AN *IN VITRO* STUDY ON THE CLEANING ABILITY ON THE ROOT CANAL IRRIGATION TECHNIQUES USING TWO ROTARY NITI SYSTEMS

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by

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Dedication

To my Beloved Family

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KAJIAN SECARA IN VITRO TERHADAP KEBOLEHAN MEMBERSIH TEKNIK PENGAIRAN KANAL AKAR MENGGUNAKAN DUA SISTEM NITI BERPUTAR

ABSTRAK

Sasaran: Untuk menentukan dan membandingkan kecekapan pembersihan oleh dua sistem pengairan kontemporari dengan jarum pengairan konvensional menggunakan dua sistem NiTi berputar.

Kaedah: 144 gigi kekal manusia yang dicabut berakar tunggal dibahagikan secara rawak kepada empat kumpulan: sistem pengairan EndoVac, jarum pengairan NaviTip FX, jarum 25G konvensional dan kawalan. Kumpulan tersebut dibandingkan menggunakan sistem TF dan RaCe berputar. Keratan bersiri berketebalan empat mikron disediakan pada 1.5 dan 3.5mm daripada foramen apikal dan imej yang dirakam menggunakan mikroskop optikal dan dianalisa menggunakan perisian Mirax. Analisis statistik dilakukan menggunakan Ujian Kruskal-Wallis ($p < 0.05$) diikuti oleh perbandingan antara kumpulan menggunakan ujian Mann-Whitney ($p < 0.008$).

Keputusan: Walaupun kebolehan membersih sistem pengairan EndoVac secara signifikannya lebih baik daripada pengairan jarum konvensional menggunakan sistem rotary TF dan RaCe pada 3.5 dan 1.5mm ($p < 0.008$), tiada perbezaan signifikan di antara jarum NaviTip FX dan jarum pengairan konvensional pada kedua-dua tahap. Dengan mengecualikan kebolehan membersih pada 1.5mm menggunakan TF, tiada perbezaan signifikan di antara sistem EndoVac dan jarum NaviTip FX ($p > 0.008$). Pada kedua-dua tahap, kebolehan membersih sistem pengairan TF dan RaCe dengan kesemua sistem pengairan tidak berbeza secara signifikan.

Kesimpulan: Sistem pengairan EndoVac mempunyai kebolehan mencuci lebih baik daripada NaviTip FX dan jarum konvensional dengan kedua-dua sistem TF dan NiTi RaCe berputar, terutamanya pada 1.5mm daripada foramen apikal. Sistem TF dan rotary RaCe mempunyai kebolehan membersih yang sama dengan kesemua sistem pengairan.

AN *IN VITRO* STUDY ON THE CLEANING ABILITY ON THE ROOT CANAL IRRIGATION TECHNIQUES USING TWO ROTARY NITI SYSTEMS

ABSTRACT

Aim: To determine and compare the cleaning efficacy of two contemporary irrigation systems with conventional irrigation needles using two different rotary NiTi systems.

Methods: 144 single rooted extracted human permanent teeth were divided randomly into four groups: EndoVac irrigation system, NaviTip FX irrigation needle, Conventional 25G needle and control. The groups were compared using TF and RaCe rotary systems. Four-micron-thick serial sections were prepared at 1.5 and 3.5mm from the apical foramen and the images were captured using optical microscopy and analyzed using Mirax software. The statistical analysis was performed using Kruskal-Wallis Test ($p < 0.05$) followed by intergroup comparison using Mann-Whitney Test ($p < 0.008$).

Results: While the cleaning ability of EndoVac irrigation system was significantly better than conventional needle irrigation using both TF and RaCe rotary systems at 3.5 and 1.5mm ($p < 0.008$), there is no significant difference between NaviTip FX needle and conventional needle irrigation at both levels. With the exception of the cleaning ability at 1.5mm using TF, there is no significant difference between EndoVac system and NaviTip FX needle ($p > 0.008$). At both levels, the cleaning ability of TF and RaCe rotary systems with all irrigation systems was not significantly different.

Conclusions: EndoVac irrigation system has better cleaning ability than NaviTip FX and conventional needle with both TF and RaCe rotary NiTi systems, especially at 1.5mm from the apical foramen. TF and RaCe rotary systems have similar cleaning ability with all irrigations systems.

CHAPTER ONE

INTRODUCTION

1.1 Study Background

1.1.1 Rotary Instrumentation

Elimination of microorganisms and pathologic debris are the most important objective of root canal therapy. The process of chemo-mechanical debridement has been described as the removal of all the root canal system contents before and during shaping. Thorough instrumentation of the apical region has long been considered to be an essential component in the cleaning and shaping process (Baugh and Wallace, 2005).

The design features of the cutting blade of endodontic instruments are important and may affect the cleansing efficiency of the instruments (Jeon *et al.*, 2003). It is also important that endodontic instruments will remove dentine and pulpal debris from the entire root canal wall and create a canal free from bacteria (Foschi *et al.*, 2004). Nickel titanium instruments (NiTi) are more flexible than stainless steel instruments and have the ability to revert to their original shape after flexure. It has been reported that NiTi instruments are 2 to 3 times more flexible than stainless steel instruments and more resistant to fracture (Inan *et al.*, 2007).

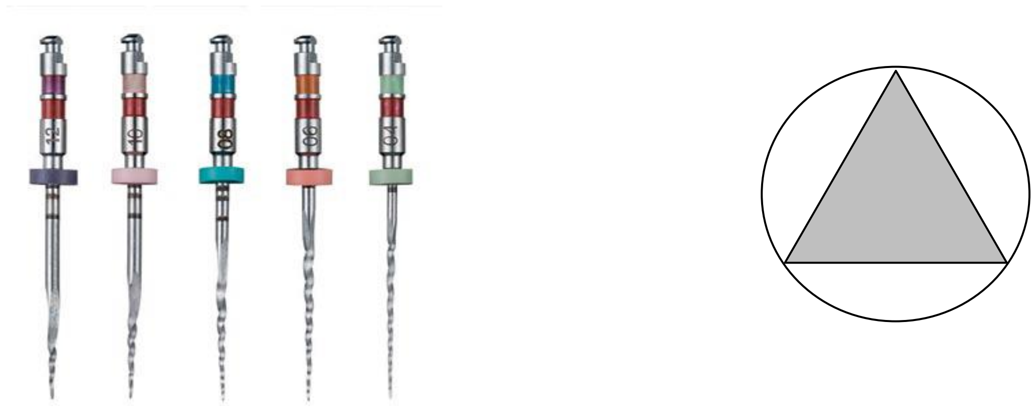
The reamer with alternating cutting edges (RaCe) rotary instruments have a triangular cross sectional design and alternating cutting edges, a design that is claimed to perform two functions: to eliminate screwing-in and blocking in continuous rotation and to reduce the working torque. These characteristics may allow the instrument to rotate inside the canal without having continuous contact with the walls (da Silva *et al.*, 2005) as shown in Fig. 1.1.

(a) **(b)**

Figure 1.1: a) RaCe system showing the alternating cutting edges (Koch and Brave, 2002)

b) Cross section of the file system

The Twisted file (TF) is a recently introduced nickel titanium (NiTi) rotary system with different manufacturing process aiming to improve the root canal preparation procedure (Fig. 1.2). TF is made triangular in cross section by twisting the nickel titanium during the R phase, which is a different phase of crystalline structure. Once twisted, the file is heated and cooled again to maintain its new shape and also to convert it back into the super elastic austenite crystalline structure (Gambarini *et al.*, 2008).



(a) **(b)**

Figure 1.2: a) TF rotary file system (Mounce, 2008)

b) Cross section of the file system

1.1.2 Smear layer

Removal of pulp tissue and elimination of microorganisms and their toxins from the root canal system are the most important objectives for successful root canal therapy. The combination of mechanical instrumentation and irrigation would aid in achieving clean root canal cavity walls, thus paving the way for favourable clinical outcomes (Goel and Tewari, 2009).

McComb and Smith (1975) were the initial investigators to show the presence of a smear layer in instrumented root canals (Goel and Tewari, 2009). The smear layer has been defined as a layer of debris on the surface of dental tissues created by cutting a tooth. It varies in thickness, roughness, density and degree of attachment to the underlying tooth structure according to the surface preparation (Oliveira *et al.*, 2003).

The removal of the smear layer is less predictable in the apical third as compared with the coronal and middle thirds of the root. This could be attributed to comparatively smaller apical root canal dimensions hindering the penetration of irrigants and resulting in limited contact between root canal walls and irrigants (Goel and Tewari, 2009).

1.1.3 Irrigation

Adequate removal of the vital and necrotic remnants of pulp tissue, microorganisms and their toxins from the root canal system is a fundamental prerequisite for successful endodontic treatment. Owing to the complexity and irregular structure of the root canal system, it is not possible to ensure adequate elimination of all pulp tissue remnants and microbial irritants via mechanical instrumentation alone (Shin *et al.,* 2010).

Accordingly, the method for irrigating the root canal system has been claimed to be the most critical step during root canal treatment (Shin *et al.,* 2010). The principle goal for this endodontic procedure is to remove pulp tissue, microorganisms and the dentine debris formed after mechanical instrumentation from the root canal system (Shin *et al.,* 2010).

Sodium hypochlorite (NaOCl), in a 3-6% concentration is an irrigant solution used widely in root canal treatment because of its bactericidal properties and the ability to dissolve organic tissues but NaOCl has not been shown to be effective in removing the smear layer. Decalcifying solutions such as phosphoric acid, citric acid and EDTA (Ethylene Diamine Tetraacetic Acid) have been reported as suitable for removing the smear layer (Takeda *et al.*, 1999).

EDTA can be either liquid or gel. The liquid solutions of EDTA and EDTA-C [EDTA associated with Cetavlon (cetyl trimethyl ammonium bromide)] are the most commonly used (Marques *et al.*, 2006). EDTA acts on the inorganic part of the smear layer and it is biocompatible with pH 7.3 (Pécora *et al.*, 1993).

The EndoVac system is introduced into the canal and removed by negative pressure at working length (Nielsen and Craig Baumgartner, 2007). One advantage of the EndoVac irrigation system seems to be the ability to safely deliver the irrigant to the working length. However, the possibility of blockage of its microcannula is considered to be its main disadvantage (Nielsen and Craig Baumgartner, 2007).

The EndoVac apical negative pressure irrigation system (Discus Dental, Smart Endodontics, USA) has 3 components: Master Delivery Tip (MDT) (Fig. 1.3a), the Macrocannula (MACRO) (Fig. 1.3b) and the Microcannula (MICRO) (Fig. 1.3c) (Desai and Himel, 2009).

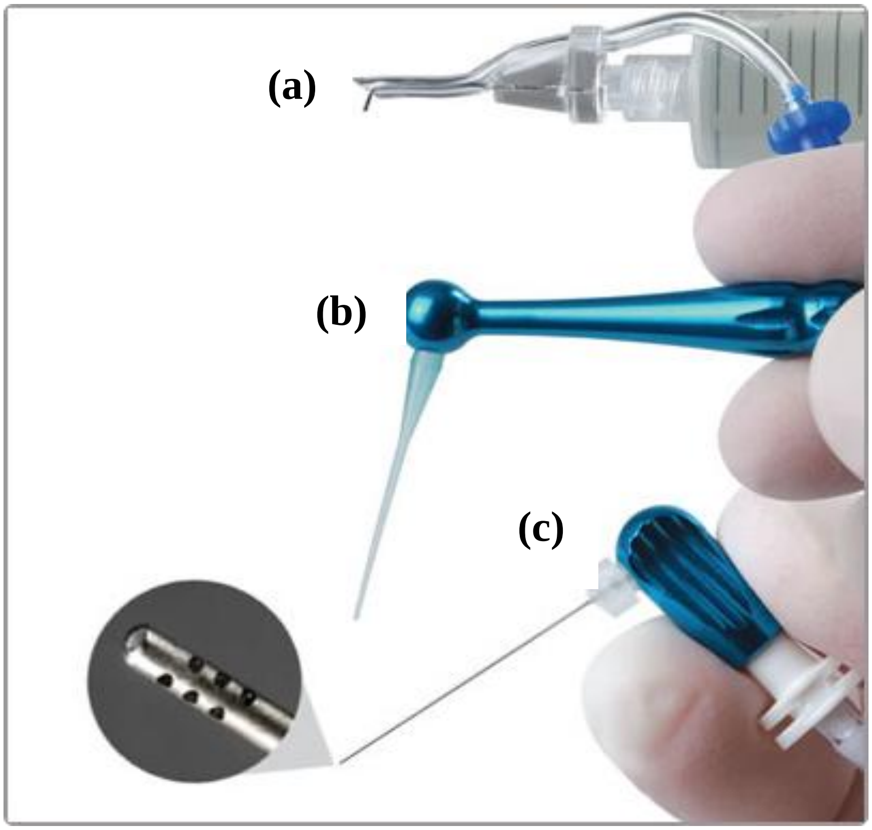


Figure 1.3: (a) EndoVac master delivery tip; **(b)** EndoVac macrocannula; **(c)** stainless steel microcannulae are shown inserted in their respective titanium components. The micro's tip (enlargement) terminates with array of twelve 100-mm holes (only 6 are visible) extending between an area 0.2–0.7mm from the spherical end of the cannula (*http://www.dentalproductshopper.com/endovac2*)

Few years ago, a size 30 gauge irrigation needle covered with a brush (NaviTip FX, Ultradent, USA) was introduced into the market (Fig. 1.4). Al-Hadlaq *et al*. (2006) showed that this irrigation needle can exhibit cleaner instrumented root canal walls in the coronal third than the NaviTip needle without brush. However, the cleaning ability at the apical and middle thirds was not significantly different. In the contrary, Goel and Tewari (2009) reported an adequate removal of all smear layer and debris at the apical third, when this irrigation technique is activated via a scrubbing motion.

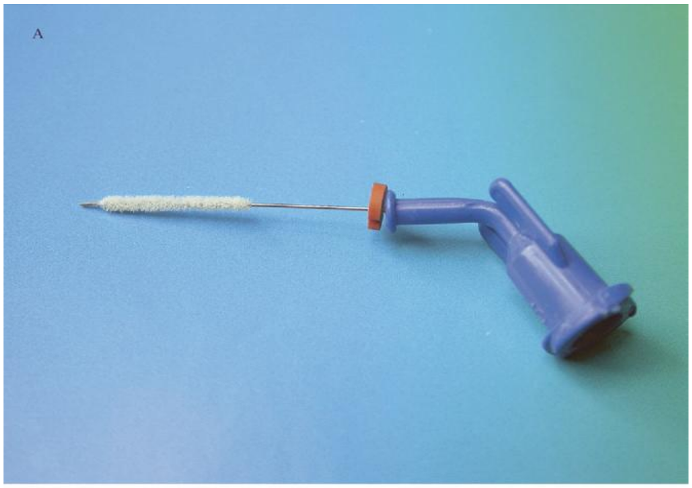


Figure 1.4: NaviTip FX irrigation system (Al-Hadlaq *et al.*, 2006)

1.2 Statement of the problem

A) There are many advantages for the nickel titanium rotary over the stainless steel hand instrumentation systems:

- It can provide an even and tapered radicular access in the root canal system.
- Fewer instruments are required.

Despite these advantages, many issues regarding the suitability of nickel titanium rotary system providing optimum cleaning and shaping to the root canal dentin walls.

B) Although irrigation using traditional needles is one of the most commonly used techniques during root canal treatment, it exhibits some disadvantages such as:

- Its rigidity.
- Being vented at the end which can increase the chance of passing the irrigants into the periapical tissues, causing undesired tissue reactions.

Although some modifications and improvements have been introduced, but many clinicians argues are present regarding the most suitable irrigation technique that can provide adequate cleaning to the root canal walls.

In an attempt to overcome these inherent disadvantages and to achieve favorable clinical outcomes, a number of nickel titanium rotary systems and irrigation techniques are recently introduced into market including TF and RaCe rotary systems, EndoVac and NaviTip FX irrigation systems.

1.3 Justification of the study

Since there is no publication focused on the cleaning ability of EndoVac and NaviTip FX irrigating systems using two rotary NiTi systems, this study will show the ability of EndoVac and NaviTip FX irrigating systems to provide clean root canal walls using TF and Race NiTi rotary file systems. In addition, the cleaning ability of TF and RaCe rotary NiTi files will be determined. It is hoped that the results of this study would help endodontists to perform cleaning and shaping with better treatment outcomes through choosing the most suitable irrigation system together with a suitable rotary NiTi system for optimum cleaning of the whole root canal cavity walls.

1.4 Objectives of The Study

1.4.1 General Objective

To compare cleaning efficacy of new irrigating systems with conventional irrigation needles using two different rotary NiTi systems.

1.4.2 Specific Objectives

- To determine and compare the cleaning ability of EndoVac, NaviTip FX and conventional 25G irrigation systems using TF rotary system.
- To determine and compare the cleaning ability of EndoVac, NaviTip FX and conventional 25G irrigation systems using RaCe rotary system.
- To determine and compare the cleaning ability of TF and RaCe rotary systems using EndoVac, NaviTip FX and conventional 25G needle irrigation systems.

1.5 Study Hypotheses

- EndoVac and NaviTip FX irrigation systems will show better cleaning ability than the conventional 25G needle system using TF rotary system.
- EndoVac and NaviTip FX irrigation systems will show better cleaning ability than the conventional 25G needle system using RaCe rotary system.
- TF and RaCe rotary systems will exhibit different cleaning ability of the dentin walls.

CHAPTER TWO

LITERATURE REVIEW

2.1 Root Canal Cleaning and Shaping

Successful root canal treatments mostly depend on the removal of microorganisms by using chemo-mechanical instrumentation of the root canal system, including the removal of infected dentin and organic tissues via dissolution and shaping. Thus, the cleaning ability of a root canal instrument is crucial to the outcome of a root canal treatment (Schäfer *et al.*, 2006). Successful canal shaping provides good access for disinfectants and creates an adequate form for the final seal during root canal obturation (Ahlquist *et al.*, 2001).

Endodontic procedures are performed to prevent apical periodontitis by removing canal contents, such as necrotic and vital organic tissues, dentinal chips/debris and other microorganisms (Youngson *et al.*, 1995; Abbott, 2002; Haapasalo, 2008).

The use of hand and rotary instruments for the cleaning and shaping of root canal systems is one of the key methods for removing root canal contents. Such method includes mechanically debriding the canal space, creating a reservoir to facilitate the delivery of disinfecting irrigation solutions and medicaments, and modifying the three-dimensional anatomy to accommodate effective obturation (Schilder, 1974; Peters, 2004; Haapasalo, 2008).

Many endodontic instruments have been designed for various procedures performed within the pulp chamber and root canal system. The instruments utilized for root canal preparation was classified into three groups by Himel *et al.* (2006). Group 1 includes manually operated instruments, such as K- and H-type instruments. Group 2 includes engine-driven instruments that possess latch-type attachments such as Gates Glidden (GG) burs. Group 3 includes engine-driven instruments that have similar designs as the manual instruments but with handles replaced with attachments for latch-type dental handpiece such as nickel-titanium (NiTi) rotary files.

2.1.1 Manual Instrumentation

Manual root canal instruments were first introduced in the early to mid-19th century and remained the primary instruments used for root canal preparation until the late 1980s. The K-type instruments, which were created by the Kerr Company in the early 1900s, are the oldest instruments used for cutting and machining dentin (Hülsmann *et al.*, 2005; Himel *et al.*, 2006).

A K-type instrument is fabricated by grinding tapered stainless steel wire into a tapered square or triangular cross-section. The ground wire is then twisted to create a file or reamer with the former having more flutes and less space between the flutes than the latter. These instruments penetrate and enlarge root canals via the compression-and-release destruction of the dentinal walls. K-type files have the ability to rotationally cut clockwise and counterclockwise upon insertion and withdrawal, respectively. On the other hand, the H-type instrument is ground from a tapered stainless steel blank. The Hedstrom file, which is a specific type of H-type file, is formed by grinding a single continuous flute. H-type instruments possess spiral edges with angles facing the handle of the instrument that only allow cutting during withdrawal. The positive rake angle of the flutes in H-type files is responsible for the enhanced cutting efficiency of H-type files compared with K-type files. Nevertheless, manual instruments remain crucial components for all root canal instrumentation procedures (Himel *et al.*, 2006).

Gates-Glidden drills (GG) were introduced in 1885 (Hülsmann *et al.*, 2005). It is a stainless-steel, engine-driven instruments that are attached to a low-speed dental handpiece via a latch-attachment. A GG drill has a long thin cylindrical shaft with parallel walls and a short cutting head. The cutting head has an elliptical shape that allows for the efficient removal of dentin in the coronal and middle aspects of the canal to facilitate straight-line access. GG drills are available in lengths of 15 and 19mm with tip diameters ranging from 0.4mm to 1.4mm. GG drills are easy to remove in the event of separation because a fracture-point is mechanically incorporated high in the shank region. Clinicians must take special care to avoid using GG drills laterally or beyond curvature because of the high risk of perforation, especially in furcation areas. Overall, GG burs are inexpensive, safe and clinically effective instruments (Himel *et al.*, 2006; Krell, 2009).

2.1.2 Rotary Instrumentation

Rotary instrumentation of root canals dates back to 1889 when Rollins created the first endodontic handpiece (Hülsmann *et al.*, 2005). Structural limitations of steel instruments contributed to the high incidence of procedural accidents, and thus, manual instrumentation prevailed as the primary mode of root canal preparation for almost a century. The introduction of NiTi endodontic instruments repopularized the rotary instrumentation of root canals in the early 1990s (Walia *et al.*, 1988). The NiTi alloy proved to be more flexible and resistant to torsional fracture than stainless steel, allowing greater instrument control in small, curved canals. These favorable characteristics led to the creation of countless file systems with various designs and shapes. Various instrumentation techniques have also been advocated and are largely dependent on the file system (Himel *et al.*, 2006; Krell, 2009). Manual instruments are basic necessities for all root canal preparations; however, NiTi rotary instruments and advanced preparation techniques can circumvent some of the major shortcomings of traditional instruments and devices (Hülsmann *et al.*, 2005).

Schilder (1974) emphasized the importance of the ideal cleaning and shaping of a “sterilized” root canal system for three-dimensional obturation. He advocated the following essential mechanical and biological guidelines to facilitate a successful root canal preparation:

- The root canal preparation should exhibit a continuous taper from the cement-enamel junction to the apex.
- The diameter of the root canal preparation should be wider at every point coronally and narrower at every point apically.
- The root canal preparation should flow with the original canal space.
- Transportation should be avoided to retain the position of the apical foramen.
- The apical opening of the canal should remain as small as possible.
- Instruments should always remain confined to the root canal system.
- Extra care should be taken in necrotic cases to avoid apically extruding the debris into the periapical tissues.

- Success of the root canal therapy hinges on its ability to remove organic debris from the canal system.
- Single canals should be cleaned and shaped in one appointment.
- Adequate space must be created to facilitate the delivery of intracanal medicaments.

2.1.3 RaCe File System

A reamer with alternating cutting edges (RaCe) file contains a safety tip and triangular cross-section. Moreover, a RaCe file possesses an alternating spiral and an 8 mm cutting shank, providing variable helical angles and pitches. The angle and pitch enhance the "antiscrewing-in" characteristic of a RaCe file (Zand *et al.*, 2007).

Advantages of a RaCe file

- A RaCe file contains twisted areas that alternate with straight areas similar with conventional files. The alternating areas provide a larger space for debris and reduce the tendency of threading.
- The square cross-sectional shapes in the small instruments form sharp cutting edges (15/0.02 and 20/0.02), whereas RaCe instruments contain convex triangles similar to ProTaper (Dentsply Maillefer, Switzerland) and FlexMaster (VDW, Germany).
- Active cutting regions are reduced on certain instruments (9mm to16mm).
- The two largest instruments (35/0.08 and 40/0.10) are available in NiTi and stainless steel, with the latter being more efficient.

- The NiTi surface is treated chemically, resulting in an obviously smoother surface compared with other instruments (Baumann, 2005).

2.1.4 Twisted File System

Twisted file (TF) instruments were introduced into the market through a new manufacturing process. This manufacturing process includes file blank twisting, R-phase heat treatments, and specific surface treatments and it was used to decrease the formation of machining defects during the grinding process. A TF is composed of triangular cross-sections, which are created by twisting nickel titanium during the R-phase handling. The twisting process optimizes the grain structure and eliminates the formation of micro-fractures, making the file more durable. The manufacturer (SybronEndo, USA) claims that this manufacturing technology increases cyclic-fatigue resistance (Oh *et al.*, 2010).

Angular deflection is not only influenced by the alloy properties or manufacturing processes, but also by rotary NiTi file designs. TF instruments exhibit the highest angular deflection values among other rotary NiTi files such as Profile, K3 and M2 which would improve significantly the prevention of intra-canal breakage (Gambarini *et al.*, 2009).

Kim *et al*. (2010) compared the fatigue resistance of traditional, ground NiTi rotary instruments with TF instruments and examined the fracture characteristics of fatigued fragments. They investigated the surface characteristics of size #25, 0.06 tapered, TF, RaCe, Helix and ProTaper F1 instruments by using a scanning electron microscope (SEM) before being subjected to a cyclic (rotational bending) fatigue test. The time until fracture was recorded to calculate the number of revolutions for each instrument. The data were compared for differences by using analysis of variance (ANOVA) and post hoc Scheffe´ test. The fragments were examined in lateral view at various magnifications by using the SEM. The TF exhibited a significantly higher resistance to cyclic fatigue compared with the other NiTi files that were manufactured through grinding ($P < 0.05$). In addition, the electropolished (TF and RaCe) and non-electropolished (Helix and ProTaper) instruments generated different crack propagation paths.

Oh *et al.* (2010) examined the effects of the manufacturing methods (ground, electropolished and twisted) and the cross-sectional areas (CSAs) of NiTi rotary instruments on cyclic fatigue resistance. They rotated 80 NiTi rotary instruments (ISO 25/.06 taper) from four brands (K3, ProFile, RaCe and TF) in a simulated root canal with a pecking motion until fracture, and the number of cycles to failure (NCF) was calculated. The 3mm CSA from the tip of the new instruments was calculated for each brand and the correlation between the CSA and the NCF was evaluated. All fractured surfaces were analyzed using SEM to determine the fracture mode, and the TF instruments were found to be the most resistant to fatigue failure. The resistance to cyclic failure increased with decreasing CSA. All fractured surfaces exhibited ductile and brittle properties.

Park *et al*. (2010) extensively investigated the cyclic fatigue of a number of NiTi rotary instruments including TF and RaCe systems. Five millimeters of the tip of each file was embedded in a composite resin block. Uniform torsional stresses were applied repetitively using an endodontic motor with an auto-stop mode until the files succumbed to torsional failure. The number of load applications that led to fracture was recorded, and all fracture surfaces were examined under SEM. The results should that the TF had the lowest torsional resistance. SEM examination revealed a typical torsional-fracture pattern characterized by circular abrasion marks and skewed dimples near the center of rotation for TF and RaCe rotary systems.

Yum *et al*. (2011) investigated the torsional strength, distortion angle and toughness of various NiTi rotary files including TF and RaCe rotary systems. The 25/.06 taper size of TF and RaCe files were tested with the same diameter at D5. A metal mounting block with a cubical hole was constructed, in which the 5mm of the file tip was rigidly held in place in the block by filling the mold with a composite resin. The files were subjected to clockwise rotation at 2 rpm in a torsion tester, and the torque and angular distortion were monitored until the file failed. The results showed that TF and RaCe exhibited significantly lower yield strength compared with the other systems. Moreover, TF exhibited a significantly lower ultimate strength compared with the other files. ProFile exhibited the highest distortion angle at break, followed by TF. Both TF and RaCe showed a lower toughness value compared with others.

2.2 Irrigation System

Irrigation facilitates clean root canal systems by flushing debris and they serve as bactericidal agents, tissue solvents and lubricants. Debris is defined as dentin chips and residual vital and necrotic pulp tissues that are loosely attached to the root canal wall, which is infected in most cases. The presence of debris on prepared root canal surfaces prevents the efficient removal of microorganisms, which is one of the major goals of thorough debridement of a root canal system. Furthermore, a smear layer that has a surface film thickness of 1µm to 2µm is formed and remains adherent to the root canal wall after instrumentation. This smear layer consists of dentin particles, pulp tissues, bacterial components and retained irrigants. Moreover, the smear layer occludes dentinal tubular openings (Al-Hadlaq *et al.*, 2006).

2.2.1 Irrigant Functions

The irrigant function includes:

- Lubrication of instruments.
- Flushing out of root canal debris.
- Chemical degradation of residual pulp tissues.
- Chemical degradation of smear layers on instrumented surfaces.
- Chemical degradation of microbial biofilms on instrumented and un-instrumented surfaces.
- Antibacterial action against root canal microbial flora (Gulabivala and Stock, 2004).

2.2.2 EndoVac System

The EndoVac is a negative pressure irrigation system invented by John Schoeffel (Schoeffel, 2007; Schoeffel, 2008; Schoeffel, 2009; Discus Dental, 2010). The EndoVac system generates a negative pressure that draws irrigation solutions apically through suction from the high-volume evacuation of the dental unit. The EndoVac system comprises a master delivery tip (MDT), macrocannula and microcannula. The MDT delivers copious amounts of irrigation solution to the access opening while simultaneously evacuating debris and excess solution. The macrocannula removes debris that remains in the canal from instrumentation and simultaneously delivers irrigation solutions from the MDT. The microcannula evacuates microscopic debris and irrigation solutions from the apical extent of the root canal down to the level of the working length through microscopic, laser-drilled holes (Schoeffel, 2007; Schoeffel, 2008; Schoeffel, 2009; Discus Dental, 2010). The inventor (John Schoeffel) suggests that the EndoVac system is capable of removing gases that accumulate at the apical extent of the root canal system during irrigation. The "vapor lock" effect and apical debridement and disinfection of the root canal system are theorized to be eliminated and enhanced, respectively (Schoeffel, 2008).

The EndoVac irrigation system claims to be safe and able to maximize the cleaning and disinfection of root canals, especially in the apical third. Although the EndoVac microcannula effectively aspirates irrigants in the most apical area of the canal, its effect on disinfection is not pronounced because of small-sized perforations, which might become even smaller because of debris clogging. Debris clogging reduces fluid flow in the apical canal. In addition, the concomitant and more potent coronal aspiration of the MDT competes with the microcannula for fluid evacuation. Nevertheless, the microcannula allows the irrigant to effectively reach the apical canal and suctions nearly 50% of the fluid delivered by the master delivery tip (Brito *et al.*, 2009).

Neilsen and Baumgartner (2007) investigated the apical debridement efficacy of the EndoVac system compared with the standard needle irrigation of a root canal at 1 and 3mm from the working length, respectively. One tooth of each matched pair was instrumented and irrigated using the EndoVac, which uses negative pressure to deliver irrigating solutions to the working length. The other tooth of the matched pair was instrumented and irrigated with a 30-gauge ProRinse irrigating needle. All teeth were irrigated with NaOCl and EDTA for a predetermined amount of time. The total volume of the irrigant used was recorded. After instrumentation and irrigation, the teeth were fixed, decalcified, and sectioned at 1 and 3mm from the working length. The results showed that the application of EndoVac resulted in better debridement than needle irrigation at the 1mm level; however, there was no significant difference between the groups at the 3mm level.

Hockett *et al.* (2008) compared the antimicrobial efficacy of the EndoVac system with that of the standard needle irrigation of pre-shaped root canals. Their *in vitro* study aimed to determine whether irrigation with apical negative pressure is more effective than traditional positive-pressure irrigation in eradicating *E. faecalis* from pre-shaped root canals. 54 extracted mandibular molars were instrumented to produce either a non-tapered or tapered preparation, sterilized, inoculated with *E. faecalis* for 30 days, and then randomly assigned into the following groups: Group 1, non-tapered preparation and negative-pressure irrigation; Group 2, non-tapered preparation and positive-pressure irrigation; Group 3, tapered preparation and positive-pressure irrigation; and Group 4, tapered preparation and negative-pressure irrigation. Mesial canals were sampled before and after final irrigation, and the samples were incubated aerobically for 48 h at 37 °C.

SEM analysis confirmed dense bacterial colonies in the positive control, and this result is consistent with that of the biofilm formation. A statistically significant difference between the apical negative-pressure irrigation and positive-pressure irrigation was observed ($p < 0.05$). No statistically significant difference in colony-forming units (CFUs) between sizes #35 and #45 and between tapered and non-tapered preparations was observed. The results of their *in vitro* study showed that apical negative-pressure irrigation has the potential to achieve better microbial control compared with traditional irrigation delivery systems.

Brito *et al.* (2009) compared the effectiveness of the EndoVac system, the EndoActivator, conventional syringe and needle irrigation techniques in eradicating *E. faecalis* within a root canal system. Root canals from extracted teeth were contaminated with *E. faecalis* for seven days, and then the samples were randomly distributed into three experimental groups: Group 1 includes conventional irrigation with NaviTip needles inserted up to 3mm short of the working length; Group 2 is similar to Group 1 but is supplemented with final irrigant activation by the EndoActivator system; and Group 3 includes irrigation with the EndoVac system. NaOCl and EDTA were the irrigants used in all experimental groups. The results showed that all groups demonstrated a highly significant reduction in the bacterial populations.

Townsend and Maki (2009) compared the efficacy of mechanical bacterial removal from plastic-simulated root canals irrigated with a number of irrigation systems including EndoVac and MiniEndo II (ultrasonic agitation). The control group with brain-heart infusion (BHI) broth (sterile) received only needle irrigation, and the remaining groups were incubated with BHI inoculated with *E. faecalis*. Sterile water was the irrigant used in all treatments. After irrigation, the remaining bacteria were stained with 0.1% crystal violet, which were extracted using a detergent and measured spectrophotometrically. The results of their study showed that ultrasonic agitation is significantly more effective than needle irrigation and EndoVac irrigation in removing bacteria.

Desai and Himel (2009) evaluated the safety of various intracanal irrigation systems by using relative amounts of apical extrusion from irrigation solutions. The objective of their project was to evaluate the safety of various intracanal irrigation systems by measuring the apical extrusion of irrigants. 22 single canals of extracted mature teeth were instrumented and secured through the lid of a scintillation vial to apically collect extruded irrigants. A precision syringe pump delivered controlled amounts of irrigants at a constant flow. The irrigation systems used include EndoVac micro and macro cannulae, EndoActivator, Max-IProbe needle, Ultrasonic Needle Irrigation and Rinsendo. The EndoVac micro and macro cannulae groups did not extrude irrigants. No statistically significant difference between the EndoVac micro and macro cannulae and the EndoActivator group was found. The EndoActivator extruded significantly less irrigant than the Manual, Ultrasonic and Reinsendo groups. No statistically significant differences among the Manual, Ultrasonic and Rinsendo groups were found. Their study showed that the EndoVac did not extrude irrigants after deep intracanal delivery and irrigant suctioning from the chamber to the full working length. EndoActivator had a minimal, although statistically insignificant amount of irrigants extruded out of the apex when delivering irrigants into the pulp chamber and initiating sonic energy after placing the tip into the canal. Manual, Ultrasonic and Rinsendo groups exhibited significantly greater amounts of extrusion compared with EndoVac and EndoActivator.

Brunson *et al.* (2010) determined the effects of apical preparation size and taper on the volume of irrigation solution delivered to the working length of root canals that were irrigated using the EndoVac system. 40 intact human single-rooted teeth were randomly distributed into two separate phases. The first phase determined the small apical size that allows more volume of irrigants at working length. All samples had the same taper and were sequentially instrumented to sizes of 30.06, 35.06, 40.06 and 45.06. The second phase determined the taper that allows more volume of irrigants at working length. The teeth were sequentially instrumented to sizes of 40.02, 40.04, 40.06 and 40.08. All samples were irrigated using the microcannula, and the volume of NaOCl suctioned at working length under negative pressure was measured during a period of 30 seconds by using a custom recovery device. An increase in size from ISO #35 to ISO #40 resulted in a percentage gain of approximately 44% in the mean irrigant volume, whereas an increase in size from ISO #40 to ISO #45 resulted in a percentage gain of approximately 4%. An increase in taper from 0.02 through 0.08 resulted in percentage gains of approximately 74%, 5.4%, and 2.4%.

Shin *et al.* (2010) investigated 69 single-rooted teeth that were divided into three groups according to the root canal irrigation system (24G and 30G needles and EndoVac). Each group was further divided into three subgroups according to the master apical file (MAF) size (#25, #40, and #60). 4um-thick serial sections were prepared at 1.5 and 3.5mm from the apical level, and photographs were taken for the analysis. Significant differences between the EndoVac system and conventional needle irrigation in removing debris were detected at both apical levels ($p < 0.05$). The MAF size was found to have a positive relationship with irrigation efficacy ($p < 0.05$).

Parente *et al.* (2010) compared between a ‘Closed’ and an ‘Open’ system design in smear layer and debris removal using either manual dynamic agitation and the EndoVac irrigation system. 40 teeth were divided into four groups and subjected to a standardized instrumentation protocol. Final irrigation was applied with either manual dynamic agitation or the EndoVac on groups of teeth with or without a sealed apical foramen. SEM was used for evaluating the smear and debris scores. The ability of manual dynamic agitation to remove smear layer and debris in a closed canal system was significantly less effective than in an open canal system and significantly less effective than the EndoVac ($p < 0.001$).

Siu and Baumgartner (2010) compared the debridement efficacy of EndoVac irrigation versus conventional needle irrigation *in vivo*. Seven adult patients with a total of 22 matched pairs of single-canal vital teeth with fully formed apices were recruited. Canals were instrumented to a master apical file size #40/.04 taper. One tooth from each matched pair was irrigated by using the EndoVac system. The other tooth was irrigated by conventional needle irrigation. Five additional teeth were used as positive controls. A #10 K-file was inserted into the control canals to determine working length (WL), with no other instrumentation or irrigation performed to confirm the presence of debris. The teeth were extracted, fixed and decalcified. Six histologic slides each 6mm thick were made from sections at 1 and 3mm from WL and stained. The slide with the most debris was photographed at each level for each tooth. The median amount of debris remaining at 1mm was 0.05% for the EndoVac group and 0.12% for the conventional irrigation