V, Condorelli GG, Rapisarda E (2001) evaluated defects if NiTi rotary instruments before and after usage in extracted Mandibular molar teeth. The GT Rotary NiTi rotary instrument was fixed into a custom made holde and photographed in a scanning Electron microscope at x260 to x 12000 magnification at preset points. Instrument tested were 5 GT Rotary files of size 35 (1.2 taper), size 20 (1.0 taper, 0.8 taper & 0.6 taper) each. They were used in 12 root canals. The used instruments were cleaned and re-examined in SEM as done preoperatively. The defects included microfracture, complete file fracture, metal stripping, pitting, disruption of cutting edge, fretting, plastic deformation, craters, Debris and blunt edges. The results showed no sign of complete instrument fracture or plastic deformation during the test. Metal strips were noticed even before file usage and was most prevalent defect identified. Imperfections observed on files were defects like pitting, scrapping and blunt cutting edges.

Yared GM, BouDagher FF, Machtou P. (2001) evaluated the influence of rotational speed, torque, and operator experience with a specific Ni–Ti rotary instrumentation technique on the incidence of locking, deformation and separation of instruments. Profile NiTi rotary instruments size 15 to 40 6% taper were used in a crown-down technique. In one group of canals (*n*= 300) speeds of 150, 250 and 350 rpm (subgroups 1, 2 and 3) were used. Each one of the subgroups included 100 canals. In a second group (*n*= 300) torque was set at 20, 30 and 55 Ncm (subgroups 4, 5 and 6). In the third group (*n*= 300) three operators with varying experience (subgroups 7, 8 and 9) were also compared. Each subgroup included the use of 10 sets of Profile NiTi rotary Instrument and 100 canals of extracted human molars. Each set of Profile NiTi rotary Instrument was used in upto 10 canals and then sterilized before each case. Sodium Hypochlorite 2.5% was used as an irrigant. The number of locked, deformed, and separated instruments or the different groups, and within each part of the study was analysed statistically for significance with chi-squared tests. In group 1 only one instrument was deformed in the 150-rpm group and no instruments separated or locked. In the 250-rpm group instrument separation did not occur. However, a high incidence of locking, deformation and separation was noted in the 350-rpm group. In general, instrument sizes 30–15 locked, deformed and separated. Overall, there was a trend toward a higher incidence of instrument deformation and separation in smaller instruments. Locking and separation occurred during the final passage of the instruments, in the last (tenth) canal in each subgroup. In the second group, neither separation nor deformation and locking occurred during the use of the ProFile instruments, at 150 rpm, and at the different torque values. In the third group, chi-squared analysis demonstrated that significantly more instruments separated with the least experienced operator.Instrument locking, deformation, and separation did not occur with the most experienced operator. Preclinical training in the use of the PRI technique with crown-down at 150 rpm were crucial in avoiding instrument separation and reducing the incidence of instrument locking and deformation.

Dartar MO, akman A, Zaimoglu L, Bilgic S. (2002) evaluated and compared the corrosion rates of the stainless-steel endodontic files when immersed in 0.2% chlorhexidine gluconate, 5.25% NaOCl, chlorinated soda with KOH and 17% EDTA irrigating solutions. Corrosion rates of stainless-steel K-files in irrigating solutions were determined electrochemically by the Tafel extrapolation method. The cutting flutes of files were immersed in solutions and used as an electrode. A saturated calomel electrode (SCE) was used as a reference, and a platinum plate was used as a counter electrode. In order to determine corrosion rates, the linear part of anodic currents obtained from electrochemical current-potential curves, was extrapolated to corrosion potentials. The results showed that the corrosion rates of stainless-steel files in the tested solutions from the highest to the lowest were 0.2% chlorhexidine gluconate > 5.25% NaOCl > chlorinated soda with KOH > 17% EDTA. It was concluded that 0.2% chlorhexidine gluconate, 5.25% NaOCl and chlorinated soda with KOH causes severe corrosion on the surface of selected stainless-steel files.

Yared GM, BouDagher FF, Machtou P, Kulkarni GK (2002) evaluated the influence of rotational speed, torque, and operator experience on the incidence of locking, deformation, and separation of instruments when using a specific Ni–Ti rotary instrumentation technique in extracted human teeth. Greater Taper Ni–Ti rotary instruments were used in a crown-down technique. In one group (rotational speed evaluation) of canals (n=300) speeds of 150, 250 and 350 rpm (subgroups 1, 2 and 3) were used. Each one of the subgroups included 100 canals. In a second group (evaluation of torque) (n=300) torque was set at 20, 30 and 55 Ncm subgroups 4, 5 and 6). In the third group (evaluation of operator proficiency) (n=300) three operators with varying experience (subgroups 7, 8 and 9) were also compared. Each subgroup included the use of 10 sets of GT rotary instruments and 100 canals of extracted human molars. Each set of instruments was used in up to 10 canals and sterilized before each case. Sodium hypochlorite 2.5% was used as an irrigant. The number of locked, deformed, and separated instruments was recorded for each group. When the influence of rotational speed was evaluated, instrument deformation and separation did not occur in subgroups 1 (150 rpm), 2 (250 rpm) and 3 (350 rpm). Instrument locking occurred in subgroup 3 only. In torque evaluation, neither separation, deformation nor locking occurred during the use of the instruments, at 150 rpm, and at the different torque values. When the operators were compared, although two instruments were separated in canals prepared by the least experienced operator, Instrument locking, deformation, and separation did not occur with the most experienced operator. None of the instruments separated with the trained operator.

Li UM, Lee BS, Shih CT, Lan WH, Lin CP (2002) evaluated the cyclic fatigue of 0.04 ProFile nickel titanium rotary instruments operating at different rotational speeds and varied distances of pecking motion in metal blocks that simulated curved canals. A total of 150 ProFile instruments were made to rotate freely in sloped metal blocks at speeds of 200, 300, or 400 rpm by a contra-angle handpiece mounted on an Instron machine. The electric motor and Instron machine were activated until the instruments were broken in two different modes, static and dynamic pecking-motion. The fractured surfaces of separated instruments were examined under a scanning electron microscope. The results demonstrated that the time to failure significantly decreased as the angles of curvature or the rotational speeds increased. However, as pecking distances increased, the time to failure increased. This was because a longer pecking distance gave the instrument a longer time interval before it once again passes through the highest stress area. Microscopic evaluation indicated that ductile fracture was the major cyclic failure mode. To prevent breakage of a NiTi rotary instrument, appropriate rotational speeds and continuous pecking motion in the root canals were recommended.

Arens FC, Hoen MM, Steiman HR, Dietz GC (2003) analyzed the number and types of defects observed in single-use of rotary nickel-titanium instruments. Every ProFile Series 29.04 taper nickel-titanium instrument used during a 4-week period in an endodontic specialty practice was collected. All instruments were new and were used by experienced clinicians during a single patient visit. The instruments were routinely used in a crown-down manner with RC Prep lubrication and copious irrigation. The instruments were used in a MicroMega 324 air motor in a 6:1 gear reduction contra-angle at 333 rpm. The instruments were collected, ultrasonically cleaned, sterilized, and inspected at x16 magnification. Torsional, flexural, and fracture defects were recorded. A total of 786 ProFile Series 29 nickel-titanium rotary instruments were evaluated out of which 115 (14.63%) showed some type of defect after one clinical use. Size 3 instruments had the highest defect rate (22.66%) followed by size 5 (17.30%), size 2 (17.24%), and size 4 instruments (16.10%). The size 6 and size 7 instruments showed minimal defects (2.38% and 4.76%, respectfully). Seven of 786 files had fractured (0.891%). There was no statistically significant difference in the type of failure seen within each file size. It was concluded that defects can occur even with new files in the hands of experienced endodontist and for an absolute safety a single-use approach should be followed.

Hulsmann M, Herbst U, Schafers F (2003) compared several parameters of root canal preparation using two different rotary nickel titanium file systems FlexMaster and HERO 642. Fifty extracted human mandibular molars with root canal curvatures between 20 and 408 were embedded into a muffle system. All root canals were prepared to size 45 using a high-torque motor with FlexMaster and HERO 642 file systems. Irrigation was performed with 2 mL of 3% NaOCl after each instrument size. The following parameters were evaluated: straightening of curved root canals, postoperative root canal diameter, working safety (file fractures, perforations, apical blockages, loss of working length), cleaning ability and working time. It was found that Both NiTi systems maintained the curvature well. One file was fractured with the FlexMaster system, but further procedural incidents were not recorded. HERO 642 preparations resulted in a round diameter in 25%, oval shape in 47% and irregular cross-sections in 28% of the cases. Mean working time was shorter for HERO 642 (66.0 s) than for FlexMaster (71.1 s). Both systems respected original root canal curvature well and were safe.

O Hoy PYZ, Messer HH, Palermara JEA (2003) evaluated the effect of repeated cleaning procedures on fracture properties and corrosion of NiTi files. New NiTi files were subjected to 2,5 and 10 cleaning cycles with the use of either diluted bleach as disinfectant. Each cleaning cycle consisted of scrubing, rinsing and immersing in sodium hypochlorite for 10 minutes followed by 5 minutes of ultrasonication. Files were then tested for torsional failure and flexural fatigue and observed for evidence of corrosion using SEM. Four brands of NiTi files were immersed in either Milton’s solution or diluted bleach overnight and evaluated for corrosion. Upto 10 cleaning cycles did not significantly reduce the torque at the fracture or number of revolutions to flexural fatigue. Although decreasing values were found with increasing number of cleaning cycles using Milton's Solution. Files immersed in sodium hypochlorite solution overnight displayed corrosion.

Peters OA, Peters CI, Schonenberger K, Barakow F (2003) investigated physical parameters for ProTaper NiTi rotary instruments whilst preparing curved canals in maxillary molars in vitro. A novel torque-testing platform was used to prepare root canals in 15 extracted human maxillary molars with ProTaper rotary instruments. Peak torque and force was registered along with numbers of rotations required to shape the canals. Canals were divided into 'wide' and 'constricted' groups depending on canal volumes assessed by micro computed tomography. Mean scores for each instrument type were calculated. Mean torque varied between 0.8 -0.5 and 2.2 -1.4 N cm whilst mean force ranged from 4.6 -2.6 to 6.2- 2.7 N. Mean numbers of rotations totalled up to 21. It was concluded that no ProTaper instrument fractured when a patent glide path was present. There were significant positive correlations between canal geometry and physical parameters during shaping.

Yun HH and Kim SK (2003) compared the root canal shaping abilities of 4 nickel-titanium rotary instruments ProFile, GT Rotary, Quantec, and ProTaper. The files were used to instrument 48 simulated curved root canals in plastic blocks with the crown-down technique. One operator prepared all the canals until reaching an apical canal size of #30. The instrumentation time, changes of canal dimension and curvature, canal aberration, and instrument deformation were evaluated. It was found that the ProTaper took significantly less instrumentation time, removed more canal wall (especially at the inner side of the canal curve), lessened the canal curvature, and induced more instrument deformation than did the other instruments tested. It was concluded that although ProTaper files cut more canal wall more quickly than the other instruments in the curved canal, they were also the instruments that most frequently became deformed.

Martín B, Zelada G, Varela P, Bahillo JG, Magán F, Ahn S, Rodríguez C (2003) evaluated the effect of rotational speed and the angle and radius of curvature of root canals on the fracture of two types of nickel-titanium rotary instruments: K3 and ProTaper. A total of 240 root canals of extracted human maxillary and mandibular molars were divided into two groups of 120, according to the angle of the canal curvature (group A: <30 degrees, group B: >30 degrees). Each group was then divided into two subgroups of 60 canals in order to perform instrumentation using K3 and ProTaper rotary instruments at three different rotational speeds: 150, 250 and 350 r.p.m. (20 canals at each rotational speed). Each instrument was used a maximum of 20 times and at one rotational speed only. The angle and radius of canal curvature were measured in the only group in which fractures actually took place (group B). There were a total of 22 instrument fractures; all of these occurred in canals with curves >30 degree. It was demonstrated that the files used at a rotational speed of 350 r.p.m. were more likely to fracture than those used at 250 r.p.m. and than those used at 150 r.p.m. A decrease in the angle of curvature of the canal also significantly reduced the likelihood of fracture. These relationships remained significant after being adjusted for the potential interactions between the remaining variables. No significant differences were found between the files or the radii of the canals. Instrument fracture was associated with rotational speed and the angle of curvature of the canal.

Schafer E, Dzepina A, Danesh G (2003) compared the bending properties of different rotary nickel-titanium instruments and investigated the correlation between their bending moments and their cross-sectional surface areas. Resistance to bending was determined according to International Standards Organization publication 3630-1. The sample size was 10 files for each type, taper, and size. The cross-sectional surface area of all instruments was determined by using scanning electron microscope photographs of the cross section. The images were scanned and the area was calculated by using special software. The results showed that bending moments were significantly lower for ProFile and RaCe files than for all other files tested. K3 files were significantly less flexible than all other instruments. The correlation between stiffness and cross-sectional area was highly significant. It was recommended that nickel-titanium files with tapers greater than .04 should not be used for apical enlargement of curved canals because these files are considerably stiffer in comparison to those with .02 or .04 tapers.

Crumpton LBJ and Mc Clanahan (2003) reviewed the nickel titanium rotary instruments to bring clinicians up to date with the current and popular endodontic rotary nickel- titanium instrument system and techniques. Since the end of the nineteenth century, automated root canal instrumentation had been available, but systems had many problems. The challenges of increased canal blockage, instrument breakage, and insufficient canal debridement were related to the use of stainless steel instruments and have been dramatically improved with the introduction of nickel -titanium (NiTi) files. The first useable NiTi alloy was developed by William Buehler in 1960 investigated the feasibility of using this alloy in the fabrication of endodontic files and showed that NiTi files had two to three times the elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture when compared with stainless steel files of the same size. These features led to better centering of the instruments within the canal, less straightening of the canal, fewer elbows and ledges, and less transportation. NiTi rotary instrumentation should always be performed with slow-speed, low-torque or "right-torque" electric motors. A variety of motors exist from varying manufacturers including the Tecnika ATR and Aseptico ITR both of which were designed specifically for endodontics.These types of electronic motors have pre-programmed speed and torque values preset by the manufacturer for their recommended instruments. The units also allowed the operator to adjust the manufacturers' settings to the specific needs of the user. An additional benefit to the electric motors was the auto-reverse feature which was activated prior to reaching the elastic torque limit of the file, potentially reducing the possibility of instrument separation. Also available were air driven motors that connected to a slow-speed attachment on the dental unit. The air driven motors were less expensive than the electric motors. However, they were unable to control torque and do not had an auto-reverse feature. The past few years have seen a dramatic increase in the number of manufacturers producing NiTi rotary files.

Berutti E, Chiandussi G, Gaviglio I, Ibba A (2003) compared and analysed Torsional and Bending Stresses in Two Mathematical Models of Nickel-Titanium Rotary Instruments: ProTaper versus ProFile using finite element analysis. During root canal instrumentation, nickel-titanium rotary instruments are subjected to continual stresses inside the canal due to its anatomy and the hardness of the dentin. The files must therefore be both stress-resistant and elastic. The nonlinear mechanical behavior of the alloy used to manufacture the files was taken into account during the study. The distribution of stresses due to torsional and bending moments was compared in the two experimental models. The ProFile model was found to be more elastic than the ProTaper model. Under equal loads, the ProTaper model showed lower and better distributed stresses than the ProFile model.

Darabara M, Bourithis L, Zinelis S, Papadimitriou GD (2004) evaluated the pitting and crevice corrosion characteristics of stainless steel (SS) and NiTi endodontic files in R-EDTA and NaOCl irrigating solutions. The corrosion behaviour of two H-files produced from different SS alloys and one file produced from NiTi alloy was determined in R-EDTA and NaOCl irrigating solutions by the cyclic potentiodynamic polarization method. The cutting flutes of 12 files of each material were embedded in an epoxy resin, polished, exposed to the irrigating solutions and used as an electrode. An Ag/AgCl electrode was used as a reference, a platinum plate was used as a counter electrode and polarization curves were obtained for all files in R-EDTA and NaOCl irrigating solutions in 37°C. Corrosion potential, Corrosion current density and Pitting potential were calculated from each curve. Cyclic polarization curves presented negative hysteresis which meant that pitting or crevice corrosion were not evident for all the materials examined in both irrigating solutions. In NaOCl all materials showed significantly higher as well as lower corrosion and corrosion current density compared with R-EDTA reagent. They concluded that none of the tested materials was susceptible to pitting or crevice corrosion in R-EDTA and NaOCl solutions and from this standpoint the alloy were found appropriate for the production of endodontic files.

Kim JI, Liu Y, Miyazaki S (2004) presented the first comprehensive study of ageing-induced multiple-stage R-phase transformation. The ageing temperatures investigated in this study were in the range of 473–573 K which was 100–200 K below the conventional ageing temperature range of Ni-Ti. The occurrence of the complex transformation behaviours indicated that Ni-rich NiTi alloys were unstable at even these low temperatures. This had direct implication for the property stability of NiTi alloys in many applications. It was found that the thermal treatment did not affect surface morphology but brought changes in the instrument bulk with the appearance of the R-phase. It was revealed that the appearance of a mixed phase of austenitic and martensitic phase increased the flexibility of NiTi instruments and suggested that this might also affect other important clinical properties such as fracture resistance.

Peters OA, Barbakow F, Peters CI (2004) identified the factors that influence shaping outcomes with NiTi files. The factors observed were preoperative root-canal anatomy and instrument tip design. Other, less significant factors included operator experience, rotational speed, and specific instrument sequence. It was suggested that successful endodontic therapy depends on many factors, but one of the most important factor was canal preparation. The reason stated for this was as it determined efficacy of all subsequent procedures that included mechanical debridement, creation of space for medicament delivery and optimized canal geometries for adequate obturation. Other than canal anatomy, instrument tip design was also identified as a potential factors for preparation outcomes.

Fife D, Gambarini G, Britto LR, Gainesville F, Sapienza L (2004) evaluated the cyclic fatigue of ProTaper nickel-titanium (NiTi) rotary instruments after multiple clinical uses. Two hundred twenty-five ProTaper instruments were divided into 3 groups: A 75 used as controls, B 75 used in 2 molars (6-8 canals), and C 75 used in 4 molars (12-16 canals). The number of rotations to breakage and the fractured tip length were recorded for each file. 3 instrument separated during intracanal use, even if they were reused for a number of cases (4 molar cases). It was clear that prolonged reuse of NiTi rotary instruments strongly affected instrument's fatigue.

Linsuwanont P, Parashos P, Messer HH (2004) developed and evaluated an effective cleaning procedure for rotary nickel-titanium (NiTi) endodontic instruments. New rotary instruments (ProFile size 25/.04) were contaminated by preparing canals of extracted teeth. Three factors were evaluated to develop an effective cleaning sequence: dry or moist storage before cleaning; mechanical removal (brushing); and chemical dissolution in 1% NaOCl with ultrasonication. Debris on flutes was scored after staining in situ with Van Gieson's solution at x45 magnification. Debris was classified as stained or unstained particulate debris and organic film, and rated as none, slight, moderate or heavy. The effectiveness of a recommended cleaning sequence was tested on different instrument types and in private endodontic practices. All new instruments showed metallic spurs and fine particulate debris on the surfaces. After contamination, brushing alone removed most particulate debris, but did not remove organic film. NaOCl effectively removed organic film. Under laboratory conditions, the sequential cleaning procedures (moist storage, brushing followed by immersion in 1% NaOCl and ultrasonic cleaning) totally removed organic debris. Dry storage before cleaning or autoclaving with debris present reduced cleaning effectiveness. In three private practices, the cleaning protocol substantially reduced biological contamination, but complete cleaning was not always achieved (87% clean). They concluded that complete removal of organic debris from instruments was feasible using a combination of mechanical removal and chemical dissolution, but required meticulous attention to details.

Parashos P and Messer HH (2004) conducted a survey to ascertain the extent of the adoption and use of rotary nickel–titanium (NiTi) instruments and techniques in general dental practice and specialist endodontic practice in Australia in 2001. A questionnaire survey comprising 43 questions was developed by first creating questions, then pilot testing with 10 postgraduate students in endodontics, followed by a final revision. The final series of questions covered demographics, patterns of rotary NiTi usage, issues associated with NiTi usage and training in NiTi use. The sampling frame was 908, comprising 64 endodontists and 844 general dentists. The overall response rate was 87%. Rotary NiTi instruments were used by 22% of general dentists and 64% of endodontists. The two main reasons for not using rotary NiTi were 'no perceived advantage' and 'too fragile'. Instrument fracture had been experienced by 74% of respondents, and 72% of these had fractured one to five files for the two main perceived reasons of 'excessive pressure on the file' and 'over-usage'. The next two most common problems encountered were 'binding' (53%) and 'ledging' (45%). Very high proportions of positive experiences were noted. Most respondents (73%) had attended one or more continuing education courses, most of which were provided by dental supply companies (64%). It was concluded that the results indicate a sensible and responsible approach to the incorporation of rotary

NiTi instruments and techniques into root canal treatment. Dentists were aware of the limitations of the new technology, but were taking steps to become familiar with the properties and behaviour of the instruments. Instrument fracture was common, but it was of low frequency and did not deter dentists from using the technology.

Buchanan LS (2005) reviewed the design features of the NiTi GT System of Instruments and outlined the technique for their safe and effective use. Specifically, crown-down technique for cleaning and shaping was discussed. Apart from this the importance of measuring the apical diameter after initial shaping of the canal was highlighted .Finally it was addressed that appropriate file selection for specific forms of anatomy must be kept in mind of clinician before beginning the root canal therapy.

Gunday M, Sazak H, Garip Y (2005) used Schneider, Weine, and Long-Axis techniques for comparing the measurement of canal curvature. One hundred mandibular first and second molar teeth were used and radiographs were taken after inserting size 10 K-files into the mesiobuccal root canals. The radiographic findings were digitized on a computer, and the three different curvature angles were measured from drawings of the same root canal and compared statistically. The term "canal access angle" was introduced and it was defined by examining the morphology of canal curvature. There was a positive correlation between the canal access angle and curvature height. The results indicated that the canal access angle is a more effective way of evaluating the root canal curvature

Hulsmann M, Peters OA, Dummer PM (2005) reviewed the mechanical preparation of root canals that included shaping goals, techniques and the technique. It was stated that preparation of root canal systems includes both enlargement and shaping of the complex endodontic space together with its disinfection. A variety of instruments and techniques have been developed and described for this critical stage of root canal treatment. Although many reports on root canal preparation could be found in the literature, definitive scientific evidence on the quality and clinical appropriateness of different instruments and techniques remained elusive. To a large extent it was believed that this was because of methodological problems, making comparisons among different investigations that were difficult if not impossible. The following conclusions were drawn the use of NiTi instruments resulted in less straightening and better centred preparations of curved root canals, the use of NiTi instruments alone does not resulted in complete cleanliness of the root canal walls, cleanliness decreased from the coronal to the apical part of the root canal, the use of a paste-type chelator during preparation does not removed the smear layer completely, the use of NiTi instruments with active cutting blades was found superior to instruments with radial lands in terms of root canal cleanliness, when used according to the manufacturers' guidelines NiTi instruments were found safe to use, the use of instruments with safety tips were preferred with respect to working safety, the use of a special motor with constant speed, low torque and torque-control was recommended.

Bahia MGA and Buono VTL (2005) evaluated fatigue resistance of nickel-titanium rotary instruments after clinical use in curved root canals. The changes in fatigue resistance of nickel-titanium rotary ProFile instruments after clinical use for shaping 10 curved molar root canals were evaluated in this study. Twenty-five sets of files #20, #25, and #30 and tapers .04 and .06 were divided into 2 groups, one with 10 sets of new files that were tested in a fatigue test bench device as a control. The other, experimental group, with 15 sets of clinically used files, was tested in the same device. A statistically significant decrease in the number of cycles to failure was observed in the used files, as compared with the fresh ones. The fracture point was the same for all files tested. It was concluded that the clinical use of ProFile instruments for shaping curved canals reduces their fatigue resistance.

Veltri M, Mollo A, Mantovani L, Pini P, Balleri P, Grandini S (2005) conducted a comparative study to analyse Hero shaper and Mtwo instruments in preparation of curved root canal canals. In the study, the blade designs were grouped into two categories. Active cutting angle- they had sharp blades projecting from the middle of the shaft and Radial landed blades- with a flat surface at the blade margin. Mtwo files had two blades and featured a large groove between them. This design claimed to reduce the core diameter and increase the flexibility while Hero Shaper had triple helix cross section and the angle increased from the tip to the shank which claimed to reduce threading, while the pitch varied according to the taper. It was claimed to increase the efficiency, flexibility and strength of the instrument. In the apical region, preparation were centered in the canal. A mean loss of working length of 0.55 mm for Mtwo and 0.58 mm for Hero Shaper was detected. No aberrations were seen and no instruments separation was observed.

Calas P (2005) studied the adapted pitch concept claimed by Manufacturer of Hero Shaper file system. They stated that the adapted pitch concept involves varying the pitch and the length of the cutting portion as a function of the taper of the instruments. It was suggested that by modifying these parameters, it was possible to select the instrument with the strength, efficacy, flexibility, and taper best suited for the root canal being prepared. In the Hero Shapers sequence, instruments with a 0.06 taper were used to prepare and enlarge the coronal and middle thirds of the canal. These instruments had a longer pitch for enhanced flexibility and dentine cutting efficacy. The removal of dentinal chips was facilitated and the tendency to screw in was reduced. Instruments with a 0.04 taper were used to prepare the apical portion because they had a shorter pitch and cutting portion (12 mm), which made them stronger and more flexible. Thus apical curvatures without deviating from the initial canal axis was negotiated. The files were used in a continuous rotation mode (450–600 r.p.m.) to progressively prepare the root canal (crown-down). The sequences were selected based on the difficulty of the original canal shape.

Ruddle CJ (2005) studied ProTaper NiTi instruments which represented a new generation of instruments for shaping root canals. A unique feature of ProTaper instruments was that each file had changing percentage tapers over the length of its cutting blades. ProTaper instruments also had convex, triangular cross-sections, a changing helical angle and pitch over their cutting blades and a non-cutting, modified guiding tip. The ProTaper system comprised of three Shaping and three Finishing instruments.

Spili P, Parashos P, Messer HH (2005) evaluated the frequency of instrument fracture and its impact on treatment outcome using an analysis of specialist endodontic practice records involving 8460 cases. A case-control study of treatment outcomes was conducted on a subset of 146 teeth with a retained instrument fragment (plus 146 matched controls), for which clinical and radiographic follow-up of at least 1 year was available. Masked radiographs were assessed by two calibrated examiners. Overall prevalence of retained fractured instruments was 3.3% of treated teeth. In the case-control study, overall healing rates were 91.8% for cases with a fractured instrument and 94.5% for matched controls. Healing in both groups was lower in teeth with a preoperative periapical radiolucency (86.7% versus 92.9%). In the hands of skilled endodontists prognosis was not significantly affected by the presence of a retained fractured instrument.

Ullmann CJ and Peters OA (2005) evaluated static fracture loads of ProTaper Nickel-Titanium instruments that had been subjected to various degrees of cyclic fatigue. Torque and angle at failure of new instruments and instruments that had been stressed to 30, 60, or 90% of their cyclic fatigue rotations in a simulated canal (90 degrees and 5 mm radius) were tested according to ISO 3630-1. With unused ProTaper instruments, resistance to cyclic fatigue decreased with diameter increase and ranged from 158 to 450 rotations. Torque at failure ranged from 0.5 to 2.1 Ncm and showed a strong linear relationship to instrument diameter (r = 0.9) while angle at failure was weakly related to diameter (r = 0.46). Cyclic prestressing significantly reduced torsional resistance in finishing files, while shaping files were largely unaffected. It was concluded that build-up of tension within NiTi rotary instruments depends on instrument diameter. It was recommended that clinically, larger instruments that have been subjected to some cyclic fatigue should be used with great care or discarded.

Grande NM (2006) determined the role of instrument design and its effect on fatigue life of two nickel titanium rotary systems (Mtwo and ProTaper) under cyclic fatigue stress in simulated root canals. Cyclic fatigue testing of instruments was performed in stainless steel artificial canals with radii of curvature of 2 or 5 mm and an angle of curvature of 60 degree. A total of 260 instruments were rotated until fracture occurred and the number of cycles to failure were recorded. The morphology of NiTi rotary instruments was investigated by measuring the volume of millimetre slices of each instrument size starting from the tip to the shank by means of micro-computed tomography analysis. The results showed that the cycles to failure significantly decreased as the instrument volume increased for both the radii of curvature tested. The radius of curvature had a statistically significant influence on the fatigue life of the instruments. Larger instruments underwent fracture in less time under cyclic stress than smaller ones. It was concluded that the metal volume in the point of maximum stress during a cyclic fatigue test could affect the fatigue life of NiTi rotary instruments. The larger the metal volume, the lower the fatigue resistance.

Malagino G. (2006) studied Mtwo endodontic instruments. Mtwo endodontic instruments were new generation of NiTi rotary instruments. The standard set for this system includes four instruments with variable tip sizes ranging from #10 to #25, and tapers ranging from .04 to .06 (size 10/.04 taper, size 15/.05 taper, size 20/.06 taper, size 25/.06 taper). After this basic sequence, that gives the canal a #25/.06 shape, the system is conceived to permit three different approaches to root canal preparation. The first sequence allows clinicians to achieve enlarged apical diameters using the size 30 .05 taper, 35 .04 taper or 40 .04 taper; the second leads to a .07 taper that can facilitate vertical condensation of gutta-percha, maintaining a size #25 apical preparation; and the third implies the use of the Mtwo apical files .

Miyai K, Ebihara A, Hayashi Y, Doi H, Yoneyama T (2006) investigated the relationship between the functional properties and the phase transformation of nickel–titanium endodontic instruments. Five types of rotary nickel titanium endodontic instruments with a 0.30 mm diameter tip (EndoWave, HERO 642, K3, ProFile.06, and ProTaper) were selected to investigate torsional and bending properties, and phase transformation behaviour. Maximum torque and angular deflection at fracture were measured. Bending load of the instruments was measured in a cantilever-bending test at 37 degree celcius with the maximum deflection of 4.0 mm. A stainless steel K-file was used for reference. Phase transformation behaviour was measured by differential scanning calorimetry (DSC). From the DSC curve, transformation temperatures were calculated. The maximum torsional torque values of HERO 642, K3 and ProTaper were significantly higher ($P < 0.05$) than those of EndoWave, ProFile and Kfile. The K-files had the lowest torque value. Angular deflection at fracture was significantly higher ($P < 0.05$) for K-files than that for any nickel–titanium instrument. It was concluded that the functional properties of nickel–titanium endodontic instruments, specially their flexible bending load level, were closely related to the transformation behaviour of the alloys.

Parashos P and Messer HH (2006) reviewed about the rotary NiTi Instrument fracture and its consequences. The predisposing factors summarized by them were Instrument design (cross section and file design), alloy composition, size and taper of instrument, manufacturing process (Inclusions like oxide particles and Surface irregularities like milling grooves or multiple cracks or pits or regions of metal rollover). They summarized the current understanding of the prevalence, causes, management of instrument fracture and its impact on prognosis of the treatment and laid down recommendations concerning clinical decision making associated with fractured rotary NiTi instruments. The mean clinical fracture frequency of rotary NiTi instruments is approximately 1.0% with a range of 0.4 to 3.7%.The reasons for fracture of rotary NiTi instruments are complex and multifactorial, one of the most important of which may be the operator's skill and experience (4, 9, 13, 35– 40). Operator-related factors such as their proficiency with the instrument and the decision on the number of uses of the instrument was also considered important factor for instrument failure. Fracture of metal was classified as either brittle or ductile. The brittle fractures occurred in metals with poor ductility. Typically there was an initiation of cracks at the surface of the metal, and stress concentration at the base of the crack that resulted in its propagation either along grain boundaries (intergranular) or between specific crystallographic planes (cleavage fracture) The crack thus behaved as a stress-raiser, because an applied load, instead of being spread over a smooth surface, was concentrated at one point or area. The unit stress applied was much higher and exceeded the tensile strength at that point or surface. It was discussed that in brittle fractures crack fronts creates ridges that spread along different planes within the alloy and generally radiate away from the origin of the crack, producing the so-called chevron pattern whereas in ductile fractures microvoids are produced within the metal and nucleation, growth, and microvoid coalescence ultimately weaken the metal and results in fracture. It was revealed that metal fatigue and finally fracture of instrument results from repeated applications of stress, leading to cumulative and irreversible changes within the metal. It may be caused by tensile, compressive, or shear forces as well as corrosion, wear, or changes produced by thermal expansion and contraction. NiTi instruments rotating around a curvature for a prolonged period of time are subjected to repeated tensile and compressive stresses such that during each rotation the inner surface of the instrument is compressed and the outer surface is under tension. This results in work hardening within the metal and initiation of cracks leading to eventual cyclic flexural fatigue. Files fractured with fewer rotations as the radius of curvature decreased or the angle of curvature increased. Partially fatigued instruments when used clinically were flexed, revealed fractures associated with surface flaws. The prolonged clinical use of rotary NiTi instruments significantly reduced their cyclic flexural fatigue resistance. The conclusion of this review summarized the following guidelines for a successful and safe treatment : A Glide path and canal patency with small (at least #10) hand files should be created; Ensure straight line access and good finger rests; Use a crown-down shaping technique as suggested by manufacturer of the instrument system; Use stiffer, larger, and stronger files to create coronal shape before using the narrower, more fragile instruments in the apical regions; Use a light touch only and never push hard on the instrument, Use pecking action in increments as large as allowed by the particular canal anatomy and instrument design characteristics, Do not hurry instrumentation, and avoid rapid jerking movements; Be cautious of any clicking of instrument in the canal during use, Replace the files sooner after use in very narrow and very curved canals, Examine files regularly during use, preferably with magnification, Keep the instrument moving in a chamber flooded with irrigant such as sodium hypochlorite, Avoid keeping the file in one spot particularly in curved canals and with larger and greater taper instruments and First practice the new technique while using a new instrument system.

Spanaki VAP, Kerezoudis NP, Zinelis S (2006) evaluated the failure mechanism of ProTaper Ni–Ti rotary instruments fractured under clinical conditions. A total of 46 ProTaper instruments that failed (fractured and/or plastically deformed) during the clinical use were collected from various dental clinics, whereas a new set of ProTaper instruments served as control. After inspection under stereomicroscopy the instruments were classified into three categories: (i) plastically deformed but not fractured, (ii) fractured with plastic deformation and (iii) fractured without plastic deformation. Three instruments from each group were analysed with computerized X-ray microtomography to detect surface and internal defects, whilst all the fracture surfaces were investigated under SEM. The results showed that 17.4% of the discarded instruments were only plastically deformed, 8.7% were fractured with plastic deformation and 73.9% were fractured without plastic deformation. Micro-XCT revealed instruments without any surface or bulk defects along with a few files with crack development below the fracture surface. No defects were identified in the unused instruments. SEM examination of fractured surfaces demonstrated the presence of dimples and cones, a typical pattern of dimple rupture developed because of ductile failure. It was concluded that a single overloading event caused ductile fracture of ProTaper instruments which was accepted as the most common fracture mechanism encountered under the clinical conditions.

Tripi TR, Bonaccorso A, Condorelli GG (2006) compared the fatigue resistance of rotary nickel-titanium endodontic instruments to assess the influence of both instrument design and surface treatment on flexural fracture reistance. A total of 120 instruments were tested. Among the tested instruments there were ProFile, RaCe, K3, Hero, and Mtwo file systems. A scanning electron microscope for each instrument was performed before start and after fracture to determine the mode of fracture and the aspect of tips and cross-sectional surface areas. The results obtained showed that the ProFile instruments gave the best values for fatigue resistance. It was observed that for RaCe instruments the surface treatment reduces the presence of micro-cracks, surface debris and machining damage. In RaCe instruments the electro-polishing surface treatment increased the fracture fatigue resistance. It was concluded that the instrument design was found to be an important factor in determining the fatigue resistance of a NiTi rotary instrument.

Alexandrou GB, Chrissafis K, Vasiliadis LP, Pavlidou E, Polychroniadis EK. (2006) investigated surface and microstructure of two popular brands of NiTi rotary endodontic instruments. Scanning electron microscopy (SEM) and differential scanning calorimetric (DSC) studies were utilized to investigate surface and microstructure of two brands of rotary nickel-titanium (NiTi) endodontic instruments, in the as-received condition and after subjection to 1, 6, and 11 sterilization cycles. A total of 66 ProFile (n=33) and Flexmaster (n=33) files were examined. SEM observations indicated the presence of surface imperfections and adherent material in all new and sterilized instruments and an increase in surface roughness of the instruments that underwent multiple sterilizations. DSC measurements showed that the specimens of both brands, in the as-received condition and after 11 sterilizations, were completely austenite in the oral environment temperature, suggesting that they are capable of superelastic behavior in appropriate clinical conditions.

Alexandrou GB, Chrissafis K, Vasiliadis LP, Pavlidou E, Polychroniadis EK (2006) evaluated the effect of repeated dry heat sterilization on surface characteristics and microstructure of Mani nickel-titanium rotary instruments. Thirty-three new Mani NRT instruments, size 30, taper 0.04 and 25 mm in length were examined. Twenty-seven instruments were divided into three groups for surface characterization by scanning electron microscopy (SEM). In the first group (n = 3), instruments were examined in the 'as-received' condition and after they had been subjected to 11 sterilization cycles. In the second and third subgroups (n = 12), 12 instruments were prepared for cross-section and a further 12 for longitudinal sectional analysis and evaluated in subgroups of three, after 0, 1, 6 and 11 sterilization cycles. The remaining six instruments were analysed with differential scanning calorimetry (DSC), three in the 'as-received' condition and three after being subjected to 11 cycles of sterilization. Scanning electron microscopy observations indicated the presence of debris, pitting and deep milling marks in both new and sterilized files. After 11 sterilization cycles, debris remained and surface roughness was increased significantly. DSC analyses showed that the specimens in the 'as-received' condition and after 11 sterilization cycles were in the austenite phase or a mixture of austenite and R-phase at 37 degrees C. The machining defects and structural imperfections of new Mani instruments were indicative of the difficulty in manufacturing nickel-titanium endodontic instruments. DSC measurements suggested that Mani instruments were capable of superelastic behaviour under clinical conditions.

Plotino G, Grande NM , Sorci E , Malagnino VA, Somma F (2006) evaluated the cyclic fatigue of Mtwo Ni–Ti rotary instruments after controlled clinical use in molar teeth. Methodology Twenty Mtwo instruments of each size were selected and divided into two groups: group A consisted of 10 new instruments (control group); group B consisted of 10 used instruments. Each instrument in group B was used to clean and shape 10 root canals of molar teeth in patients. Cyclic fatigue testing of instruments was performed in tapered artificial canals with a 5-mm radius of curvature and a 60 angle of curvature. In all 140, instruments were rotated until fracture and the number of cycles to failure was recorded. A reduction of cycles to failure between new (group A) and used (group B) instruments was apparent. A statistically significant difference was noted between instruments of groups A and B in all sizes with the exception of size 40, 0.04 taper. Conclusions Clinical use significantly reduced cyclic fatigue resistance of Mtwo rotary instruments when compared with an unused control group. However, all the instruments had minimal instrument fatigue when discarded after controlled clinical use.

Iqbal MK, Kohli MR, Kim JS (2006) investigated the incidence of hand and rotary instrument separation (IS) in the endodontics graduate program at the University of Pennsylvania between 2000 and 2004. In 4,865 endodontic resident cases the incidence of hand and rotary IS was 0.25% and 1.68%, respectively. The odds for rotary IS were seven times more than for hand IS. The probability of separating a file in apical third was 33, and 6 times more likely when compared to coronal and middle thirds of the canals. The highest percentage of IS occurred in mandibular (55.5%) and maxillary (33.3%) molars. Furthermore, the odds of separating a file in molars were 2.9 times greater than premolars. Among the ProFile series 29 rotary instruments, the .06 taper # 5 and # 6 files separated the most. There was no significant difference in IS between the use of torque controlled versus non torque controlled handpieces, nor between first and second year residency.

Antonnio B, Tripi TR, Canatore G, Condorelli GG (2007) investigated the surface properties of NiTi files. They evaluated the effects of sterilization process, sodium hypochlorite irrigation and manufacturing / electropolishing technique on fatigue resistance of NiTi endodontic files. It was found that a high concentration of carbon, oxygen and environmental contaminants existed on surface of NiTi files. There were negative effects of repeated sterilization process which lead to decrease in cutting efficiency as a result of titanium oxide in the surface layer. The sodium hypochlorite treatment during irrigation of canals resulted in marked surface modifications on NiTi files. There was galvanic reaction that lead to shaft corrosion and metal deposition on the tip and flutes of the NiTi instrument. The electropolishing of NiTi instrument resulted in improvement of surface composition and properties of NiTi instrument that produced a surface layer free of organic and inorganic contaminants and thus increases the fracture resistance of Niti instrument.

Anderson ME, Price JWH, Parashos P (2007) investigated the effect of electropolishing on cyclic flexural fatigue and torsional strength of rotary nickel-titanium endodontic instruments. Electropolished and nonelectropolished ISO size 30 (0.04 taper) EndoWave, ProFile and RaCe instruments from the same manufacturing batches were investigated. The number of rotations to fracture and torque at fracture were determined and compared among the instruments tested. Instruments were viewed under a scanning electron microscope (SEM) to assess the degree and quality of electropolishing. Overall, electropolished instruments performed significantly better than nonelectropolished instruments in cyclic fatigue testing and, to a lesser extent, in static torsional loading. When viewing electropolished instruments with the SEM, milling grooves, cracks, pits, and areas of metal rollover were observed, although they were more evident in the nonelectropolished instruments. Electropolishing may have beneficial effects in prolonging the fatigue life of rotary NiTi endodontic instruments. The benefits of electropolishing were likely to be caused by a reduction in surface irregularities that serve as points for stress concentration and crack initiation.

Cheung GSP and Darvell BW (2007) compared the low-cycle fatigue behaviour of ProFile, K3, HeroShaper and FlexMaster NiTi instruments. A total of 286 NiTi rotary instruments from four manufacturers were constrained into a curvature by three rigid, stainless steel pins whilst rotating at a rate of 250 rpm in deionized water until broken. The number of revolutions was recorded using an optical counter and an electronic break-detection circuit. The surface strain amplitude, calculated from the curvature and diameter of the fracture cross-section was plotted against the number of cycles to fracture for each instrument. It was found that nearly all ProFile instruments demonstrated crack initiation at the cutting edge or the ‘radial land’ region. For the K3 group, crack initiation appeared somewhat erratic; origins of fatigue-cracking could be found not only at the cutting edge, but also at various places along the flute. The HERO Shaper and FlexMaster instruments generally had the crack origins located at the cutting edge except when a subsurface void or inclusion was present elsewhere. The number of crack initiation site was significantly different between groups with K3 (59%) having the highest incidence of multiple crack origins, followed by FlexMaster (55%), HERO (35%) and ProFile (23%) instruments. It was concluded that the Low Cyclic Fatigue life of NiTi instruments declined with an inverse power function dependence on surface strain amplitude but was not affected by the cross-sectional shape of the instrument.

Cheung GSP and Darvell BW (2007) examined the fatigue behaviour using a strain life approach, and determined the effect of water on the fatigue life of a 212 ProFile NiTi rotary file. ProFile (size 25, taper 0.04 and 0.06) were subjected to rotational bending either in air or under water and the number of revolutions till fracture (N_f) were recorded using an optical counter and an electronic break detection circuit. The effective surface strain amplitude (ea) for each specimen was determined from the curvature of the instrument and the diameter of the fractured cross-section. A total of 212 instruments were tested. A strain-life relationship typical of metals was found. The number of revolutions till fracture declined with an inverse power function dependence on surface strain amplitude. A fatigue limit was present at about 0.7% strain. The apparent fatigue-ductility exponent, a material constant for the LCF life of metals, was found to be between -0.45 and -0.55. There was a significant effect of the environmental condition on the LCF life, water being more detrimental than air. It was concluded that the fatigue behaviour of NiTi rotary instrument is typical for most metals, provided that the analysis was based on the surface strain amplitude, and showed a high-cycle and a Low cycle Fatigue region. The LCF life was found to be adversely affected by water.

Cheung GSP and Darvell BW (2007) examined the topographic features of the fracture surface of a rotary NiTi instrument ProFile system, due to fatigue failure, and correlated the measurements with the cyclic load. A total of 212 ProFile rotary instruments were subjected to a rotational-bending test at various curvatures until broken. The fracture surface of all fragments was examined by SEM to identify the crack origins. The crack radius, i.e. extent of the fatigue-crack growth towards the centroid of the cross-section, was also measured, and correlated with the strain amplitude for each instrument. Results obtained showed that all fracture surfaces exhibited the presence of one or more crack origins, a region occupied by microscopic striations, and an area with microscopic dimples. The number of specimens showing multiple crack origins was significantly greater in the group fatigued under water than in air. A linear relationship between the reciprocal of the square root of the crack radius and the strain amplitude was discernible, the slopes of which were not significantly different for instruments fatigued in air and water. It was concluded that the fatigue behaviour of NiTi instruments was adversely affected by water, not only for the low-cycle fatigue life, but also the number of crack origins. There appeared a critical extent of crack propagation for various strain amplitudes leading to final rupture.

Camara AC, Aguiar CM, Poli de Figueiredo JA (2007) assessed the risk of deviation of the root canals prepared by 3 HERO rotary systems, used solely or in association, by means of preoperative and postoperative imaging of a cross-section of their coronal, middle, and apical thirds. Fifty mesiobuccal canals of human first molars were randomly divided into 5 groups of 10 specimens each: group A, HERO 642; group B, HERO 642 + HERO Apical; group C, HERO Shaper; group D, HERO Shaper + HERO Apical; group E (control), NitiFlex files. Fisher exact test showed that the differences between the percentages of the presence of deviation and the differences observed between the proportions of instrumented and non-instrumented walls were not statistically significant. No system presented absolute effectiveness, because each of them produced morphologic changes and failed to instrument all the walls of the root canals.

Margot E. Anderson, John W.H. Price, Peter Parashos (2007) investigated the effect of electropolishing on cyclic flexural fatigue and torsional strength of rotary nickel-titanium endodontic instruments. Electropolished and nonelectropolished ISO size 30 (0.04 taper) EndoWave, ProFile, and RaCe instruments from the same manufacturing batches were investigated. The number of rotations to fracture and torque at fracture were determined and compared among the instruments tested. Instruments were viewed under a scanning electron microscope (SEM) to assess the degree and quality of electropolishing. Overall, electropolished instruments performed significantly better than nonelectropolished instruments in cyclic fatigue testing and, to a lesser extent, in static torsional loading. When viewed, electropolished instruments with the SEM, milling grooves, cracks, pits, and areas of metal rollover were observed, although they were more evident in the non-electropolished instruments. It was believed that electropolishing had beneficial effects in prolonging the fatigue life of rotary NiTi endodontic instruments. The benefits of electropolishing were likely to be caused by a reduction in surface irregularities that served as points for stress concentration and crack initiation.

Yang GB, Zhou XD, Zheng YL, Zhang H, Shu Y, Wu HK (2007) compared the shaping ability of progressive versus constant taper shaft instruments in curved root canals of extracted human teeth. A total of 40 root canals of mandibular molars with curvatures ranging between 20 to 40 degree were divided into two groups of 20 canals each and embedded in a muffle system. The root canals were sectioned horizontally at three levels before preparation and then remounted into the mould. All root canals were prepared with ProTaper (progressive taper) or Hero Shaper (constant taper) instruments. Pre- and Post-instrumentation radiographs and cross-sectional images were obtained. The parameters evaluated were: working safety (instrument failure, apical blockage and loss of working length) and shaping ability (straightening, cross-sectional area, transportation and centring ability). No instrument fracture occurred during canal preparation. One Hero Shaper instrument permanently deformed. Both instrument systems maintained working length well. The canals prepared with Hero Shaper instruments were straightened to a lesser degree. ProTaper instruments removed more dentine in the coronal and the middle sections of the canals. Canals prepared with Hero Shaper instruments had less transportation and better centring ability in the apical section. It was concluded that both instrument systems were safe to use and maintained working length well. The canals prepared with Hero Shaper had less transportation and were better centred in the apical region, possibly because their smaller taper reduced instrument stiffness.

Zinelis S, Darabara M, Takase T, Ogane K, Papadimitriou GD (2007) determined the effect of various thermal treatments on the fatigue resistance of a nickel-titanium (NiTi) engine-driven endodontic file. Fifteen groups of 5 files each of ISO 30 and taper .04 were tested in this study. The cutting tip (5 mm from the end) of files from 14 groups were heat treated for 30 minutes in temperatures 250 degrees C (Celcius), 300 degrees C, 350 degrees C, 375 degrees C, 400 degrees C, 410 degrees C, 420 degrees C, 425 degrees C, 430 degrees C, 440 degrees C, 450 degrees C, 475 degrees C, 500 degrees C, and 550 degrees C, respectively, while 1 group was used as reference. The files were placed in a device that allowed the instruments to be tested for rotating bending fatigue inside an artificial root canal. The number of rotations to breakage was recorded for each file. The 430 degrees C and 440 degrees C groups showed the highest values, with fatigue resistance decreasing for thermal treatment at lower and higher temperatures. This was believed to be due to the metallurgical changes during annealing. It was observed that the appropriate thermal treatment could significantly increase the fatigue resistance of the NiTi file tested.

Cheung GSP, Shen Ya, Darvell BW (2007) examined the low-cycle fatigue (LCF) behavior of a nickel-titanium (NiTi) engine-file under various environmental conditions. One brand of NiTi instrument was subjected to rotational-bending fatigue in air, deionized water, sodium hypochlorite, or silicone oil. The curvature of each instrument, diameter of the fracture cross-section, and the number of rotations to failure were determined. The results showed a linear relationship, on logarithmic scales, between the LCF life and the surface strain amplitude; regression line slopes were significantly different between noncorrosive (air, silicone oil) and corrosive (water, hypochlorite) environments, as well as number of crack origins. Hypochlorite was more detrimental to fatigue life than water. It was concluded that environmental conditions significantly affected the LCF behaviour of NiTi rotary instruments.

Inan U, Aydin C, Tunca YM (2007) compared the cyclic fatigue resistance of ProTaper rotary NiTi files in artificial canals with 2 different radii of curvature. Cyclic fatigue testing was performed using a device that allowed the instruments to rotate freely inside stainless steel artificial canals. The radii of curvature selected were 5 and 10 mm. The 5-mm radius group had significantly fewer NCF than the 10-mm radius group for all file sizes. Cyclic fatigue resistance of ProTaper instruments was dependent on both instrument size and radius of curvature. Especially larger-size instruments should be used with great care in curved canals.

Mc Spadden JT (2007) reviewed Nitinol and its behaviour. It was observed that Nitinol existed in three different forms: austenite, martensite and stress-induced martensite (super-elastic). Austenite nitinol was non-elastic and hard; in its martensite form, it was relatively soft and could be easily deformed; and super-elastic nitinol was highly elastic. When external stress was applied, the austenite crystalline form of nickel titanium transformed into the stress induced martensite crystalline structure that accommodated greater stress without increasing the strain. When the stress was removed without permanent deformation, the nitinol returned to its austenite structure (original shape) provided that the temperature remained within a specific range. This phenomenon was called as stress-induced thermo-elastic transformation.

Tzanetakis GN, Kontakiotis EG, Maurikou DV, Marzelou MP (2008) investigated the prevalence and management of instrument fracture during root canal preparation by postgraduate students (Department of Endodontics, Dental School of Athens) and to determine the percentage of referred cases with fractured instruments managed by the same students of the programme. A retrospective study was conducted by reviewing the dental notes of 1367 patients (2180 endodontic cases, 4897 root canals) treated between October 2001 and June 2006 by endodontic postgraduate students at the Dental School of Athens. Type of tooth and canal, type and length of fractured segments, level of instrument fracture, and management that followed were recorded. The overall prevalence of instrument fracture during root canal preparation by postgraduate students was 1.83%. The prevalence of endodontic cases with fractured instruments referred to the endodontic postgraduates was 7.41%. The prevalence of stainless steel hand and rotary nickel-titanium instrument fracture by postgraduate students were 0.55% and 1.33%, respectively. The prevalence of instruments fractured in the apical third (52.5%) was significantly higher when compared with coronal (12.5%) and middle (27.5%) thirds of the canals. The retrieval or bypass of fractured instruments was most successful in the coronal (100%) and middle (45.4%) thirds when compared with the apical third (37.5%) of the canals. The fracture frequency was higher in retreatment cases in relation to the respective rate of initial therapies. On the basis of the results of this study, the prevalence of endodontic instrument fracture by the postgraduate students was relatively low. The prevalence of fracture of nickel-titanium rotary instruments was more frequent than that of hand instruments. Retrieval or bypass of the fractured instruments in the apical third was less successful.

Aydin C, Inan U, Yasar S, Bulucu B, Tunc YM (2008) compared the shaping ability of Hero Shaper and RaCe instruments in simulated curved canals. Forty simulated canals in resin blocks were divided into 2 experimental groups, each comprising 20 resin blocks, and prepared with Hero Shaper and RaCe using the crown-down technique. Preoperative and postoperative photographs, recorded using a digital camera, were superimposed and aberrations were recorded. The Hero Shaper and RaCe instruments removed almost the same amount of material from the inner side of the simulated canals. On the outer canal wall, the RaCe instruments removed significantly more material from the first 3 mm. However, Hero Shaper removed more material from the middle and coronal aspects of the canal and the differences were statistically significant. It was concluded that the Hero Shaper instruments showed better centering ability and fewer aberrations. No instrument fractured during this study but some deformations were observed for both the tested systems.

Bui C, Clark WAT, Alapati S (2008) investigated the effect of electropolishing the ProFile Nickel Titanium rotary instruments on torque resistance, fatigue resistance, and cutting efficiency. Size 25/0.04 ProFile files that were non-polished for the control group (n = 15) and electropolished for the experimental group (n = 15) were used for each experiment. Cyclical fatigue was determined by counting rotations until breakage with an applied 30 degrees, 45 degrees and 60 degrees curve with a 5mm radius. Torque and angle at failure were measured by rotating clamped files at 2 rpm until breakage. Cutting efficiency was determined by measuring the velocity of file advancement into plastic blocks with 100-g constant force for 5 seconds. The results showed that electropolishing significantly reduced resistance to cyclic fatigue but did not affect torsional resistance. However, electropolishing reduced the angle at failure and amount of unwinding. Electropolishing did not significantly affected the cutting efficiency.

Chianello G, Specian VL, Hardt LCF, Ralsi DP, Marques JLL, Habitante SM 2008 evaluated, under scanning electron microscopy (SEM), the quality of the surface finishing of unused rotary endodontic instruments. Fifty files of ISO sizes 20, 25 and 30 from different commercial brands (ProFile, Protaper, Race, Hero and K3 Endo) were obtained, removed directly from their packages and were examined with a scanning electron microscope at x190 magnification with no previous usage .The following parameters were checked on these tested file surfaces:

cutting edge, debris, grooves, microcavities, tip shape, tip position, scraping and transition angle. The results showed except for ProFile, all commercial brands presented surface debris in 100% of samples. Only Race files showed no grooves or microcavities. K3 Endo files presented the best tip centralization. Except for ProTaper files, all commercial brands presented blunt cutting edges in 100% of samples. All types of files presented surface scraping. K3 Endo files and Protaper had a high percentage of transition angle. Under the tested conditions, it was observed that the quality of the surface finishing of the examined instruments was not as expected as no instrument was free of imperfections and most of them presented at least 2 and up to 7 types of surface defects. These results indicated that the manufacturing process and the packaging conditions of rotary endodontic files by the manufacturers were far from ideal.

Gambarini G, Grande NM, Plotino G, Somma F, Garala M, DeLuca M, Testarelli L (2008) investigated cyclic fatigue resistance of nickel titanium instruments manufactured by using new processes. This was evaluated by comparing instruments produced by using the twisted method and those using the M-wire alloy with instruments produced by a traditional NiTi grinding process. Tests were performed with a specific cyclic fatigue device that evaluated cycles to failure of rotary instruments inside curved artificial canals. The results showed that size 25 .06 taper NiTi rotary files showed a significant increase in the mean number of cycles to failure when compared with size 25 taper 0.06 K3 files. Size 20 K3 instruments showed no significant increase in the mean number of cycles to failure when compared with size 20 taper 0.06 GT series X instruments. The new manufacturing process produced nickel-titanium rotary files (TF) significantly more resistant to fatigue than instruments produced with the traditional NiTi grinding process. Instruments produced with M-wire (GTX) were not found to be more resistant to fatigue than instruments produced with the traditional NiTi grinding process.

Necchi S, Taschieri S, Petrini L, Migliavacca F (2008) conducted a study that aimed to create a computational model to simulate the mechanical behaviour of a Ni-Ti rotary endodontic instrument (ProTaper) operating in a root canal. The stress that the instrument undergoes during clinical procedures (composed of continuous insertion and removal of the instrument in and out of the canal) was studied to evaluate the effects of the canal shape on the stress state generated in the instrument. An accurate geometrical model of a Ni-Ti ProTaper F1 instrument was created. The interaction between the rotating instrument and differently shaped root canals during the insertion and removal procedure was studied using FE analyses. The complex thermo-mechanical behaviour of the Ni-Ti alloy was reproduced using an *ad hoc* computational subroutine. With the aim of demonstrating the enhanced performance of the shape memory alloy employment, the same analysis was performed on a 'virtual' ProTaper F1 made of stainless steel. The most demanding working conditions were observed in canals with sharp curves, especially in areas where the instruments had larger diameters. To prevent possible damage to instruments and fracture, it was advised that the instruments should be discarded following their use in such canals.

Versiani MA, Pascon EA, Alnes D Souja CJ, Borges MAG, Sousa Neto MD (2008) evaluated the influence of shaft design on the shaping ability of 3 rotary nickel-titanium (NiTi) systems (ProTaper, ProFile, and ProSystem GT rotary instruments) by means of spiral computerized tomography. To evaluate the influence of shaft design on the shaping ability of 3 rotary nickel-titanium (NiTi) systems. Sixty curved mesial canals of mandibular molars were used. Specimens were scanned by spiral computerized tomography before and after canal preparation using ProTaper, ProFile, and ProSystem GT rotary instruments. One-millimeter-thick slices were scanned from the apical end point to the pulp chamber. The cross-sectional images from the slices taken earlier and after canal preparation at the apical, coronal, and midroot levels were compared. The mean working time was 137.22 ± 5.15 s. Mean transportation, mean centering ratio, and percentage of area increase were 0.022 ± 0.131 mm, 0.21 ± 0.11, and 76.90 ± 42.27%, respectively, with no statistical differences. It was concluded that all the tested instruments were able to shape curved mesial canals in mandibular molars to size 30 without significant errors. The differences in shaft designs seemed not to affect their shaping capabilities.

Madarati AA, Watts DC, Qualtrough AJE (2008) reviewed the factors that are of utmost importance and in light of these, preventive procedures and measures were suggested. They also emphasized on cleaning and shaping of the root canal system being essential for successful endodontic treatment. However, despite improvements in file design and metal alloy, intracanal file separation was still a problematic incident and can occured mostly without any visible signs or permanent deformation. Only a few studies have reported high success rates of fractured file removal using contemporary techniques. Conflicting results have been reported regarding the clinical significance of retaining separated files within root canals.

Estrela C, Bueno MR, Sousa-Neto MD, Pecora JD (2008) discussed a method to determine root curvature radius by using cone-beam computed tomography (CBCT). The severity of root canal curvature is essential to select instrument and instrumentation technique. The diagnosis and planning of root canal treatment have traditionally been made based on periapical radiography. However, the higher accuracy of CBCT images to identify anatomic and pathologic alterations compared to panoramic and periapical radiographs has been shown to reduce the incidence of false-negative results. In high-resolution images, the measurement of root curvature radius can be obtained by circumcenter. Based on 3 mathematical points determined with the working tools of Planimp® software, it is possible to calculate root curvature radius in both apical and coronal directions. The CBCT-aided method for determination of root curvature radius presented in this article is easy to perform, reproducible and allows a more reliable and predictable endodontic planning, which reflects directly on a more efficacious preparation of curved root canals.

Garg G, Miglani S , Yadav S, Talwar S (2008) compared the fracture resistance of two different rotary Ni Ti instrument systems due to cyclic fatigue. The instruments compared were RaCe and a new rotary system Varitaper. The cyclic fatigue testing was conducted with the instrument rotating freely at two different angles of curvature 45 degree & 90 degree with maximum curvature at 5mm from the tip. Total 60 instruments were tested in the two groups for both angles of curvature. The instruments were rotated at 350 rpm using the ATR motor set at maximum torque, until fracture occurred. The time until fracture was recorded in seconds by using a stopwatch, and the number of rotations to fracture was then calculated and results were statistically analyzed. RaCe performed significantly better than Varitaper in cyclic fatigue testing.

Christ HJ (2008) reviewed the main design philosophies and monotonic and cyclic loading concept. Emphasis was put on a mechanistic approach avoiding a plain reproduction of empirical laws. After a short consideration of fracture as a result of monotonic loading using fracture mechanics basics, the phenomenon occurred as a consequence of cyclic plasticity that were introduced. The development of fatigue damage was treated by introducing the physical processes which were responsible for microstructural changes, led to crack initiation and determined crack propagation. From the current research topics within the area of metal fatigue, two aspects were dealt with in more detail because of their relevance to biomechanics. The first one was the growth behaviour of microstructural short cracks, which controlled cyclic life of smooth parts at low stress amplitudes. The second issue addressed the question of the existence of a true fatigue limit and was of particular interest for components which must had sustained a very high number of loading cycles (very high cycle fatigue).

Johnson E, Lloyd A, Kuttler S, Namerow K **(2008)** selected ProFile 25/.04 instruments manufactured from three variants of Nitinol (1A, 1B & 2AS) and were compared with stock production ProFile 25/.04 instruments and fatigue tested to failure. Cyclic fatigue testing was performed by rotating instruments at 300 RPM in a simulated steel root canal with 5 mm radius and 90° curve until instrument separation. Time to failure was recorded. Torsion testing was undertaken by clamping 3 mm of each instrument tip between brass plates and rotating it at 2 RPM until failure. Data was recorded for torque and angle at fracture. Statistical differences were found with nickel-titanium variant 1B (M-Wire NiTi) nearly 400% more resistant to cyclic fatigue than stock ProFile 25/.04. Torsion testing found differences between all 508 Nitinol groups and M-Wire NiTi. ProFile 25/.04 files manufactured from M-Wire NiTi had significantly greater resistance to cyclic fatigue while maintaining comparable torsional properties.

Cheung GSP and Liu C S (2009) compared the periapical healing of molar root canal treatment using nickel-titanium rotary and stainless steel hand filing techniques and found out that there was a higher incidence of procedural errors and a lower success rate for primary root canal treatment of teeth prepared with stainless steel files compared with the use of NiTi instruments in a continuous reaming action.

Correia SV 2009 tested Ni-Ti files at different temperatures and compared the number of cycles to fracture to the amount of R-phase present at those temperatures using Differential Scanning Calorimetry (DSC) analysis. Forty Eight new unused 25 mm ProFile 0.06 taper (ISO size 35) were used for rotation/flexion assays. They were divided in four groups comprising of 12 files in each group. All files were placed in the test platform so that all of them were subjected to 90º angle of curvature and 10 mm radius of curvature. Bending was imposed at 1 mm from file tip in all cases and rotation was carried out at 300 r.p.m. using a 20:1 handpiece in a motor in the presence of lubricant vaseline. According to the temperature, files were tested at 10 ºC, 20 ºC, 37 ºC, or 65 ºC. The results showed for the average number of cycles to fracture, it varies in an extremely significant way at the tested temperatures.

Extremely significant differences were found between Number of cycles till fracture by the file at 10 ºC (2235 rotations) and Nf determined for any of the other three test temperatures. The number of rotations to fracture at 20 ºC (1498 cycles) differed very significantly from the number of cycles till fracture found at either 37 ºC or 65 ºC. As for the average of the Number of cycles till fracture found at 37 ºC (960 cycles) and at 65 ºC (1021 cycles), they did not differ significantly. It was concluded from the research that the number of cycles to fracture doubled by lowering test temperature from 37 ºC to 10 ºC other conditions remaining the same. This was attributed to the structural state of the Ni-Ti alloy, as R-phase was strongly present at 10 ºC but was insignificantly there at 37 ºC.

Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G (2009) reviewed all the testing methods that evaluated cyclic fatigue of Nickel titanium rotary files. It was discussed that there is no specification or international standard to test cyclic fatigue resistance of endodontic rotary instruments, and a new standard was needed for manufacturers, scientists, and clinicians to define suitable mechanical properties of NiTi rotary instruments for a safe, efficient clinical use and to introduce universally accepted testing devices for experimental evaluation of products or prototypes. Nearly in all studies reported in the endodontic literature, the rotating file was either confined in a glass or metal tube, in a grooved block-and-rod assembly, or in a sloped metal block. There had been no mention of the ‘‘fit’’ of the instrument in the tube or groove. Because the instrument was likely to be loosely fitted, the description of the radius of curvature in the studies was likely to be overstated (i.e. the file was actually bent less severely than reported). Furthermore, each different instrument that fitted loosely inside the simulated canal device followed a more or less severe curvature depending on the stiffness of that file. This would explain the wide variation in the reported fatigue life of endodontic file. These simulated custom made devices permitted the instruments to rotate until fracture using different curvature. It was observed that the resistance of rotary file to cyclic fatigue decreased with an increase in instrument diameter. This was attributed specifically to the metal mass of the instrument in the point of maximum stress. Moreover, it was also observed that the increased severity of the angle and radius of the curve, around which the file rotated, decreased instrument lifespan in vitro and clinically. If instruments of the same dimensions would have been made to follow different trajectories in the test apparatus, a direct comparison between instruments of different brands was difficult to make, and the results obtained thus have been unreliable and inconsistent. It was evident from their review that an international standard was needed to validate a device for cyclic fatigue tests of NiTi rotary endodontic instruments. Ideally, such a device should allow testing of all instruments with a precise trajectory in terms of radius and angle of the curvature and point of the center of the curvature, allowing comparison of different instruments in different canals.

Liu J (2009) studied about a variety of metallurgical laboratory techniques to determine the origin of these improved mechanical properties for new NiTi rotary instruments made up from M wire technology. Tested samples included as-received M-Wire instruments, clinically used M-Wire instruments and conventional instruments made from super elastic NiTi wire. Vickers hardness measurements were made since hardness variations for the same type of alloy has been found to correlate with variations in mechanical properties. The microstructures of the NiTi alloys were revealed by acid etching and examined with an optical microscope and a scanning electron microscope that was also capable of X-ray energy-dispersive spectrometric analyses (SEM/EDS). Wear resistance of clinically used M-Wire instruments was investigated by examining their surfaces with an SEM. The study showed that M-Wire instruments have much higher A_f (austenite-finish) temperatures (over 40°C) than conventional superelastic rotary instruments (below room temperature) and are a mixture of martensite, R-phase and austenite at room temperature. The Vickers hardness of M-Wire instruments is significantly higher than that of conventional rotary NiTi instruments. Better wear resistance was observed with the SEM on clinically used M-Wire instruments, which presented less microcracks and evidence of permanent deformation on the surface compared with surfaces of clinically used conventional NiTi instruments. This improved wear resistance is attributed to increased hardness for surface region of the M-Wire instrument. Acid-etched M-Wire instruments (surfaces and cross-sections) presented a classical lenticular martensite structure when observed with the optical microscope and SEM. EDS analyses of the microstructures of the M-Wire instruments revealed titanium-rich precipitates. It was postulated that increased hardness, which is indicative of higher strength and improved wear resistance, was found for M-Wire instruments, compared with conventional superelastic ProFile instruments, which served as a control for this study. The improved mechanical properties of the M-Wire rotary instruments arose from strengthening mechanisms in the martensitic structure, which were induced by extensive thermomechanical processing.

Larsen CM, Watanabe I, Glickman GN, He J (2009) performed an experiment to determine if Twisted File and ProFile GT Series X were more resistant to cyclic fatigue compared with traditionally ground NiTi rotary instruments such as EndoSequence and ProFile. Size #25 TF, ES, and PF and size #20 GTX with .04 and .06 tapers were tested in a simulated canal with 60º angle of curvature and a 3-mm radius. Twisted File was significantly more resistant to cyclic fatigue. The new manufacturing processes appeared to offer greater resistance to cyclic fatigue in a simulated canal model.

Yahata J, Yoneyama T (2009) investigated the effect of heat treatment on the bending properties of nickel-titanium endodontic instruments in relation to their transformation behaviour. Nickel-titanium super-elastic alloy wire (1.00 mm Ø) was processed into a conical shape with a 0.30 mm diameter tip and 0.06 taper. The heat treatment temperature was set at 440 or 500 degrees C for a period of 10 or 30 min. Non heat-treated specimens were used as controls. The phase transformation behaviour was examined using differential scanning calorimetry. A cantilever-bending test was used to evaluate the bending properties of the specimens. The transformation temperature was higher for each heat treatment condition compared with the control. Two clear thermal peaks were observed for the heat treatment at 440 degrees C. The specimen heated at 440 degrees C for 30 min exhibited the highest temperatures for M(s) and A(f), with subsequently lower temperatures observed for specimens heated at 440 degrees C for 10 min, 500 degrees C for 30 min, 500 degrees C for 10 min, and control specimens. The sample heated at 440 degrees C for 30 min had the lowest bending load values ($P < 0.05$), both in the elastic range (0.5 mm deflection) and in the super-elastic range (2.0 mm deflection). The influence of heat treatment time was less than that of heat treatment temperature. It was postulated that change in the transformation behaviour by heat treatment might be effective in increasing the flexibility of nickel-titanium endodontic instruments.

Alapati SB, Brantley WA, Iijima M, Clark WAT, Kovarik L, Buie C, Liu J, Johnson WB (2009) introduced a novel thermomechanical processing procedure that yielded improved mechanical properties compared with conventional SE austenitic NiTi wires used for manufacture of rotary instruments. Specimens from 2 batches of M-Wire prepared under different processing conditions and from 1 batch of standard-processed SE wire for rotary instruments were examined by scanning transmission electron microscopy, temperature-modulated differential scanning calorimetry, micro-x-ray diffraction, and scanning electron microscopy with x-ray energy-dispersive spectrometric analyses. The presence of Ti_2Ni precipitates in both microstructures indicated that M-Wire and the conventional SE wire for rotary instruments are titanium-rich.

Lopes HP, Ferreira AAP, Elias CN, Moreira EJL, Oliveira JCM, Siqueira JF (2009) evaluated the effects of rotational speed on the number of cycles to fracture of rotary NiTi instruments used in preparation of curved canals. The NiTi instruments were subjected to cyclic fatigue testing. Although several factors influenced the cyclic fatigue resistance of instruments, the role of the rotational speed remained uncertain. ProTaper Universal instruments F3 and F4 were used in an artificial curved canal under rotational speeds of 300 rpm or 600 rpm. The artificial canal was made of stainless steel, with an inner diameter of 1.5 mm, total length of 20 mm, and arc at the end with a curvature radius of 6 mm. The arc length was 9.4 mm and 10.6 mm on the straight part. The number of cycles required to fracture was recorded. Fractured surfaces and the helical shafts of the fractured instruments were analyzed by scanning electron microscopy. The results showed approximately a 30% reduction in the observed number of cycles to fracture as rotational speed was increased from 300 to 600 RPM. The morphology of the fractured surface was always of ductile type, and no plastic deformation was observed on the helical shaft of fractured instruments. The findings for both F3 and F4 ProTaper instruments revealed that the increase in rotational speed significantly reduced the number of cycles to fracture.

Correia SV, M.T. Nogueira, R.J.C. Silva, L. Pires Lopes, F. M. Braz Fernandes (2009) stated that NiTi endodontic files allow for clinical enlargement of harshly curved root canals. However, files rotated under severe flexion might fracture unexpectedly, remain inside teeth and thus, hinder treatment outcome. ProFile .06(35) are among the most commonly used rotary files. 10 of these brand new instruments were used to perform DSC on their cutting regions and determine the amount of R-phase present at 10, 20, 37, and 65ºC, both during cooling and heating programmed cycles. Another 48 new ProFile .06(35) instruments underwent rotation/flexion assays at 300 rpm and 10 mm radius of curvature. Files were divided into four groups of 12 instruments each. Each group was tested at 10, 20, 37, and 65ºC. The number of cycles to fracture (Nf) and the length of the broken segment (Lf) were determined for each tested file. Results show no statistically (α=0,05) as for Lf in all groups. On the contrary, Nf depends highly on testing temperature: as temperature increases from 10 to 37 ºC, Nf strikingly decreases; from 37 and 65 ºC, no significant changes in Nf occur. As for DSC results, it is clearly shown that R-phase is most abundant at 10 ºC and consistently decreases up to 37ºC, both during heating and cooling; from 37 to 65 ºC, the quantity of R-phase in the alloy is negligible. In conclusion, it is shown that fatigue resistance in ProFile .06(35) instruments is not only highly enhanced but also proportional to the amount of R-phase in the alloy.

Al Hadlaq S M (2010) conducted a study to evaluate the cyclic flexural fatigue failure resistance of Revo S Shaper Universal rotary NiTi files and compared it to two other rotary NiTi files with similar size and taper, the Hero Shaper and the ProFile. Fifteen each of Revo-S Shaper Universal, Hero Shaper and ProFile rotary NiTi files all with the same tip diameter and taper (ISO size 25 with 0.06 taper) were assessed. The testing device was modified to fit the files used in this study by making the groove in the testing block slightly wider. Briefly, the device consisted of a steel base with a handpiece holder that positioned the hand-piece in a precise relationship to the cyclic flexural fatigue-testing block. The stainless steel cyclic flexural fatigue-testing block had a 5mm radius curved groove that was 1 mm deep and 2 mm wide. The cyclic flexural fatigue-testing block was positioned relative to the horizontal plane at an angle that allowed the hand-piece mounted file to conform to the curve of the testing block groove without the need for a covering cylinder. The resulting angle of curvature was 51° according to the Schneider method. During each testing run, the hand-piece mounted file was positioned exactly to the same point on the testing block groove. Each testing cycle consisted of three files, one Revo-S, one Hero Shaper, and one ProFile. To minimize bias, each testing cycle was started with a different file type in a non-random sequencing to ensure that each file type was used first in one-third of the cycles, second in one-third of the cycles, and third in one-third of the cycles. While testing the files, the testing block groove was lubricated with an oil. The files were rotated at a constant speed of 300 RPM using a 16:1 reduction hand-piece powered by a torque-controlled electric motor. Time in seconds to instrument fracture was monitored visually using a 1/100 second chronometer. The number of revolutions to failure was calculated. The findings of the study showed Revo-S files were the least resistant to cyclic flexural fatigue failure followed by the Hero Shaper files. The ProFile files were the most resistant to cyclic flexural fatigue failure. The mean time to cyclic flexural fatigue failure was 96.1 + 17.3 seconds for the Revo-S Shaper Universal, 120.5 + 24.3 seconds for the Hero Shaper, and 154.6 + 14.9 seconds for the ProFile. It was concluded that the Revo-S Shaper Universal rotary NiTi files were less resistant to cyclic flexural fatigue failure than the Hero Shaper and the ProFile files with similar tip diameter and taper.

Al-Hadlaq SM, AlJarbou FA, AlThumairy RI (2010) investigated cyclic flexural fatigue resistance of GT series X rotary files made from the newly developed M-wire nickel-titanium alloy compared with GT and Profile nickel-titanium files made from a conventional nickel-titanium alloy. Fifteen files, size 30/0.04, of each type were used to evaluate the cyclic flexural fatigue resistance. A simple device was specifically constructed to measure the time each file type required to fail under cyclic flexural fatigue testing. The results of this experiment indicated that the GT series X files had superior cyclic flexural fatigue resistance than the other 2 file types made from a conventional nickel-titanium alloy (P = .004). On the other hand, the difference between the Profile and the GT files was not statistically significant. The findings of this study suggest that size 30/0.04 nickel-titanium rotary files made from the newly developed M-wire alloy have better cyclic flexural fatigue resistance than files of similar design and size made from the conventional nickel-titanium alloy.

Condorelli GG, Bonaccorso A, Smecca E, Sehafer E, Cantatore G, Tripi TR (2010) assessed the failure mechanism of rotary NiTi instruments by chemical, structural and morphological analyses to find out the effects of surface and bulk treatments on their resistance to fatigue fracture. Thermal treatment (350–500°C) was performed on electropolished (EP) and non-electropolished (Non-EP) RACE NiTi rotary files of length 25mm ISO no.25 taper 0.04. Total fnumber of files tested were seventy two. Bulk and surface chemical composition and crystallographic structures were determined by energy-dispersive X-ray spectroscopy, X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD) to evaluate the effects of thermal treatment and electropolishing on the NiTi alloy. Fatigue tests of all instruments were performed. Surface morphology before and after the tests, and fractured section were analysed using scanning electron microscopy to determine crack extensions. The results obtained showed that before thermal treatment, significant differences in fatigue resistance between Electropolished and Non-Electropolished instruments (the number of revolutions to failure(N_f) was 385 and 160, respectively) were attributed to differences in the surface morphology of the instruments. SEM analysis of the fracture surfaces indicated that flexural fatigue fractures occurred in two steps: first by a slow growth of initial cracks and then rapid rupture of the remaining material. Thermal treatment did not affect the surface morphology but resulted in significant changes in the instrument bulk with the appearance of an R-phase and an improved fatigue resistance. Indeed after treatment at 500°C, N_f increased up to 829 and 474 for EP and Non-EP instruments respectively. It was concluded that both thermal treatment and electropolishing improved the resistance of NiTi rotary instruments against fatigue fracture. EP reduced machining marks and surface scratches and altered the propagation path of fatigue crack. Tortuous paths of surface cracks were observed in the absence of machining marks. XRD analysis revealed that thermal treatment led to the formation of an R-phase that increased the fatigue resistance of NiTi rotary instruments.

Gupta M, Mulay S (2010) compared fracture resistance of Protaper, Hero Shapers and Twisted Files NiTi instrument systems due to cyclic fatigue in curved canals. The purpose of this study was to investigate the effect of change in manufacturing process on cyclic fatigue resistance. This was evaluated by comparing ten Twisted files with NiTi instruments produced by a traditional grinding process that is Protaper (Ten in number) and Hero Shapers (Ten in number). The methodology involved testing the cyclic fatigue of curved root canal instrument rotating at 375 rpm. A simulated model using cylindrical pins was created such that, the instrument will bend at 60 degrees during function, maximum curvature being 5 mm from the tip of the instrument. The number of rotations and time taken for the instrument to fracture was recorded in seconds using a stopwatch. The results were analyzed statistically. It was observed that twisted files performed significantly better than Protaper & Hero Shapers. However no statistically significant difference between Protaper & Hero Shapers was observed. It was concluded that the principle of respecting grain structure during manufacturing process is a key element in withstanding stress. Maintaining the grain structure of NiTi during file manufacture, resulted in a stronger and more flexible rotary instrument. The two groups i.e. Protaper and Hero Shapers had a relatively narrow range of elasticity due to alteration in grain structure caused by grinding process. Moreover, grinding across the grain structure created microfracture points and defects along the length of the instrument. These defects caused stress concentration points that further weakened the instruments and led to separation of the instrument.

Avoaka MC and Haikel Y (2010) performed a study to evaluate the influence of the axial movement and the angle of curvature on fatigue of Ni-Ti ProFile R rotary endodontic instruments. Ni-Ti ProFile R rotary instruments, 25 mm long in the range of ISO size 15 to 40 with two tapers (00.4 and 0.06) were evaluated. Two groups consisted of the instruments with axial movement and those without axial movement. The axial movement was in the order of 2mm in corono-apical direction with a frequency of 1Hz. The concave radii incorporating a notched V-form for guiding the instruments were: 5 mm, 7.5 mm and 10 mm. The results revealed that axial movement reduces the risk of the instrument separation during the endodontic treatment.

Peters O A and Paque F (2010) reviewed most recent trends in Ni-Ti technology, instrument design, and usage parameters. The review provided clinicians a knowledge base for evidence-based practice, thus maximizing the benefits from the selection of Ni-Ti rotary instruments for root canal treatments. It was revealed in their review that stainless steel can withstand up to 20 complete bending cycles, while Ni-Ti can be bent up to 1,000 times. This difference was related to the different atomic structure of the two alloys, in particular the transition from austenite to martensite that occurs in Ni-Ti. It was postulated that the transformation characteristic depended on the ambient temperature and thermal pretreatment of the alloy but usually takes place below temperatures in the dental setting so that the alloy is in the austenitic form. In addition to the transition from austenite to martensite under load, via twinned martensite, there was also a transition from R-phase, a temperature-dependent crystalline structure, to martensite. This transition further contributed to the ability of Ni-Ti to absorb stresses and thus to resist fatigue. Moreover it was told that more rigid files can withstand more torque but are susceptible to fatigue. The greater the amount and the more peripheral the distribution of metal in cross section, the stiffer a file would be. Therefore, a file with greater taper and larger diameter was more susceptible to fatigue failure. The article stated that material imperfections such as microfractures and milling marks were believed to act as fracture initiation sites. Such surface imperfections after manufacturing could easily be removed by electropolishing process.

Plotino G, Grande NM, Cordarv M, Testarelli L, Gambarini G (2010) investigated the influence of the trajectory of NiTi rotary instruments on the outcome of cyclic fatigue tests. Ten ProFile and Mtwo instruments tip size 20 taper 0.06 and tip size 25 taper 0.06 were tested in two simulated root canals with an angle of curvature of 60 degree and radius of curvature of 5 mm but with different shape. Geometrical analysis of the angle and radius of the curvature that each instrument followed inside the two different artificial canals was performed on digital images. The instruments were then rotated until fracture at a constant speed of 300 rpm to calculate the number of cycles to failure (NCF) and the length of the fractured fragment. Mean values were calculated. The results showed that the shape of the artificial root canal used in cyclic fatigue study influenced the trajectory of the instrument. This difference was reflected by the NCF measured for the same instrument in the different artificial root canals and by the impact of the type of canal on both the NCF and fragment length. It was concluded that small variations in the geometrical parameters of the curvature of an instrument subjected to flexural fatigue could have a significant influence on the results of fatigue tests.

Gao Y, Gutmann JL, Wilkinson K, Phillips G, Johnson WB (2010) compared the cyclic fatigue resistance of ProFile Vortex rotary instruments made of two different raw materials: M-Wire and regular superelastic wire (SE-wire) at two different rotational speeds. Two hundred M-Wire blanks and 200 SE-wire blanks (similar to NiTi wires used in ProFile ISO instruments) were produced according to different thermomechanical processes. Based on the mechanical design of commercially available ProFile Vortex instruments (25 mm in length, same tip size 30, taper 0.04 and 0.06), both M-Wire and SE-wire were machined to produce 100 units for each 30.04 and 0.06 using the same grinding machine by the same operator. Twenty instruments of each type were randomly selected for fatigue resistance testing at two different rotational speeds, 300 and 500 rpm, comprising a total of eight groups. A total of 160 ProFile Vortex files (40 units of 30.04 made of M-Wire, 40 units of 30.04 made of SE-wire, 40 units of 30.06 made of M-Wire, and 40 units of 30.06 made of SE-wire) were used for the cyclic fatigue test in this study. All instruments were tested in an artificially constructed stainless steel canal with a 5-mm radius and 90 degree angle of curvature by the same operator at an ambient temperature in general accordance with the cyclic fatigue testing protocol. The time to failure was recorded, and the total number of cycles to failure was calculated and compared for a total of 160 samples. Fracture surfaces of broken instruments were also observed under scanning electron microscopy. Over 50% of broken files made of SE-wire exhibited multiple crack initiation sites compared with the single crack initiation on files made of M-Wire. The results showed overall, there were significant differences in rotary instruments made of different materials. However, for rotary instruments made from the same material (either M-Wire or SEwire), there was no significant difference of cyclic fatigue life under different rotational speeds (300 and 500 rpm). It was concluded that ProFile Vortex files made of M-Wire exhibited superior cyclic fatigue resistance (150% longer in fatigue life) compared with those made of regular SE-wire at two tested speeds (300 and 500 rpm).

Zinelis S, Eliades T, Eliades G (2010) evaluated the elemental composition, microstructure and hardness of Ni-Ti endodontic instruments and to assess the relevance of shape memory and superelastic properties. Ten brands of Ni-Ti endodontic instrument were evaluated (EndoSequence, Ergoflex K, FlexMaster, Hero 642, Hyflex X-File, K3 Endo, Liberator, NRT, Profile and ProTaper). After embedding in resin and metallographic preparation, the elemental composition, structure and hardness were evaluated employing SEM/energy-dispersive X-ray spectrometer (EDX), X-ray diffraction (XRD) and microhardness measurements. The correlation between Ni content and microhardness was also examined. All the instruments were comprised of Ni (52.1–56.2%wt) and Ti (43.8 to 47.9%wt). The ProTaper, Liberator, ProFile and K3 instruments demonstrated higher Ni content than Hylfex X-File but lower than Hero 642, NRT and Ergoflex. EndoSequence and FlexMaster had the highest Ni content. XRD analysis revealed the presence of the austenitic structure in all instruments. No correlation was found between Ni content and hardness among the instruments tested. Microstructural and hardness data confirm that the Ni-Ti instruments were manufactured by cold worked Ni-Ti and do not possess shape memory or superelastic properties. It was concluded that the endodontic instruments tested were manufactured from cold worked Ni-Ti wires and thus neither had shape memory nor superelastic properties.

Kim HC, Yum J, Hur B, Cheung GSP (2010) compared the fatigue resistance of traditional, ground nickel-titanium rotary instruments with the Twisted File and to examine the fracture characteristics of the fatigued fragment. Size #25, 0.06 tapered, TF , RaCe , Helix, and ProTaper F1 were examined with scanning electron microscope for surface characteristics before subjected to a cyclic (rotational bending) fatigue test. The time until fracture was recorded to calculate the number of revolutions for each instrument. The fragments were examined with scanning electron microscope both in lateral view and fractographically. TF showed a significantly higher resistance to cyclic fatigue than other nickel-titanium files that were manufactured with a grinding process. The path of crack propagation appeared to be different for electropolished (TF and RaCe) versus non-electropolished (Helix and ProTaper) instruments. Although all specimens showed similar fractographic appearance, which indicated a similar fracture mechanism, instruments with abundant machining grooves seemed to have a higher risk of fatigue.

Gavini G, Pessoa OF, Barletta FB, Vasconcellos MAZ, Caldeira CL (2010) assessed cyclic fatigue resistance in rotary nickel-titanium instruments submitted to nitrogen ion implantation by using a custom-made cyclic fatigue testing apparatus. Thirty K3 files, size #25, taper 0.04, were divided into 3 experimental groups as follows: group A, 12 files exposed to nitrogen ion implantation at a dose of 2.5×10^{17} ions/cm^2, accelerating voltage of 200 kV, currents of 1 µA/cm^2, 130°C temperature, and vacuum conditions of 10×10^{-6} torr for 6 hours; group B, 12 nonimplanted files; and group C, 6 files submitted to thermal annealing for 6 hours at

130°C. One extra file was used for process control. All files were submitted to a cyclic fatigue test that was performed with an apparatus that allowed the instruments to rotate freely, simulating rotary instrumentation of a curved canal (40-degree, 5-mm radius curve). An electric motor handpiece was used with a contra-angle of 16:1 at an operating speed of 300 rpm and a torque of 2 N-cm. Time to failure was recorded with a stopwatch in seconds and subsequently converted to number of cycles to fracture. Ion-implanted instruments reached significantly higher cycle numbers before fracture (mean, 510 cycles) when compared with annealed ones (mean, 428 cycles) and nonimplanted files (mean, 381 cycles). The results showed that nitrogen ion implantation improves cyclic fatigue resistance in rotary nickel-titanium instruments. Industrial implementation of this surface modification technique would produce rotary nickel-titanium instruments with a longer working life.

Park SY, Cheung GSP, Yum J, Hur B, Park JK, Kim HC (2010) evaluated cyclic fatigue of nickel-titanium (NiTi) rotary instruments and studied extensively, but there is little information available on torsional fracture. Moreover, a clinical repeated locking effect was not considered in previous studies that evaluated torsional resistance of NiTi instruments. Thus, this study was aimed to compare the repetitive torsional resistance of various NiTi instruments with clinical relevance. Five brands of NiTi rotary instruments were selected: Twisted File and RaCe systems, both with an equilateral triangular cross-section, and the ProTaper, Helix, and FlexMaster, which had a convex triangular cross-section. Five millimeters of the tip of each file was embedded in composite resin block, and uniform torsional stresses (300 rpm, 1.0 N.cm) were applied repetitively by an endodontic motor with auto-stop mode until the file succumbed to torsional failure. The number of load applications leading to fracture was recorded. All fracture surfaces were examined under the SEM. Results were analyzed nonparametrically with $\alpha = 0.05$. Under the mode of load applications in this study, TF had the lowest and FlexMaster the highest torsional resistance among the groups. Scanning electron microscopy examination revealed a typical pattern of torsional fracture for TF, RaCe, and ProTaper that was characterized by circular abrasion marks and skewed dimples near the center of rotation. In addition to these marks, Helix and FlexMaster presented a rough, torn-off appearance. It was concluded that files of same cross-sectional design may exhibit different resistance to fracture probably as a result of the manufacturing process.

Abide AE, Himel V, Hagan J (2011) evaluated the effects of manufacturing techniques on cyclic fatigue and torsional properties of nickel-titanium rotary endodontic files. Tested files included Profile Vortex, Twisted files, Series 10 NiTi files, Series 10 CM wire, Typhoon NiTi and Typhoon CM wire files. All the files tested were of ISO size 25/0.04 and ISO size 40/0.04. The simulated model had a curvature of 60 degree with a 5mm of curvature. All the files were rotated at manufactures recommended speed. Time was recorded until file fracture. The results showed that CM wire files had highest cyclic fracture resistance as compared to other tested files.

Ebihara A, Yahata Y, Miyara K, Nakano K, Hayashi Y, Suda H (2011) evaluated the bending properties and shaping abilities of nickel–titanium endodontic instruments processed by heat treatment. K3 files were heated for 30 min at 400 °C (group 400), 450 °C (group 450) and 500 °C (group 500). Files that were not heat treated served as controls. A cantilever-bending test was used to evaluate changes in specimen flexibility caused by heat treatment. Curved root canal models were prepared. The times required for preparation, deformation and fracture were recorded. Pre- and postoperative images were superimposed. The amounts of resin removed from both the inner and the outer sides of the curvature in the apical 6 mm were determined. In the cantilever-bending test, load values of the control group and group 500 were higher than those of groups 400 and 450 at the elastic range. At the superelastic range, the bending load of the control group was the highest amongst all groups. Regarding shaping ability, in the control group, root canals at the apex were transported more to the outer side of the curvature compared with those of all heat-treated groups. Root canals of group 400 at 3 mm from the apex were transported less compared with those of other groups. No significant difference was found in working time amongst the groups. In group 450, there was no plastic deformation or fracture of the file. It was postulated that heat treatment of files might improve their flexibility, making them more effective for preparation of curved canals. (Heat treatment of nickel–titanium rotary endodontic instruments: effects on bending properties and shaping abilities.

George GK, Sanjeev K, Sekar M (2011) evaluated the effect of deep dry cryotherapy on the cyclic fatigue resistance of rotary nickel titanium instruments. Twenty K3, RaCe and Hero Shaper nickel titanium instruments, size 25, 0.06 taper, were taken for this study. Ten files were untreated (control group) and 10 files were deep dry cryogenically treated. Both the untreated and cryotreated files were subjected to cyclic fatigue evaluation. Cyclic fatigue was evaluated as the number of cycles it took for fracture of the instrument within a stainless steel shaping block of specific radius and angle of curvature. The results showed a significant increase in the resistance to cyclic fatigue of deep dry cryotreated NiTi files over untreated files. It was concluded that deep cryotherapy improved the cyclic fatigue of NiTi rotary endodontic files.

Pelton AR (2011) reviewed the Nitinol fatigue especially its microstructure and fatigue mechanism. The literature demonstrated that cyclic transformations between austenite and martensite are more complicated than those that elastic (continuum) crystallographic theories predicted. Thermal and mechanical cycling process created plasticity, which was due to the effects of moving martensite interfaces. Accumulation of the dislocations modified transformational behaviour, resulted in changes in transformation temperatures, strain (under stress-control) and stress (under strain-control). It was shown that processing had a major effect on fatigue properties, whereby optimized thermomechanically treated microstructures yielded more stable behaviour than annealed microstructures.

Rodrigues RC, Lopes HP, Elias CN, Amaral G, Vieira VT, Martin ASDC (2011) evaluated, static and dynamic cyclic fatigue resistance by finding out the number of cycles to fracture (NCF) of 2 types of rotary NiTi instruments Twisted File manufactured by a proprietary twisting process and RaCe files manufactured by grinding. Twenty Twisted Files (TFs) and 20 RaCe files #25/.006 taper instruments were allowed to rotate freely in an artificial curved canal at 310 rpm in a static or a dynamic model until fracture occurred. The results obtained showed that the fracture occurred at the point of maximum flexure in the midpoint of the curved segment. The

NCF was significantly lower for RaCe instruments compared with TFs. The NCF was also lower for instruments subjected to the static test compared with the dynamic model in both groups. Scanning electron microscopic analysis revealed ductile morphologic characteristics on the fractured surfaces of all instruments and no plastic deformation in their helical shafts. It was concluded that rotary NiTi endodontic instruments manufactured by twisting presented greater resistance to cyclic fatigue compared with instruments manufactured by grinding.

Sushma J, Prashant PJ (2011) reviewed recent developments in the identification of new agents to sterilize infected root canal. It was found that the primary root canal infections were polymicrobial, typically dominated by obligatory anaerobic bacteria. The most frequently isolated microorganisms before root canal treatment included Gram-negative anaerobic rods, Gram-positive anaerobic cocci, Gram-positive anaerobic and facultative rods, *Lactobacillus* species, and Gram-positive facultative *Streptococcus* species. The obligate anaerobes were rather easily eradicated during root canal treatment. On the other hand, facultative bacteria such as non-mutans *Streptococci, Enterococci, and Lactobacilli*, once established, were more likely to survive chemomechanical instrumentation and root canal medication. In particular *Enterococcus faecalis* gained attention in the endodontic literature, as it could frequently be isolated from root canals in cases of failed root canal treatments. In addition, Yeast has also been found in root canals associated with therapy-resistant apical periodontitis. A large number of substances have been used previously as root canal irrigants including acids (citric and phosphoric), chelating agent (ethylene diaminetetraacetic acid EDTA), proteolytic enzymes, alkaline solutions (sodium hypochlorite, sodium hydroxide, urea, and potassium hydroxide), oxidative agents (hydrogen peroxide and GlyOxide), local anesthetic solutions and normal saline. The most widely used endodontic irrigant was 0.5%-6.0% sodium hypochlorite because of its bactericidal activity and ability to dissolve vital and necrotic organic tissue. However it has been shown that NaOCl solutions exert no effects on inorganic components of smear layer. Chelant and acid solutions have been recommended for removing the smear layer from instrumented root canals. Chlorhexidine digluconate, a potent antiseptic, has been used recently for as 2% concentration for root canal irrigant. Despite its usefulness as a final irrigant, chlorhexidine could not be advocated as the main irrigant in standard endodontic cases because (a) chlorhexidine was unable to dissolve necrotic tissue remnants, and (b) chlorhexidine was less effective on Gram-negative than on Gram-positive bacteria. Newer root canal irrigants advocated were MTAD, Tetraclean, Electrochemically Activated Solutions, Ozonated Water, Photon-activated disinfection and herbal irrigants(Triphala extract and green tea polyphenols). It was summarized that Triphala and GTPs were proven to be safe, containing active constituents that have beneficial physiologic effect apart from its curative property such as antioxidant, antiinflammatory, and radical scavenging activity and may have an added advantage over the traditional root canal irrigants.

Shen Y, Zhou H, Zheng Y, Campbell L, Peng B, Haapasalo M (2011) evaluated the fracture resistance of NiTi instruments from a novel controlled memory NiTi wire (CM Wire). Instruments of ProFile, Typhoon (TYP), Typhoon CM (TYP CM), DS-SS0250425NEYY (NEYY), and DS-SS0250425NEYY CM (NEYY CM) size 25/0.04 were subjected to rotational bending at the curvature of 35 and 45 degree in air at the temperature of 23+ 2°C and the number of revolutions to fracture

(N_f) was recorded. The fracture surface of all fragments was examined by a scanning electron microscope. The crack-initiation sites, the percentage of dimple area to the whole fracture cross section, and the surface strain amplitude (ea) were noted. The results obtained showed the new CM wire alloy yielded an improvement of over three to eight times in N_f of CM files than that of conventional NiTi files. The vast majority of CM instruments (50%-92%) showed multiple crack origins, whereas most instruments made from conventional NiTi wire (58%-100%) had one crack origin. The values of the fraction area occupied by the dimple region were significantly smaller on CM NiTi instruments compared with conventional NiTi instruments. The square (NEYY CM) versus the triangular (TYP CM) configuration showed a significantly different lifetime on CM wire at both curvatures. It was concluded that the material property had a substantial impact on fatigue lifetime. Instruments made from CM Wire had a significantly higher N_f and lower surface strain amplitude than the conventional NiTi wire files with identical design.

Shen Y, Zhou HM, Zheng Y, Haapasalo M (2011) examined the phase transformation behavior and microstructure of NiTi instruments from a novel controlled memory NiTi wire (CM wire). Instruments of EndoSequence (ES), ProFile (PF), ProFile Vortex (Vortex), Twisted Files (TF), Typhoon (TYP), and Typhoon CM (TYP CM), all size 25/.04, were examined by differential scanning calorimetry (DSC) and x-ray diffraction (XRD). Microstructures of etched instruments were observed by optical microscopy and scanning electron microscopy with x-ray energy-dispersive spectrometric (EDS) analyses. The DSC analyses showed that each segment of the TYP CM and Vortex instruments had an austenite transformation completion or austenite-finish (A_f) temperature exceeding

37°C, whereas the NiTi instruments made from conventional superelastic NiTi wire (ES, PF, and TYP) and TF had A_f temperatures substantially below mouth temperature. The higher A_f temperature of TYP CM instruments was consistent with a mixture of austenite and martensite structure, which was observed at room temperature with XRD. All NiTi instruments had room temperature martensite microstructures consisting of colonies of lenticular features with substantial twinning. EDS analysis indicated that the precipitates in all NiTi instruments were titanium-rich, with an approximate composition of $Ti_{(2)}Ni$. The TYP CM and Vortex instruments with heat treatment contribute to increase austenite transformation temperature. The CM instrument had significant changes in the phase transformation behaviour compared with conventional superelastic NiTi instruments.

Sanghvi Z and Mistry K (2011) reviewed the design features of different rotary instruments used for pulp space preparation. Individual design features that were believed to affect the performance of NiTi rotary instruments included variability of taper, rake angle, cross-sectional geometry, tip configuration, design of blades, helical angle and pitch. These design features influenced flexibility, cutting efficiency and safety. They observed that among the NiTi rotary file system, some have acting cutting blades and no radial land increased root canal cleanliness by removing smear layer whereas others that had passive cutting edges with radial lands seemed to burnish the smear layer. It was the combination of non-cutting tip and radial land that kept a file centered in the canal. A radial land was defined as a surface that projects axially from the central axis, between flutes, as far as the cutting edge. It was explained by the term blade support. Blade support was defined as the amount of material supporting the cutting blades of the instrument. This part of the file was called the radial land. This design feature was critical to the instrument. The less the blade support (the amount of metal behind the cutting edge) the less resistant the instrument had to torsional or rotary stresses. Most rotary files derive their strength from the mass of material in the core. Peripheral strength could also be added to a file by extending the width of the radial land.

Testarelli L, Al-Sudani D, Vincenzi V, Giansiracusa A, Grande NM, Gambarini G (2011) evaluated the bending properties of Hyflex instruments, which exhibit a lower percent in weight of nickel (52 Ni %wt) and compared them with other commercially available nickel-titanium (NiTi) rotary instruments. Ten instruments with tip size 25, 0.06 taper of each of the following NiTi rotary instrumentation techniques were selected for the study: Hyflex, EndoSequence, ProFile, Hero, and Flexmasters. All instruments from each group were tested for stiffness by comparing their bending moment when they attained a 45-degree bend. Experimental procedures strictly followed testing methodology described in ISO 3630-1. All data were recorded and subjected to statistical evaluation. The results revealed that Hyflex files were found to be the most flexible instruments, with a significant difference in comparison with the other instruments. Among the other files, a significant difference has been reported for EndoSequence instruments compared with ProFile, Hero, and FlexMaster, whereas no significant differences have been reported among those 3 files.

You SY, Kim HC, Bae KS, Baek SH, Kum KY, Lee W (2011) evaluated the shaping ability of reciprocating motion when compared with continuous rotation motion in curved root canals using NiTi rotary Protaper files. The mesiobuccal and distobuccal canals of 20 extracted maxillary molars with curvatures of 20-45 degrees were instrumented with a series of ProTaper rotary files. The canals in the continuous rotation motion (CM) group (n = 20) were prepared by using continuous rotation with pecking motion, whereas the canals in the reciprocating motion (RM) group (n = 20) were prepared with reciprocating motion (clockwise 140 degrees and counter clockwise 45 degrees). Basic geometric parameters such as curvature, root canal volume, surface area, and structure model index (SMI) before and after canal shaping were evaluated by using micro-computed tomography. The degrees and directions of transportation were also measured. The results showed that there were no significant differences between the 2 groups in canal curvature, volume, surface area, and SMI categories measured before preparation. Changes in curvature, root canal volume, surface area, and SMI were not affected by the instrumentation technique used. There were no significant differences in the degrees and directions of transportation between CM and RM groups. The application of reciprocating motion during instrumentation did not result in increased apical transportation when compared with continuous rotation motion, even in the apical part of curved canals. It was postulated that reciprocating motion might be an attractive alternative method to prevent procedural errors during root canal shaping.

Lee MH, Versluis A, Kim BM, Lee CJ, Hur B, Kim HC (2011) investigated cyclic fatigue resistance of various nickel-titanium (NiTi) rotary files under various root canal curvatures by correlating cyclic fatigue fracture tests with finite-element analysis (FEA). Four NiTi rotary instruments with different cross-sectional geometries but comparable sizes were selected for this study: ProTaper, ProFile, HeroShaper and Mtwo. The ProFile and HeroShaper files were of size 30/.06 taper, the Mtwo was of size 30/.05 taper, and the ProTaper was F3. The cyclic fatigue test was conducted in a custom-made device that simulated canals with 25°, 35°, and 45° curvature. For the FEA, the file models were meshed, and 17-mm long curved canals were modeled to have same curvatures as the cyclic fatigue tests. Numerical analysis was performed to determine the stress distributions in the NiTi instruments while they rotated in the simulated curved canals. ProTaper (the stiffest instrument) showed the least cyclic fatigue resistance and highest stress concentration for all tested curvatures, whereas Mtwo showed the best cyclic fatigue resistance. A comparison between the FEA and fatigue results showed that when stresses increased, the number of instrument rotations to fracture decreased. Maximum stresses in the instruments predicted the approximate location of the fatigue fracture. The stiffer instrument had the highest stress concentration in FEA and the least number of rotations until fracture in the cyclic fatigue test. Increased curvature of the root canal generated higher stresses and shortened the lifetime of NiTi files.

Casper RB, Roberts HW, Roberts MD, Himel VT, Bergeron BE (2011) compared the effects of multiple autoclaving cycles on the torsional load resistance of these 3 new rotary endodontic files Recent innovative manufacturing techniques have produced nickel-titanium (NiTi) rotary instruments with reports of superior properties compared with standard NiTi files. These include Profile Vortex made from M-Wire (PV), Twisted Files (TF), and 10 Series files made from CM Wire (CM). Sterilization is recommended before use and is repeated if files are reused and/or carried forward between cases. PV, TF, and CM files (n = 100; size 25/.04) were divided into 5 groups (n = 20). Files were steam autoclaved for 1, 2, 3, and 7 sterilization cycles. A control group was not subjected to autoclaving. Files were tested in a torsiometer in general accordance with ISO 3630-1 standards. Torsional load and degrees of rotation to failure were recorded. Autoclave cycles had no significant overall effect on file performance for any of the instrument systems tested. PV and CM displayed significantly greater resistance to torsional load than TF but were not different from each other. Angular deflection values for TF and CM were significantly higher than for PV, with TF demonstrating greater rotational distortion than CM. Repeated steam autoclaving did not affect the torsional resistance for unused files of the systems evaluated.

Lopes HP, Chiesa WMM, Correia NR, Navegante NC , Elias CN, Moreira EJL, Chiesa BEC (2011) evaluated the effects of curvature location along an artificial canal on cyclic fatigue (CF) of an Mtwo rotary instrument, verifying the number of cycles to fatigue fracture (NCF) and morphologic characteristics of the fractured instruments. CF testing of instruments was performed in artificial canals with curvature radii of 10 mm and arc lengths of 11 mm. Mtwo rotary instruments size 40, 0.04 taper were used in 2 groups (n = 10): group A, curvature positioned on middle part; group B, apical curvature. All instruments were rotated until fracture. The number of cycles to failure was registered. Fractured surfaces and the helical shafts of the instruments were analyzed by scanning electron microscopy. NCF for groups A and B had significant statistic differences. The highest values were found in the group where the curvature was positioned on the apical part of the canal. No plastic deformation was observed on the helical shafts. The number of cycles to fracture of the Mtwo instruments increased when the arc was changed from the middle to the apical part of the canal. The morphologic characteristics of the fractured surfaces were of the ductile type.

Baek SH, Lee CJ, Versluis A, Kim BM, Lee WC, Kim HC (2011) evaluated the theoretical effect from pitch and cross-sectional geometry on torsional stiffness of nickel-titanium (NiTi) instruments. Finite element models of NiTi rotary instruments with different cross-sectional geometries and different number of threads were made for comparison of torsional stiffness. Four cross-sectional shapes were tested: triangle, slender rectangle, rectangle, and square. Taper and external peripheral radius were the same for all models, whereas cross-sectional area and/or center core area were varied. Three pitch values (5, 10, and 15 threads) were tested for each type of cross-sectional geometry. The torsional stiffness of the 12 resulting finite element models was calculated by twisting the file shanks 20 degrees while holding the file tip at apical 4 mm. The file models with larger pitch (fewer threads) had lower torsional stiffness. The models with the rectangular cross section had higher torsional stiffness than models with the triangular cross section, even when the cross-sectional areas were the same or the center core area was smaller. File models with larger cross-sectional area had higher torsional stiffness. Torsional deformation and/or fracture of NiTi rotary files might be reduced by reducing the pitch (increasing the number of threads) and increasing the cross-sectional areas rather than the center core area.

Yum J, Cheung GSP, Park JK, Hur B, Kim HC (2011) compared torsional strength, distortion angle, and toughness of various nickel-titanium (NiTi) rotary files. Five NiTi rotary instruments with different cross-sectional geometries were selected: TF and RaCe with equilateral triangle, ProTaper with convex-triangle, ProFile with U-shape, and Mtwo with S-shape. The size 25/.06 taper of TF, RaCe, ProFile, and Mtwo and the ProTaper F1 files were tested, all with the same diameter at D5. A metal mounting block with a cubical hole was constructed in which 5 mm of the file tip was rigidly held in place by filling the mold with a resin composite. The files were subjected to clockwise rotation at 2 rpm in a torsion tester. The torque and angular distortion were monitored until the file failed. The data were compared statistically for the yield and ultimate strengths, plastic hardening period, and toughness. TF and RaCe showed significantly lower yield strength than other systems. TF had a significantly lower ultimate strength than other files, whereas Mtwo showed the greatest. ProFile showed the highest distortion angle at break, followed by TF. ProFile also showed the highest toughness value, whereas TF and RaCe both showed a lower toughness value than the others. Fractographic examination revealed typical pattern of torsional fracture for all brands, characterized by circular abrasion marks and skewed dimples near the center of rotation. The 5 tested NiTi rotary files showed a similar mechanical behavior under torsional load, with a period of plastic deformation before actual torsional breakage but with unequal strength and toughness value.

Bardsley S, Peters CI, Peters OA (2011) investigated the impact of three RPM setting on peak torque and apically directed force during root canal preparation. Both the number of rotations in curved canals and torque are related to fracture resistance of nickel-titanium rotaries via the respective mechanisms of brittle and flexural failure. Increased rotational speed (rotations per minute [RPM]) may lead to higher cutting ability and could overcompensate for increased fatigue. The impact of three RPM settings on peak torque (Nmm) and apically directed force (N) during root canal preparation were investigated *in vitro*. S-shaped canals in plastic blocks (n = 12/group) were instrumented with Vortex rotaries sizes #15 to 30 with a .04 taper. Rotaries were used in a manufacturer-recommended sequence: #30, 25, and 20 in a crown-down approach progressively deeper into the canal, #15 to the working length, and apical enlargement with sizes 20 and 25 to WL. A total of 216 preparation procedures were performed using a custom testing platform. RPM was set at 200, 400, or 600; automated axial feed mirrored clinical handling, resulting in two in-and-out movements, each to preset insertion depths. Torque and apical force were continuously recorded and peak values statistically contrasted using analysis of variances. No file fractures were observed in any of the three experimental groups. Peak torques and forces varied by instrument size and were highest at 200 RPM for all sizes; torque and force were reduced by 32% and 48%, respectively, at 400 RPM. Increasing RPM to 600 did not result in further reductions. The number of discernible peaks for torque (threshold: 0.3 Nmm) and force (threshold: 0.2 N) significantly decreased from 200 RPM to 400 RPM and did not decrease further with 600 RPM. It was concluded that rotational speed had a significant impact on preparation with Vortex rotaries, with instruments at 400 RPM generating lesser torque and force compared with 200 RPM.

Pirani C, Cirulli PP, Chersoni S, Micele L, Ruggeri O, Prati C (2011) compared cyclic fatigue resistance of four nickel-titanium rotary systems and evaluated their surface, fractographic, and matrix morphology. Methods: Four models of endodontic rotary files (EasyShape , ProTaper,, NRT and AlphaKite were subjected to fatigue testing in artificial canals with angle of curvature of 45 and 60 and a radius of curvature of 5 mm until fracture occurred. Nickel-titanium (NiTi) alloy properties were investigated by light microscopy, environmental scanning electron microscopy (ESEM), and energy dispersive x-ray spectrophotometry (EDS). ESEM analysis was conducted on new files to examine surface characteristics and on fractured samples to identify the crack origin and the fractographic features. The results showed that NRT files had the highest fatigue resistance followed by AlphaKite, EasyShape, and ProTaper. All the new files presented surface imperfections. Fractographic analysis found the crack initiation to originate at the level of surface irregularities. Optical microscope inspection of the NiTi alloy matrix disclosed different-sized nonmetallic inclusions among models. EDS analysis of these inclusions showed that they were composed of carbon and oxygen in addition to nickel and titanium. Under light microscopy, austenitic grains appeared larger near the handle and smaller near the tip in all instruments. Conclusions: NRT files presented the longest fatigue life. All samples showed surface irregularities and nonmetallic inclusions. Austenitic grains were smaller near the tip than near the handle. The angle of curvature was confirmed to influence the fatigue life of NiTi instruments

Fayyad DM and Elgendy AAE (2011) compared the efficacy of the cutting ability of two different instruments, concerning changes in the dentin thickness removed and root canal volume, by using multislice computed tomography scanning. Thirty single-rooted mandibular premolars were divided into two equal groups according to the preparation system used: the twisted file (TF) and ProTaper. Dentin thickness along the whole length of the root canal and canal volume were measured before and after instrumentation by using multislice computed tomography scanning and image analysis software. ProTaper removed significantly more dentin from the mesiodistal and buccolingual directions of the root canal than the TF. No significant difference was recorded for the changes in root canal volume between the two systems. The TF system was found to cut dentin efficiently with more uniform cutting than ProTaper system.

Chirani RA , Chevalier V , Chirani SA , Calloch S (2011) compared numerically the bending and torsional mechanical behavior of 5 endodontic rotary Ni-Ti instruments with equivalent size and various designs for tapers, pitch, and cutting blades. First, the geometries of Hero (20/0.06), HeroShaper (20/0.06), ProFile (20/0.06), Mtwo (20/0.06), and ProTaper F1 were generated by finite element code. Then, the two most representative clinical loadings, i.e., bending and torsion, were studied with an ad hoc model for the superelasticity of Ni-Ti. Bending was generated by tip deflection and torsion by a constant twist-angle of the tip. The results obtained showed that the Protaper F1 presented the greatest level of bending stress and torque. Hero and HeroShaper were more rigid than ProFile and Mtwo files.

Al Sudani D , Grande NM, Platino G, Pompa G, Di Carlo S, Testarelli L, Gambarini G (2012) tested the fatigue resistance of nickel-titanium rotary files in a double curvature (S-shaped) artificial root canal and compared those results with single curvature artificial root canals. Two nickel-titanium endodontic instruments consisting of identical instrument sizes (constant .06 taper and 0.25 tip diameter) were tested, ProFile instruments and Vortex instruments. Both instruments were tested for fatigue inside an artificial canal with a double curvature and inside a curved artificial canal with a single curvature. Ten instruments for each group were tested to fracture in continuous rotary motion at 300 rpm. Number of cycles to failure (NCF) was calculated to the nearest whole number, and the length of the fractured fragment was measured in millimeters. The NCF value was always statistically lower in the double curved artificial canal when compared with the single curve in both the apical and coronal curvatures. Statistically significant differences were noted between instruments of the same size of different brand only in the single curve; ProFile registered a mean of 633.5 ± 75.1 NCF, whereas Vortex registered a mean of 548 ± 48.9 NCF. The results suggested that the more complex is the root canal, the more adverse were the effects on the cyclic fatigue resistance of the instruments.

Bouska J, Justman B, Williamson A, Delong C, Qian F (2012) compared cyclic fatigue resistance of the new size 30 Profile Vortex files with ISO size 30 files of Twisted File, ProFile, GTX, and EndoSequence. Size 30 files with a constant .06 taper were rotated at manufacturer-recommended speed and torque settings in a simulated canal until failure. Significant differences were found between the various brands of files. The differences between file brands may be because of a different manufacturing process or differences in file design.Based on a simulated canal model, the PV, TF, and GTX files appear to offer greater cyclic fatigue resistance than ES and PF files.

Duan YY, Niag H, Zhe J, Mei XX, Qin S (2012) evaluated the effect of four Ni-Ti rotary instruments on the preparation of L-shaped resin root canals. 40 L-shaped resin root canals (curvature=38.5 degree) were divided randomly into four groups depending on instrument to be tested Hero642, Protaper, K3 and Mtwo. Resin root canals were prepared according to the protocols. Preparation time was recorded.

Original and postoperative canal images were scanned and superimposed. The preparation effect was evaluated by computer software, such as resin removal amount in inner and outer wall of root canals, change of curvature degree and radius, etc. The preparing time of K3 was the longest and that for Mtwo was the shortest. Resin removal amount showed significant difference among the four instruments in inner root canal wall at BC, O and HO as well as in outer root canal wall at AC, HO and O. Protaper achieved the largest tapered canal,but was the worst for centering ability in the bend. Apical transportation increased near to apical foramen. The four Ni-Ti rotary instruments showed no significant difference regarding safety, undesirable shape, change of root canal's curvature degree and radius except two instrument fracture cases (K3 and Protaper) and two step cases (K3). Postoperative working length tended to be shorter and root canals were straightened. It was concluded that Mtwo prepared simulated resin curved root canals fast. Postoperative root canal's taper by Protaper was significantly larger than Hero642. The 4 Ni-Ti rotary instruments performed good cutting ability and kept root canal's original curvature well

Ferreira MA, Luersen MA, Borges PC (2012) reviewed Nickel Titanium Alloys and their properties. Nickel-titanium alloys have shown a growing evolution, from the conventional type with distinctive martensitic characteristics until the current ones with thermoelastic and superelastic (pseudoelastic) properties. It was stated that many nickel-titanium alloys available as superelastic do not correspond to manufacture’s specifications being just less stiff than stainless steel alloys. It was concluded that an ideal alloy would be one that presented a Transition Temperature Range which coincided with or which would be really close to the temperature of the buccal cavity (A_f) in order to allow stress induced martensite to be formed; one which did not show a shift of transition temperature range because of the stress applied and would have good springback at room temperature; and which showed a small difference between the plateaus (little hysteresis) and the magnitude between the plateaus would be within tension levels compatible with biological dental movement..

Gao Y, Gutmann JK, Wilkinson K, Maxwell R, Ammon D (2012) studied raw materials (including stainless steel, conventional superelastic nickel-titanium [NiTi], M-Wire NiTi, and Vortex Blue NiTi) were used to create ProFile Vortex designed 25/.06 instruments and subject these instruments to testing for fatigue resistance, torsional properties, flexibility, and Vickers microhardness. They concluded that NiTi shape memory alloy appeared to be a superior material option compared with stainless steel for its use in the application of endodontic rotary instruments. Vortex Blue and M-Wire offered functional advantages over conventional superelastic NiTi. Vortex Blue showed improved fatigue resistance and flexibility compared with ProFile Vortex M-Wire.

Kim H C, Kwak SW, Cheung GSP, Ko DC Cheung SM, Lee W (2012) compared the cyclic fatigue resistance and torsional resistance of these 2 files, Reciproc and WaveOne. Cyclic fatigue test with a simultaneous pecking motion was performed with the instrument (n =10 each) operating in the recommended motion until fracture for the Reciproc R25 and WaveOne Primary files. ProTaper F2 was tested in continuous rotation to serve as a control for comparison. The number of cycles to fracture (NCF) was determined by measuring the time to fracture. The length of the fragment was measured and the fracture surface was examined by using scanning electron microscopy. Torsional strength was measured by using a torsiometer after fixing the apical 5 mm of the instrument rigidly. Statistical analysis was performed by using one-way analysis of variance. The results showed that Reciproc had a higher NCF.Both reciprocating files demonstrated significantly higher cyclic fatigue and torsional resistances than ProTaper. However, it was stated that that the new concept of reciprocating instrument and the use of only one instrument to enlarge the canal, regardless of the preexisting canal condition (such as dimension and curvature), into a final size and taper seemed to go against the current instrumentation protocol that required the gradual enlargement of the canal with a series of instruments until the desired shape was obtained. It was concluded that both brands of NiTi file used with a reciprocation motion seemed to have superior mechanical properties. Reciproc could be suited for preparing the canals with more abrupt curvature because of its good fatigue resistance and WaveOne for constricted canals that might induce higher torsional stresses.

Plotino G, Al- Sudani D, Pulino S, Grande NM, Marcoli PA, Pizzi S, Testarelli L, Gambarini G (2012) evaluated the effect of autoclave sterilization on cyclic fatigue resistance of rotary endodontic instruments made of traditional and new nickel-titanium (NiTi) alloys. The four NiTi rotary endodontic instruments of the same size (tip diameter 0.40 mm and constant .04 taper) were selected: K3, Mtwo, Vortex, and K3 XF prototypes. They concluded that repeated cycles of autoclave sterilization do not seem to influence the mechanical properties of NiTi endodontic instruments except for the K3 XF prototypes of rotary instruments that demonstrated a significant increase of cyclic fatigue resistance.

Yamamura B, Cox TC, Heddaya B, Flake NM, Johnson JD, Paranjpe A (2012) evaluated the transportation and centering ability of two Niti rotary systems made from traditional nickel-titanium (NiTi) and M-Wire technology. EndoSequence and Vortex are two recently developed rotary file systems that are made with traditional nickel-titanium (NiTi) and M-Wire technology respectively. The effects of M-Wire and conventional NiTi on transportation and centering ability was evaluated in mesial roots of mandibular molars by using micro–computed tomography imaging. Sixteen extracted mandibular molars with mesiobuccal and mesiolingual canals with separate foramina were used. Pre-instrumentation scans of all teeth were taken, and the teeth were divided into 2 groups. In group 1, the mesiobuccal canals were instrumented with Vortex files and the mesiolingual canals with EndoSequence files. In group 2, the mesiobuccal canals were instrumented with EndoSequence files and the mesiolingual canals with Vortex files. Two file sizes were compared, 30/.04 and 40/.04. Post-instrumentation scans were performed, and the 2 scans were compared to determine centering ability and transportation. The amount of transportation at 1, 3, and 5 mm was similar for both file types in both file sizes. Transportation toward the furcation area at 7 mm was greater with the 30/.04 Endosequence files compared with the Vortex 30/.04 files, but there was no difference in size 40/.04 files.

Bhagabati N, Yadav S, Talwar S (2012) compared Twisted File (TF) with 3 traditionally manufactured systems to determine whether changes in the manufacturing process improved the cyclic fatigue resistance. Four rotary file systems, (1) ProFile (PF), (2) Mtwo, (3) K3, and (4) TF, were tested in artificial canals with 45° and 90° angles of curvature. Ten instruments each of the 4 file systems were tested in both angles of curvature (n = 10). All instruments had identical size and taper (.06/0.25 tip diameter). A statistically significant difference ($P < .05$) was noted between TF and other nickel-titanium instruments in both 45° and 90° angles of curvature. TF showed the greatest mean number of cycles to failure. There was no statistical difference between PF and K3 in both canal curvatures; however, statistically significant difference was observed between Mtwo and the other 2 traditionally manufactured instruments. Mtwo showed the lowest mean number of cycles to failure. Under the conditions of this study, size .06/0.25 TF was significantly more resistant to fatigue than the other 3 instrument systems produced with the traditional grinding process.

Kim JY, Cheung GSP, Park SH, Ko DC, Kim JN, Kim HC (2012) evaluated the effect of cyclic fatigue on the torsional resistance of nickel-titanium (NiTi) rotary instruments. ProFile (#25/0.06) and ProTaper (F1), both of which have the same external diameter at D5, were tested using a fatigue testing machine for the mean number of cycles of failure (mNCF). Then, new files were cyclic precycled to 4 conditions (ie, 0%, 25%, 50%, and 75% of the mNCF) before the torsional resistance test was performed on these cyclic preloaded files. A uniform clockwise rotation was applied to the file in a straight state in a torsion tester. The torsional load and distortion angle were recorded during rotation until the file succumbed to the torque. The toughness was computed. The results showed that in both ProFile and ProTaper groups, the 75% preloading groups had significantly lower torsional strength than other preloaded files. In the ProFile group, the 50% and 75% preloading groups had a smaller distortion angle until fracture than the 25% and no preloading groups. The 75% preloading group showed a lower toughness value than the 25% and no preloading groups. In the ProTaper group, all preloading groups had less distortion and toughness than the no preloading group. Fractographic examinations revealed the 75% preloaded files showed less amount of reverse-wound flute than other preloading groups. It was concluded that approximate 75% cyclic fatigue may reduce the torsional resistance of NiTi rotary instruments significantly.

Burroughs JR, Bergeron BE, Roberts MD, Hagan JL, Himel VT (2012) determined the shaping ability of 3 nickel-titanium (NiTi) endodontic file systems by measuring canal transportation. Seventy-two S-shaped canals in resin blocks were randomly allocated into 3 groups (n = 24): the Self-Adjusting File (SAF) group, the Typhoon group (Typhoon rotary files with Controlled Memory Wire), and the Vortex group (ProFile Vortex rotary files with M-Wire NiTi). Blocks were secured in a jig for imaging standardization and instrumentation stabilization. Gates Glidden and PathFile drills (25 mm/.02 taper) were used to prepare the glide paths. For the Typhoon and Vortex groups (25 mm/.04 taper), canals were flooded with sterile water and instrumented using a crown-down technique from sizes 40 to 20/.04 and then apically enlarged to size 30/.04. The SAF group (25 mm) was instrumented with constant sterile water irrigation in a light-pecking, transline motion. Pre- and post-instrumentation images were taken at 40 magnification and layered, and canal transportation was measured. After adjusting for the level and canal wall side, the mean transportation was found significantly higher for the Typhoon and Vortex groups compared with the SAF group. Additionally, the mean transportation was significantly higher for the Typhoon group versus the Vortex group. It was concluded that SAF showed less canal transportation.

Zhou HM, Shen Ya, Zheng W, Li Li, Zheng YF, Haapasalo M (2012) investigated the structure and mechanical properties of newly developed controlled memory (CM) nickel-titanium wires used in the manufacture of rotary endodontic instruments. The composition and the phase transformation behavior of both types of wires were examined by x-ray energy dispersive spectroscopy and differential scanning calorimetry, respectively. Conventional superelastic (SE) nickel-titanium wire was used as a control. The mechanical properties of the wires at selected temperatures (room temperature, 37C, and 60C) were evaluated with tensile, cyclic tensile, and cantilever bending tests by using an Instron 3365 universal testing machine. The data of austenitic transformation finishing temperature (Af) were analyzed statistically by using 1-way analysis of variance test at a significance level of $P < .05$. Results: The raw CM wires contained a nickel content of 50.7% 0.5% and possessed a relatively higher Af than SE wires ($P < .05$). The critical plateau stress and ultimate tensile strength of the CM wires were lower than they were for the SE wires, but the maximum strain before fracture of the CM wires (58.4% 7.5% to 84.7% 6.8%) was more than 3 times higher than it was for SE wires (16.7% 3.8% to 27.5% 5.4%). The maximum strain of the CM wires with a diameter of 1.22 mm tested at room temperature (23C 2C) was up to 84% 6.4%. CM wires were not SE at either room temperature or 37C; however, they exhibited superelasticity when heated to 60C. Conclusions: The raw CM wires exhibited different phase transformation behavior and mechanical properties when compared with SE wires, attributing to the special heat treatment history of CM wires. It was concluded that the instruments manufactured from CM wires had greater flexibility than similar instruments made of conventional SE wires.

Shen Ya, Qian W, Abtin H , Haapasalo M (2012) examined the fatigue behavior of 2 types of nickel-titanium (NiTi) instruments made from a novel controlled memory NiTi wire (CM wire) under various environment conditions. Three conventional superelastic NiTi instruments of ProFile , Typhoon and DS-SS0250425NEYY and 2 new CM wire instruments of Typhoon CM and DS-SS0250425NEYY CM were subjected to rotational bending at the curvature of 35° in air, deionized water, 17% EDTA, or deionized water after immersion in 6% sodium hypochlorite for 25 minutes, and the number of revolutions of fracture (N(f)) was recorded. The fracture surface of all fragments was examined by a scanning electron microscope. The crack-initiation sites and the percentage of dimple area to the whole fracture cross-section were noted. Two new CM Wire instruments yielded an improvement of >4 to 9 times in N(f) than conventional NiTi files with the same design under various environments. The fatigue life of 3 conventional superelastic NiTi instruments was similar under various environments, whereas the N(f) of 2 new CM Wire instruments was significantly longer in liquid media than in air. The vast majority of CM instruments showed multiple crack origins, whereas most instruments made from conventional NiTi wire had one crack origin. The values of the area fraction occupied by the dimple region were significantly smaller on CM NiTi instruments than in conventional NiTi instruments under various environments . Within the limitations of this study, the type of NiTi metal alloy (CM files vs conventional superelastic NiTi files) influences the cyclic fatigue resistance under various environments. The fatigue life of CM instruments was longer in liquid media than in air.

Shen Y, Coil JM, Zhou HM, Tam E, Zheng YF, Haapasalo M (2012) analysed the incidence and mode of ProFile Vortex instrument defects during a predefined schedule of clinical use by the undergraduate students in a dental school setting and to examine the metallurgical characteristics of unused and clinically used Vortex instruments. A total of 2,203 ProFile Vortex instruments discarded after single use from the undergraduate students program over 24 months were collected and examined for defects using a stereomicrosocpe at 10 x magnification. The incidence and type of instrument defects or separation were analyzed. The lateral surfaces of part of the defected instruments and fracture surfaces of fractured files were examined using scanning electron microscopy. Unused and clinically used files were examined by differential scanning calorimetry and X-ray diffraction. Vickers hardness of the files was measured with a 200-g load. Only 1 of the 2,203 files fractured during clinical use. The cause of fracture was shear stress, and the file also showed unwinding of the helix structure. None of the remaining 2,202 files exhibited unwinding after clinical use. Blunt apicals were detected in 86 used files (3.9%). Austenite-finish temperatures were very similar for as-received, used files with defects and used files without defects, all exceeding 50_C. No difference in microhardness was detected among these 3 instrument groups. X-ray diffraction results showed that NiTi files had austenite structure at room temperature. The risk of ProFile Vortex fracture is very low when files are used 1 time by undergraduate students. Unwinding of the files was not detected except for the fractured file. Clinical single use had no detectable effect on austenite-martensite phase transformation of the files. Unused and clinical single-use files contain a similar phase structure at body temperature.

Jia Ye and Gao Y (2012) characterized microstructural changes of M-Wire throughout the cyclic fatigue process under controlled strain amplitude. The average fatigue life was calculated from 30 M-Wire samples that were subjected to a strain-controlled (4%) rotating bend fatigue test at room temperature and rotational speed of 300 rpm. Microstructural evolution of M-Wire has been investigated by different metallurgical characterization techniques, including differential scanning calorimetry, Vickers microhardness, and transmission electron microscopy at 4 different stages (as-received state, 30%, 60%, and 90% of average fatigue life). During rotating bend fatigue test, no statistically significant difference was found on austenite finish temperatures between as-received M-Wire and fatigued samples. However, significant differences were observed on Vickers microhardness for samples with 60% and 90% fatigue life compared with as-received and 30% fatigue life. Coincidentally, substantial growth of martensite grains and martensite twins was observed in microstructure under transmission electron microscopy after 60% fatigue life.The results of the present study suggested that endodontic instruments manufactured with M-Wire were expected to have higher strength and wear resistance than similar instruments made of conventional superelastic NiTi wires because of its unique nano-crystalline martensitic microstructure.

Ferreira MDA, Luersen MA, Borges PC (2012) reviewed nickel-titanium wires using Entrez- PubMed-OLDMEDLINE, Scopus and BioMed Central from 1963 to 2008. Papers in English and French describing the behavior of these wires and laboratorial methods to identify crystalline transformation were considered. A total of 29 papers were selected. Nickel-titanium wires show exceptional features in terms of elasticity and shape memory effects. However, clinical applications requested a deeper knowledge of these properties in order to allow the professional to use them in a rational manner. In addition, the necessary information regarding each alloy often does not corresponded to the information given by the manufacturer. Many alloys called "superelastic" do not presented this effect; they just behaved as less stiff alloys, with a larger springback if compared to the stainless steel wires. Laboratory tests were the only means to observe the real behaviour of these materials, including temperature transition range (TTR) and applied tensions.

Santos MD, Gavini G, Siqueira EL, Costa CD (2012) assessed the effect of nitrogen ion implantation on the flexibility of rotary nickel-titanium (NiTi) instruments as measured by the load required to bend implanted and non-implanted instruments at a 30° angle. Thirty K3 files, size #40, 0.02 taper and 25-mm length, were allocated into 2 groups as follows: group A, 15 files exposed to nitrogen ion implantation at a dose of 2.5×10^{17} ions/cm^2, voltage 200 KeV, current density 1 μA/cm^2, temperature 130°C, and vacuum conditions of 10×10^{-6} mm Hg for 6 hours; and group B, 15 non-implanted files. One extra file was used for process control. All instruments were subjected to bend testing on a modified troptometer, with measurement of the load required for flexure to an angle of 30°. The mean load required to bend instruments at a 30° angle was 376.26 g for implanted instruments and 383.78 g for nonimplanted instruments. The difference was not statistically significant. The findings showed that nitrogen ion implantation has no appreciable effect on the flexibility of NiTi instruments.

Versluis A, Kim HC, Lee WC, Kim BM, Lee CJ, (2012) evaluated how the pitch and cross-sectional geometry affected flexural stiffness and stresses. Finite element models of rotary instruments with 4 cross-sectional geometries (triangle, slender-rectangle, rectangle, square) and 3 pitches (5-, 10-, 15-threads) were created, featuring superelastic nickel-titanium properties. All models had the same length, taper, and external peripheral radius; cross-sectional area and/or center-core area varied. The clamped shaft was rotated axially, while the tip was deflected 5 mm. Flexural stiffness and maximum von Mises stresses were calculated. Stiffness and maximum stress decreased with decreasing pitch (increasing threads). Doubling or tripling the threads for the triangular or rectangular cross sections decreased the stiffness and stress 6% and 12%, respectively; square cross sections were less affected (1% and 3% decrease, respectively). Square cross sections (higher cross-sectional and center-core areas) had higher stiffness and stresses than other models with same deflection. Rectangular and triangular models with the same center-core areas had similar stresses, but the rectangular model was 30%–40% stiffer. The slender-rectangle had the smallest center-core area and the lowest stiffness and stresses. Both rectangular cross sections caused stiffness and stress variations with rotation angle (13% for slender-rectangle); larger pitch caused more variation. Under the same tip deflection (simulating canal curvature), flexural stiffness and stress correlated with center-core area. Increasing pitch increased flexural stiffness and stresses. They postulated that shape is the main determinant of mechanical performance for nickel-titanium rotary instruments.

Pelton AR, Fino DJ, Vein L, Bonsignore C, Saffari P, Launey M, Mitchell MR (2013) investigated the rotary bending fatigue properties of medical-grade Nitinol wires under conditions of 0.5–10% strain amplitudes to a maximum of 107 cycles. The results provided an insight into the behavior of Nitinol under fully reversed fatigue conditions for three compositions, two surface conditions and three test temperatures. For pseudoelastic conditions, there are four distinct regions of the strain cycle curves that are related to phases (austenite, stress-induced martensite, and R-Phase) and their respective strain accommodation mechanisms. In contrast, there are only two regions for the strain-cycle curves for thermal martensite. It was further observed that the strain amplitude to achieve 107-cycles increased with both decreasing test temperature and increasing transformation temperature. Fatigue behaviour was not strongly influenced by wire surface condition. SEM of the fracture surfaces showed that the fatigue fracture area increased with decreasing strain amplitude.

Dagna A, Poggio C, Beltrami R, Colombo M, Bianchi S (2013) evaluated and compared in vitro the cyclic fatigue resistance of three NiTi single-file systems (One Shape, Reciproc and Wave One) after immersion in 10% EDTA solution over different time periods. Cyclic fatigue test of three NiTi single-file systems was performed in a curved stainless steel artificial canal with 60° angle and 5 mm radius of curvature. Fourty five files of each One Shape, Reciproc R25 and Wave One were tested after three different immersion protocols: 1min. in 10% EDTA at 37°C, 5 min in 10% EDTA at 37°C and no immersion. The number of cycles to fracture (NCF) was determined by measuring the time to fracture. The data were compared for differences by using 2-way analysis of variance (P=0.05).In general, resistance to cyclic fatigue was not significantly affected by immersion in 10% EDTA. Reciproc R25 showed the highest cyclic fatigue resistance in all groups. It was concluded that 10% EDTA did not decreased or increased the cyclic fatigue resistance of NiTi single-file systems appreciably in vitro. Reciproc R25 was more resistant, but the new rotary One Shape instruments showed good mechanical resistance, similar to Wave One Primary files developed for reciprocating motion.

Pereira ESJ, Singh R, Arias A, Peters OA (2013) assessed torque and force for simulated canal preparation with a new root canal instrument, ProTaper Next. Six sets of ProTaper Next Instruments (X1–X5) were used to prepare thirty six artificial canals. Files were divided into 6 groups. Different settings of rotations per minute (250, 300, and 350 rpm) and numbers of in-and-out movements to reach working length (3 or 4 insertions [ins]) were applied in each group (250 rpm/ 3 ins, 250 rpm/4 ins, 300 rpm/3 ins, 300 rpm/4 ins, 350 rpm/3 ins, and 350 rpm/4 ins) by using an automated torque bench. Peak torques (Ncm) as well as positive and negative forces (N) were registered. Preliminary data for angle and stationary torque at failure were also obtained and compared with peak torque for each instrument. Significant differences in peak torque, positive force and negative force were found for ProTaper Next instruments overall. X2 showed the highest torque with all settings. X5 showed the highest positive force in all groups. X1 and X2 showed the highest negative forces for all groups except for 350 rpm/4 ins. Significantly lower torque and positive force were measured in the group 350 rpm/4 insertions for all instruments except for X4. In contrast, X1 showed a significantly lower negative force for 350 rpm/4 ins. Torque at failure according to American Dental Association no. 28/ISO 36030-1 was lower for X1, X2, and X3 than torque during simulated canal preparation. It was concluded that using ProTaper Next at 350 rpm and with 4 in-and-out movements resulted in lowest levels of peak torque as well as positive and negative forces.

Love RM and Masi OV (2013) determined the shaping and centering ability of Twisted File (TF), HERO Shaper file and the ProFile 0.06 in simulated curved root canals. Sixty simulated root canals of either 20°, 10 mm radius (n=30) or 30°, 6 mm radius (n=30) canal curvatures were prepared with three file systems in a variable tip, modified Crown Down technique. Mean changes on the inner and outer canal walls were analysed for shaping and centering ability of the systems. There were no significant differences in canal preparations between the 20° and 30° canal curvatures with each system. All file systems produced well-tapered canal preparations. The results showed Hero shaper removed the least canal wall material. Twisted File showed a better ability to remove inner canal wall material and remain centered in the apical third while Profile and Hero transported to the outer wall. It was concluded that all systems produced clinically acceptable canal shapes. TF files showed a better ability to instrument the inner canal wall and remain centered in the apical region. HERO Shaper file was observed to remove the least material in all regions.

Ruddle CJ, Machtou P, West JD (2013) reviewed the new generation of endodontic NiTi files. Importantly, they summarized the file systems according to their generations. The First generation NiTi files had passive cutting radial lands and fixed tapers of 4% and 6% over the length of their active blades (GT files).The single most important design feature of first generation NiTi rotary file was passive radial lands, which encouraged a file to stay centered in canal curvatures during work. Second generation NiTi rotary files had active cutting edges and require fewer instruments to fully prepare a canal (Endo Sequence and BioRaCe*)*. The clinical breakthrough occurred when ProTaper came to market utilizing multiple increasing or decreasing percentage tapers on a single file. This revolutionary, progressively tapered design limited each file's cutting action to a specific region of the canal and afforded a shorter sequence of files to safely produce deep Schilderian shape. During this period, manufacturers began to focus on other methods to increase the resistance to file separation. Some manufacturer's electropolished their files to remove surface irregularities caused from the traditional grinding process. Third Generation NiTi Files showed improvements in NiTi metallurgy. Manufacturers began to focus on utilizing heating and cooling methods to reduce cyclic fatigue of rotary NiTi instruments and improve safety when used in more curved canals. This generation of NiTi instruments significantly reduced cyclic fatigue and hence occurrence of file breakage. (Twisted File, Hyflex, GT, Vortex and Wave One).Fourth generation NiTi files utilized reciprocation (M4, Endo Express and Endo-Eze). This generation of instruments mostly employed single file technique. ReDent-Nova *(Henry Schein)* introduced the Self Adjusting File (SAF). This file has a compressible open tube design that was purported to exert uniform pressure on the dentinal walls, regardless of the cross-sectional configuration of the canal. The most popular single file concept of this generation was WaveOne and Reciproc. Fifth generation NiTi files were designed such that the center of mass and/or the center of rotation are offset (Protaper Next). In rotation, these files with an offset design produced a mechanical wave of motion that travelled along the active length of the file. This offset design served to further minimize the engagement between the file and dentin. In addition, an offset design enhances augering debris out of a canal and improves flexibility along the active portion of a Protaper Next file. Protaper Next files had 3 significant design features that included progressive percentage tapers on a single file, M-wire technology and the offset design. It has been shown that M-wire, a metallurgically improved version of NiTi, reduced cyclic fatigue by 400% when comparing files of the same D0 diameter, cross-section, and taper. The third design feature of Protaper next was related to its offset cross-sectional design. This offset design generated a traveling mechanical wave of motion along the active portion of a file. This swaggering effect served to minimize the engagement between the file and dentin compared to the action of a fixed tapered file with a centered mass of rotation.

Rubini AG, Sannino G, Pongione G, Testarelli L, Al Sudani D, Jantarat J, De Luca M, Gambarini G (2013) compared the resistance to cyclic fatigue of Hyflex size 40 taper0.04 nickel titanium instruments used in continuous rotation versus reciprocating motion. Twenty four Hyflex size 40 taper.04 nickel titanium instruments were randomly divided in two groups (n=12 each), and submitted to a cyclic fatigue test. The first group (CR group) were used with a continuous rotation, while the second one (RCP group) with a reciprocating motion. The cyclic fatigue tests were performed by using a stainless steel block containing an artificial canal shaped with a 135° angle. All instruments were rotated or reciprocated until fracture occurred. The time to fracture was recorded visually with a 1/100 second chronometer. Data were recorded and statistically analysed. The results indicated that instruments used with a reciprocating motion showed a significant increase in the meantime to failure when compared to those used in continuous rotation. It was concluded that reciprocating motion extended resistance to cyclic fatigue of the tested nickel titanium instruments, when compared to continuous rotation.

Morgental RD, Pelisser FVV, Kopper PMP, Figueiredo JAP, Peters OA, (2013) evaluated the influence of rotational speed and number of uses on the cutting efficiency of four nickel-titanium coronal flaring instruments against two substrates, bovine dentin and acrylic blocks. BioRaCe BR0, HyFlex CM1, ProFile OS#2, and ProTaper Sx were used in simulated lateral action against both substrates at 250 and 500 rpm up to five times, producing five notches in each block. Notch areas and lengths were measured under a stereomicroscope. Against both substrates, HyFlex CM1 and ProFile OS#2 were the most and the least cutting efficient instruments, respectively. Against acrylic, area and length values at 500 rpm were significantly higher than those at 250 rpm for all brands. Against dentin, significant differences were detected between 250 and 500 rpm for HyFlex CM1 and ProTaper Sx (area) and for BioRace BR0, HyFlex CM1, and ProTaper Sx (length). Regarding cutting efficiency loss, area and length for notches 1 and 2 (first notches) and 4 and 5 (last notches) were similar against acrylic. Against dentin, length values for notches 1 and 2 were significantly higher than those for notches 4 and 5 in ProFile OS#2 and ProTaper Sx. A strong correlation was detected between the overall results obtained on acrylic and dentin for area and length, although further analysis showed that data against acrylic were a poor predictor of data against dentin after repeated use. It was concluded that HyFlex CM1 was the most cutting efficient instrument in lateral action. An increase in rotational speed improved the cutting efficiency.

Santos LDA, Bahia MGA, Casas EB, Buono VT (2013) evaluated the flexibility and torsional stiffness of a controlled memory (CM) NiTi file and compared its mechanical responses with those of a superelastic NiTi file with the same geometry using finite element simulation. Hyflex CM file with a tip size of 30 and a 0.06 taper was selected. The geometric model for finite element analysis was generated by micro–computed tomographic scanning, and the data for the constitutive model of controlled memory NiTi were obtained from the literature. The CM NiTi file exhibited the least bending moment and maximum stress value (523 MPa) under 45 degree bending simulation. It was found that the higher flexibility and potential fatigue resistance of the CM NiTi files were confirmed indicating that this new technology represents an improvement in the mechanical behaviour of the rotary NiTi files.

Shen Ya, Cheung GSP (2013) evaluated the performance and mechanical properties of nickel-titanium (NiTi) instruments that were influenced by factors such as cross-section, flute design, raw material, and manufacturing processes. Many improvements have been proposed by manufacturers during the past decade to provide clinicians with safer and more efficient instruments. The mechanical performance of NiTi alloys remained a sensitive to their microstructure and associated thermo-mechanical treatment history. Heat treatment or thermal processing was considered as one of the most fundamental approaches toward adjusting the transition temperature in NiTi alloy, which affected the fatigue resistance of NiTi endodontic files. The newly developed NiTi instruments made from controlled memory wire, M-Wire or R-phase wire represented the next generation of NiTi alloys with improved flexibility and fatigue resistance. The advantages of NiTi files for canal cleaning and shaping were decreased canal transportation and ledging, a reduced risk of file fracture, and faster and more efficient instrumentation. It was emphasized that the clinician must understand the nature of different NiTi raw materials and their impact on instrument performance.

Shen Y, Coil JM, Zhou H, Zheng Y, Haapasalo M (2013) analysed the type and location of defects in HyFlex CM instruments after clinical use in a graduate endodontic programme and also examined the impact of clinical use on their metallurgical properties. Total of 468 HyFlex CM instruments discarded from a graduate endodontic programme were collected after use in three teeth. The incidence and type of instrument defects were analysed. The lateral surfaces of the defect instruments were examined by scanning electron microscopy. New and clinically used instruments were examined by differential scanning calorimetry (DSC) and x-ray diffraction (XRD). Vickers hardness was measured with a 200-g load near the flutes for new and clinically used axially sectioned instruments. The results of the 468 HyFlex instruments tested showed no fractures were observed and 16 (3.4%) revealed deformation. The DSC analyses showed that HyFlex instruments had an austenite transformation completion or austenite-finish (Af) temperature exceeding 37 °C. The Af temperatures of HyFlex instruments (with or without defects) after multiple clinical use were much lower than in new instruments. The enthalpy values for the transformation from martensitic to austenitic on deformed instruments were smaller than in the new instruments at the tip region. XRD results showed that NiTi instruments had austenite and martensite structure on both new and used HyFlex instruments at room temperature. No significant difference in microhardness was detected amongst new and used instruments (with and without defects).They concluded that the risk of HyFlex instruments fracture in the canal was very low when instruments were discarded after three cases of clinical use. New HyFlex instruments were a mixture of martensite and austenite structure at body temperature. Multiple clinical use caused significant changes in the microstructural properties of HyFlex instruments. It was recommended smaller size NiTi instruments should be considered for a single-use only.

Brown TA (2013) evaluated the effect of NiTi metallurgy and file design on torsional failure resistance, cyclic fatigue resistance, and flexibility. Vortex, Profile, and Mtwo files were each fabricated from superelastic NiTi, M-wire, and Blue Wire. 15 files from each group were used in the torsional failure test, 15 for cyclic fatigue testing, and 10 for flexibility. Results were analyzed to determine the effect of NiTi type on a given file design and file design on a specific type of NiTi. The results of the cyclic fatigue testing showed that for every file design tested, cycles until failure were highest for files made of Blue Wire, followed by M Wire, and finally Superelastic NiTi files. When comparing file designs in Superelastic NiTi, Mtwo had fewer cycles until failure than ProFile and Vortex. There was no significant difference between ProFile and Vortex. ProFile had the highest number of cycles until failure when compared with both Mtwo and Vortex, while there was no significant difference between Mtwo and Vortex. Mtwo had a higher number of cycles until failure than Vortex in Blue Wire. There was no significant difference when ProFile was compared with Mtwo and Vortex.

Cassim I (2013) evaluated three different gilde path preparation techniques using stainless steel hand K files, Stainless steel hand k files in M4safety reciprocating handpiece and pathfiles and Xplorer NiTi rotary files. The results showed that there were more abberations when hand k files were used for preaparing glide path during a root canal treatment as compared to other tested techniques.

Ninan E and Berzins DW (2013) investigated the torsion and bending properties of shape memory files (CM Wire, HyFlex CM, and Phoenix Flex) and compare them with conventional (ProFile ISO and K3) and M-Wire (GT Series X and ProFile Vortex) NiTi files. Sizes 20, 30, and 40 (n = 12/size/taper) of 0.02 taper CM Wire, Phoenix Flex, K3, and ProFile ISO and 0.04 taper HyFlex CM, ProFile ISO, GT Series X, and Vortex were tested in torsion and bending per ISO 3630-1 guidelines by using a torsiometer. Significant interactions were present among factors of size and file. Variability in maximum torque values was noted among the shape memory files brands, sometimes exhibiting the greatest or least torque depending on brand, size, and taper. In general, the shape memory files showed a high angle of rotation before fracture but were not statistically different from some of the other files. However, the shape memory files were more flexible, as evidenced by significantly lower bending moments. Shape memory files showed greater flexibility compared with several other NiTi rotary file brands

Lopes HP, Gambarra S T, Elias CN, Siqueira JF , Inojosa IF, Lopes WS, Vieira VT (2013) compared the mechanical properties of endodontic instruments made of conventional nickel-titanium (NiTi) wire (K3) and Revo-S SU), M-Wire (ProFile Vortex), or NiTi alloy in R-phase (K3 XF). The test instruments were subjected to mechanical tests to evaluate resistance to bending (flexibility), cyclic fatigue, and torsional load in clockwise rotation. In the bending resistance test, flexibility decreased in the following order: K(3)XF > Revo-S SU > ProFile Vortex > K(3). The ranking in the fatigue resistance test was the following: K(3)XF > K(3) > ProFile Vortex > Revo-S SU. In the torsional assay, the angular deflection at failure decreased in the following order: K(3)XF > Revo-S SU > K(3) > ProFile

Vortex. For the maximum torque values, the ranking was K(3) > K(3)XF > ProFile Vortex > Revo-S SU. The results showed that the K(3)XF instrument, which is made of NiTi alloy in R-phase, had the overall best performance in terms of flexibility, angular deflection at failure, and cyclic fatigue resistance. In addition to the alloy from which the instrument is manufactured, the design and dimensions are important determinants of the mechanical performance of endodontic instruments.

Cho OI, Versluis A, Cheung GSP, Ha JH, Bock H, Kim HC (2013) compared the cyclic fatigue resistance of nickel–titanium (NiTi) files obtained in a conventional test using a simulated canal with a newly developed method that allowed the application of constant fatigue load conditions. ProFile and K3 files of #25/.06, #30/.06, and #40/.04 were selected. Two types of testing devices were built to test their fatigue performance. The first (conventional) device prescribed curvature inside a simulated canal (C-test), the second new device exerted a constant load (L-test) whilst allowing any resulting curvature. Ten new instruments of each size and brand were tested with each device. The files were rotated until fracture and the number of cycles to failure (NCF) was determined. Groups with significant difference after the L-test were divided into 4 clusters, whilst the C-test gave just 2 clusters. From the L-test, considering the negative correlation of NCF, K3 gave a significantly lower fatigue resistance than ProFile as in the C-test. K3 #30/.06 showed a lower fatigue resistance than K3 #25/.06, which was not found by the C-test. Variation in fatigue test methodology resulted in different cyclic fatigue resistance rankings for various NiTi files. They concluded that new methodology standardized the load during fatigue testing, allowing determination fatigue behavior under constant load conditions.

Diemer F, Michetti J, Mallet JP, Piquet R (2013) assessed the role of an asymmetric cross-section on the behavior of the instrument by measuring the stresses generated during the preparation of a simulated canal. They observed that there are two factors that affect the choice of instruments for root canal preparation: its ability to achieve the canal's shaping and its safety. Three 25-mm-long, 0.06 taper, ISO size #30 helical nickel-titanium instruments were tested. The first HeroShaper used had a symmetric triple helix section (H0). The others, based on the HeroShaper design, had a constant asymmetry of 4/100 mm (H4) or 6/100 mm (H6). Six canals were prepared using each instrument, and the experimental conditions (ie, speed and movement) were the same for each sample. A dynamometer with a sensitivity of 0.1 N recorded the stresses transmitted by the instruments. Torque and apical force increased proportionally with instrument penetration. At the end of the preparations, the axial stress averaged 7.39 N for the symmetric instrument and 5.92 and 5.15 N for the asymmetric instruments, which indicated a significant statistical analysis of variance. The average torque was low (1.05-1.13 N.cm), which indicated a nonsignificant statistical analysis of variance. Hence it was concluded that , axial stresses decreased, but torque did not change with an asymmetric triple helix cross-section.

Saleh AR, Gilani PV, Tavanafar S, Schafer E (2013) compared the shaping ability of 4 different single-file systems in simulated S-shaped canals. Sixty-four S-shaped canals in resin blocks were prepared to an apical size of 25 using Reciproc, WaveOne, OneShape, and F360 (n = 16 canals/group) systems. Composite images were made from the superimposition of pre- and post instrumentation images. The amount of resin removed by each system was measured by using a digital template and image analysis software. Canal aberrations and the preparation time were also recorded. Canals prepared with the F360 and OneShape systems were better centered compared with the Reciproc and WaveOne systems. Reciproc and WaveOne files removed significantly greater amounts of resin from the inner side of both curvatures. Instrumentation with OneShape and Reciproc files was significantly faster compared with WaveOne and F360 files. No instrument fractured during canal preparation. All single-file instruments were safe to use and were able to prepare the canals efficiently. However, it was concluded that single-file systems that had less taper seemed to be more favorable when preparing S-shaped canals.

Agrawal V, Rajesh M, Kapoor S, Patel M (2014) reviewed the potential root canal irrigants with their advantages and limitations with their future aspect in endodontic irrigation. Endodontic therapy involved the removal of all vital or necrotic tissue, microorganisms, and microbial by-products from the root canal system. This could be achieved through chemo mechanical debridement of root canal. Sodium hypochlorite solutions were recommended as the main irrigant used since a long time. This was due to their broad antimicrobial spectrum as well as their unique capacity to dissolve necrotic tissue remnants. Chemical and toxicological concerns were discussed and their use with different approaches to enhance local efficacy without increasing the caustic potential was laid down. In addition, chelating solutions were recommended as adjunct irrigant to prevent the formation of a smear layer and/or its removal before filling the root canal system was advised. Along with traditional irigants, newer irrigants were also studied for potential replacement of sodium hypochloride. It was advised that a hypochlorite solution should be employed throughout instrumentation, without altering it with EDTA or citric acid. Between instruments, canals should be irrigated using copious amounts of the hypochlorite solution. Once the shaping procedure gets completed, canals should be thoroughly rinsed using aqueous EDTA or citric acid. Each canal should be rinsed for at least 1 min using 5 to 10ml of the chelator irrigant. It was claimed that after the smear layer removal, a final rinse with an antiseptic solution proved beneficial and chlorhexidine appeared to be the most promising agent to be used as a final irrigant in this situation. It had an affinity for dental hard tissues and, once bound to a surface, it prolonged antimicrobial activity, a phenomenon called substantivity. It was after the introduction of MTAD as irrigant, a new irrigating regimen was followed that included initial rinse with 1.3% NaOCl for 20 min and followed by final rinse with MTAD for 5 min.

Capar ID, Ertas H, Arslan H (2014) compared the cyclic fatigue resistance of the following NiTi instruments ProTaper Sx, HyFlex 25 taper 0.08 and Revo-S SC1. Three groups of nickel-titanium (NiTi) endodontic instruments were tested in steel canals with a 3-mm curvature radius and 60° ($n = 18$) and 45° of curvature ($n = 18$). The length and diameter of the fractured fragment and the total area of the fractured surface of each instrument were measured. At the 60° of curvature, Revo-S had the highest fatigue resistance, HyFlex had the second highest fatigue resistance, and ProTaper Universal had the least fatigue resistance. At the 45° of curvature, the Revo-S and HyFlex showed superior cyclic fatigue resistance compared with the ProTaper. The length of the fracture fragment of the ProTaper instrument was longer than that of the other groups at the 60° of curvature. At the 45° of curvature, the length of the fracture fragment of the ProTaper and HyFlex instruments was longer than that of Revo-S. The mean diameter and surface area of the HyFlex instruments in the fractured part was higher than that of other groups at both angles of curvature. It was concluded that Revo-S SC1 and HyFlex 25.08 instruments showed better cyclic fatigue resistance than the ProTaper Sx instrument.

Dina Al Sudani (2014) analyzed the surface defects on HyFlex CM instruments after use and determined their ability to return to their original shape after autoclaving. Twenty-four new HyFlex CM files were scanned using micro-computed tomography before the initial use, after use until defects were visible and after autoclaving. Surface analysis was performed on each file to determine the changes in the files after deformation; defects were recorded as unwinding and curving. These changes were categorized according to the severity, and the initial and final scans of the files were superimposed to illustrate the recovery of the files to their original shape. Almost all files exhibited visible defects without fractures, including unwinding and curving associated with unwinding. The most frequently observed defect was unwinding of the spirals (100%), whereas curving associated with unwinding was infrequently observed. The greatest frequency of curving occurred in the small files #20/0.04 and #20/0.06, the difference was statistically significant from all file sizes. The majority of the files (79%) were able to restore the unwinding and regain their original shape after autoclaving. The highest rate of unrestored files was observed on #20/0.04 and #20/0.06 instruments, and the difference was statistically significant from all file sizes. It was concluded that HyFlex CM nickel-titanium files appeared to regain their original shape after sterilization.

Dhingra A, Gupta R, Singh A (2014) compared the canal curvature modifications after instrumentation with Protaper Next, Protaper Universal and Wave One rotary file. Ninety freshly extracted mandibular teeth were taken for the study and were divided into two groups of 30 teeth each. Teeth with previous endodontic treatments, metal restorations, resorptions, incomplete apex formations and multiple visible foramina were excluded. 3D image acquisition was performed using the CBCT CS 9300. All CBCT measurements were performed by a single experienced investigator. Subsequently, access cavities were prepared, the working length was established. The teeth were sectioned vertically into two halves with the help of a diamond disc. Root canal preparations were performed using Protaper Next, Wave One & ProTaper file instrumentation systems in all the groups in strict accordance with each manufacturer's recommendations. CBCT images were obtained before and after instrumentation with Glide path at 90μ high resolution dental mode. The technical outcomes were then compared at 0, 1, 2, 3,4, 5,6 and 7mm intervals to evaluate the progressive changes in canal shape after using various Rotary single file systems. Centric ability was the parameter which was evaluated. The Present Study evaluated the Centric Ability of three endodontic file system i.e Protaper Next, Wave One & Protaper. The results showed a significant difference between the three groups. It was concluded that Protaper Next file system showed the better centric ability followed by Reciprocating Wave One & Protaper file system.

Dagna A , Claudio Poggio, Riccardo Beltrami1, Marco Colombo, Marco Chiesa, Stefano Bianchi (2014) evaluated the cyclic fatigue resistance of three single-use nickel–titanium (NiTi) file systems. Forty files each of One Shape (OS), Reciproc R25 (R25), WaveOne (WO) file, and ProTaper (PT) F2 (as control group) were tested in four curved artificial canals with different angles and radii of curvature. The number of cycles to fracture (NCF) was determined. The results showed that all single use instruments were more resistant than traditional rotary instrument used as control. R25 showed the highest cyclic fatigue resistance. One Shape and WO files showed similar cyclic fatigue resistance values, higher than PT F2. It was concluded that R25 was the most fatigue resistant. It was concluded that One Shape rotary file system seemed to have good mechanical resistance similar to NiTi files developed for reciprocating motion.

Karova E and Pirinska ST (2014) traced the lifespan of One Shape files used in severely curved canals of resin blocks and extracted teeth. The cumulative survival of tested files in both groups revealed significant difference. One Shape files manifested a lifespan similar to that of other NiTi systems with continuous rotation. One hundred canals were shaped and all instruments worked till their fracture. The One Shape files were used for the preparation of 100 canals: 50 Endo-Training Block simulators and 50 canals of freshly extracted molars, after an initial creation of a glide path. The artificial canals had a 0.02 taper, an apical diameter of 0.15, a 65 degree curvature and a 7.5 mm curvature radius. Only the mesial canals of mandibular molars and the buccal canals of maxillary molars with preserved apical foramen and curvature more than 30º were shaped. The angle and radii of canals curvature were determined by a radiographic image. Initially, all canals were scouted to full working length with a #10 hand K-file. During mechanical instrumentation each file was coated with Glyde to act as a lubricant, and a copious irrigation with 5.25% NaOCl was carried out. One Shape files worked till fracture occurred. The instrumentation of all canals was performed by a single operator. Average lifespan and cumulative survival at the time of One Shape files were tested. The average lifespan in the group of artificial canals was 4.63±1.30 canals and of extracted teeth 8.40±1.34 canals. The cumulative survival of tested files in both groups revealed significant difference. One Shape files manifested a lifespan similar to that of other NiTi systems with continuous rotation.

Karova E and Pirinska ST (2014) compared instrument life of WaveOne and One Shape single-file techniques used for the instrumentation of artificial curved canals after a glide path creation. Canal preparation was performed on 100 Endo-Training Block simulators divided in two equal groups, depending on the file used. Average lifespan and cumulative survival at the time of WaveOne files with reciprocating rotation and One Shape files with continuous rotation, after a glide path creation, were tested. All shaping instruments worked till fracture occurred. During mechanical instrumentation each file was coated with Glyde to act as a lubricant, and copious irrigation with 5.25% NaOCl was carried out. Twelve shaping files were used in canals preparation, after their initial enlargement, and ten of them broke: 2 Wave One files and 8 One Shape files. The average lifespan of one WaveOne file was 17.50±2.12 canals and of one One Shape file–4.63±1.30 canals. The WaveOne instruments presented a significantly longer survival than the One Shape files. It was concluded that WaveOne files showed significantly higher resistance to fracture compared with the One Shape files and hence instrumentation with files with reciprocal motion increases significantly instruments life and makes them safer during shaping of root canals.

Pedulla E, Savio FL, Boninelli S, Plotino G, Grande NM, Rapisarda E, Elnaghy AMG (2014) compared the cyclic fatigue resistance of ProTaper Next files with Twisted Files, Hyflex CM and ProTaper Universal NiTi rotary files. ISO size 25, .06 taper for PTN X2, TF, HF and PT F1 size 20, .07 taper were rotated in simulated canals until failure and the number of cycles to failure (NCF) was recorded to evaluate their cyclic fatigue resistance. A scanning electron microscope was used to characterize the topographic features of the fracture surfaces of broken files. Twisted Files had a significantly higher resistance to cyclic fatigue than the other instruments. No significant difference was found in NCF between Protaper Next and Hyflex CM. However, there was a significant difference of both these systems with Protaper Universal files which exhibited the lowest mean NCF. The ranking in the NCF values was Twisted files followed by ProTaper Next followed by Hyflex CM and Protaper Universal. The fractured cross-sections of all the tested files revealed crack origins, fatigue zone and an overload fast fracture zone. The new ProTaper Next had greater resistance to cyclic fatigue compared with ProTaper and HyFlex CM but not the Twisted Files.

Higueras JJP, Arias A, Macorra JC, Peters OA (2014) compared the cyclic fatigue resistance of ProTaper Universal and Protaper Next files at different curvatures. A total of 420 files (240 PTU, S1, F1, F2, and F3 and 180 PTN, X1, X2, and X3) were divided in 14 groups of 30 instruments each. Instruments in groups S1–5, F1–5, X1–5, F2–5, X2–5, F3–5, and X3–5 were tested at 5 mm from the tip. Groups S1–12, X1–12, and F1–12 were tested at 12 mm from the tip because S1, X1, and F1 instruments have the same diameter at that level. Groups F2–8, X2–8, F3–8, and X3–8 were tested at 8 mm (F2/X2 and F3/X3, respectively, had the same diameter at 8 mm). All files were rotated at 300 rpm until fracture. CF resistance was tested in stainless steel curved canals (60 degree angle of curvature and radius 3 mm). Time to fracture was recorded. PTN instruments showed significantly longer than PTU files at all tested levels except for S1, which was the significantly the most resistant instrument to CF at 5 mm from the tip. It was concluded that PTU S1 was significantly the most resistant instrument at 5 mm from the tip. PTN files were significantly more resistant to cyclic fatigue than PTU instruments at all the other tested levels.

Plotino G, Grande NM, Cotti E, Testarelli L,Gambarini G (2014) evaluated the difference in cyclic fatigue resistance between Vortex Blue and Profile Vortex nickel-titanium rotary instruments. The size and taper (15/.04, 20/.06, 25/.04, 25/.06, 30/.06, 35/.06, and 40/.04) were chosen. Ten instruments from each system and size were tested for cyclic fatigue resistance, resulting in a total of 140 new instruments. All instruments were rotated in a simulated root canal with a 60 degree angle of curvature and a 5-mm radius of curvature. The observations laid down whenever the file fracture during rotation. The number of cycles to failure and the length of the fractured tip were recorded for each instrument in each group. The mean values and standard deviation were calculated. When comparing the same size of the 2 different instruments, a statistically significant difference was noted between all sizes of Vortex Blue and Profile Vortex instruments except for tip size 15 and .04 taper. It was concluded that Vortex Blue showed a significant increase in cyclic fatigue resistance when compared with the same sizes of ProFile Vortex.

Kaur A , Chaudhary D, Kukreja N, Bansal A, Bansal J, Kukreja U, (2014) reviewed Nickel titanium rotary single file systems like One Shape, F-360 etc. The single file systems need no disinfection, cleaning, sterilizing and organizing the NiTi files as compared to conventional file systems. Also the single file system provided optimal cutting efficiency along with better control of file breakage and thus increased patient safety and no risk for cross contamination. The Single File System was found an exciting new concept in the preparation of the root canal. Whilst other, teaching advocated the use of multiple NiTi files of different diameter and taper to gradually enlarge the root canal but with these single file system only one file was required to prepare the canal to an adequate size and taper, even in narrow and curved canals. The advantages were laid down for use of single file system that included Single file used for RCT, Unique double S cross-section, Sharp cutting edge, Large chip space, Lower bending moment, Excellent cleaning, Time saving, No special motor required, Single cone obturation and lastly more economical.

Tsujimoto M, Irifune Y, Tsujimoto Y, Shizuka Y, Watanabe I, Hayashi Y (2014) investigated the surface and fractured structure, and physicochemical properties related to cyclic fatigue in various nickel-titanium (Ni-Ti) files. Among a total of 10 groups of Ni-Ti files, conventional Ni-Ti files (Profile and K3) and new-generation Ni-Ti files Profile Vortex [PV], Vortex Blue [VB], and K3 XF [XF]) with the same tip diameter (ISO size 25) and two types of taper (0.04 and 0.06). Scanning electron microscopy of the file surface structure, differential scanning calorimetry (DSC) and cyclic fatigue resistance tests were conducted. The results showed that many mechanical grooves were recognized on the file surface. The surface in the

Profile group was extremely smooth compared to that observed for the other files. Many shallow hollows besides mechanical grooves were noted on the surface in the XF group. A smooth curve was observed in the Profile, K3 and PV groups. Defined peaks in DSC were observed in the VB and XF groups. The taper 0.04 files exhibited a statistically higher number of cycles to fracture than the taper 0.06 files in all groups. Cracks along the mechanical grooves were observed in the Ni-Ti files, with the exception of the XF group. The start of cracking was detected at U-shape sites in the Profile group, the cutting edge in the PV and VB groups and radial islands in the K3 and XF groups.

Van der Vyver PJ, Botha FS, de Wet FA (2014) provided the clinical guidelines for the use of Protaper Next rotary files in complex and challenging endodontic cases. The complex case included S shaped or bayonet shaped root canal treatment. The protaper Next file set comprised of five instruments and most of the root canals could be prepared by using only the first two instruments. The first instrument in the file system was Protaper Next X1, with a tip size of 0.17mm and a 4% taper. This instrument was used after creation of a reproducible glide path by means of hand instruments or rotary Pathfile. The Protaper Next X1 was always followed by the second instrument: the Protaper Next X2 (0.25mm tip and 6% taper). The Protaper Next X2 was regarded as the first finishing file in the system as it left the prepared root canal with adequate shape and taper for optimal irrigation and root canal obturation. The PTN X1 and X2 had an increasing and decreasing percentage tapered design over the active portion of the instruments. The last three finishing instruments were the Protaper Next X3 (0.30mm tip with 7% taper), Protaper Next X4 (0.40 mm tip with 6% taper) and the Protaper Next X5 (0.5mm tip with 6%

taper). These instruments had a decreasing percentage taper from the tip to the shank. The Protaper Next X3, X4 and X5 could be used to either create more taper in a root canal or to prepare larger root canal systems. The article summarized the advantages of the Protaper Next files that included these files manufactured from M-Wire technology that contributed towards more flexible instruments, increased safety and protection against instrument fracture allowing the clinician to treat more complex root canal systems with a high level of success rate. Moreover, the instruments had a bilateral symmetrical rectangular cross section with an offset from the central axis of rotation (except in the last 3mm of the instrument, D0-D3) creating an asymmetric rotary motion. The exception is the Protaper X1, which has a square cross section in the last 3mm to give the instruments a bit more core strength in the narrow apical part. The asymmetric rotary motion allowed the instrument to experience a rotational phenomenon known as precession or swagger. The benefits of this file design reduced the engagement between the instrument and the dentine walls that further contributed to a reduction in taper lock, screw-in effect and stress on the file. The file design also ensured debris removal in a coronal direction because of the off-centre cross-section that allowed for more space around the flutes of the file. This led to improved cutting efficiency. The swaggering (asymmetric) rotary motion of the instrument initiated activation of the irrigation solution during canal preparation which improved debris removal and reduced the risk of instrument fracture because there was less stress on the file and more efficient debris removal. Every instrument was capable of cutting a larger envelope of motion (larger canal preparation size) compared to a similarly-sized instrument with a symmetrical mass and axis of rotation. This allowed the clinician to use fewer instruments to prepare a root canal to the adequate shape and taper to allow for optimal irrigation and obturation. There was a smooth transition between the different sizes of instruments because the design ensured that the instrument sequence itself expands exponentially.

Shinde TV (2014) reviewed the recent NiTi rotary file system that was manufactured from CM wire technology. It was discussed that the new technology of controlled memory files had the potential to consistently shape canals and clean root canal systems significantly better when the coronal two-thirds of the canal was first pre-enlarged followed by preparing its apical one third. First hyflex file 08/25 as an orifice opener in light pecking motion without any pressure was used after obtaining a glide path. 08/25 was the only file with neutral rake angle rest all the files have positive rake angle. This working length is then transferred to the further Hyflex shaping files. Subsequently 04/20 and 04/25 hyflex files are introduced into the canal gently with light pecking motion without any pressure. To optimize the safety and efficiency, the shaping files were used to follow glide path passively along the lateral surfaces of the canal to selectively cut the dentin on the outstroke. 06/20 hyflex file was introduced up till the junction of middle and apical one third in well lubricated and irrigated canals. The intend to use 06/ taper is to precisely enlarge and shape the critical junction between middle and apical third which is the prone for most of the endodontic mishaps such as instrument separation, canal blockage, perforation, transporation etc. Adequate enlargement of this narrowest part of the canal also facilitates copious irrigation to liberate the debris out of the canal. Conclusively, the apical portion of the canal is shaped with either 04/30 hyflex file or with 04/40 hyflex file. Utmost care should be taken to maintain minor diameter throughout the procedure. Adequate lubrication of canals with EDTA, gauging-tuning and scouting recapitulation with copious irrigation with warm sodium hypochlorite is key to success. The distinctive features of these files were accelerated flute design and increasingly wider flutes, absence of radial lands, variable pitch and constant helical angles, design of neutral rake angle.

Elnaghy AM (2014) compared the cyclic fatigue resistance of ProTaper Next files (PTN) with Twisted Files (TF), HyFlex CM (HF) and ProTaper Universal (PT). Size 25, .06 taper for PTN X2, TF, HF and PT F1 size 20, .07 taper were rotated in simulated canals until failure, and the number of cycles to failure (NCF) was recorded to evaluate their cyclic fatigue resistance. A scanning electron microscope was used to characterize the topographic features of the fracture surfaces of broken files. Twisted Files showed significantly higher resistance to cyclic fatigue than the other instruments. No significant difference was found in NCF between PTN and HF ($P > 0.05$); however, there was a significant difference of both these systems with PT, which exhibited the lowest mean NCF. The ranking in the NCF values was: TF > PTN > HF > PT. The fracture cross-sections of all brands revealed similar fractographic features, including crack origins, fatigue zone and an overload fast fracture zone. He concluded that the new ProTaper Next had greater resistance to cyclic fatigue compared with ProTaper and HyFlex CM but not the Twisted Files.

Sood A, Jindal V, Chhabra A, Arora A, Vats A (2015) evaluated the apical transportation, centering ability and cyclic fatigue resistance of Hero shaper, Twisted file, Hyflex file and RACE rotary file systems. Mesiobuccal roots of eighty maxillary molars were divided into four groups and instrumented with Hero shaper, Twisted file, Hyflex file and RACE rotary file systems with a final apical size being 25/.04.

Apical deviation was assessed by the radiographic platform method that enables obtaining superimposed images of the first and last instrument used in root canal preparation in the same radiograph. Forty canals were sectioned at 7mm from the apex and stereomicroscopic Images were taken at 6x magnification before and after instrumentation for evaluation of centering ability. The cyclic fatigue testing was conducted with the instrument rotating freely at angles of curvature of 45 degree. Total 10 instruments were tested in each group. The instruments were rotated at 400 rpm using the X-smart motor until fracture occurred. There was no statistically significant difference between the four groups in apical transportation and centering ability whereas twisted files showed the maximum cyclic fatigue resistance. The different rotary file systems provided minimum canal transportation and the twisted file performed significantly better in terms of cyclic fatigue resistance.

Saklecha B, Tekale PD, Kulkarni RS, Gedam R, Acharya VD, Jaiswal VS (2015) reviewed various methods of sterilization by focusing on the guidelines for an effective and efficient orthodontic practice. Sterilization is a process by which an article, surface or medium is freed of all micro-organisms either in vegetative or spore state. Control of infection that spreads through various instruments and armamentarium used in the field of orthodontics and dentistry in general was of utmost importance as a preventive measure for cross infection.

Pirani C, Cirulli PP, Chersoni S, Micele L, Ruggeri O, Prati C (2015) compared cyclic fatigue resistance of four nickel-titanium rotary systems and to evaluate their surface, fractographic, and matrix morphology. Four models of endodontic rotary files EasyShape, ProTaper, NRT and AlphaKite were subjected to fatigue testing in artificial canals with angle of curvature of 45 and 60 degree and a radius of curvature of 5 mm until fracture occurred. Nickel-titanium (NiTi) alloy properties were investigated by light microscopy, environmental scanning electron microscopy (ESEM), and energy dispersive x-ray spectrophotometry (EDS). ESEM analysis was conducted on new files to examine surface characteristics and on fractured samples to identify the crack origin and the fractographic features. The results showed that NRT files had the highest fatigue resistance followed by Alpha-Kite, EasyShape, and ProTaper. All the new files presented surface imperfections. Fractographic analysis found the crack initiation to originate at the level of surface irregularities. Optical microscope inspection of the NiTi alloy matrix disclosed different-sized non-metallic inclusions among models. EDS analysis of these inclusions showed that they were composed of carbon and oxygen in addition to nickel and titanium. Under light microscopy, austenitic grains appeared larger near the handle and smaller near the tip in all instruments. They concluded that NRT files presented the longest fatigue life. All samples showed surface irregularities and non-metallic inclusions. Austenitic grains were smaller near the tip than near the handle. The angle of curvature was confirmed to influence the fatigue life of NiTi instruments.

Cheng P, Hui WU, Lei W, Xin HU, Shu D, Changyi LI, Lianyun Z (2015) evaluated and compared the cyclic resistance of ProTaper Universal (size 25/08) and ProTaper Next (size 25/06) instruments in artificial canals with different curvatures. A total of thirty ProTaper Universal and 30 ProTaper Next instruments were divided into 6 groups (n = 10) and were operated into artificial canals with 3 different angles of curvature (45°, 60°, 90°). The canal length was kept consistent. The number of cycles to fracture (NCF) was counted until file fracture occurred, at which point, the length of the fragment was measured. Cross sections of the fractured files were scanned by an electron microscope. In the fatigue test, the ProTaper Next displayed more resistance in 45° and 60° canals whereas ProTaper Universal exhibited a better operability in 90° canals. The average length of the fragments from ProTaper Next was significantly shorter than that from ProTaper Universal in 90° canals. The cross sections of the fractured surfaces became flatter when the curvature angles decreased from 90° to 45°. ProTaper Next was more reliable when shaping in curved canals, whereas ProTaper Universal was more suitable for the preparation of root canals with severe curvatures

Bhatt A, Gupta V, Rajkumar B, Arora R (2015) reviewed about working length determination and its clinical implications. The determination of accurate working length is one of the most critical steps in the endodontic therapy. The cleaning, shaping and obturation cannot be accomplished accurately unless the working length is determined precisely. It was concluded that the predictable endodontic success demands an accurate working length determination of the root canal.

Karova E (2015) investigated the lifespan of One Shape files used in severely curved canals of resin blocks and extracted teeth. One Shape files were used for the preparation of 100 canals: 50 Endo-Training Block simulators and 50 canals of freshly extracted molars, after an initial creation of a glide path. The artificial canals had a 0.02 taper, an apical diameter of 0.15, a 65 degree curvature and a 7.5 mm curvature radius. Only the mesial canals of mandibular molars and the buccal canals of maxillary molars with preserved apical foramen and curvature more than 30º were shaped. The angle and radii of canals curvature were determined by a radiographic image. The teeth selected were intact, without advanced attrition, abrasion, erosion or crown fracture. Each tooth crown was sectioned before the instrumentation, so that 3 mm of the crown walls above the cement enamel junction were preserved. The teeth were kept in a solution of 5.25% NaOCl for 30 minutes after the extraction and later they were immersed in a physiological (salt) solution. Initially, all canals were scouted to full working length with a #10 hand K-file. G-Files were used for the glide path creation. The system consists of two instruments 21-25-29 mm long, with 0.03 taper size of the tip ISO 12 and 17 and variable cross-section throughout the length of the instrument. The 3 cutting edges are on three different radiuses relative to the axis of the canal, leaving a large and efficient area for upward debris removal. The shaping was finished with the One Shape files. Following the instructions of the producer the files were operated using The WaveOne Endodontic system. The One Shape files worked with continuous rotation (rotation speed – 400 rpm, torque - 2.0 gr/cm^2). The G-Files were used with rotation speed of 300 rpm and torque - 0.6 gr/cm2. The amount of pressure applied to all files was the pressure that could be applied to a sharp #2 pencil without breaking the lead. The files were never forced into the canal. During mechanical instrumentation each file was coated with Glyde to act as a lubricant, and a copious irrigation with 5.25% NaOCl was carried out. One Shape files worked till fracture occurred. The instrumentation of all canals was performed by a single operator. Average lifespan and cumulative survival at the time of One Shape files were tested. The average lifespan in the group of artificial canals was 4.63±1.30 canals and of extracted teeth 8.40±1.34 canals. The cumulative survival of tested files in both groups revealed significant difference. One Shape files manifested a lifespan similar to that of other NiTi systems with continuous rotation.

Duke F. (2015) evaluated and compared the fatigue resistance of ProFile Vortex (VX) and Vortex Blue (VB) files in two different artificial double curvature canals (DC1 and DC2) and in an artificial single curvature canal (SC). The bending moment of VX and VB was assessed. The bending moment (g·cm) was used to measure flexibility of VX and VB (size 25/.04, length: 25mm) according to ISO 3630-1 specifications. Both files types were tested for cyclic fatigue failure inside canals containing: a single curvature (SC: 60^{o} curvature, 5 mm radius) and two canals with different double curvature (DC); [DC1: coronal curvature of 60^{o} and 5 mm radius, and apical curvature of 30^{o} and 2 mm radius; DC2: coronal curvature of 60^{o} and 5 mm radius, and apical curvature of 60^{o} and 2 mm radius]. The number of cycles to failure (NCF) was recorded and the fracture surface of all fragments was examined with a scanning electron microscope (SEM) to confirm cyclic fatigue failure and for qualitative analysis of pattern of fracture. The results showed that VX and VB followed slightly different trajectories in the identical canals, especially in double curvature canals. The mean bending moment value was significantly lower for VB than for VX. NCF for the two files were significantly higher in the single curvature canal (SC) compared to the two double curvature canals (DC1 and DC2).

Of the double curvature canals, the NCF was significant higher in DC1 than in DC2 for VB but not for VX. In the SC group, VB had NCF superior to VX. In DC1 and DC2 groups, NCF of VX and VB was not statistically different from each other. Multiple crack origins were observed for iii the majority of files fractured in DC1 and DC2 canals. DC1 and DC2 canals demonstrated a more stressful and challenging anatomy than the SC canal for VX and VB. In double curvature canals, degree of curvature and radius, and the file's flexibility may affect the mean NCF.

Kang G and Song D (2015) reviewed the structural fatigue of NiTi shape memory alloys (SMA). The structural fatigue of NiTi SMA where, fatigue rupture is caused by a constant or cyclic mechanical loading was addressed. Firstly, the macroscopic and microscopic observations to the structural fatigue of NiTi SMAs was summarized. Secondly, advances in the mechanism of fatigue rupture and the fatigue failure models were discussed. The fatigue failure of the NiTi Shape memory alloys were summarized as follows: the observations were mainly focused on the mechanical fatigue of NiTi SMA where the cyclic transformation was induced by stressor strain-controlled cyclic loading, but the thermo-mechanical fatigue failures caused by the thermal cycling were investigated insufficiently, only the one undergoing the thermal cycling with a constant axial stress or strain was conducted. The most fatigue tests were performed under the cyclic uniaxial, bending and torsional loading conditions, much effort should be paid to the non-proportionally multiaxial fatigue of NiTi SMAs. The existing researches only address the fatigue of NiTi SMAs with constant stress or strain amplitude and at constant temperature and loading rate, the studies with varied stress or strain amplitude and at varied temperature and loading rate were found to be insufficient. Although there existed some researches that have discussed the effect of the extent of martensite transformation on the thermo-mechanical fatigue of NiTi SMA but more systematic experimental observations were needed to reveal the interaction of fatigue damage and martensite transformation in NiTi SMA. Most of fatigue tests were conducted under the strain-controlled cyclic loading conditions, the interaction of fatigue damage and transformation ratcheting occurred in the NiTi SMA under the stress-controlled cyclic loading conditions has not been investigated thoroughly.

Gagliardi J (2015) compared shaping characteristics and torsional profiles of the ProTaper Gold system (PTG) were compared with that of ProTaper NEXT (PTN) and ProTaper Universal (PTU) systems. Twenty-four mandibular first molars with 2 separate mesial canals were matched anatomically by micro-CT and prepared with rotary systems (n =16) to F2 or X2 instruments, respectively. Co-registered images were evaluated for 2- and 3-dimensional morphometric measurements. Maximum torque and angle of deflection were determined for 30 new or used PTG, PTN and PTU X2 or F2 instruments. It was found PTG and PTN produced less transportation and % decrease in dentin thickness than PTU. PTN had less canal wall contact than PTG and PTU. PTN demonstrated the lowest maximum torque and angle of deflection at fracture and overall mean torque and angle of rotation at fracture decreased after use.

Kumar SR and Gade V (2015) reviewed single file NiTi rotary systems for root canal preparation. The file systems included Waveone, Reciproc, One Shape and

F360. They also stated that cleaning and shaping of root canals is a major step in root canal treatment procedure, which aims at removal of all the tissue debris from the root canal space while removing the inner layers of root canal dentin. With Nickel titanium (NiTi) rotary instruments this goal is easier to achieve, even in curved root canals. The recently introduced Single file NiTi-rotary systems such as WaveOne, Reciproc, OneShape & F360 claimed to be able to completely prepare and clean root canals with only one instrument. It was concluded that the use of single file rotary systems was cost effective, time saving, reduced instrument fatigue and possible cross-contamination.

Mayhew and Kusy 2015 studied the effects of sterilization on the mechanical properties and the surface topography using 0.017 x 0.025-inch Nitinol and Titanal wires. Three approved heat sterilization methods were used dry heat, formaldehyde-alcohol vapor, and steam autoclave. Elastic moduli were obtained on 1-inch segments in 3-point bending. Laser scans of flatwise wire surfaces were conducted to detect surface alterations whether caused by tarnish, corrosion, or pitting. Tensile properties were determined on 7-inch lengths: the 0.1% yield strength, the ultimate tensile strength, and the percent elongation at break. The results showed that no detrimental changes were observed for either the selected mechanical properties or the surface topography. When the mean values of the two products were compared, Nitinol was less compliant but stronger than Titanal. Laser spectroscopy showed that Titanal possessed at least three times more specular reflectivity than Nitinol.

Sunil Kapila, Haugen and Watanabe 2015 investigation determined the effects of in vivo recycling interposed by dry heat sterilization (together referred to as clinical recycling, CR) on the load-deflection characteristics of nickel-titanium alloy wires. To differentiate the effects of dry heat sterilization (DHS) from those of CR on the behavior of these wires, a series of wires were also subjected to DHS only. Two types of nickel-titanium wires, namely Nitinol and NiTi were subjected to a three-point bending test in an as-received condition (T_0), after one cycle (T_1), and two cycles (T_2) of DHS or CR. Ten wires comprised each subsample. Both DHS alone, as well as CR, produced significant changes in the loading and unloading characteristics of Nitinol and NiTi wires. It was observed that the force levels during loading and unloading were substantially increased for both types of wires after CR. Most of these changes in load-deflection characteristics occurred between T_0 and T_1. They concluded that, clinical recycling appears to reduce the "pseudoplasticity" and "pseudoelasticity" of NiTi wires and increases the stiffness of both NiTi and Nitinol wires. (Load-deflection characteristics of nickel-titanium alloy wires after clinical recycling and dry heat sterilization.

Seago ST, Bergeron BE, Kirkpatrick TC, Roberts MD, Roberts HW, Himel VT, Sabey KA (2015) evaluated the recent nickel-titanium manufacturing processes have resulted in an alloy that remains in a twinned martensitic phase at operating temperature. This alloy has been shown to have increased flexibility with added tolerance to cyclic and torsional fatigue. This study assessed the effect of repeated simulated clinical use and sterilization on cutting efficiency and flexibility of Hyflex CM rotary files. Cutting efficiency was determined by measuring the load required to maintain a constant feed rate while instrumenting simulated canals. Flexibility was determined by using a 3-point bending test. Files were autoclaved after each use according to the manufacturer's recommendations. Files were tested through 10 simulated clinical uses. The results showed that the repeated simulated clinical use and sterilization showed no effect on cutting efficiency through 1 use and no effect on flexibility through 2 uses.

Vinothkumar TS, Kandaswamy D, Prabhakaran G, Rajadurai A (2015) investigated the role of dry CT conditions on the microstructure of martensitic SM NiTi alloy. Experiments were conducted on Ni-51 wt% Ti-49 wt% SM alloy. Five cylindrical specimens and five sheet specimens were subjected to different CT conditions: Deep CT (DCT) 24 group: −185°C; 24 h, DCT 6 group: −185°C; 6 h, shallow CT (SCT) 24 group: −80°C, 24 h, SCT 6 group: −80°C, 6 h and control group. Microstructure of surface was observed on cylindrical specimens with an optical microscope and scanning electron microscope at different magnifications. Subsurface structure was analyzed on sheet specimens using X-ray diffraction (XRD). Microstructures of all SM NiTi specimens had equiaxed grains (approximately 25 μm) with well-defined boundaries and precipitates. XRD patterns of cryogenically treated specimens revealed accentuation of austenite and martensite peaks. The volume of martensite and its crystallite size was found to be relatively more in Deep cryogenic treatment 24 specimen. It was concluded that Deep cryogenic treatment with 24 h soaking period increases the martensite content of the SM NiTi alloy without altering the grain size.

Scattina A, Alovisi M, Paolino DS, Pasqualini D, Scotti N, Chiandussi G, Berutti E (2015) evaluated a method to analyze stress distribution in nickel-titanium (NiTi) rotary instruments for obtaining number of cycles till fracture and failure location of NiTi rotary instruments.The method was called as FEM virtual simulation of an experimental nonstatic fatigue test. ProTaper Next (PTN) X1, X2, and X3 files (n = 20 each) were tested to failure using a customized fatigue testing device. The device and file geometries were replicated with computer-aided design software. Computer-aided design geometries (geometric model) were imported and discretized (numeric model). The typical material model of an M-Wire alloy was applied. The numeric model of the device and file geometries were exported for finite element analysis (FEA). Multiaxial random fatigue methodology was used to analyze stress history and predict instrument life. Experimental data from PTN X2 and X3 were used for virtual model tuning through a reverse engineering approach to optimize material mechanical properties. Tuned material parameters were used to predict the average NCF and failure locations of PTN X1 by FEA; t tests were used to compare FEA and experimental findings. Experimental NCF and failure locations did not differ from those predicted with FEA . Hence it was concluded that file NCF and failure location may be predicted by FEA. Virtual design, testing, and analysis of file geometries could save considerable time and resources during instrument development.

Varghese NO, Pillai R, Sujathen UN, Sainudeen S, Antony A, Paul S (2015) evaluated the resistance to torsional failure and cyclic fatigue resistance of

ProTaper Next (PTN), WaveOne, and Mtwo files in continuous and reciprocating motion. Randomized control trial in a tertiary care setting.

A total of 10 new size 25.06 taper PTN X2, 25.06 taper Mtwo files, and 25.08 taper WaveOne primary files each was selected. A custom fabricated cyclic fatigue testing device with a 70° angle of curvature and 3 mm width; curvature starting at 6 mm from the tip was used. All instruments were rotated and reciprocated till fracture occurred and time till fracture of each instrument was recorded in seconds. For torsional failure testing 5 mm tip of each file was embedded in composite resin block and uniform torsional stresses (300 rpm, 2.0 Ncm) were applied repetitively by an endodontic motor with auto stop mode until file succumbed to torsional failure. Number of load applications leading to failure was recorded. All the files showed superior resistance to cyclic fatigue in reciprocating motion when compared with continuous rotation mode. WaveOne primary files displayed maximum resistance to cyclic fatigue both in continuous and reciprocating motion. WaveOne primary files also demonstrated maximum resistance to torsional failure followed by PTN with Mtwo files exhibiting least resistance. They concluded Operating files in reciprocating motion enhances their cyclic fatigue resistance. WaveOne files showed maximum resistance to cyclic fatigue and torsional failure due to their cross-sectional diameter coupled M-Wire technology.

Krishna VV, Sujatha I, Jayalakshmi KB, Nadig PL, Chandra SSM, Mayur GN, Sivaji K, Singh GP (2015) evaluated the presence of debris on the dentinal wall of palatal root of maxillary molars and distal root of mandibular molars after instrumentation with rotary Mtwo and Protaper Next files under stereomicroscope. Materials and Methods: Forty freshly extracted human maxillary /mandibular molar teeth were selected for this study. Teeth were divided into two groups of 20 teeth each (group A and B).Teeth were decoronated at the CEJ, palatal and distal roots were taken. In group A, all the 20 canals were subjected to cleaning and shaping with rotary Mtwo files and rotary Protaper Next files in group B. After splitting the roots longitudinally, the dentinal debris of each root canal was evaluated at three areas (coronal, middle and apical thirds of the root) by means of numerical evaluation scale, under a stereomicroscope. There was no significant difference in the debris scores between the Mtwo group and Protaper Next group in the total canal area. It was concluded that both the instruments Mtwo and Protaper Next rotary systems could be used to complete the preparation of canals. The use of Protaper Next instruments resulted in better canal cleanliness in the middle part compared with Mtwo.

Rashid AA and Saleh ARM (2016) compared the shaping ability of four different single-file systems; WaveOne, Reciproc, OneShape, and F360. Stainless steel K-file (KSS) was used as a control during the preparation of simulated root canals. Eighty L-shaped canals in resin blocks were prepared to an apical size of 25 using one of the five groups (each group = 16). A series of pre- and post-operative images were taken by a digital camera (EOS 650D. Canon) and superimposed on two different layers. The amount of resin removed from both the inner and the outer sides of the canal were measured at five different points: orifice, half way of the orifice, beginning of the curvature, apex of the curve, and the apical end. The amount of resin removed by each system was measured using image analysis software. Canal aberrations and the preparation time were also recorded. There were significant differences between all single files and KSS in time for preparation while there was no significant difference between all single nickel-titanium (NiTi) files. No instrument was fractured during canal preparation. More canal aberrations were reported with hand K-files in which there was a highly significant difference compared with other single-file systems. OneShape file reported fewer canal aberrations, but all OneShape files deformed after use. There were significant differences between single NiTi files and KSSs in preserving the canal curvature while there was no significant difference between all single NiTi files. Reciproc and WaveOne files removed significantly greater amounts of resin from the inner side at the beginning and apex of the curve. Canals prepared with the F360 and OneShape systems were better centered compared with the Reciproc and WaveOne systems. It was concluded that NiTi instruments were superior to stainless steel K-files in their shaping ability. All single-file systems maintained root canal curvature well and were safe to use. Canals prepared with the F360 and OneShape systems were better centered compared with the Reciproc and WaveOne systems.

Ghattas SM and Hoen MM (2016) compared the cyclic fatigue resistance of one reciprocating and two rotary endodontic file designs. All tested files had a similar size .25-mm tip diameter and a taper of .08 mm/mm. The reciprocating file included a WaveOne. The rotary files included the latest generations of NiTi metallurgy (HyFlex CM and K XF). The tempered stainless steel artificial canal-testing device had a milled 60 degree curve with a 5-mm curvature radius shape. The canal was lubricated between each individual instrument test. All files, handpieces, and motors were used according to the manufacturer's specific directions. A jig was utilized to ensure the precise repeatable placement of all tested files. Each instrument was either rotated or reciprocated until a fracture was visually and audibly detected. Fracture times were recorded using a 1/100 second chrono-meter. A laser phototachometer (Nekio) was utilized to standardize and ensure that the rpm matched the individual manufacturer's recommendations. All files functioned as expected. The mean times to failure of the instrument groups follow: WaveOne — 61 seconds, HyFlex — CM 59 seconds, K3XF — 89 seconds. The K3XF files had a statistically significantly longer mean time to failure when compared to the WaveOne and HyFlex CM.

Chandrasekhar P, Shetty RU, Adlakha T, Shende S, Podar R (2016) evaluated and compared the cleaning efficacy of teeth instrumented with ProTaper Next and Silk File Systems. Forty permanent mandibular premolar teeth with single canal were selected. ProTaper Next file system was used to prepare the root canals of group one comprising of twenty samples, and the Silk file system was used to shape the root canals of group two. After cleaning and shaping, the teeth were sectioned longitudinally. The debris score evaluation with a stereomicroscope (30 x magnifications) preceded the statistical analysis with ANOVA and Student-t tests. Conclusion stated that no statistically significant difference seen between the two experimental groups (Protaper Next and Silk) concerning the debris in the apical, middle and coronal thirds of root canals hence rotary systems (ProTaper next and Silk) showed acceptable cleaning ability in permanent Root Canals.

Bakhai D and Hegde V (2016) evaluated and compared the surface changes of rotary nickel-titanium instruments manufactured from the Austenite phase, M-wire technology and R- phase before and after multiple uses. Sixty freshly extracted human mandibular premolars with a single, straight canal were selected. They were divided into three groups of twenty teeth each. Cleaning and Shaping was carried out using the crown down technique. All instruments were evaluated for defects under Scanning Electron Microscope (SEM) before and after multiple uses and scored for the defects. It was found that a statistically significant difference existed between the three groups in terms of resistance to surface defects. It was concluded that R-phase technology had superior resistance to surface defects, followed by M-wire and the austenitic phase.

Elemam RF, Capelas JA, Vieira MF (2016) evaluated the morphological alterations of the ProTaper next rotary file (PTN) under scanning electron microscopy (SEM). A total of eighteen simulated root canals were allocated to three groups. Six new sets of PTN instruments were used three times. Working length was obtained by ISO 10 K-file, followed by ProGlider to create a glide path. Ensuring the manufacturer's instructions with 99% ethyl alcohol for irrigation, all canals were prepared. The results obtained showed that PTNX1 and PTNX2 of each of the six systems were examined two times; before (B) and after use (A) (a total of 24 files). The files showed no pitting, corrosion, fretting, spiral distortion, disruption of cutting edges or fatigue cracks. Among these, 15 files showed no visible defects, and 9 files showed some topographic surface defects. One X2 file had a metal strip on the apical portion (from the top view) before its use (1 PTNX2). Three X1 files had blunt cutting edges of their apical and middle surfaces before use (4 PTNX1, 5 PTNX1, and 6 PTNX1); such defects persisted after usage. Small microcracks were observed on the critical point area under ×1000 magnification in two X2 files after use (1 PTNX2 and 6 PTNX2)). Moreover, only one file had fractures after its third use (5 PTNX1). The results showed blunt cutting edges in three files before use and stayed unchanged after the third use.

Topcuoglu HS, Topc G, Akti A, Deuzgeun S (2016) compared the resistance to cyclic fatigue of ProTaper Next , Hyflex CM, OneShape , and ProTaper Universal , nickel-titanium files in an artificial root canal with a double (S-shaped) curvature. A total of 160 new PTN X2, OS, HCM, and PTU F2 files were tested in an artificial stainless steel canal with a double curvature. Forty files from each system were rotated until fracture to calculate the number of cycles to failure. The length of each fractured fragment was recorded. The resistance to cyclic fatigue of the PTN X2 and HCM instruments was significantly greater the OS and PTU F2 instruments in the apical curvature. They stated that the PTN X2 and HCM instruments exhibited greater cyclic fatigue resistance than the OS and PTU F2 instruments in the apical curvature of an artificial canal with a double curvature. The PTN files (rectangular cross-sectional design) and HCM files (symmetrical triangular cross-sectional design) exhibit greater cyclic fatigue resistance than OS and PTU instruments in the apical curvature but not in the coronal curvature. In addition, this was due to metallurgical differences between instruments. PTN and HCM instruments were made with M-Wire and heat-treated NiTi alloys, respectively, whereas OS and PTU instruments was made with a conventional NiTi alloy. It was postulated that the improved cyclic fatigue resistance of PTN files might be associated with its non-uniform design and the reduced number of contact points between the instrument and the root canal walls.

Hegde MN, Sadananda V, Shetty P, Bhat G (2016) compared cyclic fatigue resistance of HyFlex CM, Mtwo, ProTaper Next and Twisted File. These four different groups of Nickel Titanium instruments HyFlex, Mtwo, ProTaper Next and Twisted files of length 25mm and taper of 0.06 were subjected to cyclic fatigue tests in a custom fabricated simulated canal with 60° curvature. The time to fracture was recorded and the number of cycles to fracture (NCF) was calculated. In accordance with findings, it was concluded that Protaper Next NiTi instruments exhibit the highest fatigue resistance followed by HyFlex CM, Mtwo and Twisted file instruments .It was postulated that the varied results could be caused by differences due to cross-sectiontional design of the instruments. The cross-sectional shapes can lead to changes in the instruments' mechanical behaviour and their design. ProTaper Next showed the highest resistance to cyclic fatigue which may be attributed to the strengthened NiTi, M-Wire and off-centred, rectangular cross section which brings about a swaggering movement during instrumentation thereby reducing binding to the root canal.

Santos LDA, Resende PD, Bahia MGA, Buono VTL (2016) evaluated and compared the effects of the presence of the R-phase in a near-equiatomic NiTi alloy on the mechanical responses of an endodontic instrument using finite element analysis. The input data for the constitutive model in the simulation were obtained by tensile testing of three NiTi wires: superelastic austenite NiTi, austenite + R-phase NiTi, and fully R-phased NiTi. The wires were also characterized by X-ray diffraction and differential scanning calorimetry. A commercially available endodontic instrument was scanned using microcomputed tomography, and the resulting images were used to build the geometrical model. The modeled instrument containing only R-phase demanded the lowest moment to be bent, followed by the one with mixed austenite + R-phase. The superelastic instrument, containing essentially austenite, required the highest bending moment. During bending, the fully R-phased instrument reached the lowest stress values; however, it also experienced the highest angular deflection when subjected to torsion. It was concluded that NiTi endodontic instruments containing only R-phase in their microstructure showed higher flexibility without compromising their performance under torsion.

Ozyurek T, Yılmaz K, Uslu G (2016), compared and evaluated the resistance of old (OGOS) and new generation (NGOS) One Shape single file systems that work with continuous rotation to cyclic fatigue under a dynamic model. Twenty pieces of old generation and twenty pieces of new generation One Shape (25/.06) files were included in the study. The files were used at 400 rpm and a 400 g cm-1 torque for OGOS and 400 rpm and a 200 g cm-1 torque value for NGOS according to the manufacturer's instructions until fracture. Two files from each group were examined with a SEM device to determine the fracture type. NGOS had a significantly higher cyclic fatigue resistance It was concluded that new generation One Shape NiTi file has been found more resistant to cyclic fatigue than the old generation. One Shape NiTi file are made of a conventional NiTi alloy and it has three variable cross-section zones, which change from three cutting edges near the tip region to two cutting edges at the end of the working part. Moreover, the asymmetric portion of the One Shape instrument is only in the 2 mm of the tip. The type of alloy that the files are made of is not the sole determining factor of the resistance shown by the files to cyclic fatigue. Design qualities of the files such as the cross-sectional shape, cross-sectional diameter, grooves and the spiral form could also affect the resistance to cyclic fatigue.

Jaureguizahar SM, Chapetti MD, Yawny AA (2016) evaluated the influence of testing temperature and deformation rate on fatigue life for characterizing structural fatigue of NiTi superelastic wires . It consisted firstly, performing low speed nearly isothermal pseudoelastic cycles in a limited region of the wire specimen. This resulted in the stabilization of the pseudooelastic behavior accompanied by a decrease in the stresses for forward and reverse transformations which allowed obtaining an equivalent to a geometric dog-bone shaped specimen due to the reduced transformation stresses in the pre-cycled region. In a second stage, by limiting the transformation active zone to the pre-cycled region, the deformation speed was increased to practical values avoiding any transformation activity outside that region. In that way, grip induced failures resulting in artificially shorter fatigue lives was completely avoided thus allowing an accurate characterization of the true structural fatigue. Additionally, strain controlled experiments on wires in fully austenite and fully martensite states have been performed. Resulting fatigue lives in these cases were at least two orders of magnitude higher compared with the pseudoelastic fatigue indicating the decisive role played by the stress induced transformation in determining fatigue life.

Singh K, Aggarwal A, Gupta SK (2016) reviewed and elaborated the metallurgic prospects of NiTi instruments. Root canal procedures are very common these days and so is the increasing demand of better root canal instruments. NiTi are one of the most common and better alloys used for manufacturing of these instruments. These instruments have better thermodynamic properties producing a shape memory effect under suitable conditions.

Uygun AD (2016) compared the cyclic fatigue resistance of ProTaper Gold (PTG), ProTaper Next (PTN) and ProTaper Universal (PTU) instruments at different levels. A total of 72 files were evaluated. The cyclic fatigue of PTU (F2), PTN (X2) and PTG (F2) at 5 mm (n = 12) and 8 mm (n = 12) from the tip in 3-mm-radius steel canals with a 60° angle of curvature was evaluated. The time to fracture was recorded. Significant differences were found amongst the instruments 5 mm from the tip. It was found that the PTG files had the highest CF resistance followed by PTN files which displayed greater CF resistance than the PTU files. The PTG and PTN files demonstrated greater CF resistance than the PTU files. It was concluded that PTG instruments were the most resistant 5 and 8 mm from the tip. The PTU files had the lowest CF resistance at all levels.

Ferreira F, Adeodato C, Barbosa I, Aboud L, Scelza P, Scelza MZ (2017) reviewed correlation between different movement kinematics and the cyclic fatigue resistance of NiTi rotary endodontic instruments. From June 2014 to August 2015, four independent reviewers comprehensively and systematically searched the Medline (PubMed), EMBASE, Web of Science, Scopus and Google Scholar databases for works published since January 2005, using the following search terms: endodontics; nickel–titanium rotary files; continuous rotation; reciprocating motion; cyclic fatigue. In addition to the electronic searches, manual searches were performed to include articles listed in the reference sections of high-impact published articles that were not indexed in the databases. Laboratory studies in English language were considered for this review. The electronic and manual searches resulted in identification of 75 articles. Based on the inclusion criteria, 32 articles were selected for analysis of full-text copies. Specific analysis was then made of 20 articles that described the effects of reciprocating and continuous movements on cyclic fatigue of the instruments. A wide range of testing conditions and methodologies have been used to compare the cyclic fatigue resistance of rotary endodontic instruments. Most studies report that reciprocating motion improves the fatigue resistance of endodontic instruments, compared to continuous rotation, independent of other variables such as the speed of rotation, the angle or radius of curvature of simulated canals, geometry and taper, or the surface characteristics of the NiTi instruments.

CHAPTER-3

AIM & OBJECTIVES

The present in-vitro study aimed to evaluate the fracture resistance of different types of endodontic rotary NiTi file.

The objectives of this study were:

- To evaluate the cyclic fracture resistance of different types of endodontic rotary NiTi files.
- To compare the cyclic fracture resistance of different types of endodontic rotary NiTi files.

HYPOTHESIS

The hypothesis states that the Hero Shaper, Protaper Next, Hyflex CM, Profile Vortex, and One Shape NiTi rotary files system will have different cyclic fracture resistance under the conditions investigated.

NULL HYPOTHESIS

The Null hypothesis states that there will be no differences in the cyclic fracture resistance of different rotary NiTi files with respect to cyclic fatigue failure under the conditions investigated.

CHAPTER-4

MATERIALS AND METHODOLOGY

The following materials were used during this in-vitro study:

1. **Hero Shapers Rotary NiTi files (Micro Mega, France).**
2. **ProTaper Next Rotary NiTi files (Dentsply Mallifer, Switzerland).**
3. **Profile Vortex Rotary NiTi files (Dentsply Tulsa Dental, OK, USA).**
4. **Hyflex CM Rotary NiTi files (Coltene Whaldent, Germany).**
5. **One Shape Rotary NiTi files (Micro Mega, France).**
6. **Glyde EDTA Gel (Dentsply Mallifer, Switzerland).**
7. **Tri Auto Mini Torque controlled Endomotor with Cordless Handpiece (J Morita, Japan).**
8. **Simulated Cyclic Fatigue Testing Apparatus.**
9. **Digital Stopwatch**

4.1 MATERIAL PROFILE:

4.1.1 Group I : Hero Shaper Rotary NiTi files (Figure 4.1 & 4.2)

Hero Shaper manufactured by Micro Mega, Besancon, France. It was introduced by Daryl Green. The Hero shaper is an instrument system which is the first rotary NiTi instrument designed without radial lands. The predecessor rotary system by Micro Mega was HERO 642 in which H meant for High, E meant for

Elasticity, RO meant for Rotation and digits 642 meant that the files in this system are available in various tapers like 0.06, 0.04 and 0.02.

Figure 4.1 Hero Shapers NiTi rotary files

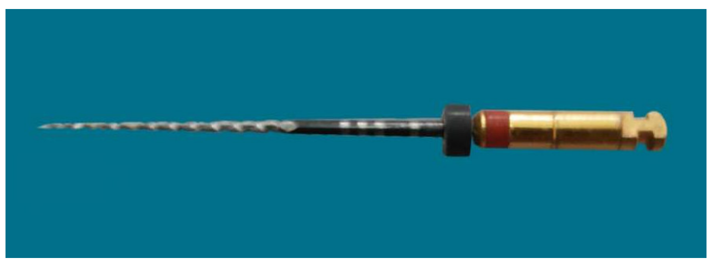


Figure 4.2: **Hero Shaper NiTi Rotary File ISO 25, taper 6%, length 21 mm.**

In 2001, Micro-Mega developed a Hero file system with a sequence that did not comprised of 0.02 taper file. Instead, it was named as HERO Shaper® for body shaping with adapted pitch concept and HERO Apical® for apical finishing of the root canal. Herso shaper are manufactured using recent M-wire NiTi technology that enhances its flexibility and resistance to cyclic fatigue in comparison to conventional NiTi rotary files.

These instruments are with different tapers (0.06 and 0.04) and three tip diameters (#20, #25, and #30) total of six shaping files.(Table 4.1)

Table 4.1: Availability of Hero Shapers Rotary Niti Files.

No. of Instruments	**File**	**Tip**	**Taper**	**Length** (in mm)
6	Classic Version	ISO 20, 25 &30 number	0.006	21,25
6	InGeT version	ISO 20, 25 &30 number	0.004	21,25,29

Available in Two Versions:

i. **Classics Version**

Classics Version (Ø 2.35 shafts) to be fitted on a gear reduction handpiece

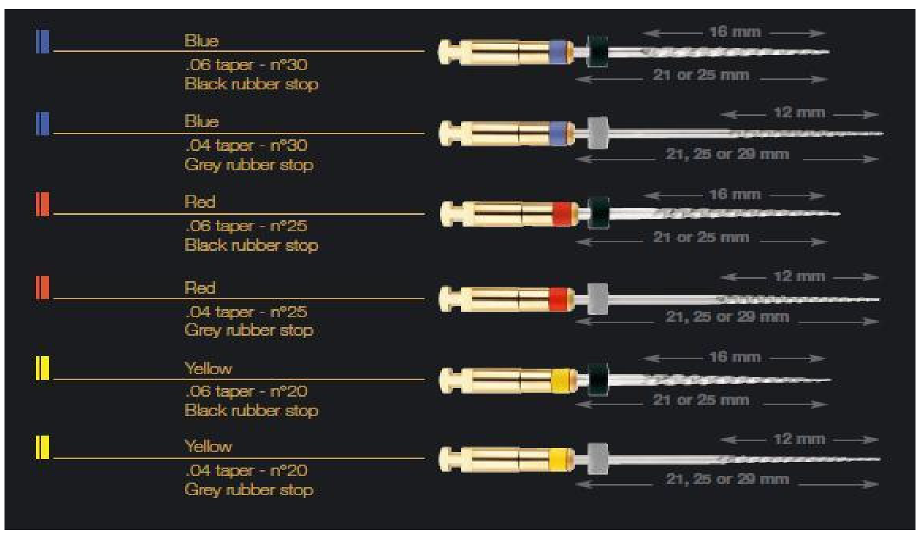


Figure 4.3: Classic version

ii. InGeT Version (Integrated Gear Technology)

The driving gear is part of the rotary file.

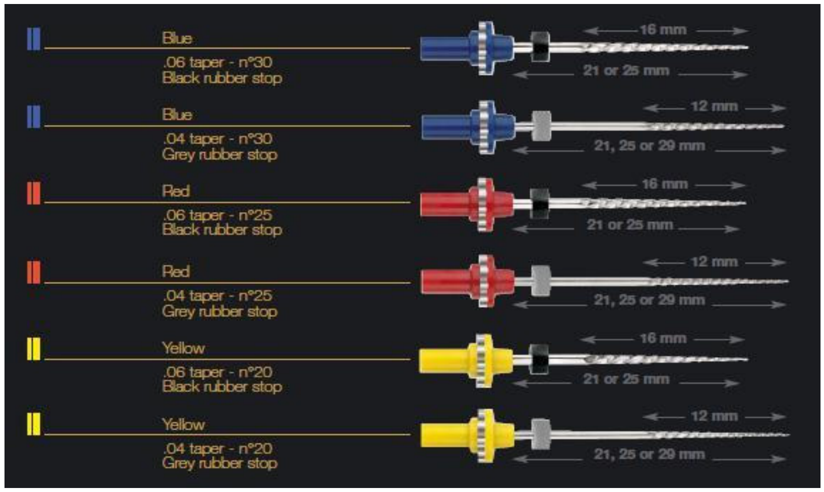


Figure 4.4: InGeT version

Tip

The tip is inactive and only serves as a guide to keep the instrument centered in the canal. The tip diameter being #20, #25, #30. (Figure 4.5).

Figure 4.5: Tip of the HERO Shapers: the tip is inactive and serves to guide the file, keeping it centered in the canal.

Taper

Available in 0.04 and 0.06 taper.

Length

The length of the cutting portion is 16 mm. Where ever possible, it is preferable to use short instruments (21mm total length) in order to simplify access to the canal. Lengthening the pitch increases flexibility and cutting efficiency. These instruments can thus negotiate canal curves.

Cross section

The cross sectional shape of the file is triple helix. The blade is lengthened to reduce rigidity. The pitch also progressively decreases from the shank to the tip. Smaller the blade angle, greater the cutting efficiency. (Figure 4.5)

Under identical working conditions, rotation speed, and pressure, an instrument with a long pitch will shape a canal more quickly than an instrument with a short pitch. Debris evacuation, i.e. dentinal chips, is facilitated by the longer pitch because evacuation is more direct and the threading-in phenomenon is reduced.

Special feature

HERO Shapers was designed with the same triple-helix cross-section. The smaller the blade angle, the greater the cutting efficiency. The key modifications in this instrument involve the pitch of the blade and the length of the cutting portion, which vary depending on the taper. By modifying these parameters, it is possible to select the strength, efficiency, and flexibility best suited for the taper and the work required of the instrument – this is known as adapted pitch concept.

Motion

Little or no pressure needs to be exerted on the head of the handpiece. Brushing technique is recommended for cleaning and shaping with HeroShapers. (Figure 4.6) The light in and out movement limits the engagement of dentine between the instrument and the canal walls.

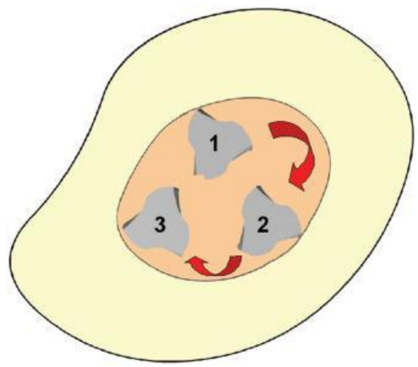


Figure 4.6: Brushing technique: the file is lightly pressed against the walls to prepare the entire root canal surface while respecting the original anatomy.

Instrumentation Protocol

a) For simple canal cases:

- A single sequence (blue wave) using two #30 files with decreasing tapers is recommended, the first with a 0.06 taper and the second with a 0.04 taper.
- The small canal curvatures and sufficiently large canal lumen allow a #15 K-file to penetrate to the apex.

b) For Intermediate canal cases:

- A sequence (red wave) using #25 files with 0.06 and 0.04 tapers are followed by a #30 file with a 0.04 taper.

c) Difficult cases: Penetration even with a #10 K file to the apex may be difficult.

Difficult canals are severely curved, occasionally with substantial mineralization, making first penetration problematical even with very small files.

- A sequence (yellow wave) using #20 files with 0.06 and 0.04 tapers are followed successively by a #25 file with a 0.04 taper and a #30 file with a 0.04 taper to full working length.

Failure Pattern

From 6 to 10 canals can generally be treated with a single HERO Shaper file. However, major constraints can cause premature metal fatigue, which is most often seen with the "unwinding" of the grooves (Anti Breakage Control). It is thus essential to comply with the recommended technique and especially, to avoid any pressure on the head of the contra-angle causing "unwinding". It is also important to scrupulously check the files after cleaning and sterilization. Instruments that show signs of wear and "unwinding" should be discarded.

4.1.2 Group II: ProTaper Next Rotary NiTi files (Figure 4.7, 4.8 & 4.9)

The ProTaper NiTi files were introduced in 2001, based on a unique concept a designed by Dr. Cliff Ruddle, Dr. John West, and Dr. Pierre Machtou. These were manufactured by Dentsply Maillefer; Ballaigues, Switzerland. The unique design factor is the varying tapers along the instruments long axis.

The Protaper Next files are available in 21mm, 25 mm and 31 mm length. (Table 4.2)

Figure 4.7 Protaper Next NiTi rotary files

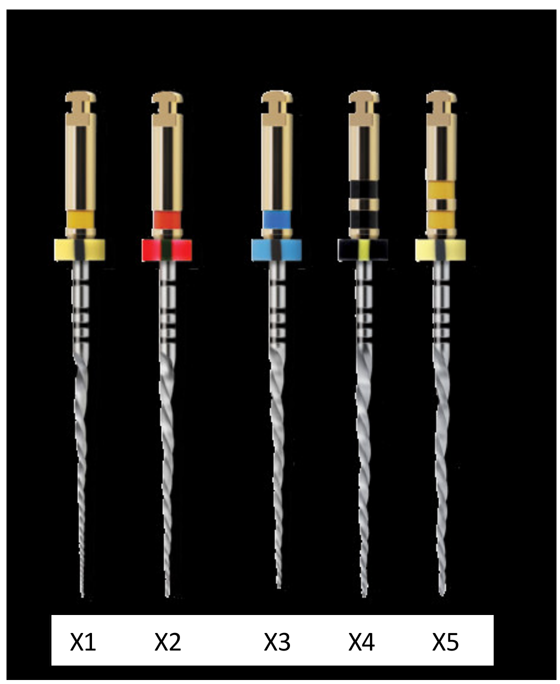


Figure 4.8: Protaper Next File system.

Figure 4.9: Protaper Next File (ISO 25, taper 6%, length 21 mm).

Table 4.2: ProTaper Next Rotary NiTi files availability.

Protaper Next Files	X1(Yellow)	X2(Red)	X3(Blue)	X4(Black)	X5 (Yellow)
Tip size	017	025	030	040	050
Taper	0.04	0.06	0.07	0.06	0.06

Taper:

Patented Variable taper along the file for effective crown down technique.

Cross section (Figure 4.10)

Protaper next has a patented off-centred rectangular cross-section which means only two points of the rectangular cross-section touches the canal wall at any one time.

Figure 4.10: ***Off centred rectangular cross section.***

Motor:

The torque controlled endomotor at a constant speed of 300 rpm and one torque setting to 2 Ncm is required for all Protaper Next files.

Features:

M-Wire

The M Wire NiTi material improves file flexibility, while still retaining cutting efficiency. This is achieved through an advanced Dentsply proprietary thermal treatment process. M-WIRE NiTi also provides greater resistance to cyclic fatigue, the leading cause of file separation.

Swaggering Effect (Figure 4.11)

Protaper Next's innovative off-centred rectangular cross section gives the file a snake-like "swaggering" movement as it moves through the root canal. This results in optimisation of root canal tracking as there are only two contact points at any one time between the file and the canal wall. The rotation of the off-centred cross section generates enlarged space for debris removal.

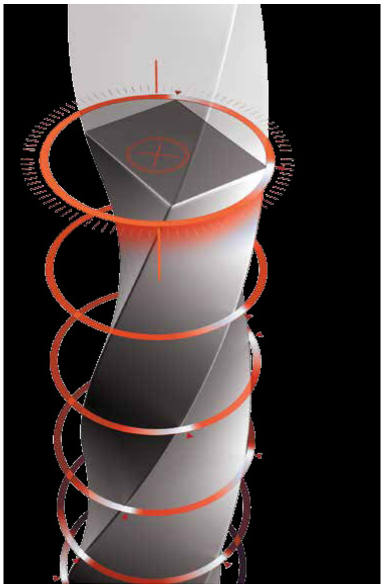


Figure 4.11: Swaggering motion in Protaper Next file

The file is designed so that its mass of rotation is offset. This leads to 3 major advantages:

1. Gives the file a snake-like "swaggering" movement as it moves through the canal. This results in optimisation of root canal tracking as only two points of the rectangular cross section touch the canal wall at a time. Reduced engagement limits undesirable taper lock, the screw effect, and the torque on any given file.
2. More cross-sectional space for enhanced cutting, loading, and removal of debris from a canal. Decreases the probability for laterally compacting debris and blocking root canal system anatomy.
3. A bigger envelope of motion. A smaller-sized and more flexible protaper next file can cut the same-size preparation as a larger and stiffer file with a centered mass and axis of rotation.

4.1.3. Group III: Profile Vortex Rotary NiTi files (Figure 4.12, 4.13 & 4.14)

Profile Vortex File system was manufactured by Dentsply Tulsa Dental Specialities, OK, U.S.A. Profile system was first introduced by Dr. Ben Johnson in 1994. It is the next generation of ProFile series with M- Wire NiTi technology that increases flexibility and resistance to cyclic fatigue over standard nickel titanium wires.

Figure 4.12 Profile Vortex NiTi rotary files

Figure 4.13: ProFile Vortex Rotary NiTi file system.

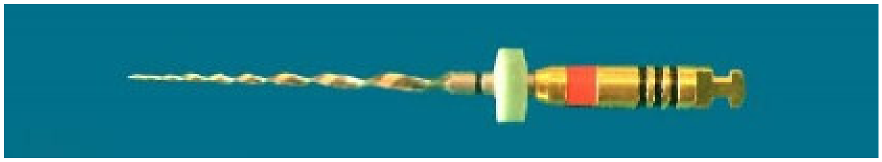


Figure 4.14: Profile Vortex (ISO 25, taper 6%, length 21 mm).

Table 4.3: Profile Vortex Rotary File system availability.

No. of Instruments	File	Tip size	Taper	Length
8	ISO 15, 20, 25, 30, 35, 40, 45 & 50.	0.15 - 0.50 mm	0.04 and 0.06	21mm, 25mm & 29 mm.

4% Taper Files have assorted pack of six files:

ISO 15(White), 20(Yellow), 25(Red), 30(Blue), 35(Green), 40(Black), 45(White), 50 (Yellow).

6% Taper Files have assorted pack of six files:

ISO 15(White), 20(Yellow), 25 (Red), 30(Blue), 35(Green), 40(Black),45(White),50 (Yellow).

Tip

Available tip diameter ranges from 0.15 to 0.5mm. (Figure 4.15)

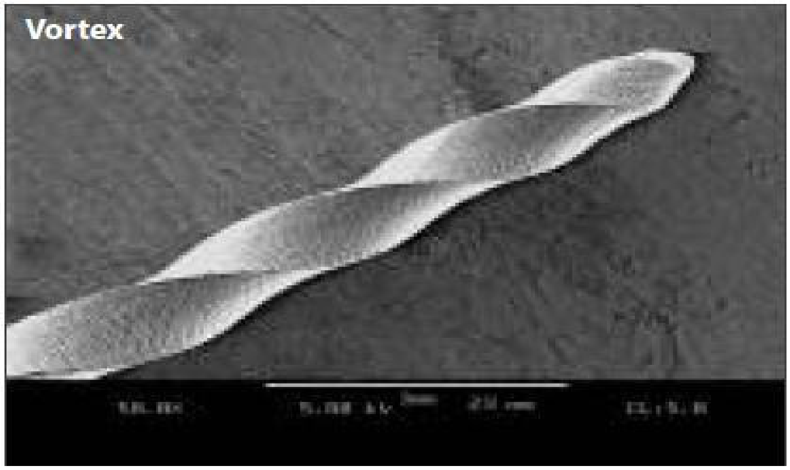


Figure 4.15: Tip of Profile Voterx file.

Taper

It is available in .04 and .06 tapers.

Length

It is available in 21, 25 and 29mm.

Cross section (Figure 4.16)

The ProFile Vortex that incorporates a more actively cutting triangular cross section along with a presumably more fatigue-resistant alloy.

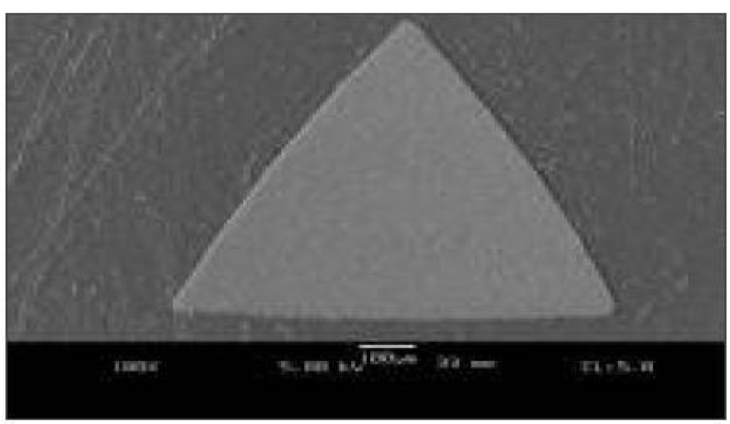


Figure 4.16: Cross-section of Profile Vortex file.

Motor used

Torque control motor used, with .04 and .06 taper 500 rpm is the speed at which they are run and torque for 0.04 taper is 75-132 N-cm and for 0.06 is 195-368 N-cm.

Instrumentation Protocol

i. Create straight line access:

Establish working length and create a glide path for ProFile Vortex® rotary files to follow:

Negotiate all root canals to their terminus with stainless steel ISO K-Files, in the presence of root canal conditioner.

Establish patency by taking a #10 K-File past the canal terminus, and at least a #15 K-File to the terminus.

ii. Shape Canal—Crown Down technique

Initiate Crown Down cleaning and shaping technique

In small canals (mesials/buccals of molars, small premolars and lower anteriors) start with a 30/.04 rotary file. Take 30/.04 to resistance or working length (whichever occurs first). If resistance is encountered before working length is obtained, go to next smaller instrument following the same protocol until working length is achieved.

Between each rotary file recapitulate with a #10 or #15 tip hand file to maintain glide path and help irrigate (NaOCl) to the canal terminus.

In larger canals (palatals/distils of molars, larger premolars, upper anteriors) begin with a 40/.04 rotary file. Use the crown down technique to resistance or working length. If resistance is encountered before working length is achieved, move on to smaller sized instruments until working length is achieved. Between instruments, recapitulate with small hand instrument to maintain a glide path to working length.

4.1.4 Group IV : Hyflex ™ CM NiTi rotary Files (Figure 4.17, 4.18 & 4.19)

These files were manufactured by Coltene Whaldent, Germany. These special files uses controlled memory technology and are extremely flexible.

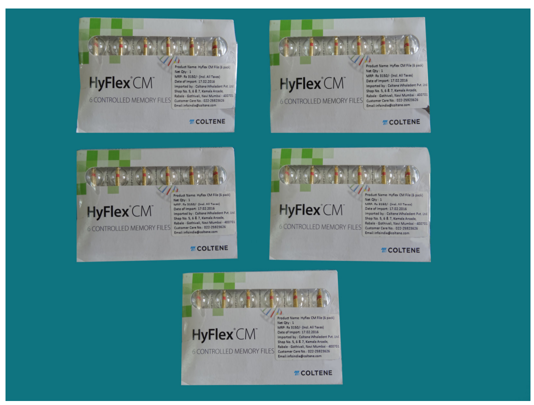


Figure 4.17: Hyflex CM NiTi rotary files

Figure 4.18: Hyflex CM NiTi Rotary File System.

Figure 4.19: Hyflex CM NiTi rotary File (ISO 25, taper 6%, length 21 mm).

Table 4.4: Hyflex CM Rotary NiTi Files Availability.

No. of	**Tip**	**Taper**	**Length**
Instruments	(mm)		
	0.25	8%	19mm
6	0.15-0.60	4%	21,25, 31 mm
	0.20-0.40	6%	21,25, 31 mm

Tip

The tip diameter ranging from 0.15 and 0.60.

Taper

Available tapers are .04, .06 and .08.

Length

It is available in 19, 21, 25 and 31mm

Cross- section

It is different for each taper and and file size ranging from triangular to square cross section as shown in (Figure 4.20)

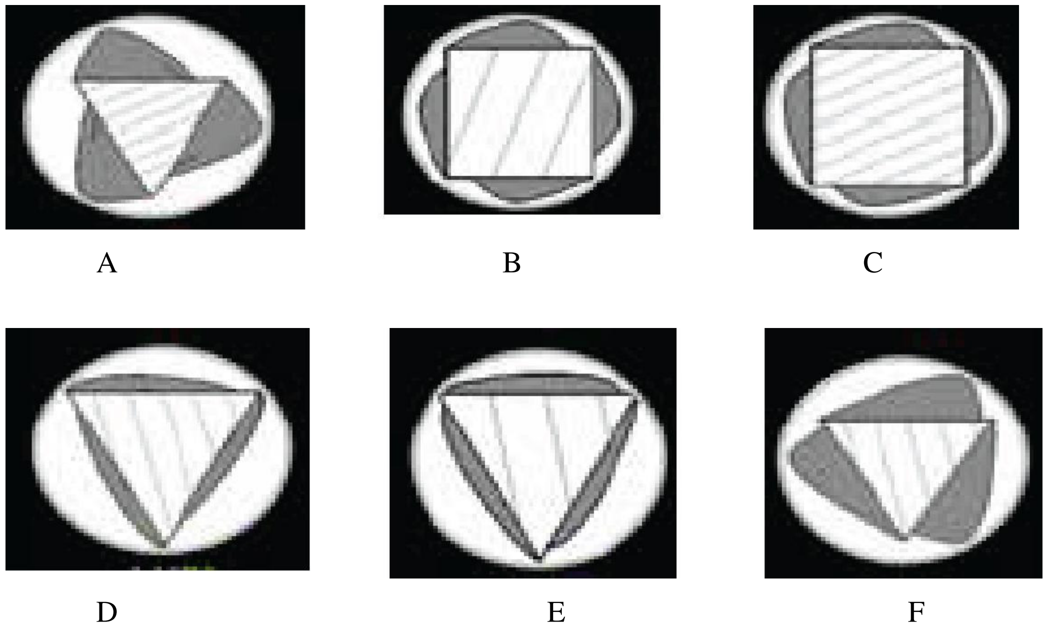


Figure 4.20: Cross-section; A .08/25, B.04/20, C.04/25, D.06/20, E.04/30, F.04/40

Special Features

- 300% more resistance to separation as compared to other Niti Files.
- Superior canal tracking without any procedural error like transportation, ledging or perforation.
- Multiuse as it regains its straightened spiral form after autoclaving the file. HyFlex CM files respond to excessive resistance with straightening of the spirals. This feature provides a clear visual opportunity to verify safe continuation of file use. The file can continue to be used, provided it has not started to rewind in the opposite direction.
- Option: During treatment place file in a glass bead sterilizer (Not for sterilization but for heat treatment) for 10 seconds and file will regain shape. (Figure 4.21)

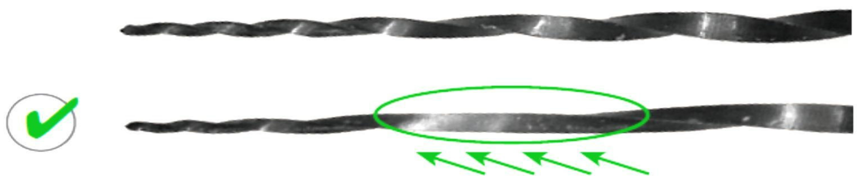


Figure 4.21: Response to excessive resistance with straightening of wire.

Care has to be taken if the spiral of the instruments starts to wind in the opposite direction during use, the files should be discarded. (Figure 4.22)

Figure 4.22: Spirals Starts winding in opposite Direction.

Instrument winding in opposite direction, such files should be discarded. The file regains shape after sterilization, thereby proving its multiuse property. (Figure 4.23)

Figure 4.23: Regains shape after sterilization

Motor used

Torque control motor with the speed control 140-550rpm and torque between 0.3-3 Ncm.

Instrumentation

1. 08/25 Orifice Opener is used enlarge the orifice and reach the working length, if the working length is reached then one must directly take .06/25 for apical enlargement (step 3) or then use

2. .04/20, Apical Enlargement, till working length is reached, followed by .04/25 for Apical Enlargement

3. .06/20, Middle Part Shaping, Working Length

4. .04/30 for apical enlargement, followed by .04/40 for further apical enlargement and confirm working length.

4.1.5 Group V: One Shape NiTi Rotary File System (Fig. 4.24, 4.25 & 4.26).

One shape files are manufactured by Micro Mega, Besancon Cedex, France. Complete canal shaping with only one single file in continuous rotation.

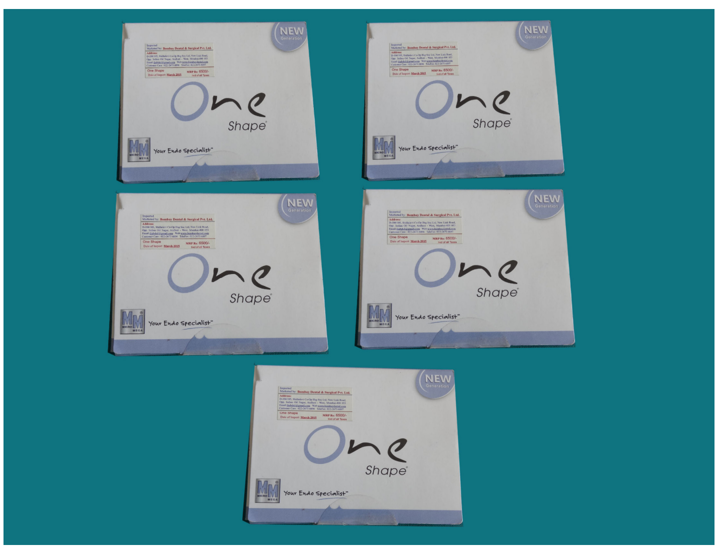


Figure 4.24 OneShape NiTi rotary files

Figure 4.25: One Shape NiTi Rotary File (Assorted)

Figure 4.26: One Shape NiTi rotary File (ISO 25, taper 6%, length 21 mm).

Table 4.5: OneShape NiTi rotary file (ISO 25, taper 6%, length 21 mm).

No of Instruments	File	Tip	#ISO	Length
Single File	1	0.25	6%	21,25 &29mm

Tip

Non cutting tip, that provides an effective apical progression.

Taper

The files have a taper 0.6

Length

It is available in 21, 25, 29 mm.

Cross section

It is seen in 3 different cross-section zones. (Figure 4.27)

First zone (apical) presents a variable 3-cutting-edge design.

- Second (middle) prior to the transition, has a cross-section that progressively changes from 3 to 2 cutting edges.
- Last (coronal) is provided with 2 cutting edges.

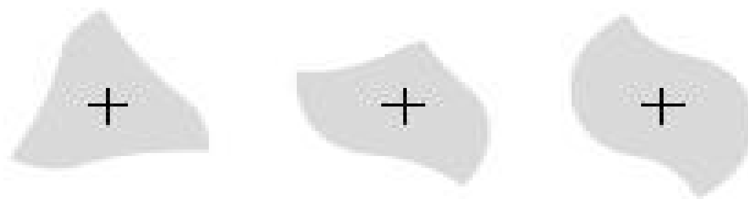


Figure 4.27: Cross Section

Special Features

The variable pitch of One Shape® reduces instrument screwing effects. ABC (Anti Breakage Control) is a safety bonus: the instrument will unwind to avoid separation.

Motor

Traditional endo handpiece placed on your unit or any other endodontic motor used in continuous rotation motion with the speed of 400rpm.

Instrumentation Protocol

a. Initial Canal Preparation

Once the access cavity is reached (access directly to the canal orifices and suppression of overhangs), the working length is determined with a small diameter precurved stainless-steel instrument (MMC files 10-15) which provide information of the root canal anatomy along with preoperative radiographs and/or apex locator.

b. If it is not possible to reach the apex with a 15 hand file

The removal of coronal constraints can be accomplished by the use Endoflare using a slight pecking motion until the working length has been achieved.

c. In case of resistance in tight canals

Use a slightly longer stroke in a pecking motion to achieve additional upward debris removal.

d. In case of significant resistance in difficult or curved canals

Remove and clean the instrument, replace the irrigant in the canal, and achieve patency with a small hand file (MMC 10) before continuing the root canal treatment. If necessary, perform an upward circumferential filling. Check apical patency if necessary. Irrigate thoroughly with sodium hypochlorite. The use of EDTA gel is recommended.

4.1.6 Glyde EDTA Gel (Dentsply Maillefer, Ballaigues, Switzerland)

Figure 4.28: Glyde EDTA Gel.

Complete cleaning of the root-canal system requires the use of irrigants that dissolve organic and inorganic material. As hypochlorite is active only against the former, other substances must be used to complete the removal of the smear layer and dentin debris. In addition, calcifications hindering mechanical preparation are frequently encountered in the canal system. Demineralizing agents such as ethylenediamine tetraacetic acid (EDTA) and citric acid have therefore been recommended as adjuvants in root canal therapy. Chelating agents were introduced into endodontics as an aid in preparation of narrow and decalcified canals by Nygaard Ostby in 1957 who recommended the use of 15% EDTA at pH 7.3.

Mechanism of action

EDTA reacts with the calcium ions in dentine and forms soluble calcium chelates. It has been reported that EDTA decalcified dentin to a depth of 20–30 μm in 5 min. The decalcifying process is self-limiting, because the chelator is used up.

Smear layer

A continuous rinse with 5 ml of 17% EDTA, as a final rinse for 3 min efficiently removes the smear layer from root canal walls. EDTA is most commonly used as a 17% neutralized solution (disodium EDTA, pH 7), but a few reports have indicated that solutions with lower concentrations (eg, 10%, 5%, and even 1%) remove the smear layer equally well after NaOCl irrigation.

Biofilm

In addition to their cleaning ability, chelators may detach biofilms adhering to root canal walls.

Dentinal property

Calt and Serper demonstrated that 10 mL irrigation with 17% EDTA for 1 minute was effective in removal of smear layer, but a 10-minute application caused excessive peritubular and intertubular dentinal erosion. Increasing contact time and concentration of EDTA from 10% to 17% as well as a pH of 7.5 versus pH 9.0 has been shown to increase dentin demineralization.

4.1.7 Tri Auto Mini (Figure 4.29)

Figure 4.29: Tri Auto Mini Endomotor and cordless Handpiece.

It is manufactured by J Morita, Japan. The high- performance Tri Auto mini endodontic motor excels with its extremely high level of flexibility .With its compact dimensions and low weight, it fits perfectly into the hand and opens up a new degree of freedom in treatment possibilities due to its rechargeable battery operation. The user can adjust file speed, torque values and various safety functions at the touch of a button and in this way increase safety for patients. And the various parameters for individual indications can be stored for even easier handling. In combination with the

Root ZV mini apex locator, you have an endometric and treatment of the very highest quality.

Flexibility

- Tri Auto mini is suitable for all standard NiTi files
- Rotational handpiece for optimum visibility in all quadrants
- Speed range from 50-1,000 rpm.
- Suitable for both right-handers and left-handers.
- Battery operated (rechargeable) and cable –free.

Treatment Comfort

- Easy-to-handle angle piece with extremely small head (9mm) for high patient comfort.
- Clear, energy-saving LC coloured display.
- Selectable signal tones.
- Variable file speeds.
- Variable torque values.
- 6 storage locations for treatment parameters.

Modular System

- Upgrade with Root ZX mini apex locator per data transfer cable.
- Additional functions for optimum preparation.
- Length measurement.

- Auto apical stop.
- Auto apical reverse
- Auto start/ stop .
- Auto apical slow down.

Safety

- Innovative Functions.
- Auto torque Reverse.
- Auto Torque Slow Down: Reduction of the rotational speed when approaching torque limitation.
- Visual indication of file position on display*.
- Change of display colour when approaching the apex*

*In combination with Root ZX mini.

Handpiece

Display: LCD

Weight: 78 gm

Motor: 50-1,000rpm

Torque: 3.9Ncm

Battery (rechargeable): 3.7 V lithium-ion

Diameter: 28 mm

Height: 150 mm

4.2 METHODOLOGY

The present in-vitro study was conducted in Department of Conservative Dentistry & Endodontics, at Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, in collaboration with Department of Mechanical Engineering, Indian Institute of Technology, Kanpur and IFFCO Amla, Bareilly, Uttar Pradesh, India.

The cyclic fracture resistance of five recent endodontic rotary NiTi files wiz Hero Shapers (Micro Mega, Besancon, France), Protaper Next (Dentsply Maillefer; Ballaigues, Switzerland), Profile Vortex (Dentsply Tulsa Dental Specialities, Tulsa, OK, U.S.A), Hyflex CM (Coltene Whaldent, Germany) and One Shape (Micro Mega, Besancon Cedex, France) were evaluated in the present study.

The **inclusion criteria** for choosing the above mentioned experimental rotary NiTi files was as follows:

1) A recent introduced rotary NiTi file system manufactured from Conventional NiTi alloy:

   One shape designated as Group V

2) A recent introduced rotary NiTi file system manufactured by M-Wire technology :

   Hero shaper designated as Group I,

   Protaper Next designated as Group II and

   Profile Vortex Designated as Group III

3) A recent introduced rotary NiTi file system manufactured by CM-Wire technology :

   Hyflex CM designated as Group IV.

Exclusion criteria:

1) Endodontic Stainless steel hand files.
2) Endodontic NiTi hand files.
3) Endodontic used files.

The five recent rotary NiTi files evaluated were Protaper Next (Dentsply Maillefer; Ballaigues, Switzerland), Hero Shapers (Micro Mega, Besancon, France), Hyflex CM (Coltene Whaldent, Germany), Profile Vortex (Dentsply Tulsa Dental Specialities, Tulsa, OK, U.S.A) and One Shape (Micro Mega, Besancon Cedex, France). All rotary NiTi files with tip size ISO 25, Length 21mm and taper 0.06 were kept standardized during this study. Total sample size of 125 rotary NiTi files were taken (25 for each group).

A simulated working model (Figure 4.30) was created similar to that of Cheung GSP *et al.* (2007) (Figure 4.31).

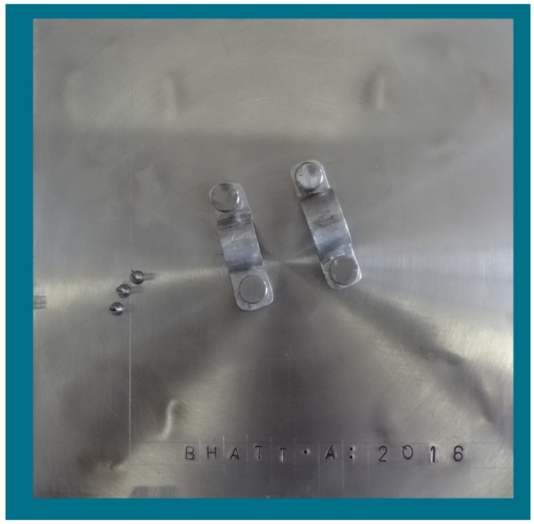


Figure 4.30: Simulated Working apparatus used in the present study.

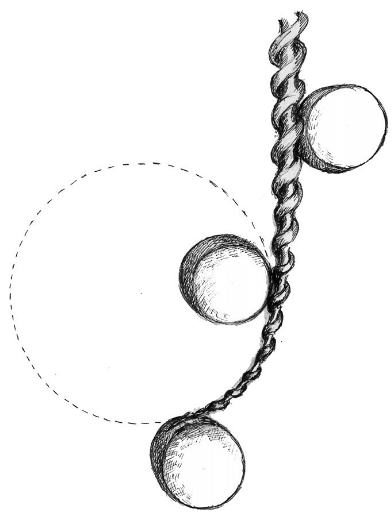


Figure 4.31: A schematic drawing of the three stainless steel pins that constrained the instrument into the desired curvature.

Description of Working Model (Figure 4.30)

The simulated working model comprised of a main stainless steel frame (SS-304) of Length 20cm, Breadth 20 cm, Height 5 mm to which two support (vise) for endomotor handpiece and three stainless steel cylinders were mounted. The endomotor handpiece was mounted to allow precise and reproducible placement of each experimental NiTi file. This ensured 3 dimensional alignment and positioning of file ISO size 25, Length 21mm and taper 0.06. Four legs made up of Stainless steel (SS304) were welded to the base of the main frame for stability of the apparatus. The level was maintained and checked by the help of level measuring gauge. The three steel cylinders (one supporting cylinder and other two shaping cylinders) of diameter 3mm were attached on 5mm thick stainless steel frame. The position of these three cylinders was such that it provided the experimental rotary NiTi file with a suitable simulated root canal of 60 degree angle of curvature and 5 mm radius of curvature. Radius was measured to the central axis of the curvature. The angle was kept 60 degree with the help of Angle Protactor Machine.

The angle of curvature was calculated by Schneider's method, which defined the angle of curvature by drawing a line parallel to the long axis of the canal and the outer line from the apical foramen to intersect with first line at a point where in the root canal began to leave the long axis of the canal.(Figure 4.31)

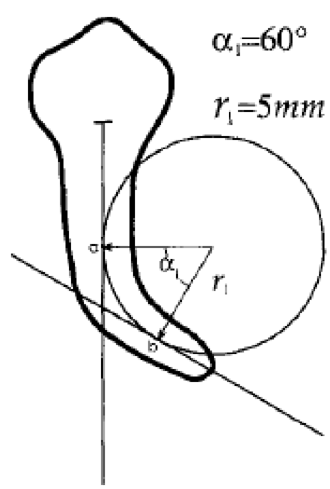


Figure 4.32: A schematic drawing of simulated root canals with an angle of curvature of 60 degrees and radius of curvature of 5 mm in the present study.

Method to evaluate cyclic fracture resistance in Experimental NiTi rotary files:

Fresh packets of the experimental rotary NiTi files were obtained from the manufacturer. A total of 125 rotary Niti Files were divided into five groups, each group comprising of 25rotary NiTi files.

- Group I consist of Hero shaper rotary NiTi files ISO 25, taper 0.06 and length 21 mm.
- Group II consist of Protaper Next rotary NiTi files ISO 25, taper 0.06 and length 21 mm.
- Group III consist of Profile Vortex rotary NiTi files ISO 25, taper 0.06 and length 21 mm.
- Group IV consist of Hyflex CM rotary NiTi files ISO 25, taper 0.06 and length 21 mm.
- Group V consist of One Shape rotary NiTi files ISO 25, taper 0.06 and length 21 mm.

The instrumentation protocol was followed for each experimental file group:

The experimental file of the designated group was coated with a layer of root canal lubricant (EDTA gel). It was placed in endomotor handpiece with its rubber stopper at the support pin/cylinder and end between two shaping pin/cylinders. The torque of 2.5N/cm and rpm of 400 was pre-set in endomotor handpiece. The file was then allowed to move and simultaneously the stopwatch was started. The time till fracture of experimental file was recorded in seconds by using a stopwatch.

The number of rotations till fracture was than calculated using the Formula (formula 4.1):

$$\text{No. of rotation to fracture} = \frac{400}{60} \times \text{ Time taken to fracture (in seconds)}$$

Formula4.1: For number of rotation till fracture.

The above instrumentation protocol was followed for all the 25 rotary NiTi files in each designated group. The observations and results were laid down and further statistical analysis was performed. **(Table 1, Table 2)**

Figure 4.33 Digital Stopwatch

The time till fracture of experimental file was recorded in seconds by using a stopwatch.

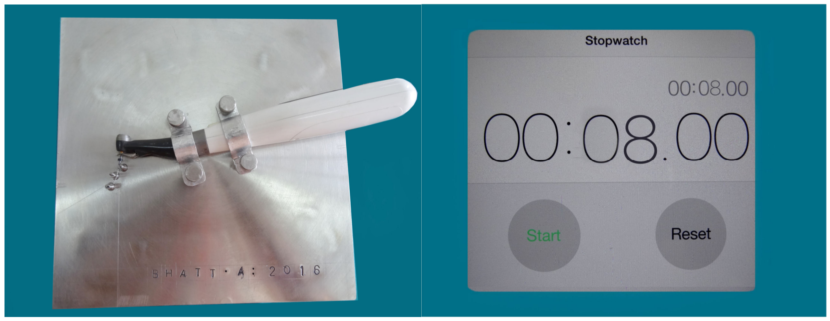


Figure 4.34 HeroShaper Group I

Figure 4.35 Protaper Next Group II

Figure 4.36 Profile Vortex Group III

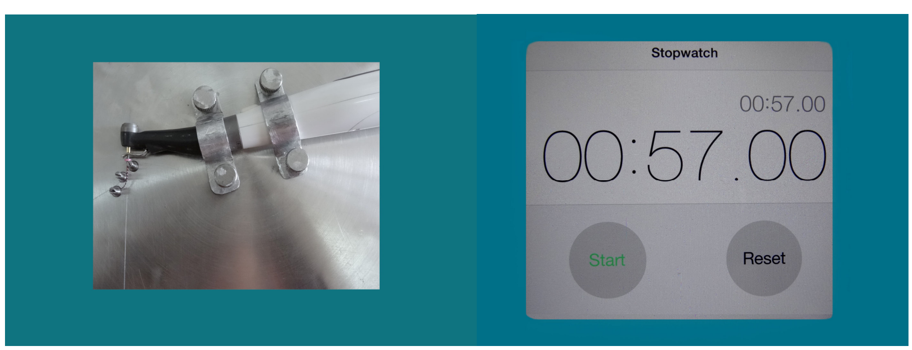


Figure 4.37 Hyflex CM Group IV

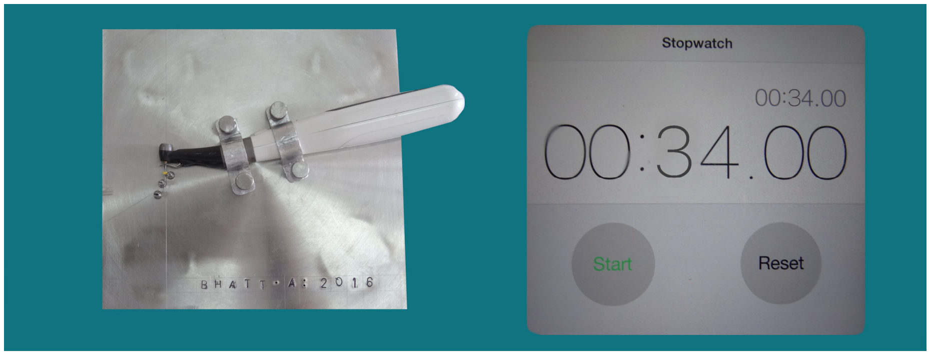


Figure 4.38 One Shape Group V

STATISTICAL TOOLS USED

The statistical analysis was done using SPSS (Statistical Package for Social Sciences) Version 15.0 statistical Analysis Software. The values were represented in Number (%) and Mean±SD.

The following Statistical formulas were used:

1. **Mean**: To obtain the mean, the individual observations were first added together and then divided by the number of observation. The operation of adding together or summation is denoted by the sign Σ.

   The individual observation is denoted by the sign X, number of observation denoted by n, and the mean by $\overline{X}$.

$$\overline{X} = \frac{\Sigma X}{\text{No. of observations (n)}}$$

2. **Standard Deviation**: It is denoted by the Greek letter σ.

$$\sigma = \sqrt{\frac{\Sigma (X - \overline{X})^2}{n}}$$

3. **Median**: For a distribution with odd number of data point, the middle value on arranging the data in ascending or descending manner. For a series with even number of data points, average of two consecutive middle values was taken as the median value.

4. **Analysis of Variance: Analysis of Variance** (ANOVA): The ANOVA test was used to compare the within group and between group variances amongst the study groups. Analysis of variance of different study groups at a particular

time interval revealed the differences amongst them. ANOVA provided "F" ratio, where a higher "F" value depicted a higher inter-group difference.

$$: F = \frac{\text{Mean of Sum of Between Group Differences}}{\text{Mean of Sum of within Group Differences}}$$

Differences	**Sum of Squares**	**df**	**Mean Square**	**F**
Between Groups	A	N_1	$X=A/N_1$	X/Y
Within Groups	B	N_2	$Y=B/N_2$	

5. Post-Hoc Tests (Tukey-HSD)

$$\frac{M_1 - M_2}{\sqrt{MS_w\left(\frac{1}{n}\right)}}$$

M = treatment/group mean
n = number per treatment/group

- Calculate an analysis of variance (e.g., One-way between-subjects ANOVA).
- Select two means and note the relevant variables (Means, Mean Square Within, and number per condition/group)
- Calculate Tukey's test for each mean comparison
- Check to see if Tukey's score is statistically significant with Tukey's probability/critical value table taking into account appropriate df within and number of treatments.

6. Level of significance: "p" is level of significance

$p > 0.05$ Not significant

$p < 0.05$ Significant

$p < 0.01$ Highly significant

$p < 0.001$ Very highly significant

7. **Weibull's Analysis:** Weibull's analysis is a linear regression based analysis for life expectancy of products with similar physical properties. It uses the equation $y = \alpha + \beta x$.

CHAPTER-5

OBSERVATIONS

OBSERVATIONS

Table 5.1: Time taken (in seconds) by experimental files in each group until fracture.

S.NO	Group I (n=25)	Group II (n=25)	Group III (n=25)	Group IV (n=25)	Group V (n=25)
1	12	24	14	52	40
2	8	22	10	50	38
3	10	18	12	58	32
4	8	18	10	54	30
5	12	26	14	56	34
6	10	18	12	58	30
7	10	22	14	57	34
8	9	24	10	58	36
9	8	24	10	55	38
10	7	20	12	56	38
11	10	18	12	58	30
12	10	22	14	57	34
13	9	24	10	58	36
14	8	24	10	55	38
15	7	20	12	56	38
16	12	26	14	56	34
17	8	18	10	54	30
18	10	18	12	58	32
19	8	22	10	50	38
20	12	24	14	52	40
21	9	22	14	50	36
22	8	18	12	54	34
23	10	24	10	52	30
24	8	18	10	54	38
25	12	24	10	50	40

Table 5.2: Number of cycles performed by experimental files in each group until files fractures.

S.NO	Group I (n=25)	Group II (n=25)	Group III (n=25)	Group IV (n=25)	Group V (n=25)
1	80.04	160.08	93.38	346.84	266.8
2	53.36	146.74	66.7	333.5	253.46
3	66.70	120.06	80.04	386.86	213.44
4	53.36	120.06	66.7	360.18	200.1
5	80.04	173.42	93.38	373.52	226.78
6	66.7	120.06	80.04	386.86	200.1
7	66.7	146.74	93.38	380.19	226.78
8	60.03	160.08	66.7	386.86	240.12
9	53.36	160.08	66.7	366.85	253.46
10	46.69	133.4	80.04	373.52	253.46
11	66.7	120.06	80.04	386.86	200.1
12	66.7	146.74	93.38	380.19	226.78
13	60.03	160.08	66.7	386.86	240.12
14	53.36	160.08	66.7	366.85	253.46
15	46.69	133.40	80.04	373.52	253.46
16	80.04	173.42	93.38	373.52	226.78
17	53.36	120.06	66.7	360.18	200.1
18	66.7	120.06	80.04	386.86	213.44
19	53.36	146.74	66.7	333.5	253.46
20	80.04	160.08	93.38	346.84	266.8
21	60.03	146.74	93.38	333.5	240.12
22	53.36	120.06	80.04	360.18	226.78
23	66.07	160.08	66.7	346.84	200.1
24	53.36	120.06	66.7	360.18	253.46
25	80.04	160.08	66.7	333.5	266.8

CHAPTER-6

RESULTS

The present study was carried out with an aim to evaluate the fracture resistance of different types of endodontic rotary files. For this purpose, five different types of endodontic rotary files were chosen for assessment. Table 6.1 below shows the distribution of samples of five different types of endodontic rotary files used in the study:

Table 6.1: Distribution of Samples according to type

SN	Group	Commercial file type and specification	No. of samples	Percentage
1.	I	Hero Shaper 60^{o}	25	20
2.	II	Protaper Next 60^{o}	25	20
3.	III	Profile Vortex 60^{o}	25	20
4.	IV	Hyflex CM 60^{o}	25	20
5.	V	One Shape 60^{o}	25	20

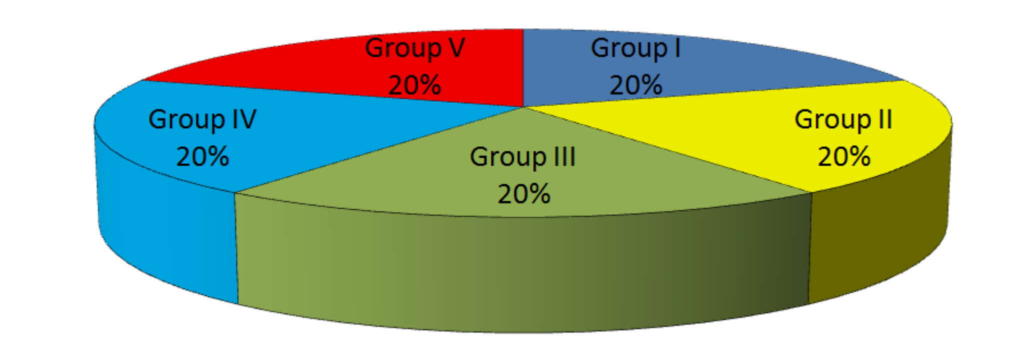


Figure 6.1: Distribution of samples according to Group

A total of five commercial file types were selected for the purpose of study with each type represented by 25 (20%) of samples. Group I comprised of 25 (20%)

Hero Shaper 60^o files, Group II comprised of Protaper Next 60^o Files, Group III comprised of 25 (20%) Profile Vortex 60^o Files, Group IV comprised of 25 (20%) of Hyflex CM 60^o files and Group V comprised of 25 (20%) of One Shape 60^o files.

Table 6.2: Distribution of Samples in different groups according to time taken for fracture

S.NO	Group I (n=25)	Group II (n=25)	Group III (n=25)	Group IV (n=25)	Group V (n=25)
1	12	24	14	52	40
2	8	22	10	50	38
3	10	18	12	58	32
4	8	18	10	54	30
5	12	26	14	56	34
6	10	18	12	58	30
7	10	22	14	57	34
8	9	24	10	58	36
9	8	24	10	55	38
10	7	20	12	56	38
11	10	18	12	58	30
12	10	22	14	57	34
13	9	24	10	58	36
14	8	24	10	55	38
15	7	20	12	56	38
16	12	26	14	56	34
17	8	18	10	54	30
18	10	18	12	58	32
19	8	22	10	50	38
20	12	24	14	52	40
21	9	22	14	50	36
22	8	18	12	54	34
23	10	24	10	52	30
24	8	18	10	54	38
25	12	24	10	50	40

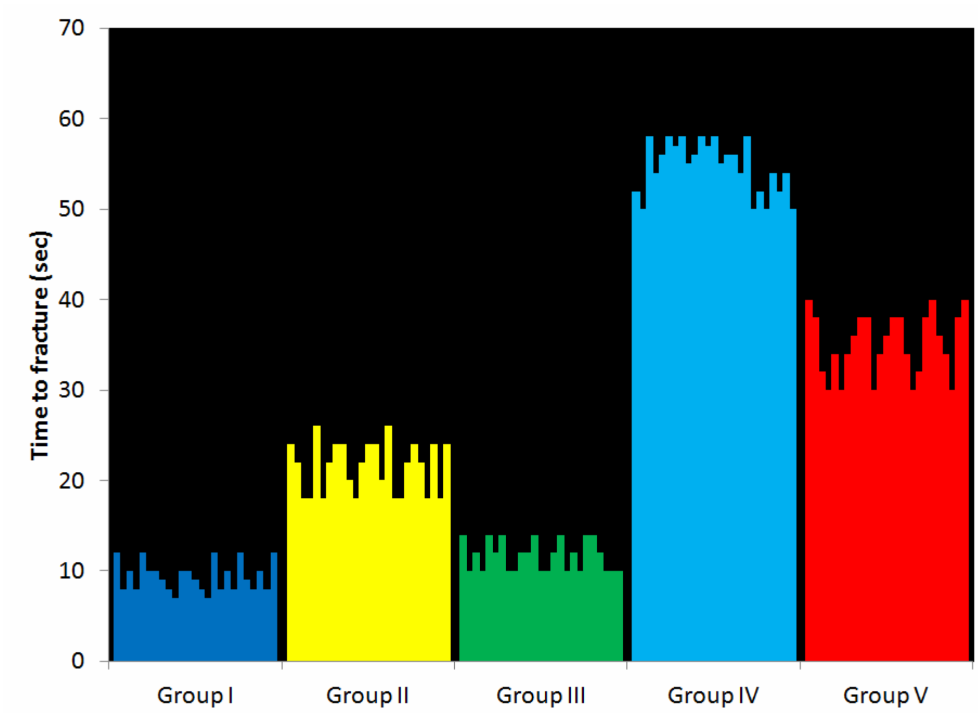


Fig. 6.2: Area Plot showing time taken for fracture

Table 6.2 shows absolute values for time taken to fracture in different groups and the same are being shown as area plots in Fig. 6.2. The largest area is covered by Group IV whereas Groups I and III cover smallest areas. Groups II and V have covered areas smaller than Group IV and larger than Groups I and III.

Table 6.3: Summary Statistics of Time taken to fracture

Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower	Upper		
I	25	9.40	1.63	0.33	8.73	10.07	7.00	12.00
II	25	21.52	2.84	0.57	20.35	22.69	18.00	26.00
III	25	11.68	1.70	0.34	10.98	12.38	10.00	14.00
IV	25	54.72	2.85	0.57	53.54	55.90	50.00	58.00
V	25	35.12	3.47	0.69	33.69	36.55	30.00	40.00
Total	125	26.49	17.04	1.52	23.47	29.50	7.00	58.00

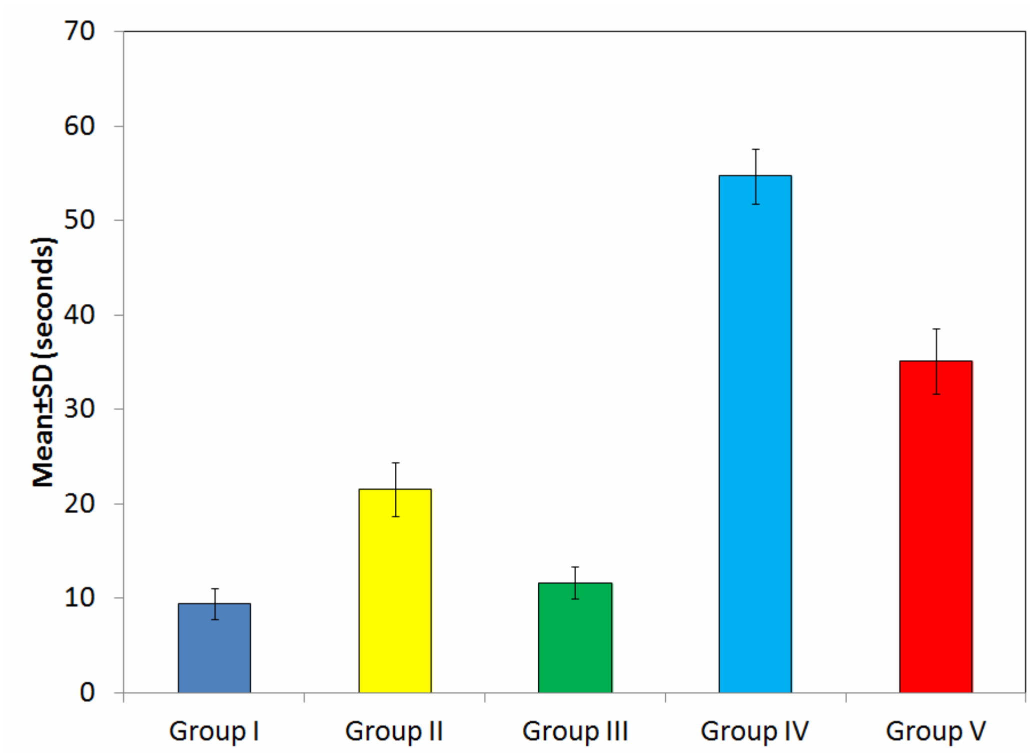


Figure 6.3: Comparison of time taken to fracture among different groups

Time taken to fracture ranged from 7 to 58 seconds in different groups. Mean time taken to fracture was minimum in Group I (9.40±1.63 sec) followed by Group III (11.68±1.70 sec), Group II (21.52±2.84 sec), Group V (35.12±3.47 sec) and Group IV (54.72±2.85 sec) respectively.

Table 6.4: Analysis of variance for time taken to fracture in different groups

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	35187.872	4	8796.968	1301.070	<0.001
Within Groups	811.360	120	6.761		
Total	35999.232	124			

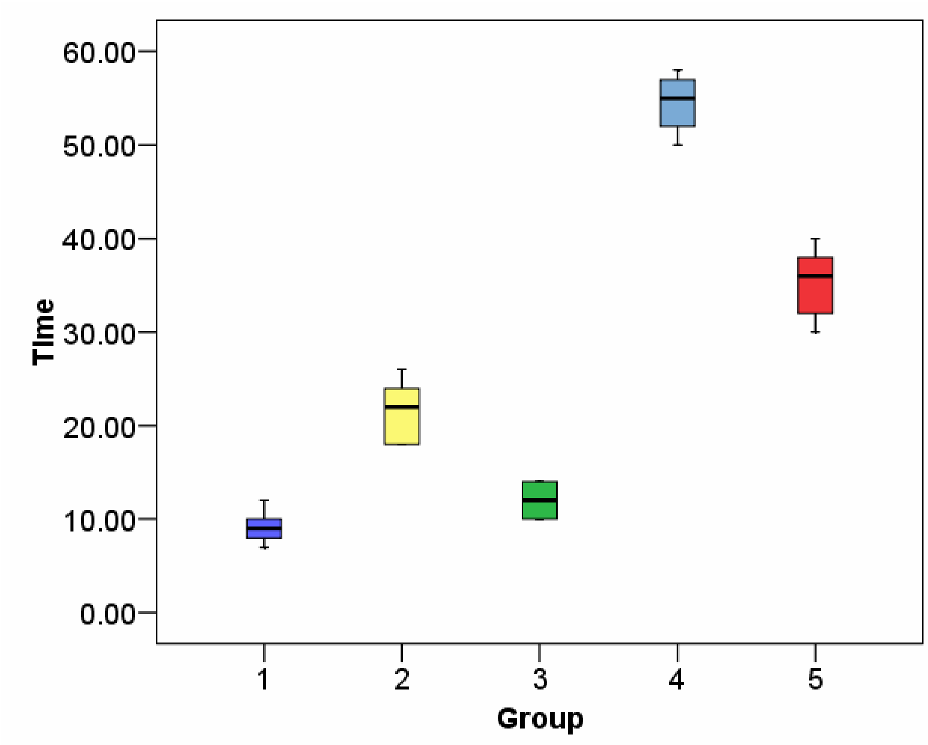


Figure 6.4: Box plot showing dispersion of time taken to fracture values in different groups

Analysis of variance and box plot thereafter show a statistically significant intergroup difference ($p<0.001$). Values in Group I and III were of lower order whereas values in Group IV were of higher order. Values in Groups II and V were of middle order. Almost no overlapping in the interquartile range of different groups was observed.

Table 6.5: Statistical evaluation of Between Group differences in time taken to fracture (Tukey HSD test)

SN	Comparison	Mean difference	SE	'p'
1.	Groups I vs II	-12.12	0.74	<0.001
2.	Groups I vs III	-2.28	0.74	0.020
3.	Groups I vs IV	-45.32	0.74	<0.001
4.	Groups I vs V	-25.72	0.74	<0.001
5.	Groups II vs III	9.84	0.74	<0.001
6.	Groups II vs IV	-33.20	0.74	<0.001
7.	Groups II vs V	-13.60	0.74	<0.001
8.	Groups III vs IV	-43.04	0.74	<0.001
9.	Groups III vs V	-23.44	0.74	<0.001
10.	Groups IV vs V	19.60	0.74	<0.001

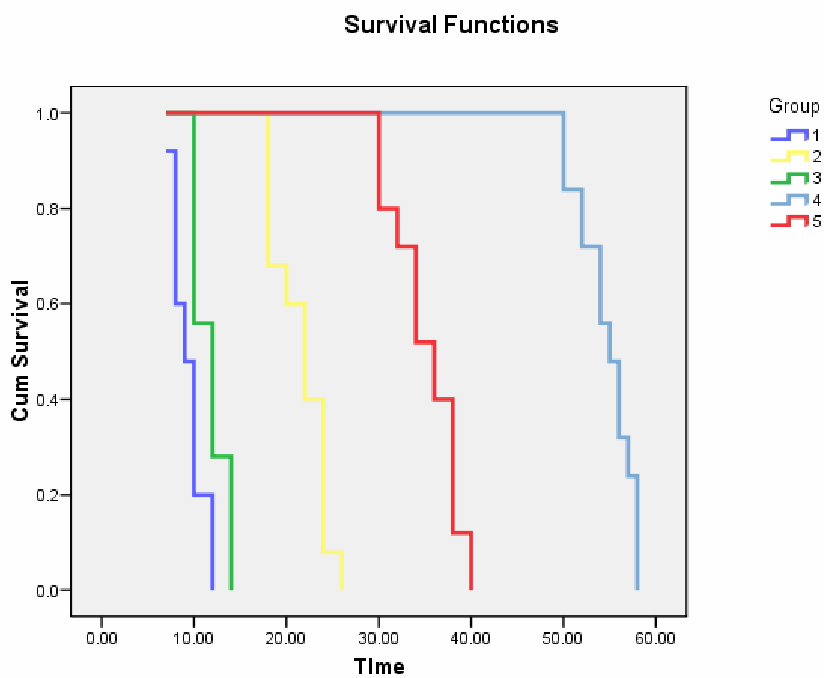


Figure 6.5: Survival Curve showing survival time in different groups (χ^2=226.387, df=4; p<0.001 – Log rank test)

The survival analysis showed a statistically significant difference in time related survival function in different groups (χ^2=226.387, df=4; p<0.001 – Log rank test) (Fig. 6.5).

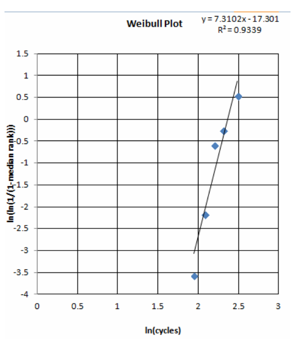
All the between group differences were significant. Minimum difference was observed between Groups I and III (2.28±0.74) and maximum between Groups I and IV (45.32±0.74). On the basis of above evaluation, the following order of time taken to fracture was observed in different groups:

Group I < Group III < Group II < Group V < Group IV

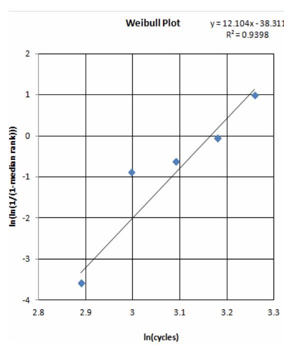
Table 6.6: Results of Weibull's Analysis and Probability of Survival for different groups (Survival time in sec)

Group	Weibull's modulus (β)	Characteristic survival time (completed cycles) (α)*	Probability of survival (in %) for cycles (no.)				Survival Time for 99%, 95%, and 5% probabilities of survival (Number of completed cycles)		
			11 s	22 s	38s	50s	99%	95%	5%
I	7.31	11	28.47	0	0	0	5	7	12
II	12.10	24	99.99	66.5	0	0	16	18	25
III	12.01	13	89.79	0	0	0	9	10	14
IV	24.19	57	100	100	100	95.74	47	50	59
V	13.98	38	100	99.94	30.12	0	27	30	40

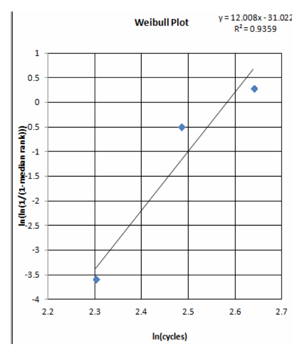
*Time till which 63.2% of samples will survive



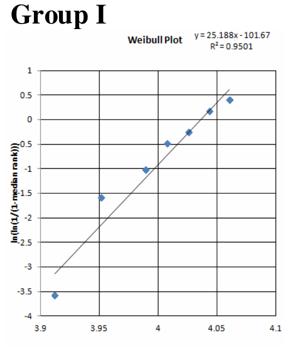
Group I



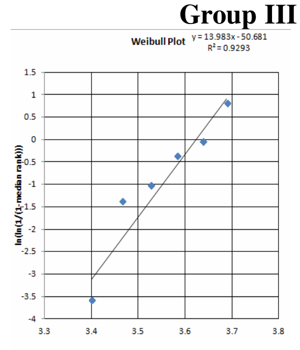
Group II



Group III



Group IV



Group V

Figure 6.6: Weibull Plots for different groups

The Weibull's modulus values ranged from 7.31 (Group I) to 24.19 (Group IV). Characteristic survival time (seconds in integer) was maximum for Group IV (57 sec) and minimum for Group I (11 sec).

On evaluating the % survival for different quartiles of cumulative survival time (of all the five groups) at 11s, 22s, 38s and at 50s was 28.47%, 0%, 0% and 0% for Group I, 99.99%, 66.5%, 0% and 0% for Group II, 89.79%, 0%, 0% and 0% for Group III, 100%, 100%, 100% and 95.74% for Group IV and 100%, 99.94%, 30.12% and 0% for Group V respectively.

The survival time (in integer seconds) for 99%, 95% and 5% samples was 5s, 7s and 12s respectively for Group I, 16s, 18s and 25s respectively for Group II; 9s, 10s and 14s respectively for Group III; 47s, 50s and 59s respectively for Group IV; and 27s, 30s and 40s respectively for Group V.

This evaluation showed that Group IV had the longest survival time whereas Group I had minimum survival time and this trend was also seen for 99%, 95% and 5% of the sample proportions.

Table 6.7: Distribution of Samples in different groups according to number of cycles till file survived

S.NO	Group I (n=25)	Group II (n=25)	Group III (n=25)	Group IV (n=25)	Group V (n=25)
1	80.04	160.08	93.38	346.84	266.8
2	53.36	146.74	66.7	333.5	253.46
3	66.70	120.06	80.04	386.86	213.44
4	53.36	120.06	66.7	360.18	200.1
5	80.04	173.42	93.38	373.52	226.78
6	66.7	120.06	80.04	386.86	200.1
7	66.7	146.74	93.38	380.19	226.78
8	60.03	160.08	66.7	386.86	240.12
9	53.36	160.08	66.7	366.85	253.46
10	46.69	133.4	80.04	373.52	253.46
11	66.7	120.06	80.04	386.86	200.1
12	66.7	146.74	93.38	380.19	226.78
13	60.03	160.08	66.7	386.86	240.12
14	53.36	160.08	66.7	366.85	253.46
15	46.69	133.40	80.04	373.52	253.46
16	80.04	173.42	93.38	373.52	226.78
17	53.36	120.06	66.7	360.18	200.1
18	66.7	120.06	80.04	386.86	213.44
19	53.36	146.74	66.7	333.5	253.46
20	80.04	160.08	93.38	346.84	266.8
21	60.03	146.74	93.38	333.5	240.12
22	53.36	120.06	80.04	360.18	226.78
23	66.07	160.08	66.7	346.84	200.1
24	53.36	120.06	66.7	360.18	253.46
25	80.04	160.08	66.7	333.5	266.8

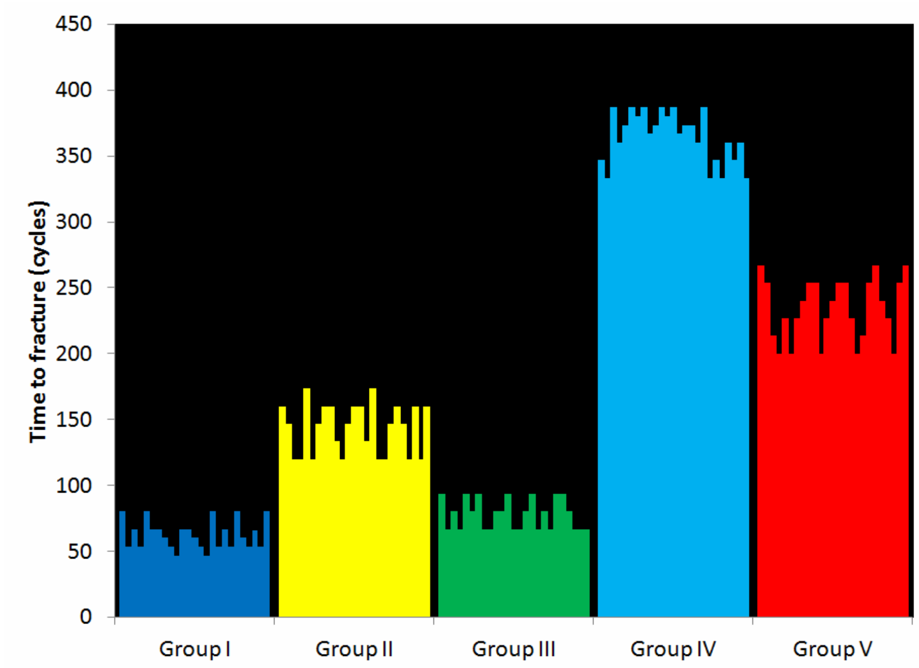


Figure 6.7: Area Plot showing time taken for Cycles before fracture

Table 6.7 shows absolute values for number of cycles before fracture in different groups and the same are being shown as area plots in Fig.6.7. The largest area is covered by Group IV whereas Groups I and III cover smallest areas. Groups II and V have covered areas smaller than Group IV and larger than Groups I and III.

Table 6.8: Summary Statistics of Number of cycles before fracture

Group	n	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower	Upper		
I	25	62.67	10.88	2.18	58.18	67.17	46.69	80.04
II	25	143.54	18.98	3.80	135.71	151.37	120.06	173.42
III	25	77.91	11.35	2.27	73.22	82.59	66.70	93.38
IV	25	364.98	19.01	3.80	357.13	372.83	333.50	386.86
V	25	234.25	23.13	4.63	224.70	243.80	200.10	266.80
Total	125	176.67	113.65	10.17	156.55	196.79	46.69	386.86

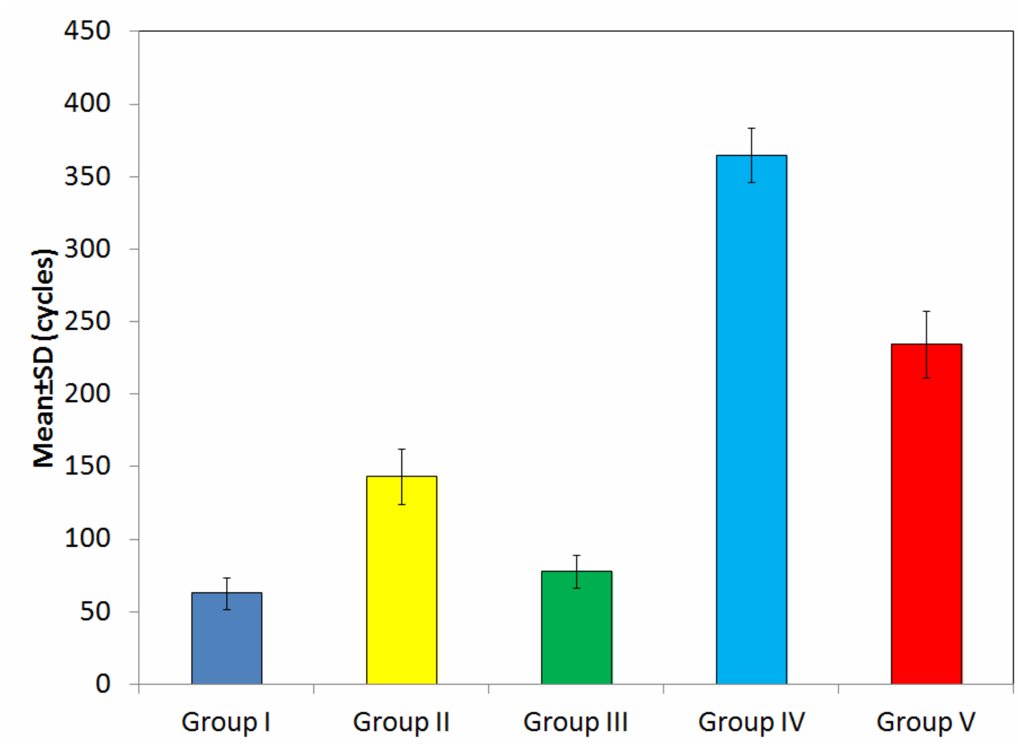


Figure 6.8: Comparison of number of cycles before fracture among different groups

Number of cycles before fracture ranged from 46.69 to 386.86 cycles in different groups. Mean number of cycles before fracture was minimum in Group I (62.67±10.88 cycles) followed by Group III (77.91±11.35 cycles), Group II (143.54±18.98 cycles), Group V (234.25±23.13 cycles) and Group IV (364.98±19.01 cycles) respectively.

Table 6.9: Analysis of variance for number of cycles before fracture in different groups

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1565613	4	391403	1301	<0.001
Within Groups	36092	120	301		
Total	1601705	124			

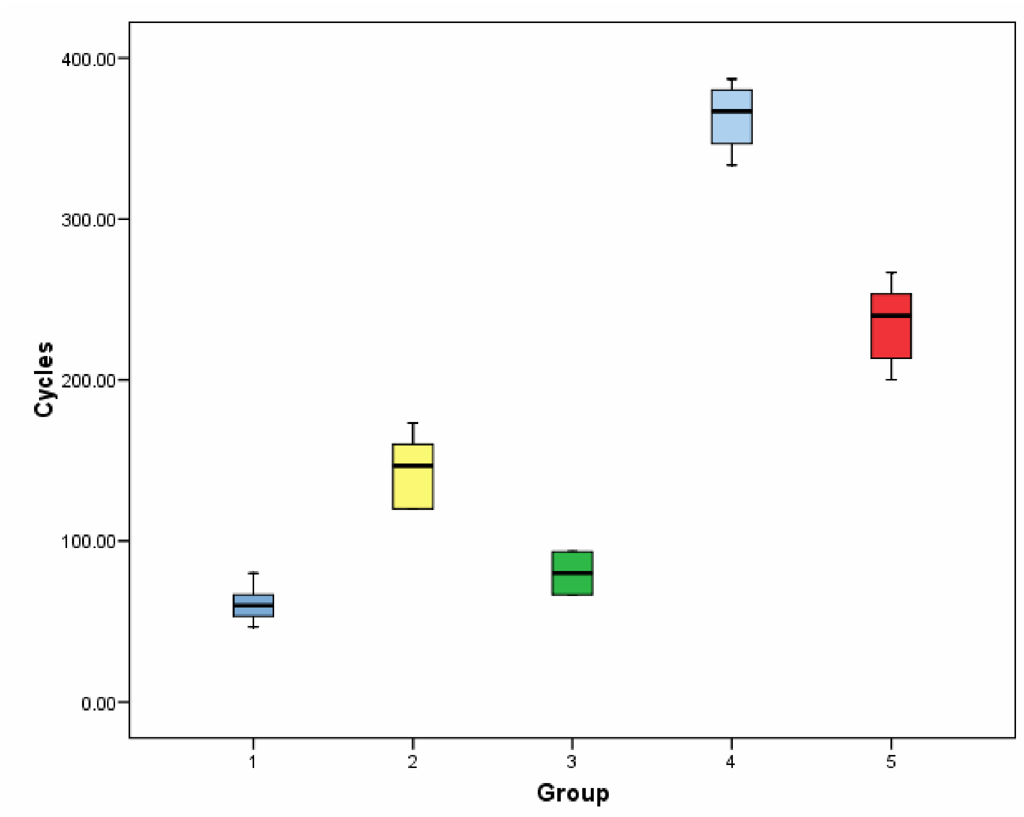


Figure 6.9: Box plot showing dispersion of number of cycles before fracture values in different groups

Analysis of variance and box plot thereafter show a statistically significant intergroup difference ($p<0.001$). Values in Group I and III were of lower order whereas values in Group IV were of higher order. Values in Groups II and V were of middle order. Almost no overlapping in the interquartile range of different groups was observed.

Table 6.10: Statistical evaluation of Between Group differences for number of cycles before fracture (Tukey HSD test)

SN	Comparison	Mean difference	SE	'p'
1.	Groups I vs II	-80.87	4.91	<0.001
2.	Groups I vs III	-15.23	4.91	0.020
3.	Groups I vs IV	-302.31	4.91	<0.001
4.	Groups I vs V	-171.58	4.91	<0.001
5.	Groups II vs III	65.63	4.91	<0.001
6.	Groups II vs IV	-221.44	4.91	<0.001
7.	Groups II vs V	-90.71	4.91	<0.001
8.	Groups III vs IV	-287.08	4.91	<0.001
9.	Groups III vs V	-156.34	4.91	<0.001
10.	Groups IV vs V	130.73	4.91	<0.001

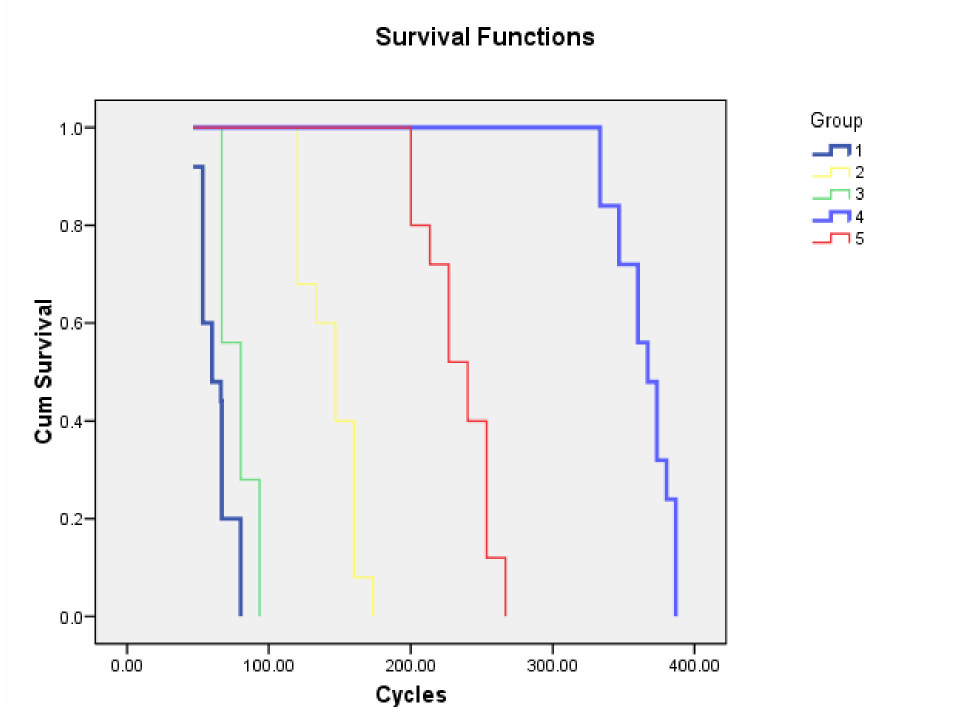


Figure 6.10: Survival Curve showing survival cycles in different groups (χ^2=228.736, df=4; p<0.001 – Log rank test)

The survival analysis showed a statistically significant difference in number of cycles related survival function in different groups (χ^2=228.736, df=4; p<0.001 – Log rank test) (Fig. 6.10).

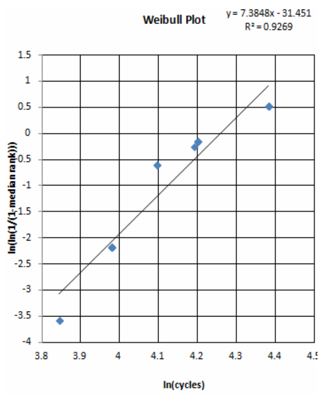
All the between group differences were significant. Minimum difference was observed between Groups I and III (15.23±4.91) and maximum between Groups I and IV (302.31±4.91). On the basis of above evaluation, the following order of time taken to fracture was observed in different groups:

Group I < Group III < Group II < Group V < Group IV

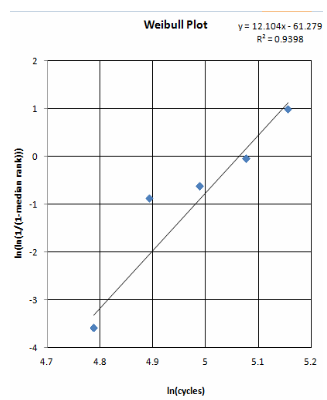
Table 6.11: Results of Weibull's Analysis and Probability of Survival for different groups (Number of Cycles)

Group	Weibull's modulus (β)	Characteristic survival time (completed cycles) (α)*	Probability of survival (in %) for Number of cycles				Survival Time for 99%, 95%, and 5% probabilities of survival (Number of cycles)		
			68.75	**137.5**	**237.5**	**300**	**99%**	**95%**	**5%**
I	7.31	71	44.47	0	0	0	37.8	47.3	82.1
II	12.10	158	100	83.1	0	0	101.3	123.6	173.0
III	12.01	88.0	95.19	0	0	0	60.2	69.0	96.8
IV	25.19	378	100	100	100	99.7	314.6	335.7	394.5
V	13.98	250	100	100	61.7	0.0	180.0	202.3	270.6

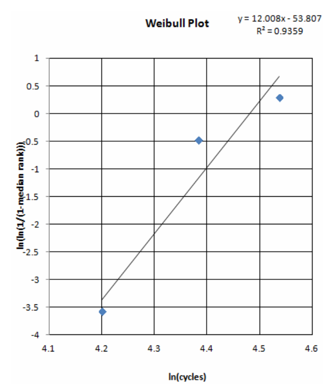
*Time till which 63.2% of samples will survive



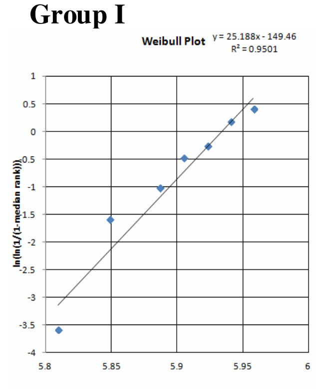
Group I



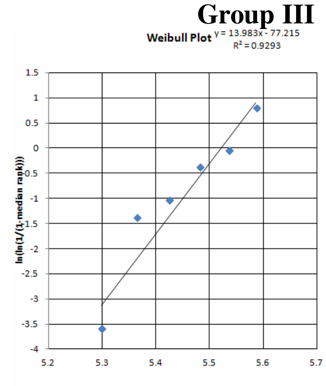
Group II



Group III



Group IV



Group V

Figure 6.11: Weibull Plots for different groups

The Weibull's modulus values ranged from 7.31 (Group I) to 25.19 (Group IV). Characteristic survival (cycles) was maximum for Group IV (378 cycles) and minimum for Group I (71 cycles).

On evaluating the % survival for different quartiles of cumulative survival (of all the five groups) at 68.75, 137.5, 237.5 and at 300 cycles was 44.47%, 0%, 0% and 0% for Group I, 100%, 83.1%, 0% and 0% for Group II, 95.19%, 0%, 0% and 0% for Group III, 100%, 100%, 100% and 99.7% for Group IV and 100%, 100%, 61.7% and 0% for Group V respectively.

The survival (number of cycles) for 99%, 95% and 5% samples was 37.9, 47.3 and 82.1 cycles respectively for Group I, 101.3, 123.6 and 173.0 respectively for Group II; 60.2, 69 and 96.8 respectively for Group III; 314.6, 335.7 and 394.5 respectively for Group IV; and 180, 202.3 and 270.6 cycles respectively for Group V.

This evaluation showed that Group IV had the longest survival time whereas Group I had minimum survival time and this trend was also seen for 99%, 95% and 5% of the sample proportions.

CHAPTER-7

DISCUSSION

The present in-vitro study was conducted in Department of Conservative Dentistry & Endodontics, at Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, in collaboration with Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, Uttar Pradesh, and IFFCO Amla, Bareilly, Uttar Pradesh, India.

The cyclic fracture resistance of five recent endodontic rotary NiTi files Hero Shapers (Micro Mega, Besancon, France), Protaper Next (Dentsply Maillefer; Ballaigues, Switzerland), Profile Vortex (Dentsply Tulsa Dental Specialities, Tulsa, OK, U.S.A), Hyflex CM (Coltene Whaldent, Germany) and One Shape (Micro Mega, Besancon Cedex, France) were evaluated in the present study.

The **inclusion criteria** for choosing the above mentioned experimental rotary NiTi files was as follows:

1) A recent introduced rotary file system manufactured from Conventional NiTi alloy:

   One shape designated as Group V

2) A recent introduced rotary file system manufactured by M-Wire technology :

   Hero shaper designated as Group I,

   Protaper Next designated as Group II and

Profile Vortex Designated as Group III

3) A recent introduced rotary file system manufactured by CM-Wire technology :

   Hyflex CM designated as Group IV.

Exclusion criteria:

1) Endodontic Stainless steel hand files.
2) Endodontic NiTi hand files.
3) Endodontic used files.

The present study design was based on the studies conducted by Haikel Y *et al.* (1999), Grande NM *et al.* (2006), Cheung GSP *et al.* (2007), Garg G *et al.*(2008), Gupta M *et al.* (2010), Yong G *et al.* (2010), Al-Hadlaq SMA *et al.* (2010), Shen Ya *et al.* (2011) , Plotino G *et al.* (2014), Sood A *et al.* (2015), Karova E *at el* (2015) and Hegde M *et al.* (2016).

To evaluate the cyclic fracture resistance of the experimental NiTi rotary files it was decided to take 125 samples based on statistical analysis which would show reliable and significant result. Total sample size of 125 rotary NiTi files was selected (25 samples in each experimental group). The present in-vitro study comprised of direct comparison of cyclic fatigue resistance among the NiTi rotary files being tested, therefore a separate control group was not required.

To have uniformity in this comparative study, all the rotary NiTi experimental files with ISO no.25, Length 21mm and Taper 0.06 were kept standardized during the study. The similar standardization parameters were followed in the previous studies conducted by Garg G *et al.* (2008), Gupta M *et al.* (*2010)* and Al-Hadlaq.SM *et al.* (2010).

Several studies like Pruett *et al.* (1997), Mize *et al.* (1998), Haikel Y *et al.* (1999), Yared *et al.* (1999, 2000), Plotino G *et al.* (2004, 2009), Bahia MGA *et al.* (2005) evaluated cyclic fracture resistance of endodontic files that used artificial canals which were constructed by bending glass or metal into cylindrical tubes with different inner diameters and different point of maximum curvature and using different radii and angles of curvature. This artificial bent tube apparatus arrangement was avoided in the present study. The reasons attributed as pointed out by studies conducted by Yared *et al.* (1999, 2000), Melo MC *et al.* (2002), Bahia MGA *et al.* (2005), Cheung GSP *et al.* (2007) was that the cylindrical tubes did not sufficiently restrict the instrument shaft, which spring back into its original straight shape, aligning into a trajectory of greater radius and reduced angle. Because of the inner diameter of the tubes (glass or metal) being greater than that of the instruments, an instrument rotated in the tube followed a trajectory that was not predictable and without the parameters of radius and angle of curvature and point of maximum curvature that were established when constructing the artificial canals.

Moreover, if the files of the same dimensions followed different trajectories in the test apparatus, a direct comparison between instruments of different brands would be difficult to establish and the results obtained may be unreliable and not consistent. Furthermore, it was unclear what the predictability of the parameters like radius and angle of curvature and point of maximum curvature obtained by bending a straight metal or glass tube.

Another drawback with loose-fitting canal was that the file may ‘‘walk’’ or vibrate in that space, leading to a change in the magnitude of stress and possibly leading to variations in the results. Another method of producing curvatures for cyclic fracture test was reported by Li UM *et al.* (2002), and Ray JJ *et al.* (2007) and they showed that the resting of the file against an inclined grooved block produced root canal curvature. This method had a significant shortcoming in that this method of determining canal curvature ignored the radius of curvature. Brown TA (2013) found that there was very little scope to confine the files to a particular trajectory, so problems were arising similar to the simulated canal method described previously.

As mentioned earlier, bending properties of different files may determine a different trajectory if the file is not constrained in a precise trajectory. When the testing is completed for all different files at a given angle to ensure consistency, the bending properties of the different files will differ depending on the different angles of curvature, thus biasing the results and the comparisons.

To limit these problems, Cheung GSP *et al.* (2007) constrained the instrument into a desired curvature using three stainless steel pins /cylinders (Figure 5). They used three smooth cylindrical pins of 2-mm diameter from a high hardness stainless steel mounted in acrylic shims, which were adjustable in the horizontal direction and the position of the these pins determined the curvature of the instrument. It was reported by Plotino G. *et al.* (2009) that in a three-point bending test of NiTi wires such constraints would produce a curvature that is circular.

A non-dental customized apparatus was made to evaluate cyclic fatigue resistance for the present study that provided standardization of assay conditions and minimized other mechanisms of file fracture other than cyclic fatigue. This was done in accordance to the study design provided by the study of Yao JH *et al.* (2006). Similar apparatus design was used in study of Youssef H *et al.* (1999) and Cheung GSP *et al.* (2007).

The simulated working model comprised of a main stainless steel frame (SS-304) of Length 20cm, Breadth 20 cm, Height 5 mm to which two support (vise) for endomotor handpiece and three stainless steel cylinders were mounted. The endomotor handpiece was mounted to allow precise and reproducible placement of each experimental NiTi file. This ensured 3 dimensional alignment and positioning of file ISO size 25, Length 21mm and taper 0.06. Four legs made up of Stainless steel (SS304) were welded to the base of the main frame for stability of the apparatus. The level was maintained and checked by the help of level measuring gauge. The three steel cylinders (one supporting cylinder and other two shaping cylinders) of diameter 3mm were attached on 5mm thick stainless steel frame. The position of these three cylinders was such that it provided the experimental rotary NiTi file with a suitable simulated root canal of 60 degree angle of curvature and 5 mm radius of curvature. Radius was measured to the central axis of the curvature. The angle was kept 60 degree with the help of Angle Protactor Machine.

The simulated root canals with an angle of curvature of 60 degrees and radius of curvature of 5 mm were based on the findings of the study done by Pruett J.P *et al.* 1997 that stated that the stress levels induced by curvatures smaller than 5 mm of radius and 30 degree in angle did not result in instrument separation.

Root canal curvature was historically defined using the method introduced by Schneider in 1971 .This method used only a single parameter to define an angle in degrees. To determine the degree of root curvature, Schneider drew a line parallel to the long axis of the canal. A second line was drawn from the apical foramen to intersect with the first line at the point where the canal began to leave the long axis of the canal. The acute angle formed was defined as the degree of root curvature (Figure 7.1).

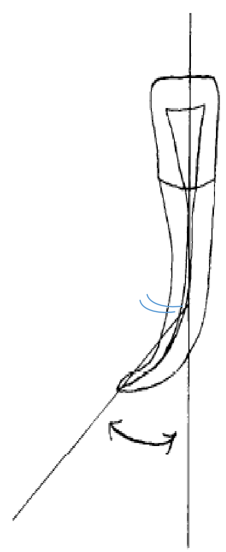


Figure 7.1: Degree of root curvature depicted by Schneider Method.

On the other hand, Pruett at al. reported that two parameters i.e. angle of curvature and radius of curvature were the factors which influenced cyclic fracture resistance.(Figure 7.2) Pruett JP *et al.* 1997.

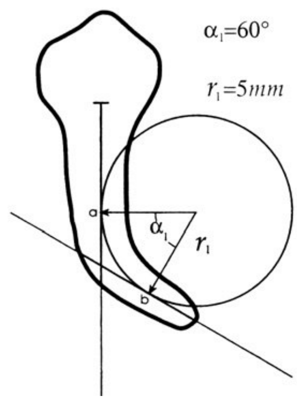


Figure 7.2: Radius of curvature and angle of curvature depicted by Pruett *et al.*

They described a new method of describing canal geometry using these two parameters. Radius of curvature (r_1) and angle of curvature (α_1) were determined on the same tooth. Angle of curvature was determined by the angle formed by the lines that intersected at the circle's center. These two lines were perpendicular to the lines drawn along the long axes of the coronal and apical portions of the root canal space. Points a and b were the points wherein the canal deviated from the straight lines and either begin or end the curved portion of the root canal space. Angle was taken to be the angle formed by the arc in degrees between points a and b. The arc lied on a circle whose size was specified by it's radius, and the circle's radius was taken to be the radius of curvature of the canal. The circle's radius was the radius (r_1) of the curved portion of the root canal space and defined how abruptly the canal curves.

Sample Size and Grouping

Fresh unused packets of the experimental rotary NiTi files were obtained from the manufacturer. A total of 125 rotary Niti Files were divided into five groups, each group comprising of 25 rotary NiTi files. For standardization of the complete study, ISO size 25 no. , Taper0.06 and Length 21 mm was chosen.

All the experimental rotary endodontic rotary files chosen were of length 21mm. This was done to follow standardization throughout the study. Moreover, the average length of human permanent posterior tooth is 21mm according to M. Ash (2001). Hence, 21 mm length was kept as a standardized working length for all the experimental files being tested.

The experimental rotary NiTi files introduced recently were chosen on the basis of their generation / manufacturing process. They were further grouped accordingly.

Grouping:

- Group I consist of Hero shaper rotary NiTi file manufactured from M-Wire technology.
- Group II consist of Protaper Next rotary NiTi file manufactured from M-Wire technology.
- Group III consist of Profile Vortex rotary NiTi file manufactured from M-Wire technology.
- Group IV consist of Hyflex CM rotary NiTi file manufactured from CM-Wire technology.
- Group V consist of One Shape rotary NiTi file manufactured from Conventional NiTi alloy.

The following instrumentation protocol was followed for each experimental file group being tested for cyclic fracture resistance in this study. The protocol followed was in accordance with the study conducted by Gupta M *et al.* (2010).

The experimental file (Group I) was coated with a layer of root canal lubricant EDTA gel. It was then placed in endomotor handpiece with its rubber stopper at the supporting steel cylinder and end between two shaping steel cylinders. The torque of 2.5N/cm and rpm of 400 was preset in endomotor handpiece and was kept constant for each experimental group being tested.

The file was then allowed to rotate and simultaneously the digital stopwatch was started. The time (in seconds) till the fracture of experimental file occurred was recorded by using the digital stopwatch.

The number of rotations made by file till its fracture was than calculated using the formula (formula 6.1):

$$\text{No. of cycles till fracture (NCF)} = \frac{400}{60} \text{ x Time taken till fracture (sec.)}$$

where 400 is revolution per minute (r.p.m)

The above instrumentation protocol was followed for all ISO 25 taper 6% and length 21mm experimental NiTi rotary files in each designated group. The observations and results were laid down. The statistical analysis was performed.

To understand fracture resistance of a rotary NiTi file one has to know about the factors which influence the cyclic fracture resistance. As the reasons are complex therefore a proper understanding of the mechanisms for failure could provide insight for instrument design and the manufacturing process. As previously stated, the comparison with the manufacturing of stainless steel instruments with the manufacturing of NiTi endodontic instruments is more complex because these files have to be machined from wire blanks rather than twisting the wire blanks.

The factors affecting cyclic fracture resistance are manufacturing process (Work Hardening/Heat Treatment), Surface imperfections on manufactured file, Electropolishing process, Metal Alloy from which a file is manufactured, File design, Radius of curvature and Angle of curvature.

It has been believed by Walia *et al.*(1988), Eggert *et al.*(1999), Kuhn G *et al.*(2001) that Surface imperfections such as scratches, transitional angles, microcavities, and debris could be introduced during the manufacturing of a file. Chianello *et al.* (2008) found that no NiTi instrument was free of imperfections and most of the files tested presented 2 to7 types of surface defects. The relationship between manufacturing imperfections and breakage of rotary instruments had been investigated by Kuhn *et al.* (2001) and Cheung *et al.* (2007a). According to studies by Alapati *et al.* (2003), Borgula *et al.* (2005), Cheung GSP *et al.*(2007a) it is reported that surface imperfections may serve as stress concentrators and induce crack initiation and propagation, resulting in reduced fatigue life of a endodontic file.

To reduce these surface imperfections which persisted after manufacturing of files, Electropolishing was preferred method of choice for surface finishing opted by manufacturers of rotary NiTi file. According to Anderson M.E *et al.* (2007) electropolishing is a controlled chemical process that involves submerging the instrument, acting as an anode, into an electrolytic solution that contains a cathode. When a low current is passed though the solution, a balance is achieved between the formation of a passive layer and dissolving of the surface into the electrolyte, leading to selective removal of protruding surface defects.

Kuhn G *et al.* (2001) research found that fracture of metal will begin with the formation of microcracks at the surface of the metal and is then followed by crack propagation and finally rupture of the metal as the cracks coalesce. Cracks will initiate in small surface defects, and, as such, the initiation stage of metal fracture is greatly facilitated by pre-existing surface irregularities. Failure is then largely a process of crack propagation. In contrast, when cracks are not present on the surface of the material, failure will be a function of first crack initiation, then propagation, and finally rupture. Considering that crack initiation may comprise a major proportion of fatigue life, resistance to fatigue can be enhanced by a smooth, defect-free surface.

Another possible explanation given by Shaw MC *et al.* (2005) for the enhanced performance of the electropolished files was the elimination of residual stresses. When an instrument is machined, plastic deformation (smearing) occurs at the surface of the metal thus resulting in residual stresses that remain at the surface. The effect of residual stresses on material fracture depends largely on the type of residual stress (compressive or tensile) and the type of loading the material is under (static load or fatigue). Compressive residual stresses would have a beneficial effect on the fatigue life because they delay crack initiation and propagation. Conversely, it has been stated by Mc Evily AJ *et al.* (2002) and Hutchings MT *et al.* (2005) that the tensile residual stresses would significantly reduce the fatigue life of materials because they accelerate crack initiation and growth. Under repeated cycles of loading, residual stresses (whether beneficial compressive stresses or detrimental tensile stresses) plays a significant role in determining the fatigue life of the material. Anderson. ME (2007) suggested that by removing the surface layer of the instrument, electropolishing may potentially eliminate residual stresses.)

However, study by Cheung GSP *et al.* (2007b) showed that surface smoothness from electropolishing did not enhance the low-cycle fatigue resistance of rotary instruments. So the effect of instrument surface defects on fatigue failure was found to be controversial.

It has been reported by Walia H *et al.* (1998), Sotokawa T (1988) and Pruett JP *et al.* (1997) that the phenomenon of repeated cyclic metal fatigue may be the most important factor in instrument fracture during cyclic fatigue test. When instruments are placed in curved canals, they deform and stress occurs within the instrument. The half of the instrument shaft on the outside of the curve is in tension and the half on the inside is in compression. Consequently, each rotation causes the instrument to undergo one complete tension-compression cycle. The stress levels are the greatest in the area of curvature. More severe bends create greater stress. Moreover, Crandall SH *et al.* (1972) observed that larger and stiffer instruments experiences greater stress than smaller instruments when confined to the same curved canal shape.

Research conducted by Tepel J *et al.* (1997), Pruett JP *et al.* (1997)and Camps JJ *et al.* (1994) revealed that the resistance to fracture measured as angular deflection before fracture, was found to be lower for the NiTi instruments. The phase changes along with the stress-induced transformation can be slow thermoelastic or burst type of martensite. During the crystal changes, the instrument becomes very prone to fracture. This is of special concern when used for rotary instruments. Upon rotation, abruptly changed stress levels cause movement of dislocation defects and breaks anatomic bonds within the matrix, leading to crack initiation and propagation.

Typically, there exists a crack initiation site at the metal surface, and propagation of crack would occur because of stress concentration at the crack tip. The fracture of NiTi rotary instruments during clinical use could be due to cyclic loading or a single episode of sudden overload. Previously it was assumed by the findings of study done by Parashos *et al.* (1994) that the fracture and separation of NiTi endodontic instruments were mainly due to cyclic loading. Work hardening, which occurs from plastic deformation below the recrystallization temperature (at which the cold-worked microstructure is replaced by new stress-free grains), strengthens a metal by the formation of a high density of dislocations. But studies conducted by Kuhn *et al.* (2002), Alapati *et al.* (2006) and Parashos *et al.* (2006) have suggested that work hardening of NiTi rotary instruments induced during the manufacturing process and clinical use may be detrimental to their mechanical properties. Work hardening at the tip region of the files due to the manufacturing process, also may play a role for fracture of NiTi endodontic instruments. Rotating NiTi instruments in curved root canals are subjected to fluctuating tensile and compressive stresses, which may result in work hardening of the metal and induce the initiation of microcracks.

Kuhn *et al.*(2002) and Zinelis S *et al.* (2007) postulated that heat treatment of NiTi used for endodontic instruments could alter the crystal phases of nickel titanium that are present in a file at room temperature and thus alter the behaviour characteristics of that NiTi instrument. One study found that heat treatment at certain temperatures could increase the resistance to cyclic fatigue failure while other temperatures were detrimental. Another study by Alapati SB *et al.* (2009) found that heat treatment of as received files would potentially alter the file from austenite alone at room temperature to a mixture of austenite with martensite and/or R-phase.

In addition to the raw material used, file design has an effect on the performance of endodontic instruments. Factors such as flute design, cutting efficiency, and amount of file contact with dentin are some of the variables considered in file design. Camps JJ *et al.* (1995) found that the cross section of files played a significant role in determining file flexibility. It was found by Brown TA (2013) that the instruments made from superleastic NiTi with a larger mass of metal in cross section were found to be less flexible.

The Volume per mm may be a useful parameter for relating the morphologic characteristics of the file in terms of fatigue resistance. This value represents the metal mass of the instrument considering both the core and the blades, being influenced by the different geometric designs. It also permits comparisons between non-standardized instruments in taper and diameter, e.g. ProTaper, for which precise measures along the shaft are difficult to quantify, with standardized instruments, for which taper and diameter are clearly identifiable.

According to previous studies conducted by Serene *et al.*(1995), Pruett JP *et al.*(1997), Haikel *et al.*(1999), Gambarini *et al.* (2001), Melo *et al.* (2002), Peters & Barbakow (2002), it has been shown that the fatigue life of NiTi rotary instruments has significant influence of the radius of curvature. It was concluded that the number of cycles till fracture (NCF) significantly increases as the radius of curvature increases. Simulated root canals with an angle of curvature of 60 degree and a radius of curvature of 2 and 5 mm were used based on the findings of study conducted by Pruett *et al.* (1997). It was concluded by Grande NM *et al.* (2006) that an increasing angle and a decreasing radius of canal curvature significantly decreased the number of rotation the instrument could with stand before fracture occurred.

Clinical cyclic fatigue studies by Gambarini (2001) and Plotino *et al.* (2006) reported that the prolonged clinical use of NiTi engine-driven instruments reduced their resistance to cyclic fatigue. It has been described a reduction in the lifespan ranging from 35.9% to 62.3% and from 15.2% to 62% respectively.

On contrary the study by Yared *et al.* (2000) and Plotino *et al.* (2006) did not support these findings. This is due to the fact that when a curved root canal instrument rotates, any points within it in the curved segment are subjected to the maximum stress, except those in the centre (neutral axis), are subjected to repeated tensile or compressive strains. The farther away from the central axis, the greater the imposed strain at that point. This explains why instruments of a larger diameter are affected by fatigue more than smaller ones.

In the present study, results obtained showed that Group IV rotary file (Hyflex CM) had longest survival time with a mean value of 54.72 seconds before fracture followed by Group V rotary file (One Shape) followed by Group II rotary file (Protaper Next) followed by Group III rotary file (Profile Vortex). The minimal survival time was showed by Group I rotary file (Hero Shapers).

Number of cycles before fracture ranged from 46.69 to 386.86 cycles in different groups. Mean number of cycles before fracture was minimum in Group I (62.67±10.88 cycles) followed by Group III (77.91±11.35 cycles), Group II (143.54±18.98 cycles), Group V (234.25±23.13 cycles) and Group IV (364.98±19.01 cycles) respectively.

The longest survival time or maximum number of cycles till fracture was exhibited by Hyflex CM (Group IV) files in the present study.

The reasons attributed for this behaviour could be due to:

- The composition of Hyflex CM files that has low % weight of nickel. (50% wt. Ni)
- The greater Austenite finish (A_f) temperature (more than 37^0 C), which had mixture of both Austenite and Martensitic structures at room temperature. (Ya S *et al.* 2011)
- Stable Martensitic structure.
- Proprietary Processing.

It is believed that the material property had a substantial impact on the fatigue lifetime. This have been proved by Johnson E *et al.* (2008) in his research which showed that the Hyflex Controlled Memory rotary files made form CM wire had a significantly higher resistance to fracture with lower surface strain amplitude than conventional NiTi wire files with same design.

Zhou HM *et al.* (2012) stated that the nickel content especially had a great influence on the transformation temperatures in turn affecting the cyclic fracture resistance. It has been reported that the phase transformation temperature shifts 12°C toward a lower temperature when the nickel atom content of a Ni-rich Ni-Ti alloy increases by 0.1%. Conversly, the transformation temperatures increases as the nickel content decreases.

Furthermore, Zinelis *et al.* (2007) showed that Hyflex CM files have a lower percentage of nickel (52.1 % wt) than do conventional NiTi files. The exact thermo-mechanical treatment of CM wires remains unknown due to proprietary issue and lacks investigation in literature till date. Nevertheless, it is clear that this new technology represents an improvement in the flexural behaviour and fatigue resistance.

Hyflex CM rotoary file are made of martensitic active alloys. Martensitic active wires at room temperature shows a very poor resistance to stress and discrete springback property that accepts only a certain bend and after removing it the wire moves discretely toward the original shape but not completely because of the force decay. However, when heat gain occurs from the mouth, they initiate an austenitic crystalline alteration and starts becoming more resistant to stress and regaining their initial shape, thus confirming the shape memory effect. Once the heat is removed or the wire is cooled down, they present their initial characteristic, having predominantly a martensitic crystalline structure. In this alloy, there exists a mixed or rhombohedral phase (R phase) at room temperature that coexist with austenite and martensite structure.

For the martensitic active alloys there is a temperature range in which these phenomena take place where M_f (martensite finish) and M_s ((martensite start) indicate a higher level of martensite and lower level of martensite temperature respectively.

It was highlighted by Gurgel JA *et al.* (2001) that in the martensitic stage, two effects are noticed. In the first one, after some initial deformation, the crystallographic variants could be found in 24 shapes of coexisting martensite and after the removal of force, these variants reorganize themselves in their initial positions and the wire returns to its original shape. In the second case, the nickel-titanium wire shaped in the austenitic state is cooled down until it reaches the martensitic state. If during the process the material is deformed, it returns to its initial shape after heating. Austenitic structures are face-centred cubic (α) phase while martensitic structures correspond to body-centred cubic (β) phase. They have exactly the same chemical constitution, but because of their different crystallographic structure, they do not exhibit the same mechanical behaviour. Between initial levels of each transformation, the alloys begin to show some crystalline transformation. The highest temperature in which it is still possible to find the formation of martensite is called M_d.

Martensite normally forms at the M_s (martensite start) temperature but can form prematurely above the M_s temperature if stress is present. Below the M_s temperature, deformation occurs by martensitic twinning. Between the M_s temperature and the austenite final A_f temperature, the martensite is stress-induced but once induced is stable. It was concluded from the finding of the research conducted by Meling TR *et al.* (1998), Ferreira MDA *et al.* (2012) that above the M_d temperature, the deformation is there and martensite can no longer be stress induced.

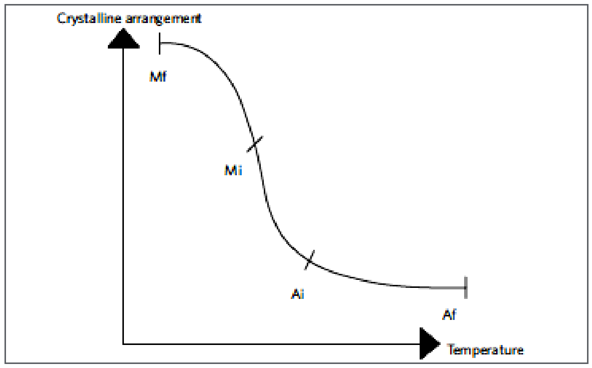


Figure 7.3 Austenitic-martensitic transformation of crystalline arrangements vs. temperature

Figueiredo *et al.* (2009) explained the mechanism for this increase in cyclic fracture resistance. The crack propagation in martensite, that presented a large number of highly branched cracks which propagated very slowly. In contrary, in superelastic NiTi only a few fatigue cracks nucleated and the propagation was faster. Knowing that martensite was less stiff compared with austenite, it was likely that all of the tested shape memory files possessed some martensite at the expense of austentice and this at least partially accounted for their lower stiffness. This decreased stiffness of the files influenced the fatigue properties.

Shen Ya *et al.* (2012) observed increased fatigue resistance in files manufactured via controlled memory proprietary processing. The reason for this behaviour was that for a given strain, a more flexible file would experience less stress, allowing for a longer fatigue lifetime. It was postulated by Otsuka K *et al.* (1998, 2005) that martensite in near-equiatomic NiTi alloys had a lower critical plateau and ultimate tensile strength compared with austenite. This postulation has been confirmed by finding of study by Zhou H *et al.* (2012) that used stress-strain curves to explain this phenomenon exhibited by controlled memory NiTi wires. Moreover, the transformation temperatures increased as the nickel content decreased.

In the study conducted by Santos L D A *et al.* (2013) on hyflex CM files, it has been reported that there is presence of low stress in the Hyflex CM NiTi files during the fatigue simulation test which supported a superior flexural fatigue resistance. This was attributed due to the fatigue life which was directly related to the stress levels attained during cyclic loading.

A study conducted by Plotino G *et al.* (2009) also reported that the cyclic fatigue resistance evaluation of Hyflex CM, ProFile and Profile Vortex File systems in a simulated root canal with a 60° angle of curvature showed greater fatigue resistance by Hyflex CM files than ProFile and Vortex systems.

Peters OA *et al.* (2014) reported that Hyflex CM files were highly flexible and had higher fatigue resistance than files made of conventional NiTi alloy.

The results of this in-vitro study are in accordance to the various other researches conducted by Capar *et al.*(2014), Shen Ya *et al.* (2011), Shen Ya *et al.* (2013), Shen Y *et al.* (2012) and Santos LDA *et al.* (2013) that had shown that Hyflex CM file is superior most in terms of cyclic fracture resistance as compared to the other tested NiTi files. It was observed that One Shape file (Group V) was successor in term of survival time or number of cycles made till fracture after Group IV files in the present study.

One Shape file manufactured by Micro Mega Company, Besancon, France belongs to group of single file system. This instrument is made of a conventional austenite 55 NiTi alloy. It has asymmetric triangular file geometry. In the tip region, the cross section represents three cutting edges while in the middle of the cross-sectional design progressively changes from a three-cutting-edge design to two cutting edges. At the shank, the S-shaped cross section shows two cutting edges, resembling the cross-sectional design of Reciproc instruments. This design is helpful in elimination of threading and binding of the file in continuous rotation. This file is characterized by different cross-sectional designs over the entire length of the working part and its design is alleged to guarantee more flexibility.

The present in- vitro study results showed good cyclic fatigue resistance for One Shape file. This can be attributed due to its variable cross section with small residual core and electropolished surface of file as supported in the findings of study done by Dagna A *et al.* (2014). According to the manufacturer, the variable horizontal cross-section design of the file reduces the effect of the file being screwed into canal walls. Also, the manufacturer claimed that by increasing the pitch length between the variable horizontal cross-sections in One Shape file, the flexibility of the file has improved leading to increase in file's resistance to cyclic fatigue. This finding has been also supported by the results obtained in the study by Taha Ozyurek *et al.* (2016).

Protaper Next File (Group II) had more cyclic fracture resistance than Profile Vortex and Hero Shapers files in the present study.

The cyclic fatigue resistance of Protaper Next files was found to be superior because of the manufacturing of file using M Wire. It has been proved by the finding of the study done by Johnson E *et al.* (2008) that M wire, a metallurgically improved version of NiTi which has been derived from proprietary thermomechanical process that reduces cyclic fatigue by 400% when comparing files of the same D_0 diameter, cross-section and taper.

The study conducted by Elnaghy AM *et al.* (2014) for evaluation of cyclic fracture resistance of Protaper Next files stated that the improved cyclic fatigue resistance of Protaper Next files could be associated with its non-uniform design and the reduced number of contact points between the instrument and the root canal walls.

Various studies have been conducted by Uygun *et al.* (2015), Perez-Higuers *et al.* (2014), and Caper *et al.* (2014) to examine the propensity of Protaper Next files till fracture during use and reason for it. It was reported that there is minimal crack formation initiation in these files and this tendency was a reason for greater fracture resistance of Protaper Next file.

It was also been observed in the research conducted by Higgueras JJP *et al.* (2014) that Protaper Next files had higher cyclic fatigue resistance than its own other variant Protaper Universal files at all the tested lengths.

Cheng GSP *et al.* (2015) studied the cyclic fracture resistance of protaper Next files and Files manufactured with conventional NiTi alloy and observed that cyclic fatigue resistance of Protaper Next files was higher than the conventional NiTi files due to manufacturing of these files by M wire.

The result obtained in current study were in agreement to the findings of the above mentioned researches but at the same time were contrary to the results obtained by study performed by Topcuoglu H S *et al.* (2016) that reported Hyflex

CM and Protaper Next files had a greater cyclic fatigue resistance than One Shape Files.

The results of the present in-vitro study reported that the cyclic fatigue resistance of Profile Vortex file (Group III):

Profile Vortex files manufactured by Dentsply Tulsa Dental Specialties, Tulsa, OK have a triangular cross section file design with no radial lands and has a variable helical angle design. It is manufactured from M wire technology. This new alloy (M-Wire) was composed of SE508 nitinol that had undergone a proprietary method of treatment comprised of drawing the raw wire under specific tension and heat treatments at various temperatures, resulting in a material that includes portions in both the martensitic and the premartensitic R-phase while maintaining a pseudoelastic state. According to Shen Ya *et al.* (2011, 2012) and Johnson E *et al.* (2008) and Mc Kelvey AL *et al.* (2001), various forms of the NiTi material (stable or superelastic austenite or stable martensite) have a similar ultimate strength but a different fatigue behaviour. The superelastic NiTi possesses the lowest fatigue-crack initiation threshold and the worst crack propagation properties among the three forms, the best being the stable martensitic structure. The findings of studies conducted by Johnson E *et al.* (2008) and Yong G *et al.* (2010, 2012) found that Vortex instruments made from the M-Wire exhibited superior cyclic fatigue resistance compared with those made of regular superelastic NiTi files.

Yong G *et al.* in 2010 showed that file made from M Wire has a single crack initiation site as compared to multiple crack initiation sites on files made of regular NiTi wire. Yong G. *et al.* (2010) also stated that M wire files showed increased resistance to fracture due to fatigue due to better re-orientation capability of Martensitic variants because of the lower symmetry of the monoclinic crystal structure of martensite than the cubic crystal structure of austenite. Together with the austenite-to-martensite phase transition mechanism, the favourable reorientation of localized martensite variants would provide a better accommodation of deformation during bending rotation fatigue and effectively reduce the time on formation and accumulation of microstructural defects such as surface irregularities or subsurface voids in which fatigue cracks could nucleate.

According to Mc Kelvey *et al.* (2001), the fatigue crack growth resistance of the martensite was found to be superior to that of the stable austenite, particularly in the near threshold by comparing the fatigue behaviour of the various microstructures in Nitinol. It was found by Mc Kelvey *et al.* (2001), Yan W *et al.* (2002), Dauskardt RH *et al.* (1989), Yi S *et al.* (2000, 2001) and Yong G *et al.* (2010) that at the same stress intensity level, the fatigue crack propogation speed of austenitic structure is much faster than martensite. This is generally explained by a small-volume contraction (-0.5%) during austenite-to-martensite transformation that has a deleterious effect on the fatigue resistance by locally raising the stress intensity at the crack tip.

Yong G. *et al.* (2010) also showed that Vortex instruments made of M-Wire exhibited superior cyclic fatigue resistance (an approximately 150% longer fatigue life) compared with those made of regular wire. The Vortex was superior even when the geometric design and the surface finish were kept identical. Therefore, the superior cyclic fatigue resistance was attributed to the microstructure resulting from the chemical composition and manufacturing techniques of NiTi alloy. Similar finding was shown by research performed by Alapati *et al.* (2009) and Plotino G *et al.* (2014).

Kim JY *et al.* (2012) stated that profile vortex system is more resistance to cyclic fatigue.It was believed due to Enthalpy changes and different A_f temperature. A_f temperature was upto 50^0 C and Martensitic phase transformation condition existed at room temperature.

Study performed by Yong G *et al.* (2012) also demonstrated the results similar to the present study. They found that M-Wire manufactured files like Profile Vortex showed substantial growth of the martensite grains and martensite twins in the microstructure after 60% of their fatigue life. This was due to its unique nano crystalline martensitic microstructure.

In the present study, the least cyclic fracture resistance or least survival time was shown by Hero Shapers file (Group I).

Hero shapers file system manufactured by Micro Mega company has a variable helical angle and adapted pitch. This means that the more tapered an instrument is, the longer is its pitch. It has a positive rake angle and the blade shows asymmetric triple helix file design. The tip is inactive in order to follow canal anatomy. An in-vitro study performed by Gupta M *et al.* (2010) evaluated cyclic fatigue resistance of Hero Shaper rotary file in a curved canal. It has been found that Hero Shapers have a relatively narrow range of elasticity due to alteration in grain structure caused by grinding process. Moreover, grinding across the grain structure creates microfracture points and defects along the length of the instrument. These defects causes stress concentration points that weaken the instruments and leads to fracture of instrument. They reported that cracks propagate at a stress level much lower than the stress usually encountered during canal instrumentation leading to sudden unexpected root canal file breakage.

A study conducted by Lee MH *et al.* (2011) evaluated cyclic fatigue of various NiTi files including Hero Shapers rotary file system using a custom made device and reported that Hero shaper files showed lower cyclic fatigue resistance that its other competitors. This was attributed to the increased stress levels in file that accelerated the fatigue process.

The studies conducted by Cheung GSP *et al.* (2011) and Capar ID *et al.* (2015) determined that instruments with a triangular cross-sectional design possessed greater cyclic fatigue resistance than those with a square cross-sectional design. This difference is related to the reduced metal mass of the files with a triangular cross section compared with files with a square cross section and similar diameter. The above reason can be attributed to the findings of the current study that showed Protaper Next files and Hyflex CM files exhibit greater cyclic fatigue resistance than One Shape. It has been found that Protaper Next files, One Shape Files and Hyflex CM files have rectangular, asymmetrical and symmetrical triangular cross-section designs, respectively.

Similar study conducted by Topcuoglu H S *et al.* (2016) evaluated resistance to cyclic fatigue in Protaper Next and Hyflex CM rotary files. They found greater cyclic fracture resistance in Hyflex CM and Protaper Next. The reasons postulated for this greater cyclic fatigue were due to metallurgical differences within the instruments. Protaper Next and Hyflex CM files are made with M-Wire and heat-treated NiTi alloys respectively whereas One shape files are made with conventional NiTi alloy.

LIMITATIONS OF THE PRESENT STUDY

A possible source of error in the cyclic fatigue experiments comes from the observer being required to manually use a stopwatch to record the time when a rotary file fractures during rotation. All known cyclic fatigue studies employ this method. Till date no device is available to detect the breakage during cyclic fatigue testing. There were no instances noted during this study where the observer missed the breakage of the instrument during rotation.

The present study being an *in-vitro* study had not mimicked the working conditions present in patients mouth when using the same experimental rotary file. For example the following factors might influence the cyclic fracture resistance of a rotary file: variation of temperature and irrigation effect on experimental file during use. Motion of experimental file, condition of file to be used (whether new or old), dentin hardness and force on file during rotation.

FUTURE SCOPE

The results of the present study showed Hyflex CM rotary NiTi file being the most superior cyclic fracture resistant with a longest survival time as compared to its competitors. These files could be helpful in clinical cases where root canal possesses a sharp bend or is S shaped canal. Based on the findings of the present study, further in vivo studies are needed to arrive at a definite conclusion.

CHAPTER-8

CONCLUSION

Within the limitations of this *in vitro* study titled "Evaluation of Fracture Resistance of Endodontic Rotary Instruments", it was demonstrated that Hyflex CM file (Group IV) was statistically more resistant to cyclic fracture failure when compared to other tested group files like One Shape file (Group V), Protaper Next file (Group II), Profile Vortex file (Group III) and Hero Shaper file (Group I).

Time taken to fracture ranged from 7 to 58 seconds in different groups. Mean time taken to fracture was minimum in Group I (9.40±1.63 sec) followed by Group III (11.68±1.70 sec), Group II (21.52±2.84 sec), Group V (35.12±3.47 sec) and Group IV (54.72±2.85 sec) respectively.

Analysis of variance and box plot thereafter show a statistically significant intergroup difference ($p<0.001$). Values in Group I and III were of lower order whereas values in Group IV were of higher order. Values in Groups II and V were of middle order. Almost no overlapping in the interquartile range of different groups was observed.

The survival analysis showed a statistically significant difference in time related survival function in different groups ($\chi^2=226.387$, df =4; $p<0.001$ – Log rank test).

All the between group differences were significant. Minimum difference was observed between Groups I and III (2.28±0.74) and maximum between Groups I and

IV (45.32±0.74). On the basis of above evaluation, the following order of time taken to fracture was observed in different groups: **Group I < Group III < Group II < Group V < Group IV**

Number of cycles before fracture ranged from 46.69 to 386.86 cycles in different groups. Mean number of cycles before fracture was minimum in Group I (62.67±10.88 cycles) followed by Group III (77.91±11.35 cycles), Group II (143.54±18.98 cycles), Group V (234.25±23.13 cycles) and Group IV (364.98±19.01 cycles) respectively.

The survival analysis showed a statistically significant difference in number of cycles related survival function in different groups (χ^2=228.736, df=4; p<0.001 – Log rank test).

All the between group differences were significant. Minimum difference was observed between Groups I and III (15.23±4.91) and maximum between Groups I and IV (302.31±4.91). On the basis of above evaluation, the following order of time taken to fracture was observed in different groups:

Group I < Group III < Group II < Group V < Group IV

This study ruled out many contributing factors like torque, rpm, motion of file, Size of file, Taper of file, Sterilization, Irrigant effect etc. for the experimental groups tested. The standardized parameters for cyclic fracture resistance test during this study kept constant were torque, rpm, angle of curvature, radius of curvature, file size, file length, file taper and method of use of file.

The null hypothesis mentioned earlier in this study was totally rejected. It stated that the different manufacturing method with thermo-mechanical treatment used for each experimental file would not affect the Number of Cycles till Fracture of file during rotation in simulated canal curvature.

The present study made a sincere attempt to meet its aim and objective to evaluate the fracture resistance of different types of endodontic rotary files manufactured from different recent manufacturing method. The maximum survival time and superior cyclic fracture resistance was shown by Hyflex CM file with least survival time and lowest NCF observed in Hero Shaper file. The clinician should always be on the lookout for potential severe changes in the root canal anatomy prior and during root canal therapy and expect potential root canal shaping difficulties even when the radiographs are seemingly within normal limits. It is also advisable that clinician should opt the rotary file system accordingly.

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APPENDIX

PUBLICATION LIST

1. Dr. Akanksha Bhatt, Dr. B Rajkumar, Dr. Vishesh Gupta. A comparative evaluation of cyclic fatigue resistance of two recent rotary NiTi endodontic file systems: An In-Vitro Study. Journal of Clinical and Public Health Research 2016; 1(1):15-7.
2. Dr. Akanksha Bhatt, Dr. B Rajkumar, Dr. Vishesh Gupta. Evaluation of Cyclic Fatigue Resistance of Rotary Niti vs Controlled Memory Endodontic File Systems: An *In-Vitro* Study. Medico Research Chronicles 2016, 3 (3), 278-82.
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SUMMARY

Endodontics has evolved and changed over the years like many other dental and medical specialties. Endodontic therapy involves the diagnosis of disease, removal of diseased tissue and filling of the root canal by an inert therapeutic material to obtain tight seal. Endodontic instruments play a major role in the success of endodontic treatment starting from the preparation of the endodontic access cavity to the final obturation of the root canal space. Among the difficulties encountered during endodontic therapy are endodontic access preparation, location of canal orifices, preparation of the canals without procedural errors, establishment and maintenance of working length. The risk of missing root canal is high because of the complexity of the root canal system. A two dimensional radiographs only cannot not judge the complete anatomy of the canal system. An aid in determining correct working length of the root canal being electronic apex locator is one of the important step to achieve endodontic success.

Earlier the instrumentation was aimed at facilitating the placement of medicaments in the root canal with little attempt to remove the organic contents from the root canal system. Later, the focus of instrumentation shifted to cleaning, shaping and filling the root canal space to facilitate the three dimensional root canal obturation.

Most of the root canals are curved whereas endodontic instruments used are manufactured from straight metal blanks. It has been seen that there is uneven force

distribution in areas where the file contacts the curved canal walls. Historically 2% taper stainless steel hand files were used to achieve a tapered preparation of the canal space along with use of Gates-Glidden drills for coronal enlargement. Technical protocols for shaping canals have evolved to achieve the objectives outlined by Schilder (1974). Serial instrumentation as adviced by Schilder in 1974 was implemented that involved usage of multiple number of hand files and reamers sequentially. This step-back technique preparation of the apical region of the root canal first, followed by coronal flaring facilitated three dimensional obturation. Since the mid 1960's until the early 1990's, root canal therapy was done in large using traditional stainless steel hand instruments of various lengths. The rigidity of stainless steel files increased as their tip size increased. Adequate apical size and canal taper after root canal preparations was still a continuous source of debate within the field of endodontics during this period. But in moderate to severe curved root canal or where difficult anatomy (e.g. S-shape) was encountered, the use of stainless steel files was found difficult and the creation of iatrogenic alteration of the canal occured.

There has been a constant quest for quicker, safer and effective endodontic file system for the treatment of curved root canal system. The introduction of rotary nickel-titanium instruments in root canal therapy promoted single visit therapy. This made the root canal therapy convenient and faster compared to conventional multistep tedious procedure with conventional stainless steel instruments.

No doubt about it that endodontic treatment has benefited from the introduction of NiTi rotary root canal instruments. However, clinicians only concern remained still about their breakage while in use. Grossman stated that a dentist who has not separated an instrument has not done enough root canals. Fracture being the most common observed procedural error that occured during clinical use of rotary NiTi instruments. It has been shown that the fracture of stainless steel files usually occurs after a visible distortion or deformation of the file. Even though NiTi instruments are stronger and more flexible than their stainless steel counterparts, these instruments can fracture within their elastic limit and that too without any visible signs of previous permanent deformation and without prior use. Researchers have reported that NiTi rotary instrument fracture was more frequent than hand instrument fracture.

The fear of instrument fracture still is the biggest deterrent to clinical adoption of rotary NiTi instruments.

The actual prevalence of such instrument breakage has been indicated to be low (about 5%) in the literature. NiTi rotary instrument fractures as a result of shear or fatigue failure, with the latter being implicated in more than one-third of those instruments fractured clinically. The term “fatigue” used refers to the fracture of materials submitted to cyclic stresses. The term “fatigue resistance” is one of the most important aspects to consider when considering materials in appliances fitted with rotary parts. Various previous studies have shown that the fatigue life of various NiTi instruments have been affected mainly by the radius of curvature and the instrument size and design.

Instruments used in rotary motion fractures into two distinct modes: torsional and flexural. The flexural fracture occurs when the cyclic load leads to metal fatigue.

Flexural fatigue (bending stress) fracture happens when a file is rotating freely in a curved canal, resulting in alternating tension and compression cycles at the point of maximum flexure which is the midpoint of the curve until fracture occurs. As an instrument is held in a static position in a curved canal and continues to rotate, one half of the instrument shaft on the outside of the curve is in tension, whereas the half of the shaft on the inside of the curve is in compression. This repeated tension-compression cycle, caused by rotation within curved canals, increases flexural fatigue of the instrument over time. Various instruments designs and manufacturing methods have been employed to make NiTi files more resistant to flexural fatigue.

AIM & OBJECTIVE

The present in-vitro study made a sincere attempt to evaluate and compare the fracture resistance of five recent NiTi endodontic rotary files i.e. Hero Shapers (Micro Mega, Besancon, France), Protaper Next (Dentsply Maillefer; Ballaigues, Switzerland), Profile Vortex (Dentsply Tulsa Dental Specialities, Tulsa, OK, U.S.A), Hyflex CM (Coltene Whaldent, Germany) and One Shape (Micro Mega, Besancon Cedex, France).

METHODOLOGY

The study was conducted in Department of Conservative Dentistry & Endodontics (Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow) in collaboration with Department of Mechanical Engineering(Indian Institute of Technology, Kanpur, Uttar Pradesh) and I F F C O (Amla, Bareilly, Uttar Pradesh, India).

The cyclic fracture resistance of five recent endodontic rotary NiTi files Hero

Shapers (Micro Mega, Besancon, France), Protaper Next (Dentsply Maillefer; Ballaigues, Switzerland), Profile Vortex (Dentsply Tulsa Dental Specialities, Tulsa, OK, U.S.A), Hyflex CM (Coltene Whaldent, Germany) and One Shape (Micro Mega, Besancon Cedex, France) were evaluated in the present study.

The inclusion criteria for choosing the above mentioned experimental rotary files was as follows:

1) A recent introduced rotary file system manufactured from Conventional NiTi alloy:

   One shape designated as Group V

2) A recent introduced rotary file system manufactured by M-Wire technology :

   Hero shaper designated as Group I,

   Protaper Next designated as Group II and

   Profile Vortex Designated as Group III

3) A recent introduced rotary file system manufactured by CM-Wire technology :

   Hyflex CM designated as Group IV.

Exclusion criteria:

4) Endodontic Stainless steel hand files.
5) Endodontic NiTi hand files.
6) Endodontic used files.

The present study design was based on the studies conducted by Cheung GSP *et al.*, Gupta M *et al.* and Haikel Y *et al.*

To evaluate the cyclic fracture resistance of the experimental files a total sample size of 125 rotary NiTi files were selected (25 samples in each experimental group). The present in-vitro study comprised of direct comparison of cyclic fatigue resistance among the NiTi rotary files being tested, therefore a separate control group was not required.

To have uniformity in comparative study, all the rotary NiTi experimental files with ISO no.25, length 21mm and taper 0.06 were kept standardized during the study.

Earlier various methods to evaluate cyclic fracture resistance of endodontic files used artificial canals that were constructed by bending glass or metal into cylindrical tubes with different inner diameters and different point of maximum curvature and using different radii and angles of curvature. This artificial bent tube apparatus arrangement was avoided in the present study. The reasons that have been also speculated in previous studies that used similar methodology are that the cylindrical tubes did not sufficiently restrict the instrument shaft, which spring back into its original straight shape, aligning into a trajectory of greater radius and reduced angle. Because of the inner diameter of the tubes (glass or metal) being greater than that of the instruments, an instrument rotated in the tube followed a trajectory that was not predictable and without the parameters of radius and angle of curvature and point of maximum curvature that were established when constructing the artificial canals. Another drawback with loose-fitting canal was that the file may ‘‘walk’’ or vibrate in that space, leading to a change in the magnitude of stress and possibly leading to variations in the results.

Another method employed for cyclic fracture resistance evaluation was by resting the file against an inclined grooved block to produce a curvature. This method had a significant shortcoming in that this method of determining canal curvature ignored the radius of curvature. There was very little scope to confine the files to a particular trajectory, so the results were unreliable every time.

To limit these problems, in the present in vitro study, a non-dental customized apparatus was made to evaluate cyclic fatigue resistance. The simulated working model constructed comprised of a main frame to which a support for endodontic endomotor unit and three steel cylinders were connected. The desired radius of curvature and angle of curvature was obtained positioning these three stainless steel pins/cylinders on the metal frame. It has been reported that in a three-point bending test of NiTi wires that such constraints would produce a curvature that is circular.

The position of shaping cylinders was such that it provided the experimental files of ISO size 25, Length 21mm and Taper 0.06. with a simulated root canal with 60 degree angle of curvature and 5 mm radius of curvature.

The simulated root canals with an angle of curvature of 60 degrees and radius of curvature of 5 mm were chosen as the previous study done by Pruett *et al.* 1997 stated that the stress levels induced by curvatures smaller than 5 mm in radius and 30 degree in angle did not result in instrument separation.

Sample Size and Grouping

Fresh unused packets of the experimental rotary NiTi files were obtained from the manufacturers. A total of 125 rotary Niti Files were divided into five groups, each group comprising of 25 rotary NiTi files to be tested. For standardization of the complete study, ISO size 25 no. , Taper 0.06 and Length 21 mm was chosen. The experimental rotary NiTi files were chosen on the basis of their generation / manufacturing process and were further grouped accordingly.

Grouping:

- Group I consist of Hero shaper rotary NiTi file manufactured from M-Wire technology.
- Group II consist of Protaper Next rotary NiTi file manufactured from M-Wire technology.
- Group III consist of Profile Vortex rotary NiTi file manufactured from M-Wire technology.
- Group IV consist of Hyflex CM rotary NiTi file manufactured from CM-Wire technology.
- Group V consist of One Shape rotary NiTi file manufactured from Conventional NiTi alloy.

The following instrumentation protocol was followed for each experimental file group being tested for cyclic fracture resistance in this study.

The experimental file was coated with a layer of root canal lubricant EDTA gel (Glyde). It was placed in endomotor handpiece with the working part of file between two shaping steel cylinders. The torque of 2.5N/cm and rpm of 400 was preset in endomotor handpiece and was kept constant for each experimental group being tested. The file was then allowed to rotate and simultaneously the stopwatch was stared. The time (in seconds) till the fracture of experimental file occurred was recorded. The number of rotations made by file till its fracture was than calculated using the formula:

No. of cycles till fracture (NCF)= $\frac{400}{60}$ x Time taken by rotary file till fracture (in seconds).

The observations and results were laid down and the statistical analysis was performed. The results obtained showed that Group IV rotary file (Hyflex CM) had longest survival time with a mean value of 54.72 seconds before fracture followed by Group V rotary file (One Shape) followed by Group II rotary file (Protaper Next) followed by Group III rotary file (Profile Vortex).

The minimal survival time was showed by Group I rotary file (Hero Shapers). (χ^2=228.736, df =4; p<0.001 – Log rank test).

The longest survival time or maximum number of cycles till fracture was exhibited by Hyflex CM (Group IV) files in the present study. The reasons attributed for this behaviour can be attributed due to:

- The composition of Hyflex CM files that has low % weight of nickel. (50% wt. Ni). Zinelis *et al.* showed that Hyflex CM files have a lower percentage of nickel (52.1 % wt). Hui-min Zhou, Shan Y *et al.* stated that the nickel content especially had a great influence on the transformation temperatures in turn affecting the cyclic fracture resistance. It has been reported that the phase transformation temperature shifts 12°C toward a lower temperature when the nickel atom content of a Ni-rich Ni-Ti alloy increases by 0.1% .

- The greater Austenite finish (A_f) temperature (more than 37^0 C), which had mixture of both Austenite and Martensitic structures at room temperature.
- Stable Martensitic structure.

It has been reported that Hyflex CM rotary file are made of martensitic active alloys. Martensitic active wires at room temperature shows a very poor resistance to stress and discrete springback property that accepts only a certain bend and after removing it the wire moves discretely toward the original shape but not completely because of the force decay. However, when heat gain occurs from the mouth, they initiate an austenitic crystalline alteration and starts becoming more resistant to stress and regaining their initial shape, thus confirming the shape memory effect. Once the heat is removed or the wire is cooled down, they present their initial characteristic, having predominantly a martensitic crystalline structure. In this alloy, there exists a mixed or rhombohedral phase (R phase) at room temperature that coexist with austenite and martensite structure.

Figueiredo *et al.* reported that NiTi wires with a stable martensitic structure had superior fatigue life. This behavior was particularly explained by the crack propagation mechanism in martensite, which presented a large number of highly branched cracks that propagated very slowly. In contrary, in superelastic NiTi only a few fatigue cracks nucleated and the propagation was faster. Knowing that martensite was less stiff compared with austenite, it was likely that all of the tested shape memory files possessed some martensite at the expense of austenite and this at least partially accounted for their lower stiffness. This decreased stiffness of the files influenced the fatigue properties.

Within the parameters of this in vitro study it can be concluded that Hyflex CM rotary Nickel Titanium file exhibits maximum cyclic fatigue resistance as compared to various other technology manufactured tested files.

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Original Research Article

EVALUATION OF CYCLIC FATIGUE RESISTANCE OF ROTARY NITI VS CONTROLLED MEMORY ENDODONTIC FILE SYSTEMS: AN *IN-VITRO* STUDY

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Abstract

The purpose of this study was to compare fracture resistance of Hyflex CM, Hero Shapers and Vortex NiTi file systems due to cyclic fatigue in curved canals. The methodology in this study involved testing the cyclic fatigue of endodontic root canal file rotating at 375 rpm. A simulated model was created such that, the instrument will bend at 60 degrees during function, maximum curvature being 5 mm from the tip of the file. The number of rotations till the instrument fractured was recorded by mathematical formula. The results were statistically analyzed. Hyflex CM performed significantly better than Vortex & Hero Shapers file system. However there was no statistically significant difference observed between Vortex & Hero Shapers file system in terms of cyclic fatigue.

Introduction

Instrument in curved and narrow root canal still remains a challenge. Introduction of NiTi instruments have revolutionized endodontics with escalation in rotary techniques and innovations in instrument design. The superelasticity of NiTi allows fully recoverable deformation upto 8% strain as compared to 1% in stainless steel.[1]Moreover, these NiTi instruments have shown to provide more predictable, centered and faster canal preparation than stainless steel instruments.[2]Despite the improvement in the design of these instruments, the unexpected instrument separation during their clinical use, still remains a major concern. The incidence of instrument separation was reported to vary from 1.7 to 14%.[3]Sattapan et al.classified the separation of NiTi rotary instruments due to "torsional failure" and "flexular fatigue". [4] Torsional failures occurs when the tip or any part of the instrument locks into the canal and the rotary motion still continues; while the flexural failure occurs due to work hardening and metal fatigue. Among these, flexural fatigue is an important factor to be considered when using these in clinic. An understanding of factors that contribute to instrument fracture is important in preventing its occurrence. These include the following: Root canal anatomy, both in terms of radius and degree of curvature, operator proficiency, operational speed and torque, previous use, sterilization procedures and cross sectional area and design of the instrument.[5]

The purpose of the present study was to investigate the effect of change in manufacturing process on cyclic fatigue resistance. This was evaluated by comparing Hyflex CM endodontic file system with two NiTi endodontic file systems Vortex and Hero Shapers produced by a traditional grinding process.

Materials and Method

The endodontic files systems evaluated were Vortex (Tulsa Dental, U.S.A.), Hero Shapers (Micromega, France) and Hyflex CM files (Coltene Whaldent, Germany). All files with tip size ISO 25 and taper 6% were selected for this study.Total 30 endodontic files were taken (10 for each group) with the stopper adjusted to obtain the desired length of 21.0 mm for each instrument.

A simulated working model (Figure 1) was created similar to that used in study done by Youssef et al (1999). Three cylindrical steel blocks were taken; one supporting block and two shaping blocks were attached on a 6 mm thick acrylic sheet which was held vertically with the help of a vise. The position of shaping block was adjusted so as to get the desired angle of 60 degrees.[6]

The angle of curvature was calculated by Schneider's method, which defined the angle of curvature by drawing a line parallel to the longaxis of the canal and the outer line from the apical foramen to intersect with first line at a point wherein the root canal began to leave the long axis of the canal.[7]

10 instruments from each experimental group were tested with the angle of curvature being 60 degrees. The instruments were rotated at 350 RPM using reduction gear handpiece (Endomate, J Morita).

The time taken to fracture the endodontic instrument was recorded using a stopwatch. The numbers of revolutions taken by each tested endodontic file was calculated using the simple formula: No. of rotation until fractured = 350/60 xTime taken till fracture (in second). The results of the study were analyzed using multiple comparison tests i.e. Holmes test, for evaluating cyclic fatigue of various tested NiTi endodontic instruments, with a level of significance (p)<0.05.

Figure 1: **Simulated Working Model**

Results

The time taken until file fracture and the number of revolutions for each instrument until got separated has been summarized in table: 1 and table: 2 respectively. A statistically significant difference (*P*<0.05) was noted between Hyflex CM Files (Colten Waldent) and theVortex Files (Tulsa Dental) and Hero Shapers (Micromega) NiTi instruments. Hyflex CM Files (Colten Waldent) instruments showed the maximum number of rotations of instrument before separation. No statistically significant difference (P>0.05) was noted between Vortex and Hero Shaper instruments.

Table 1: Comparison of time taken forseparation of various NiTi instruments.

S. No	Hyflex CM (Time in sec)	Hero Shaper (Time in sec)	Vortex (Time in sec)
1.	52	12	6
2.	50	8	8
3.	58	10	8
4.	54	8	9
5.	56	12	7
6.	58	10	6
7.	57	10	8
8.	58	9	7
9.	55	8	6
10.	56	7	8
Mean	**55.4**	**9.4**	**7.3**

Table 2: Comparison of number ofrevolutions of NiTi instruments beforeseparation

S. No	Hyflex CM (No. of revolutions until seperated)	Vortex (No. of revolutions until seperated)	Hero Shaper (No. of revolutions until seperated)
1	325	37.5	75
2	312.5	50	50
3	362.5	50	62.5
4	337.5	56.25	50
5	350	43.75	75
6	362.5	37.5	62.5
7	356.25	50	62.5
8	362.5	43.75	56.25
9	343.75	37.5	43.75
10	325	50	50
Mean	**312.5**	**46.625**	**58.75**

Mathematically, it can be shown that **Hyflex CM>Hero Shaper>Vortex**. This implies that, Hyflex CM rotary file system have more fracture resistance in comparison with Hero Shaper and Vortex rotary file instruments. A higher number of cycles to failure indicate greater resistance to cyclic fatigue of the tested instruments.

Discussion

Nickel-titanium (NiTi) was developed by Buehler et al in the Naval Ordnance Laboratory (NOL) in Silver Springs, Maryland in early 1960's.[8] Using about 55 wt% Ni and 45 wt% Ti and substituting some Ni with less than 2 wt% Cobalt; nearly the same number of Ni and Ti atoms are combined, being reflected in the term equiatomic. This alloy is very popular among Endodontists, especially for negotiating curved canals and is commonly referred to as 55 NiTi NOL.

NiTi alloys are softer than stainless steel, not heat treatable and have a low modulus of elasticity. However they have more strength, are tougher, more resilient and have two important properties i.e. the *shape memory* and *superelasticity.* These two extraordinary properties are the main reason why NiTi alloys are popular in the field of endodontics and other dental disciplines. These material properties are due to a change in the crystal structure. The low temperature phase is called 'martensitic' or daughter phase and the high temperature phase is called the 'austensitic' or parent phase. These lattice organizations can be altered by temperature or stress. During endodontic treatment, stress can be induced into the instrument, especially during instrumentation of curved canals. The austensitic phase transforms into the martensitic phase on stressing and in this form it requires only a light force to bend the instrument. After release of stresses, the metal returns to the austensitic phase and the instrument regains its original shape.[9] The improved flexibility and unique properties of NiTi have undoubtably provided better control while preparing curved canals and has made it possible to engineer greater taper instruments, thereby allowing better control in shaping the root canal.

A New files system Hyflex CM with controlled memory (CM), a metal alloy of nickel and titanium, have been introduced and manufactured by Coltene. The company reports that this file is more resistant to cyclical fatigue compared to other NiTi files, which reduces the incidence of file fracture. The purpose of this new rotary file is to simplify root canal treatment and to optimize cleaning and shaping of the canal. The cutting profile of each HyFlex® CM file facilitates penetration in the canal, and presents a root canal shape corresponding with the original anatomy. This system also offers precise apical finishing, leaving the structural integrity of the root intact after endodontic therapy. It works with an active cutting motion with variable helical angle and balanced pitch in the instrument.

Another rotary instrument which has become quite popular is Hero Shapers. It also has variable helical angle and adapted pitch; i.e. the more tapered an instrument is, the longer is itspitch. It has a positive rake angle and the blade shows a triple helix cutting edge. The tip is inactivein order to follow canal anatomy.

The principle of grain structure during manufacturing process is a key element in with standing stress. Maintaining the grain structure of NiTi during file manufacture, results in a stronger and more flexible rotary instrument. With the introduction of the Hyflex CM File having proprietary R-phase technology, mechanical rootcanal preparation may become safer and more predictable.

The other experimental two groups i.e. Hero Shapers and Vortex have a relatively narrow range of elasticity due to alteration in grain structure caused by grinding process. Moreover, grinding across the grain structure creates microfracture points and defects along the length of the instrument. These defects cause stress concentration points that weaken the instruments and can lead to separation of the instrument & hence intracanal failure. Cracks can propagate at a stress level much lower than the stress usually encountered during canal instrumentation, leading to sudden unexpected root canal file breakage.

The preliminary findings of the present study must be confirmed by more research, which should evaluate other clinically relevant mechanical properties of the Hyflex CM instruments *In- vivo*.

Conclusion

Under the limitations of the present study, itis concluded that Hyflex CM had greater resistance to cyclic fatigue than Hero Shapers and Vortex endodontic file system.

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ORIGINAL STUDY

A comparative evaluation of cyclic fatigue resistance of two recent rotary NiTi endodontic file systems - An in-vitro study.

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KEYWORDS:

Curvature, Cyclic Fatigue, Endodontics, Flexural fracture, Torsional fracture

ABSTRACT:

This study aimed to compare the cyclic fatigue fracture resistance of two different rotary NiTi instrument systems. The instruments compared were One Shape rotary endodontic file system and a new rotary system Protaper Next. The cyclic fatigue testing was conducted with the instrument rotating freely at an angle of curvature 60^0 with maximum radius of curvature at 5mm from the tip. 10 endodontic rotary files were selected in each of the two groups to be tested. The files were rotated at 375 rpm using the Tri auto mini endomotor set at 2.5 Torque, until fracture occurred. The time until fracture was recorded in seconds by using a stopwatch, and the number of rotations to fracture was then calculated and results were then statistically analyzed. The results showed One Shape (Group 1) performed significantly better than Protaper Next rotary endodontic file system (Group2) in cyclic fatigue testing.

INTRODUCTION:

Root canal preparation in narrow and curved canals is a great challenge. Rotary Ni- Ti files can be used to prepare curved canals as they are 2-3 times more elastic and flexible in bending and torsion and have Superior resistance to torsional fracture compared with similar size stainless steel files.[1]

Despite the advantages of rotary NiTi instruments, concern has been expressed by many authors and clinicians about the potential for rotary NiTi instrument to fracture within the root canal system during endodontic treatment.[2-4] Endodontic instrument fracture within canal is a complex event. Fracture occurs without warning and without any visible defects of previous permanent deformation. Hence, visible inspection is not a reliable test for testing NiTi instruments.

Two modes of fracture of rotary Ni-Ti endodontic instruments have been identified in the clinical situation: Torsional fracture and Flexural fracture.[5] Among these, flexural fatigue is an important factor in a clinical point of view. An understanding of factors that contribute to instrument fracture is important in preventing its occurrence. These include the following: Root canal anatomy in terms of radius and degree of curvature, operator proficiency, operational speed and torque, previous use, sterilization procedures and cross sectional area and design of the instrument.[6]

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Many different rotary systems are available with difference in cross sectional shape and design, taper and total number of instruments within system. But it is quite difficult to determine the best one. ProTaper Next, which is manufactured by M-Wire, has been introduced recently. This system has an off-centered rectangular cross-section design. Files manufactured with this M-wire method showed more flexible and fatigue resistance than conventionally manufactured files. This design of the cross section is found to enhance the resistance to stress and increases the efficiency of shaping due to its unique asymmetric rotary motion.[7]

The OneShape file system consists of only one instrument made of a conventional austenite 55-NiTi alloy. It is characterized by different cross-sectional designs over the entire length of the working part. In the tip region, the cross section represents three cutting edges while in the middle of the cross-sectional design progressively changes from a three cutting edge design to two cutting edges. At the shank, the S-shaped cross section shows two cutting edges, resembling the cross-sectional design of Reciproc instruments. This design is alleged to eliminate threading and binding of the instrument in continuous rotation.

The aim of this study was to evaluate and compare the cyclic flexural fatigue resistance of Protaper Next and recently introduced rotary NiTi system One Shape.

MATERIALS AND METHOD:

The endodontic rotary file system Protaper Next (Dentsply Maillefer, Ballaigues, Switzerland) and One Shape (Micro Mega, Besancon, France) were chosen. The tip size ISO 25, 21 mm in length were selected for this study.

A simulated testing apparatus was used that allowed fatigue test to be conducted in a manner similar to that of Youssef et al.[8] It comprises of three cylindrical steel blocks (one supporting block and two shaping block) attached on a 6mm thick acrylic sheet which was held vertically with the help of a vise. The positions of the shaping blocks was adjusted in order to get the desired degree of curvature (60^0) in the instrument in such a manner that maximum curvature was at 5 mm from the tip.

The angle of curvature was calculated by Schneider's method, which defined the angle of curvature by drawing a line parallel to the long axis of the canal and the outer line from the apical foramen to intersect with first line at a point where in the canal began to leave the long axis of the canal.[10]

Ten instruments were tested in each of the two experimental groups and 60^0 angle of curvature to give a total of 20 instruments tested. The instruments were rotated at 375 rpm using the Tri auto mini (J Morita, Australia) Endomotor. The time until fracture was recorded in seconds by using a stopwatch, and the number of rotations to fracture was than calculated using the simple formula: No. of rotation to fracture = 375/60 x Time taken to fracture (in seconds). Because the study was a direct comparison of fatigue resistance among groups, a separate control group was not required. Results of cyclic fatigue test were analyzed by using Paired t test using SPSS 11 Software with level of significance at $p< 0.05$.

Sample	One Shape(Group 1)	Protaper Next (Group 2)
1	154	146
2	150	150
3	148	142
4	154	145
5	152	152
6	146	148
7	153	143
8	158	151
9	151	147
10	143	138

Table 1: Table of number of rotations at fracture at 60^0 angle of curvature.

RESULTS

Observations were laid down regarding the number of rotations to fracture, when the instruments were rotated at a 60^0angleof curvature (Table 1).The statistical tools like mean &standard deviation were employed (Table 2). The results showed that the number of rotations until fracture for One Shape (Group1) was significantly greater than that of ProTaper Next (Group2) at angles of curvature 60^0.

DISCUSSION:

The present study confirmed that the number of rotation to fracture on instrument largely depends on the degree of curvature with more incidence of breakage at greater degree of curvature. This result is in accordance to other studies.[9,10] In endodontic treatment, Biomechanical preparation is very important as the outcome is largely depends on proper cleaning and shaping. A more tapered preparation results in enhanced cleaning as there is more removal of infected dentin and also endodontic irrigants can reach more apically and results in better microbial control and better debridement and also good quality obturation.[11]

	One Shape (Group 1)	Protaper Next (Group 2)
Mean	151.07	146.87
Standard Deviation	3.84	4.24

Table 2: Table of means and standard deviations of number of rotations to fracture.

Fracture of NiTi files occurs in one of two ways, flexural or torsional failure. Flexural fracture is a result of repeated compression and tension in curved canals. Torsional fracture occurs when the tip or any other part of the instrument binds to the canal walls whereas the handpiece keeps turning. In fact, NiTi files exposed to torsional stress are prone to fracture at a lower cyclic fatigue and torsional resistance decreases in used files.[12,13]

One possible method for preventing file fracture is to reduce torsional stress in the process of canal preparation. For this purpose pre flaring and the crown-down preparation have been suggested.[14]Preliminary creation of a glide path has been shown to be fundamental for safer use of NiTi rotary instrumentation.[15, 16]The root canal diameter becomes bigger than or at least the same size as the tip of the first rotary instrument used, reducing the stress the instruments suffer.

The lifespan of an instrument is directly proportional to the stress accumulated during work in the root canal.[17] It is advocated that clockwise and counter clockwise movements reduces the incidence of torsional fracture caused by taper lock.[18]

The cross cut design incorporated in the One Shape system might results in less cyclic fatigue than other instruments of similar taper as some of the values of Protaper Next. As this was an in-vitro study more clinical trials should be carried out for reaching out to reach to a definite conclusion.

CONCLUSION:

Within the limitations of this study, Oneshape file system showed significantly higher resistance to cyclic fatigue fracture as compared to the Protaper Next file system at 60^0 of curvature. Instrumentation with files with reciprocal motion increases significantly instrument life and makes them safer during shaping of root canals.

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There are no conflicts of interest.

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Original article:

A comparative analysis of cyclic fatigue resistance of new rotary NiTi file systems (Hyflex CM and One Shape): An In-Vitro Study.

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ABSTRACT

Instrument in curved and narrow root canal still remains a challenge. Introduction of NiTiinstruments have revolutionized endodontics with escalation in rotary techniques and innovations in instrument design. Despite the improvement in the design of these instruments, the unexpected instrument separation during their clinical use, still remains a major concern. The incidence of instrument separation was reported to vary from 1.7 to 14%. Among these, flexural fatigue is an important factor to be considered when using these in clinic. The present in-vitro study aimed to compare the cyclic fatigue fracture resistance of two different rotary NiTi instrument system (One Shape and Hyflex CM). The cyclic fatigue testing was conductedwith the file rotating at an angle of curvature 60^0 with maximum radius of curvature at 5mm from the tip.

Ten endodontic rotary files were selected in each of the two groups to be tested. The files were rotated with standard parameters 350 rpm and 2.5 Nmtorque using the Tri auto mini endomotor set until fracture occurred. The time until fracture was recorded in seconds by using a stopwatch, and the number of cycles till fracture was then calculated. The results were obtained and then statistically analyzed. The results showed Hyflex CM (Group 1) performed significantly better than One Shape rotary endodontic file system (Group2) during cyclic fracture resistance evaluation. A statistically significant difference ($P < 0.05$) was noted. It is concluded that Hyflex CM had greater resistance to cyclic fatigue than One Shape endodontic file system.

Keywords: Cyclic Fatigue, Cyclic fatigue resistance, Endodontics, Flexural fracture resistance.

INTRODUCTION

Root canal preparation in narrow and curved canals is a great challenge. Rotary Ni- Ti files can be used to prepare curved canals as they are 2-3 times more elastic and flexible in bending & torsion and have Superior resistance to torsional fracture compared with similar size stainless steel files.[1]

Despite the advantages of rotary Ni- Ti instruments, concern has been expressed by many authors and clinicians about the potential for rotary Ni- Ti instrument to fracture within the root canal system during endodontic treatment.[2-4]Endodontic instrument fracture within canal is a complex event. Fracture occurs without warning and without any visible defects of previous permanent deformation. Hence, visible inspection is not reliable test for testing NiTi instruments.

Two modes of fracture of rotary Ni-Ti endodontic instruments have been identified in the clinical situation: Torsional fracture and Flexural fracture.[5]Among these, flexural fatigue is an important factor in a clinical point of view. An understanding of factors that contribute to instrument fracture is important in preventing its occurrence. These include the following: Root canal anatomy in terms of radius & degree of curvature, operator proficiency, operational speed and torque, previous use, sterilization procedures and cross sectional area and design of the instrument.[6]

HyFlex™ CM NiTi Files respond to excessive resistance with straightening of the spirals,which avoids binding to the walls and therefore increases fracture resistance. This formadaptation can be reversed quickly by heat treatment (during autoclaving or with a glassbead sterilizer) returning the instruments back to their original shape. Furthermore it willstrengthen the files making them a lot more resistant to cyclical fatigue. Also it provides aclear visual opportunity to verify safe continuation of file use.[7]

The OneShape file system consists of only one instrument made of a conventional austenite 55-NiTi alloy. It is characterized by different cross-sectional designs over the entire length of the working part. In the tip region, the cross section represents three cutting edges while in the middle of the cross-sectional design progressively changes from a three cutting edge design to two cutting edges. At the shank, the S-shaped cross section shows two cutting edges, resembling the cross-sectional design of Reciproc instruments. This design is alleged to eliminate threading and binding of the instrument in continuous rotation.

The aim of this study was to evaluate and compare the cyclic flexural fatigue resistance of HyflexCM andOne Shape endodontic rotary file system.

METHOD

The endodontic rotary file system Hyflex CM (ColteneWhaldent, Germany) and One Shape (Micro Mega, Besancon, France) were chosen. The tip size ISO 25, 21 mm in length were selected for this study.

A simulated testing apparatus was used that allowed fatigue test to be conducted in a manner similar to that of Youssef et al.[8]It comprises of three cylindrical steel blocks (one supporting block and two shaping block) attached on a 6mm thick acrylic sheet/ wooden sheet which was held vertically with the help of a vise. The positions of the shaping blocks was adjusted in order to get the desired degree of curvature (60^0) in the instrument in such a manner that maximum curvature was at 5mm from the tip.

The angle of curvature was calculated by Schneider's method, which defined the angle of curvature by drawing a line parallel to the long axis of the canal and the outer line from the apical foramen to intersect with first line at a point wherein the canal began to leave the long axis of the canal.[10]

Ten instruments were tested in each of the two experimental groups and 60^0 angle of curvature to give a total of 20 instruments tested. The instruments were rotated at 375 rpm using the Tri auto mini (J Morita, Australia) Endomotor. The time until fracture was recorded in seconds by using a stopwatch, and the number of rotations to fracture was than calculated using the simple formula: No. of rotation to fracture= 375/ 60 x Time taken to fracture (in seconds). Because the study was a direct comparison of fatigue resistance among groups, a separate control group was not required. Results of cyclic fatigue test were analysed by using Paired t test using SPSS Software with level of significance at $p< 0.05$.

RESULTS

Observations were laid down regarding the number of rotations to fracture, when the instruments were rotated at a 60^0 angle of curvature (Table1).The statistical tools like mean & standard deviation were employed (Table2). The results showed that the number of rotations until fracture for Hyflex CM (Group1) was significantly greater than that of One Shape (Group2) at angles of curvature 60^0.

Table 1: Table of number of rotations at fracture at 60^0angle of curvature.

Sample	HyflexCM (Group 1)	One Shape (Group 2)
1	325	154
2	312.5	150
3	362.5	148
4	337.5	154
5	350	152
6	362.5	146
7	356.25	153
8	362.5	158
9	343.75	151
10	325	143

Table 2: Table of means and standard deviations of number of rotations to fracture.

	Hyflex CM (Group 1)	One Shape (Group 2)
Mean	312.5	151.07
Standard Deviation		3.84

DISCUSSION

The present study confirmed that the number of rotation to fracture an instrument largely depends on the degree of curvature with more incidence of breakage at greater degree of curvature. This result is in accordance to other studies.[9,10]In endodontic treatment, Biomechanical preparation is very important as the outcome is largely depends on proper cleaning and shaping.A more tapered preparation results in enhanced cleaning as there is more removal of infected dentin and also endodontic irrigants can reach more apically and results in better microbial control and better debridement and also good quality obturation[11].

Fracture of NiTi files occurs in one of two ways, flexural or torsional failure. Flexural fracture is a result of repeated compression and tension in curved canals. Torsional fracture occurs when the tip or any other part of the instrument binds to the canal walls whereas the hand piece keeps turning. In fact, NiTi files exposed to torsional stress are prone to fracture at a lower cyclic fatigue and torsional resistance decreases in used files[12,13].

One possible method for preventing file fracturein clinic is to reduce torsional stress in the process of canal preparation. For this purpose preflaring and the crown-down preparation have been suggested.[14] Preliminary creation of a glide path has been shown to be fundamental for safer use of NiTi rotary instrumentation.[15, 16] The root canal diameter becomes bigger than or at least the same size as the tip of the first rotary instrument used, reducing the stress the instruments suffer.

The lifespan of an instrument is directly proportional to the stress accumulated during work in the root canal.[17]It is advocated that clockwise and counter clockwise movements reduces the incidence of torsional fracture caused by taper lock[18].

The cross cut design incorporated in the Hyflex CM system might results in less cyclic fatigue than other instruments of similar taper as some of the values of One Shape.

It is believed that the material property had a substantial impact on the fatigue lifetime. The composition of Hyflex CM files has low % weight of nickel (50% wt. Ni) . It was also found that superior cyclic fatigue resistance of hyflex CM file is due to greater A_f temperature (more than 37^0 C),which has both mixture of Austenite and Martensitic structures at room temperature.[19,20]

The results of present study was in accordance to the study conducted by Shen Y & Zhou H M et al, Shen Y &Qian W et al and Santos L de A that showedCM wire manufactured files have more flexibility and more resistance to cyclic fatigue then M wire manufactured wire .[21-23]As this was an in-vitro study more clinical trials should be carried out for reaching out toa definite conclusion.

CONCLUSION

Within the limitations of this study, Hyflex CM file system showed significantly higher resistance to cyclic fatigue fracture compared with the One shape file system at 60^0 of curvature.

KEY NOTE

- In this era of NiTi rotary files, it is recommended that Hyflex CM files manufactured from proprietary process found superior in cyclic fatigueresistance can be used in severely curved root canals without fracture several times.

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Research Article

A COMPARATIVE EVALUATION OF FLEXURAL FATIGUE RESISTANCE OF PROTAPER NEXT AND PROFILE VORTEX: AN *IN-VITRO* STUDY.

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ABSTRACT

Background: Introduction of nickel titanium file system for root canal therapy has changed the conventional approach but instrument fracture in curved and narrow root canal still remains a challenge for operator. **Aim & objective:** This study aimed to compare the cyclic fatigue fracture resistance of two recent rotary Ni Ti file systems: Protaper Next and Profile Vortex file system. **Methodology:**The cyclic fatigue testing was conducted with the files rotating freely at an angle of curvature 60^0 with maximum radius of curvature at 5mm from the tip. Ten endodontic rotary files were selected in each of the two groups to be tested. The files were rotated at 400 rpm using the Tri auto mini endomotor with handpiece set at 2.5 Torque, until the fracture occurred. The time until fracture was recorded in seconds by using a stopwatch, and the number of rotations till fracture was then calculated and results were then statistically analyzed. **Result:**The results showed Protaper Next performed significantly ($P < 0.001$)better and had good survival time than Profile Vortex rotary file system during cyclic fatigue testing.**Conclusion:**It was concluded that Protaper Next files had greater resistance to cyclic fatigue than Profile Vortex file system.

Keywords: CyclicFatigue, Flexural fracture, Flexural resistance.

INTRODUCTION:

Introduction of Nickel titanium file system for root canal therapy has changed the conventional approach. But instrument fracture in curved and narrow root canal still remains a challenge for operator. The superelasticity of nickel titanium alloys allows fully recoverable deformation upto 8% strain as compared to 1% in stainless steel.[1] Moreover, these NiTi instruments have shown to provide more predictable, centered and faster canal preparation than stainless steel instruments.[2] The incidence of instrument separation hasbeen reported to vary from 1.7 to 14%.[3]Sattapan et al.classified the separation of NiTi rotary instruments due to "torsional failure" and "flexural fatigue".[4]The flexural failure occurs due to work hardening and metal fatigue. An understanding of factors that contribute to instrument fracture is important in preventing its occurrence. The present study evaluated the cyclic fracture resistance for Protaper Next NiTi file system with Profile Vortex NiTi file system.

Methodology

All files with tip size ISO 25 and taper 6% were selected for this study. Total 20 endodontic files were taken (10 for each group) with the stopper adjusted to obtain the desired length of 21.0mm for each instrument.

A simulated working model was created similar to that used in study done by Youssef et al (1999)and Cheung et al (2007).[5,6] Three cylindrical steel pin were taken, one supporting pin and two shaping pins were attached on a 5mm thick metal sheet which was held vertically with the help of a vise. The position of shaping pin was adjusted so as to get the desired angle of 60 degrees.The angle of curvature was calculated by Schneider's method, which defined the angle of curvature by drawing a line parallel to the long axis of the canal and the outer line from the apical foramen to intersect with first line at a point wherein the root canal

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began to leave the long axis of the canal.[7] Ten files from each experimental groups were tested with the angle of curvature being 60 degrees. The instruments were rotated at 400 RPM and torque 2.5 Nm using reduction gear handpiece (Tri Auto mini, J Morita Mfg. Corp.,Japan).

The time taken to fracture the endodontic instrument was recorded using a stopwatch. The numbers of revolutions taken by each tested endodontic file was calculated using the simple formula: No. of rotation until fractured = 400/60 x Time taken till fracture (in second) .The results of the study were analyzed using multiple comparison tests i.e. Holmes test, for evaluating cyclic fatigue of various tested NiTi endodontic instruments, with a level of significance (p) < 0.001.

Result

The time taken (in seconds) until file fracture and the number of revolutions for each file until got separated has been summarized in table 1 and table 2 respectively. A statistically significant difference (p< 0.001) was noted between Protaper Next and Profile Vortex Files during the flexural fatiguetest.

Table 1: Comparison of time taken for separation of various NiTi instruments.

S. No	Protaper Next(Time in Sec)	Profile Vortex (Time in sec)
1.	18	12
2.	22	14
3.	24	10
4.	24	10
5.	20	12
6.	26	14
7.	18	10
8.	18	12
9.	22	10
10.	24	14

Table 2: Comparison of number of cycles of NiTi instruments till fracture

S. No	Protaper Next (No. of cycles till fracture)	Profile Vortex (No. ofrevolutions until separated)
1	112.5	75.0
2	137.5	87.5
3	150.0	62.5
4	150.0	62.5
5	125.0	75
6	162.5	87.5
7	112.5	62.5
8	112.5	75.0
9	137.5	62.5
10	150.0	87.5

The results revealed that the Protaper Next file system survived more than Profile Vortex file system. This implies that, the fracture resistance was greater in Protaper Next file system than Profile Vortex file system. A higher number ofcycles to failure indicates greater resistance to cyclicfatigue of the tested instruments.

Discussion

NiTi alloys have more strength, are tougher, more resilient and have two important properties that are shape memoryand superelasticity.These material properties are due to a change in the crystal structure. The low temperature phase called as 'martensitic' or daughter phase and the high temperature phase called as 'austensitic' or parent phase. This lattice organization can be altered by temperature or stress.

During endodontic treatment, stress is induced into the instrument, especially during instrumentation of curved canals. The austensitic phase transforms into the martensitic phase on stressing and in this form it requires only a light force to bend the instrument. After release of stresses, the metal returns to the austensitic phase and the instrument regains its original shape.[8,9] The improved flexibility and unique properties of NiTi have undoubtably provided better control while preparing curved canals and has made it possible to engineer greater taper instruments, thereby allowing better control in shaping the root canal.

The cyclic fatigue resistance of Protaper Next files was found to be superior than Profile Vortex because of the manufacturing of file using M Wire. It has been proved that M wire, a metallurgically improved version of NiTi which has been derived from proprietarythermomechanical process that reduces cyclic fatigue by 400% when comparing files of the same D_0 diameter, cross-section and taper.[10]

The study conducted by Elnaghy(2014) for evaluation of cyclic fracture resistance of Protaper Next files stated that the improved cyclic fatigue resistance of Protaper Next files could be associated with its non-uniform design and the reduced number of contact points between the instrument and the root canal walls.[11]

Various studies have been conducted to examine the propensity of Protaper Next files to fracture during use and reason for it.[12,13] It was reported that there is minimal crack formation initiation in these files and this tendency was a reason for greater fracture resistance of Protaper Next file.[14] It was also been observed that Protaper Next files had higher cyclic fatigue resistance than its own other variant Protaper Universal files at all the tested lengths.

Cheng Peng et al. 2015 studied the cyclic fracture resistance of protaper Next files and Files manufactured with conventional NiTi alloy and observed that cyclic fatigue resistance of Protaper Next files was higher than the conventional NiTifiles due to manufacturing of these files by M wire.[15]

The result obtained in current study were in agreement to the findings of the above mentioned researches. The preliminary findings of the present study must be confirmed by more research, which should evaluate other clinically relevant mechanical properties of the tested files I*n- vivo*.

Conclusion

Under the limitations of the present study, it was concluded that Protaper Next files had greater resistance to cyclic fatigue than Profile Vortex file system.

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