Comparison of Three Different Nickel-Titanium Endodontic Rotary Systems in Shaping Simulated S-Shaped Canals

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COMPARISON OF THREE DIFFERENT NICKEL-TITANIUM ENDODONTIC ROTARY SYSTEMS IN SHAPING SIMULATED S-SHAPED CANALS

by

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ABSTRACT

COMPARISON OF THREE DIFFERENT NICKEL-TITANIUM ENDODONTIC ROTARY SYSTEMS IN SHAPING SIMULATED S-SHAPED CANALS

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Introduction: Preparation error may result during mechanical instrumentation because of the complex anatomy of the root canal. Thus, flexibility and resistance to fracture are ideal properties that endodontic instruments should have. The aim of the study was to compare the shaping ability of three different nickel-titanium rotary instruments in simulated S-shape root canals by measuring transportation and canal volume change CVC.

Materials and Methods: A total of 60 S-shaped canals in resin blocks were randomly allocated into 3 groups (n=20): Vortex Blue (Dentsply-Tulsa Dental Specialties), HyFlex CM (Coltène/Whaledent) and EndoSequence (Brasseler USA). Canals were filled with dye and secured in a jig for instrumentation stabilization and imaging standardization. After patency was confirmed using a size 10 K-file, groups were instrumented using a crown down technique from size 40 to 20/.04 and then apically enlarged to size 30/.04 using constant sterile water as an irrigant. Pre- and post instrumentation images were taken and layered for evaluation. Transportation and the CVC at the cervical, middle, and apical levels were measured/computed. Data obtained were statistically analyzed using a one-way ANOVA test and Tukey post hoc test.

Results: Instrumentation with HyFlex CM resulted in significantly ($p<0.05$) less canal volume enlargement overall and at all levels compared to the other two files. No significant differences ($p>0.05$) were observed between the files for apical transportation.

Conclusion: HyFlex CM showed better shaping ability than Vortex Blue and Endosequence but similar apical transportation.
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INTRODUCTION

Cleaning and shaping of the root canal space is the primary objective of endodontic therapy. Its purpose is to prepare the canal space in order to improve disinfection with the use of irrigants as part of chemo mechanical preparation (1, 2). Infiltration and subsequent infection of the root canal system by microorganisms and their byproducts is the primary etiology of endodontic pathosis (3). Chemo-mechanical preparation aims to remove microorganisms, remaining pulp tissue, and dentin debris from the root canal system (2).

The main objective of shaping is to maintain or develop a continuously tapering funnel from the canal orifice to the apex; however the complex canal anatomy causes instrumentation challenges, which may prevent adequate disinfection of the root canal system, or cause procedural errors such as instrument separation, transportation, ledges, or perforations (2, 4, 5).

Nickel-Titanium alloy (NiTi) was introduced to endodontics by Walia et al in 1988 (6). NiTi is a very unique alloy compared other alloys used in endodontics because of its mechanical properties. These include its shape memory effect and superelasticity characteristics (7). The special mechanical property called superelasticity refers that NiTi alloy is able to undergo a non-diffusive transformation of the lattice structure into a martensitic phase when suitably stressed. The stress-induced martensitic is reversible, and consequently the material shows a remarkably large elastic range and is able to recover from a much higher strain than stainless steel can withstand without breaking (8).

Basically it provides more flexibility allowing the instrument to effectively follow the original root canal pathway (6, 7).

New file designs and alloys with better mechanical properties have been and continue to be introduced by manufacturers. These new and more flexible instruments work more efficiently and safely thus preventing unwanted changes when shaping curved canals (1). HyFlex Controlled Memory (CM) rotary instruments (Coltene-Whaledent, Allstetten, Switzerland) are one of these new improved endodontic instruments. The manufacturer claims CM NiTi files have increased flexibility that is superior in maintaining the overall root canal shape due to a thermomechanical processing that control the material’s memory (9).

It is claimed that due to their increased flexibility HyFlex CM instruments are best suited to prepare curved root canals and possess a superior centring ability compared with conventional NiTi instruments (10). Currently there is only limited information available regarding the shaping ability of HyFlex CM instruments.

On the other hand, EndoSequence and Vortex Blue are rotary file systems that are made with traditional nickel-titanium and M-Wire technology, respectively. M-Wire technology was created by Dentsply Tulsa Specialties, using a thermo cycling process, which gives the characteristics of being more flexible and resistant to cyclic fatigue. Previous studies have showed better fatigue resistance of M-Wire rotary files compared with the conventional NiTi file (11).

To investigate the shaping ability of endodontic files, studies often use simulated canals with standardized lengths, curvatures, and tapers in resin blocks. Two of the main advantages of these resin blocks are that the intracanal preparation can be visualized and they are simply reproducible something that cannot be achieved with natural teeth (5, 12).

The purpose of the study was to compare the shaping ability of three different nickel- titanium rotary instruments in simulated S-shape root canals by measuring transportation, and canal volume change (CVC) at the cervical, middle, and apical levels.

LITERATURE REVIEW

The main purpose of non-surgical root canal therapy is to re-establish or preserve the health of the periradicular tissue by means of chemo-mechanical preparation of the root canal system and seal of the canals with a biocompatible material (2).

In order for a problem to happen in the pulp, there has to be an inflammatory reaction which is normally in response to irritation (13). The pulp is subject to a number of sources of irritation of which the main one is microbial irritation especially through dental decay or microleakage (14). Among the bacterias, it is common to find streptococcus, lactobacillus, actinomyces, prevotella and neisseria types (15). Proof that bacteria has a primary role in the cause of inflammation leading to pulpal pathology and periapical breakdown was first demonstrated by Kakehashi et al. study done on rats in 1965 (3). Moller et al. in 1981 confirmed what Kakehashi et al. found, but this time in a study done on 78 monkeys where the pulps were removed. A portion were kept germ free, and the others were infected intentionally with bacteria and then the canals sealed. The main finding was that the non-infected canals produced no inflammatory reactions, whereas the infected ones did. There was no evidence of hard tissue damage on the non infected canals, in fact they found some dentinal bridge formation (16).

Even though the seal of the root canal system is a very important part of the root canal therapy, it has been shown by several studies that the fundamental phase of the endodontic treatment is cleaning and shaping. If this phase is done properly, it allows to the accomplishment of the goal of sealing the root canal system (17).

Although cleaning and shaping are performed at the same time they are separate and distinct concepts. The chemical part of the treatment consists on antibacterial irrigation and the mechanical part prepares the root canal system; they both are mainly aimed at the eradication of microorganisms so disinfection of the root canal system is achieved (2, 18).

Stewart in 1955 divided the endodontic treatment into three different steps; chemo-mechanical preparation, microbial control and obturation (19). In his study Stewart realized that as the root canal was enlarged a reduction of the quantity of microorganisms existing in the canal was achieved as well as the debris that protects their growth (19). Furthermore, Bystrom and Sundqvist in 1981 showed that mechanical preparation alone will not remove all the bacteria within the canal; it is a combination of both that is needed for an effective disinfection of the canal (20).

In 1974 Schilder introduced concepts that remain the foundation of successful endodontic therapy (2):

1. Canal preparation should follow anatomy of the root canal spaces.
2. The preparation of the root canal should be a "continuously tapering funnel" from the canal orifice to the apical terminus.
3. The diameter or the funnel shape should be narrower towards the apex and wider towards the pulp chamber.
4. The end of the canal must be in its original position and not moved.
5. The size of the apical foramen should be kept as minimal as feasible.

The literature shows that the search for the right instruments and technique to prepare the canal system has proven to be difficult. It dates back to 1746 when Fouchard described the use of piano wires as instruments for preparation and cauterization of pulps (21). In the late 18th century still only primitive instruments were available for root canal therapy with just a few being thin and flexible (22). Indeed, it is not until 1838 when Edward Maynard using watch springs was credited with the development of the first endodontic hand instrument (23).

The first commercially available endodontic instrument came to the market in 1875. But instrument design continued to change through time as proper cleaning and shaping was not achieved with these early designs resulting in a great percentage of root canal treatment failures (2, 24). It was not until 1915 that K-file instruments were developed by the Kerr company. K-files are still the most commonly used stainless steel hand files in endodontics (23). The need for new more effective and refined instruments was clearly shown by Hess in 1921. Complexity of the root anatomy and canal system was the main reason for this needed change in instrument design (25).

The first rotary instruments that could be used with a dental handpiece were very thin needles with rectangular cross-section. Introduced by Oltamare, these thin instruments were placed into the root canal to the apical foramen with no friction and then rotation was started (23). It was claimed that the remains of the pulp were removed instantly and recommended these thin needles to be used in curved canals to avoid the fracture of regular hand instruments (26).

In 1955 Green et al. showed with the use of microscopes that the commercially available instruments at the time did not have any standardization having as a consequence not consistent and unpredictable shaping of the root canal system (27, 28). A few years later in 1958 a technique for more consistency in the manufacture of root canal instruments was introduced by Ingle and soon after acknowledged by the Second International Conference on Endodontics and subsequently by the American Association of Endodontists in 1962 (20). In 1974, the new principles for making root canal instruments were introduced by Federation Dentaire Internationale and the International Standards Organization and shortly after in 1976, the American Dental Association continued this path for standardization of root canal instruments when the Council on Dental Materials and Devices recognized new standards for root canal instruments (29).

Several instrumentation techniques have been introduced due to many variations in the root canal anatomy such as fins, prolongations that make it impossible for the instrument to access. The main goal of these different instrumentation techniques is to improve debridement-eradicating microorganisms. To this date there is no general consensus in which instrumentation technique is better (30, 31).

The first hand instrumentation technique introduced was called the standardized technique and used similar working length for all the instruments. The last file used gave the final shape of the root canal (32). Allison in 1979 concluded that adequate shaping and obturation was complicated given the minimal taper (0.02 mm) of the hand instruments currently available (33).

The step-back instrumentation technique was a variation of the standard technique that accommodated for the lack of tapering when shaping the canal. The stepback technique consists of a stepwise reduction of the working length in 0.5mm to 1mm increments with gradually larger instruments resulting in larger tapered canal preparations (5). Walton demonstrated the effectiveness of the step-back technique in 1976. He compared the efficiency of filing, reaming and step-back technique and showed in histologic sections that step-back filing was considerably more effective than filing and reaming (33).

Later in 1985, in order to manage more difficult cases including canal curvatures and dilacerations with minimal procedural errors, Roane & Sabala introduced the balance force technique (34). In this technique instruments are introduced into the root canal with a clockwise motion of a maximum of 180 degrees and apical advancement (the "placement phase"), followed by a counterclockwise rotation of a maximum 120 degrees with adequate apical pressure (the "cutting phase"). The final removal phase is then achieved with a clockwise rotation and withdrawal of the file from the root canal. Among the advantages of the balance force technique are good apical control of the file tip as the instrument does not cut over the complete length, good centring of the instrument because of the non-cutting safety tip, and no need to precurve the instrument (35).

The stepdown technique was also introduced around the same time. This technique consists of the shaping of the coronal two thirds of the root canal and later the apical instrumentation is performed (36). A lesser possibility of instrument transportation close to the apical constriction is expected as there is a superior control of the instrument tip due minimal restrain of the instrument as it goes most of the length of the root canal (37).

Over the years several modifications of the step-down technique were developed including the popular crown-down pressure less technique by Marshall et al. in 1980 (37). Morgan and Montgomery's study in 1984 confirmed Marshall's findings that the crown-down pressure less technique was an effective method of instrumenting curved canals. They concluded that the crown-down technique was superior to the step-back technique in the preparation of canal curvatures ranging from 10 to 35 degrees (38). Also it has been reported that the crowndown technique produced less apically extruded debris than the stepback preparation (39).

Regardless of the instrument or technique used, unique complex anatomy of the tooth makes the mechanical preparation one of the most difficult tasks. In fact, the most difficult area to clean and maintain the natural canal shape is the apical area because of the inability of the instruments to contact and plane canal walls (2, 40, 41), especially in cases where canals are curved and thin where instrumentation can lead to procedural errors (42-44).

Transportation of the root canal is an undesirable error during instrumentation in which a different pathway is created from the original canal anatomy (45). It is one of the most common technical mistake that happens when doing the instrumentation specially on curved canals (45, 46). This procedural mistake has as consequence the over-enlargement of the root canal on the out portion of the curvature and under-preparation in the inner side of the curvature at the apical portion (23).

The desirable final size of apical preparation remains controversial. It has been shown that a small apical preparation limits canal transportation and apical zipping, but at the same time it has been proven that it decreases the efficacy of the cleaning procedure

(32). It appears that, with traditional hand files, apical transportation occurs in most curved canals enlarged beyond a size #25 stainless steel file (47). However, as it was mentioned before larger preparation sizes provide adequate irrigation and debris removal as well as significantly decreasing the number of microorganisms (48). Furthermore, there are several studies which explains that irrigants are unable to reach the apical portion of the root if the canal is not enlarged to a size #35 or #40 file (49-51). Thus there appears to be a relationship between increasing the size of the apical preparation and canal cleanliness (52-54). Instrumentation techniques that encourage minimal apical preparation may be ineffective at achieving the goal of cleaning and disinfecting the root canal space (52, 54).

There are other procedural errors that can take place during canal instrumentation. Ledges, perforations and instrument separation are within these common complications (55). A ledge is created when the file attempts to continue in a straight line rather than the curved path of the canal. It will be found on the outer side of the curvature as a platform, which may be difficult to bypass as it frequently is associated with blockage of the apical part of the root (23). Initial negotiation and bypassing the ledge can be achieved using a small file with a distinct curve at the tip, whereas a slight rotation motion of the file combined with a ″picking″ motion can often help advance the instrument (56). Its occurrence is usually related to the degree of instrument design and curvature (57, 58). However, Weine et al's study demonstrated that every file, whether precurved or not tended to straighten a curved canal (5).

The least desired complication in root canal therapy is a perforation (57). They occur when an iatrogenic opening into the root wall is done. Perforations will cause chronic inflammation resulting in the formation of granulation tissue with irreversible clinical attachment loss if not repaired with the proper materials (16, 59). It has been proved by Tsesis et al in 2010 that the patient's age, perforation location and size, and tooth type significantly influenced the occurrence of perforation associated periodontal damage (60). A consecutive clinical problem of perforations is that a part of the original root canal will remain underprepared if it is not possible to regain access to the original root canal apically of the perforation (23).

The impact of such procedural errors are a direct result of the instruments used during cleaning and shaping affecting the clinical outcomes (5). The rigidity of the stainless steel alloys used to fabricate the instruments provides this main limitation especially when working on curved canals. As the file navigates around the curvature, restoring forces attempt to return the instrument back to its original shape. Also, there is more rigidity of the instruments, as its the diameter gets larger (33).

In order to limit procedural errors clinicians and manufacturers adopted a multitude of methods to overcome the unfavorable mechanical properties of stainless steel alloys when negotiating curved canals. One of the major innovations has been the introduction of nickel-titanium (NiTi) offering new perspectives for root canal preparation with the potential to avoid some of the major drawbacks of traditional instruments and devices when either rotary or hand instrumentation is employed (61).

Despite extensive use in orthodontics, Nitinol was not used in the endodontic field until 1988 when Walia et al. proposed the use of Nitinol nickel-titanium orthodontic wire to fabricate endodontic files (6). Nickel-titanium when present in a one to one atomic ratio is a unique alloy because it possesses supereslasticity and shape memory effects (7).

In order to accomplish superior outcomes during root canal instrumentation Walia et al. studied NiTi's novel metallurgic properties. Walia et al. theorized that NiTi instruments would produce less technical errors when working on curved canals due to NiTi's low modulus of elasticity giving superior flexibility to the instruments resulting in less fractures (6, 62). Due to these favorable characteristics of NiTi alloy, it was found that NiTi files could be used in continuous rotatory motion in an engine driven handpieces in order to mechanically prepare curved root canals (63). Root canal preparation can be tedious and time consuming, the conjunction of NiTi files with rotary handpiece has dramatically reduced the time for root canal preparation maintaining the canal original shape (64, 65).

In 1992, the first generation of commonly available NiTi instruments were developed by McSpadden (63). These files possessed a 0.02 taper, but were found to fracture at too great a rate while they were used clinically. In 1994, Ben Johnson introduced the first greater taper instruments, the ProFile 0.04 and 0.06 tapered instrument series (63). These types of instruments are what is now thought of as a classical design for NiTi files because they feature U-shaped grooves in the files with flat areas next to each groove known as radial lands. The radial lands allow for the file to stay centered in the canal space, while the file shapes the canal through a passive planning action (66).

Some of the characteristics of the second generation of NiTi are active cutting edges on the file without radial lands, usually requiring fewer instruments in a series in order to complete the preparation goals.

Currently, the use of NiTi rotary instruments has become the standard of care in modern endodontics; it has been confirmed by previous studies that NiTi files have superior flexibility resulting in a more centered canal preparation with less aberrations when compared to stainless steel instruments (65).

An innovative process of heat-treating Ni-Ti has been created to optimize the mechanical properties of the alloy. By using this thermal processing of NiTi it is possible to adjust the transition temperature of the NiTi alloy itself which results in an increase instrument flexibility and higher resistance to cycling fatigue (67). In 2007, Dentsply Tulsa Dental introduced the M-Wire alloy. The M-wire alloy instruments undergo a particular tension and heat treatment at different temperatures which results in a file that is stronger and more flexible than a regular NiTi alloy instrument (67, 68). Vortex Blue (Dentsply, Tulsa, OK) is a very unique instrument made from M-Wire alloy that is further processed with proprietary thermomechanical steps such that it has a “blue color” oxide surface layer. The relatively hard titanium oxide surface layer on the Vortex Blue instrument may compensate for the loss of hardness compared with ProFile Vortex M-Wire, thereby improving the cutting efficiency and wear resistance (69).

Controlled memory (CM) HyFlex (Colte`ne Whaledent, Cuyahoga Falls, OH, USA) rotary instrument was introduced in 2010. HyFlex CM files are made using a distinctive thermal manufacturing procedure that helps control the material’s memory and allows one to prebend files of greater diameter and taper. Even though the manufacturers claims that CM NiTi instruments are more flexible and resistant to fracture due to cyclic fatigue than other instruments in the market there has not been comparative studies to affirm or negate that claim. The manufacturing process for these instruments remains a mystery as the manufacturer has not yet disclosed it.

There is another popular system that the manufacturer states has higher flexibility; however, it is not heat-treated. EndoSequence (Brasseler USA® Dental, Savannah, GA) rotary instrument is made from conventional NiTi and are ground from a triangular blank. Its design incorporates an alternate contact point along the instrument's cutting length. It has been claimed that because of the lack of radial lands there is less thickness of metal; thus there is less torque needed when utilizing the file reducing the amount of fractures and there is less transportation due to its high flexibility. (70). Some of the other good characteristics that the system offers are a noncutting and the electropolishing procedure which is supposed to remove many of the machining imperfections strengthening the file and avoiding crack propagation, along with a variable pitch and helical angles reducing the tendency of the file to screw into the canal (71-73). On the other hand, it has been also reported that the EndoSequence file has a considerably higher rate of instrument fracture when compared with the ProFile system (74).

Torsional forces or fatigue happens when there is frictional resistance, at the point of curvature the molecules on the outer surface of the file are under tension while the molecules on the inner surface of the instrument are compressed. Consequently as the surface area increases along the file the more friction the more possibility for instrument fracture (75). Torsional forces may produce an unraveling of the flutes prior to fracture and inspection of the instruments after each use is critical. Usually cyclic fatigue or fracture of the instrument occurs as the file rotates in a curved canal, because of the alternation of the areas of tension and compression (76, 77). Factors influencing this include the speed of file rotation, the curvature of the canal being prepared, and the load put on the file by the operator (78). The use of lubrication and limiting the file contact by using crown down technique has been noted to reduce the torsional stress.

Effectiveness of shaping the root canal should, ideally, be studied using human teeth. However, the extensive range of variations in three-dimensional root canal morphology (shape, size and curvature) makes standardization very difficult for investigation (12). Weine et al. in 1975 introduced the use of simulated root canals formed in a polyester clear casting resin (5). Simulated curved root canals are used commonly to investigate the shaping ability of endodontic files because they can be made of any predetermined size, shape or curvature (79). Studies propose that the analysis of pre and post instrumentation root canal outlines guarantees a high degree of reproducibility and standardization of the experimental design(12). It allows measurement of deviations at any point of the root canal using PC-based measurements or subtraction radiography. Also, visualization of canal shape before and after instrumentation allows information on major preparation characteristics (80). However, although simulated canals in plastic blocks allow comparisons between instrument types and sequences under identical conditions, there are certain disadvantages as their surface texture and hardness as well as cross-sections differ when they are compared to natural teeth (12). More in detail, the microhardness of dentin has been measured as 35-40kg/mm^2 near the pulp space, while the hardness of resin materials used for simulated root canals is estimated to range 20 to 22 kg/mm^2 depending on the material used (47, 81).

Many studies have been done using Indian Ink to test shaping ability and also the apical seal. The process of making India ink was known in China as early as the middle of the 3rd millennium BC, during Neolithic China (82). The carbon pigment used in India ink was later often traded from India, thus the term India ink was coined (83).

Basic India ink is composed of a diversity of fine soot known as lampblack, combined with water to form a liquid. A binding agent such as gelatin or, more commonly, shellac may be added to make the ink more durable once dried (83). In dentistry, Yoshikawa et al. found the Indian Ink particles to be smaller than bacteria and therefore suitable indicator of apical seal (84).

Improving the mechanical properties of rotary endodontic files can help manage problems encountered when instrumenting curved canals (85). The search of the combination of the right technique with the right instrument continues a challenge.

MATERIALS AND METHODS

The NiTi rotary instruments were selected to encompass three different manufacturing processes, yet similar cross sectional design: traditional NiTi (EndoSequence-Figure 1), CM wire (HyFlex CM-Figure-2) and processed M-Wire (Vortex Blue –Figure 3). Sixty simulated S-shaped root canals in clear resin blocks (Endo Training Bloc-S; Dentsply Maillefer, Ballaigues, Switzerland), each with 20 degree apical curvature (3.5 mm radius), 30 degree coronal curvature (5 mm radius), and 16 mm canal length, were randomly assigned to 3 experimental groups (n= 20/group): HyFlex CM, EndoSequence, and Vortex Blue groups.

Figure 1 – EndoSequence File

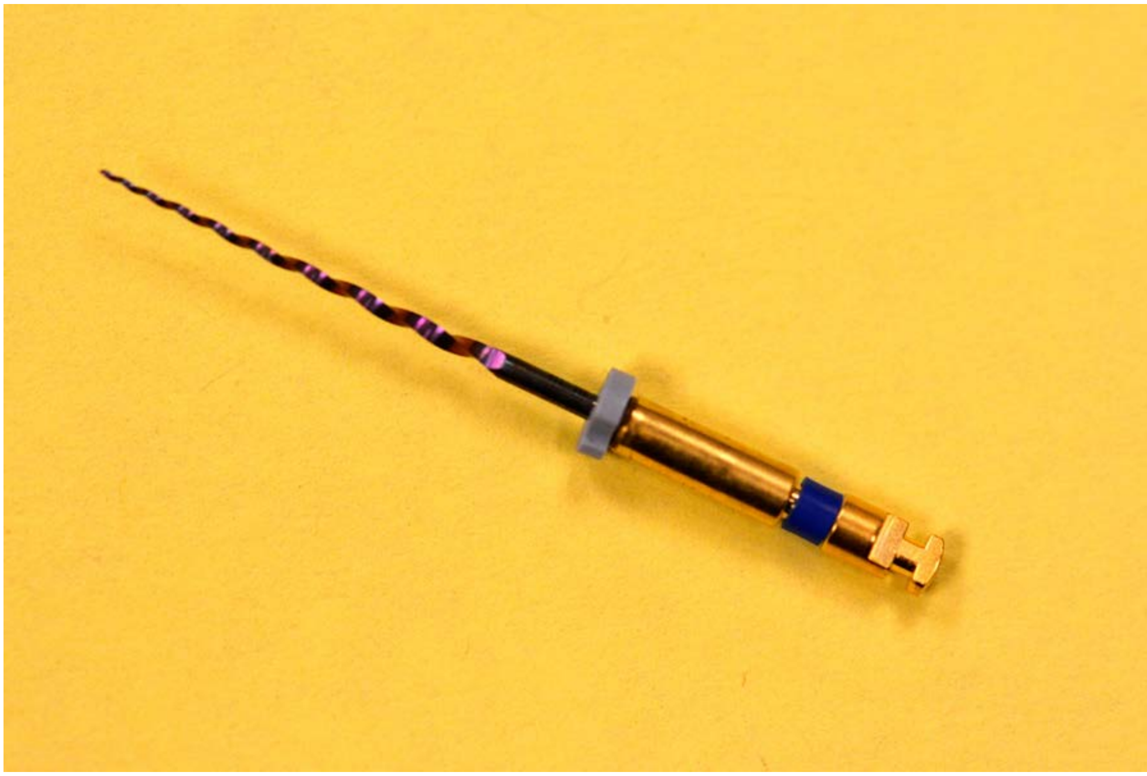

Figure 2 – HyFlex CM File

Figure 3- Vortex Blue

Simulated S-Shaped root canals were dyed with India ink using a 30-gauge insulin syringe (Figure-4). A no. 10 K-file (Dentsply Tulsa Dental Specialties) was introduced into the canal to assure penetration of the ink and prevent bubble formation. The canals were stored at room temperature for 48 h to allow for the ink to dry. A small scalpel mark was cut into the resin block near the canal top to allow for consistent orientation and placement. The canals were covered with adhesive tape and placed in a specially designed jig that allowed for resin block stabilization (Figure 5).

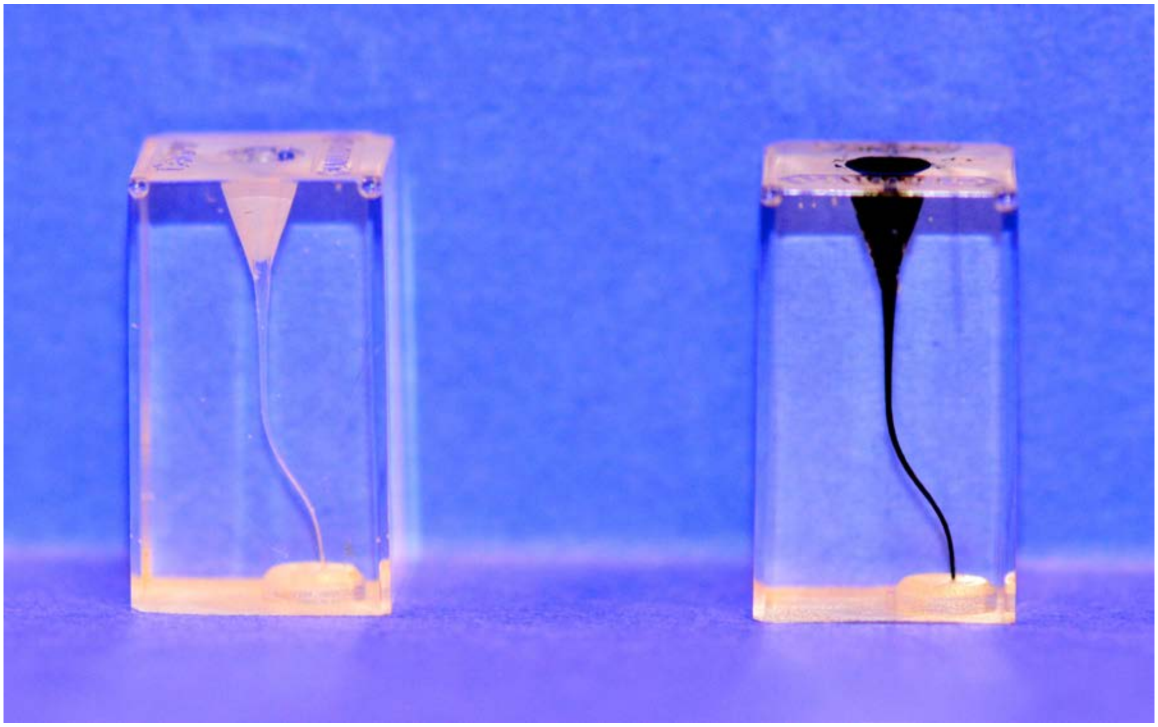

Figure 4 – S-shape resin blocks

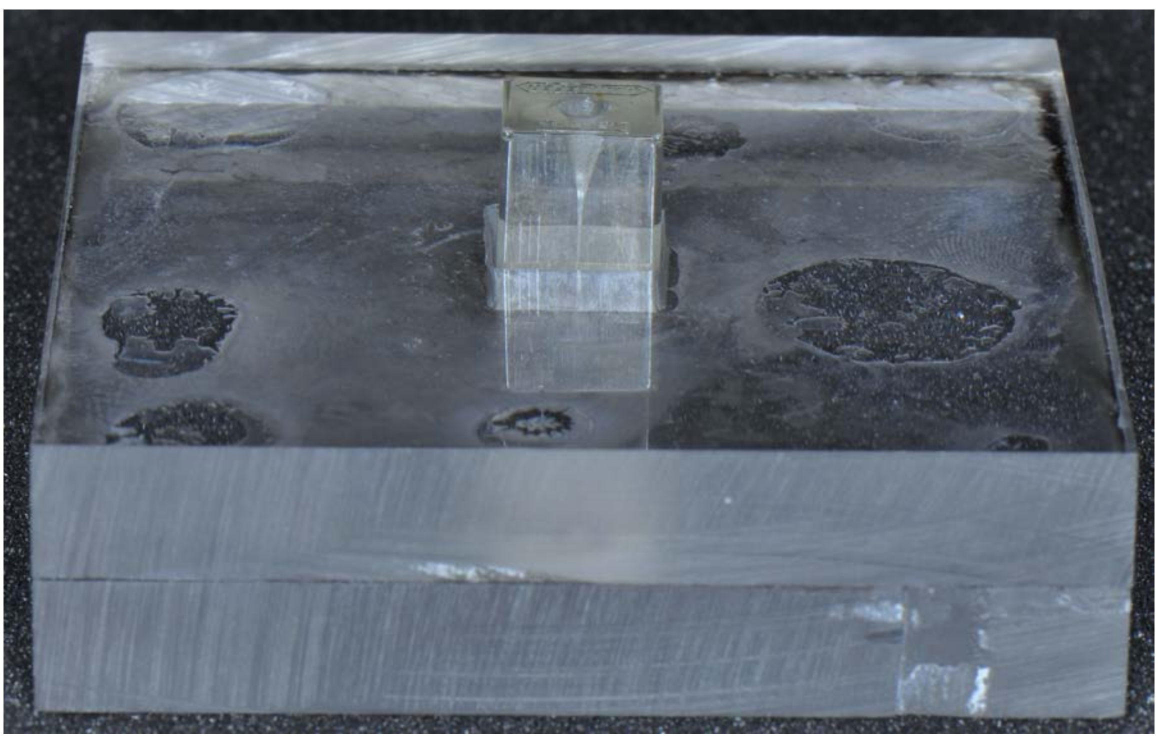

Figure 5- Stabilization Jig.

All rotary files were operated by a 1:16 reduction contra angle handpiece (Contra-angle ATR; Dentsply/Maillefer) powered by a torque-limited electric motor (ATR Technika Vision; Dentsply/ Maillefer). Patency was confirmed using a size 10 K-file (Dentsply Tulsa Dental Specialties). Each canal was shaped with new instruments lightly coated with Glyde File Prep (Dentsply Tulsa Dental Specialties). In each group, instrumentation was carried out with a crown-down technique starting with the 40/.04 instrument at 500 rpm and 2-Ncm torque as suggested by the manufacturers, followed by 35/.04, 30/.04, and 25/.04. As each instrument was changed, the canal was irrigated with 1 mL of sterile water using a 30-G side vented needle (Max-iprobe; Dentsply Rinn, Elgin, IL). In each group, the canals were instrumented to working length with 30/.04 with the same corresponding file system. The three file systems were used in a similar manner to standardize preparations for comparison during this study.

Before and after canal shaping, pre and post-instrumentation images were acquired by scanning the S-Shaped simulated canals with an Epson Expression 1680 flatbed scanner at 2400 dpi, 24bit color. The pre-instrumentation image (Image A) was dyed with the black ink. Dye was not used for the post-instrumentation image (Image B). The canals were scanned with a solid green background to provide a contrasting color compared with the original canal and instrumented canal.

Scanned images were positioned within a template in Photoshop CS6 911 pixels wide and 1563 pixel high. Image A was positioned so that the canal base was positioned at pixel row 111. The canal base started at row 1 and canal opening at row 1563. The image was saved as Image A. Image B was added as a layer and made partially transparent to facilitate positioning of the canal base so that Image B corresponded with the canal base of Image A. The canal base and the scalpel mark were used to align Image A and Image B. Upon alignment, Image A was hidden, transparency of Image B was eliminated, and Image B was saved as a JPG (Figure- 6).

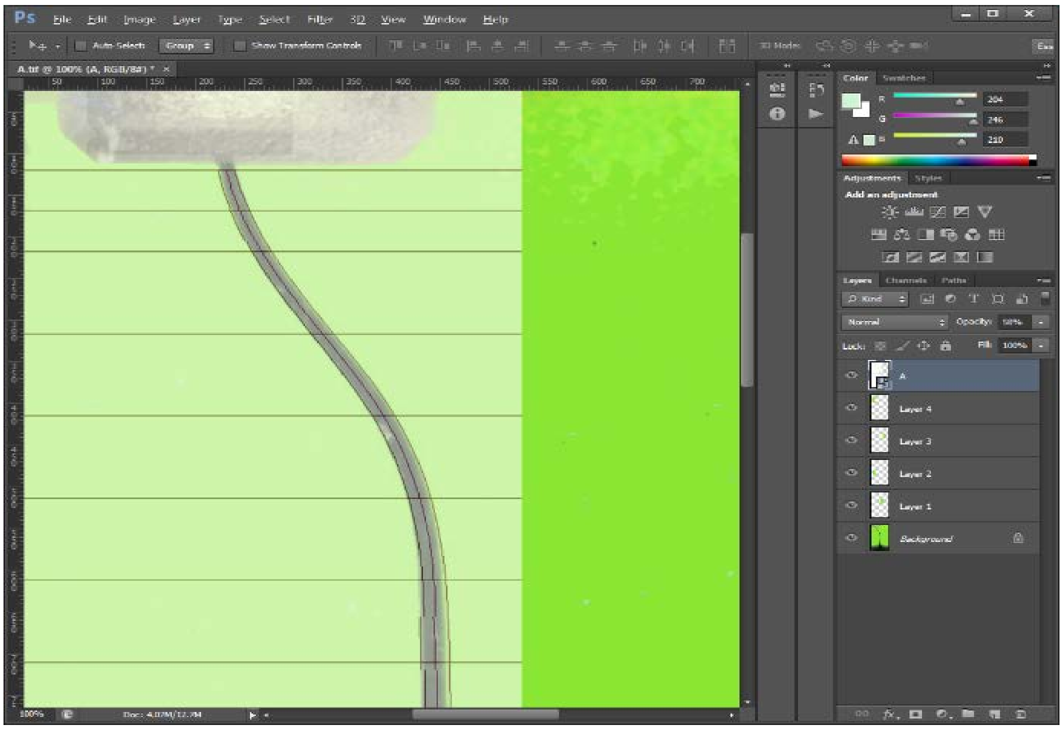

Figure 6. Template in Photoshop

Image processing occurred through a locally developed application using Delphi XE2 Version 16. The image processing extracted and reported the left and right edge of the canal from the 2 dimensional image for 9 benchmark locations: at the base of the canal, 0.5 mm above the base, and at 1 mm increments above the base of the canal (1 mm to 8 mm). The image processing performed the following algorithm and recorded values. Image processing iterated through an area of interest from the top of the image to the bottom of the image, between columns 100 and 525. Evaluation combinations were used to identify the canal in Image A and the instrumented canal in Image B. A pixel was considered "identified" if the R, G, and B values met one of the conditions.

Table 1. Evaluation conditions for image A and

Evaluation Conditions for Image A			
Condition 1	R value < 100	G value < 190	B value < 55
Condition 2	R value > 150	G value < 50	B value < 50
Condition 3	R value > 100	G value < 185	B value > 50
Evaluation Conditions for Image B			
Condition 1	R value < 120	G value < 170	B value < 50
Condition 2	R value > 100	G value < 170	B value < 30
Condition 3	R value > 90	G value < 200	B value > 50

For each row, the furthest left identified pixel column and furthest right identified pixel column were recorded in an array. Upon identification of all rows, the left and right edges were smoothed by averaging the left and right edges, respectively, between 3 rows above and 3 rows below. The smoothed left and right edges as well as the identified pixels were written to a JPG file. Then the left and right pixel columns were written to a file for the 9 benchmark locations. The area within the canal was computed as the sum of pixels between the smoothed left and right edges. Four area totals were computed, total – all pixels between 0 and 9 mm benchmark, and totals for each third of the benchmarks (0-2, 3-5, and 6-8 mm).

The Canal/Edges image was opened after image processing in Photoshop as a layer with the respective image (Figure 7). The layer was made transparent as a visual verification that left and right edges corresponded with the edges from the image.

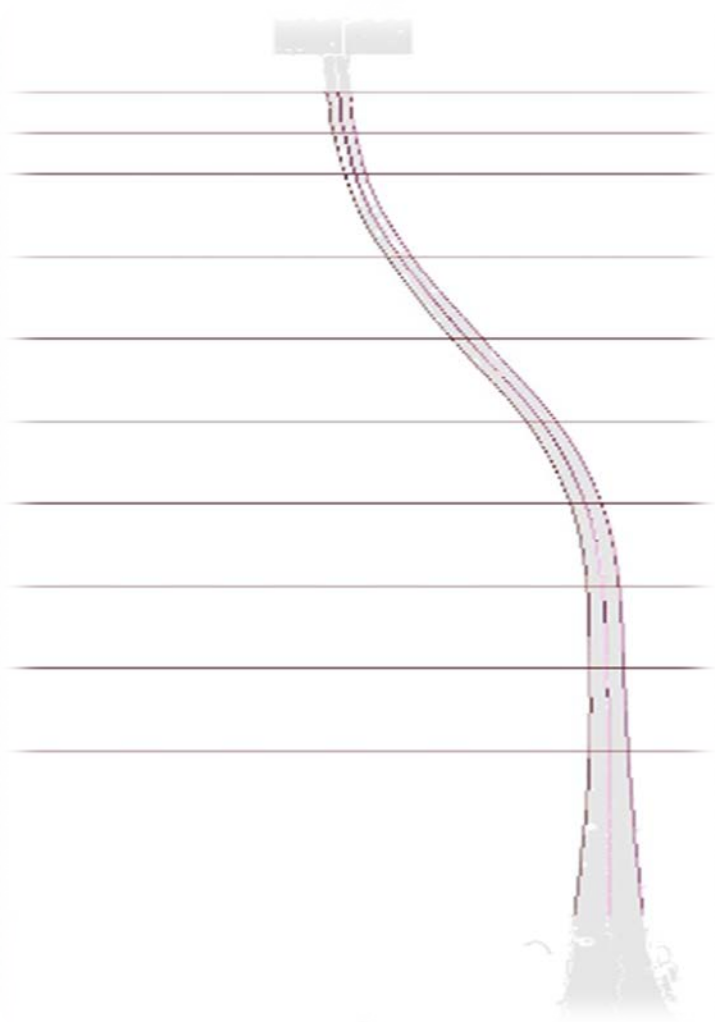

Figure 7 . Canal/Edges

Data was collected electronically and transferred to Excel (Microsoft Corporation, Redmond, WA) for further analysis. Apical transportation was defined as the distance from the pre- to the post-instrumented canal wall 0.5mm from the apex and measured on both the left and right proximal sides of the simulated canal. Transportation and the CVC were measured/computed at the cervical, middle, and apical levels.

Data obtained were statistically analyzed using a one-way ANOVA test and Tukey post hoc test for multiple comparisons to look at a significant difference in mean between the 3 shaping procedures. The software Statistical Package for the Social Sciences (SPSS) was used and the level of significance was set at P=0.05.

RESULTS

The mean percentage of area increase was 245%, 288%, and 286%, in the HyFlex CM, EndoSequence, and Vortex Blue group, respectively (Table 2). Figure 8 graphically displays that the use of HyFlex CM instruments resulted in significantly ($p<0.05$) less canal volume enlargement overall and at all levels compared to Vortex Blue and EndoSequence.

The results for apical transportation are summarized in Table 3. Results were similar and no significant differences ($p>0.05$) were obtained between the three experimental groups. Figure 9 graphically displays these results.

Table 5 shows that statistical analysis detected no significant differences in transportation in the apical portion between the three types of instruments ($P>0.05$). However, HyFlex CM had significantly less transportation in the coronal and middle thirds of the canals ($P=0.02$).

No Endosequence or Vortex Blue files fractured during the study. However four HyFlex CM .04/30 instruments fractured during instrumentation.

File	Canal Area Increase due to Instrumentation (%)			
	0-2 mm	3-5 mm	6-8 mm	Total
EndoSequence	306.6 ± 36.2	279.0 ± 18.3	290.4 ± 17.3	288.6 ± 18.0 [c]
Vortex Blue	313.5 ± 55.6	276.6 ± 28.1	283.4 ± 23.4	286.247 ± 29.4 [b]
HyFlex CM	260.6 ± 67.1	241.7 ± 39.3	241.3 ± 34.2	245.1 ± 40.9 [a]

Table 2. Canal Area Change

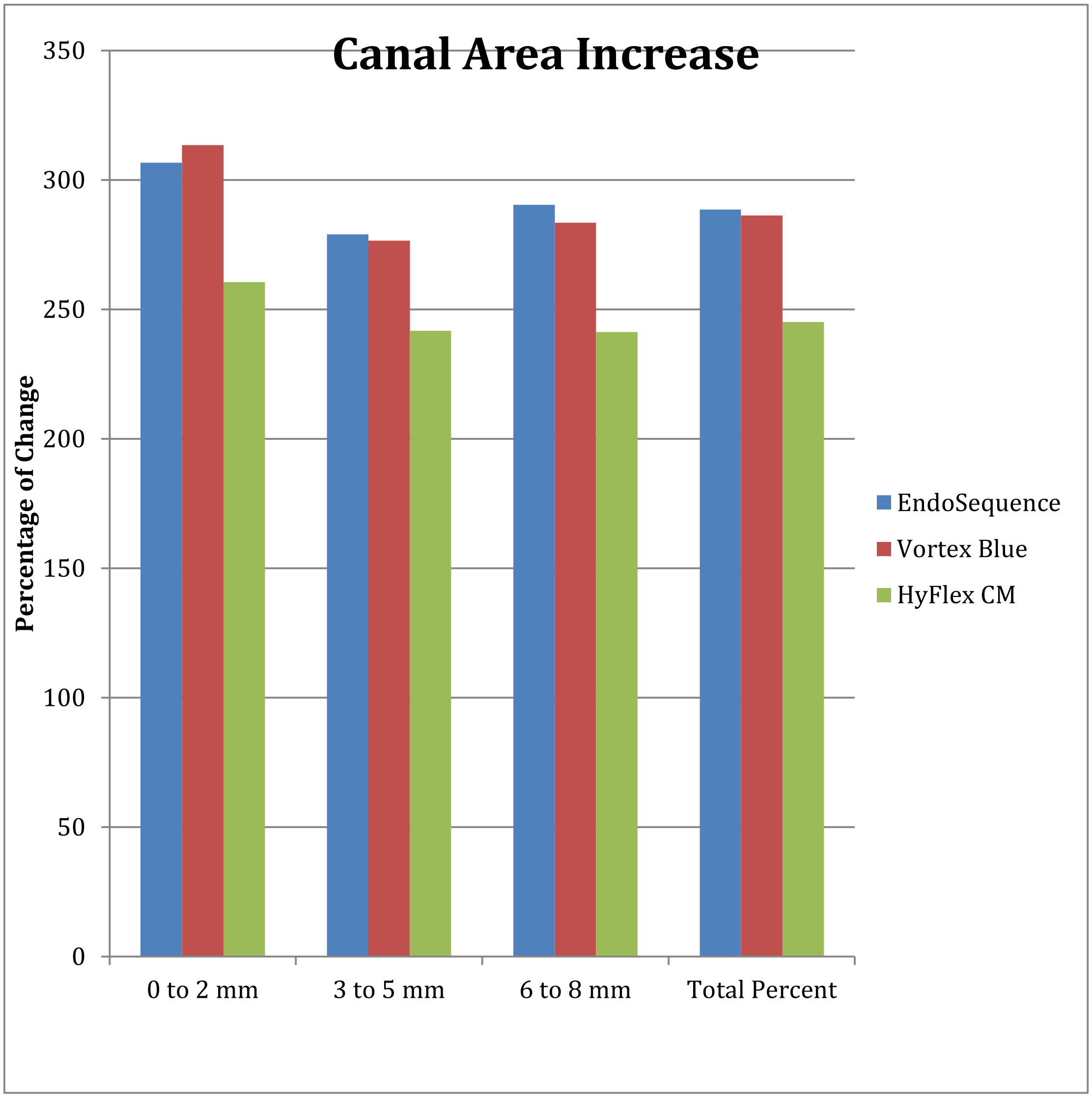

Figure 8- Change in Canal

File	N	Apical Transportation (mm)
EndoSequence	20	.036 ±.056 [a]
Vortex Blue	20	.057 ±.069 [a]
HyFlex CM	20	.018 ±.120 [a]

Table 3. Apical Transportation *

- Values of means of apical transportation ± standard deviation.

There are no significant ($p>0.05$) differences between the groups with the same letters.

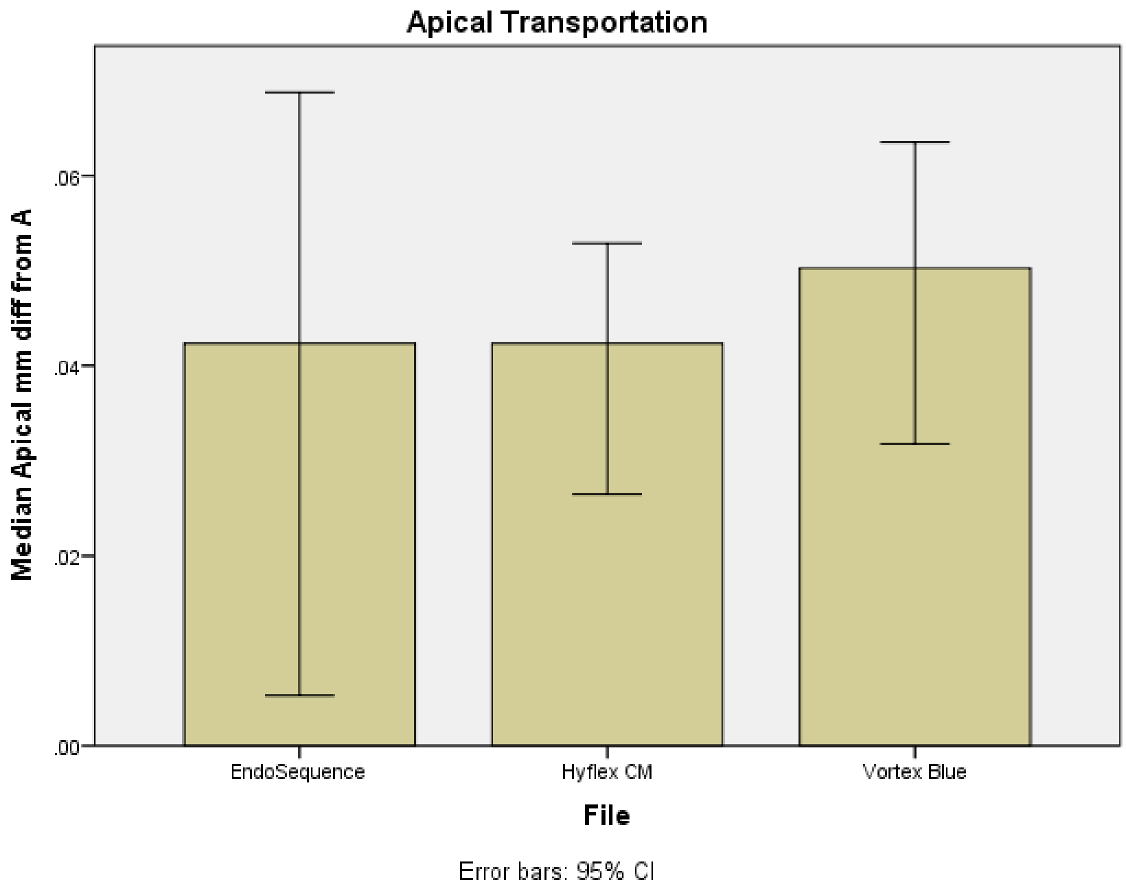

Figure 9- Apical Transportation

File	Transportation (mm)								
	0 mm	1 mm	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm
Endo-Sequence	.636±.575 [a]	.518±.065 [b]	.651±.057 [b]	.596±.042 [b]	.620±.31 [b]	.720 ± .044 [b]	.747 ± .042 [b]	.742 ± .037 [b]	.764 ± .025 [c]
Vortex Blue	.505±.121 [a]	.511±.067 [b]	.637±.095 [b]	.615±.064 [b]	.618 ± 0.42 [b]	.692 ± 0.56 [b]	.719 ± 0.57 [b]	.720 ± .042 [b]	.725 ± .028 [b]
HyFlex CM	.416±.119 [a]	.454±.084 [a]	.542±.103 [a]	.554 ± 0.45 [a]	.584 ± .027 [a]	.596 ± .088 [a]	.635 ± .521 [a]	.650 ± .030 [a]	.683 ± .039 [a]

Table 4. Transportation at Various Distances along the Canal

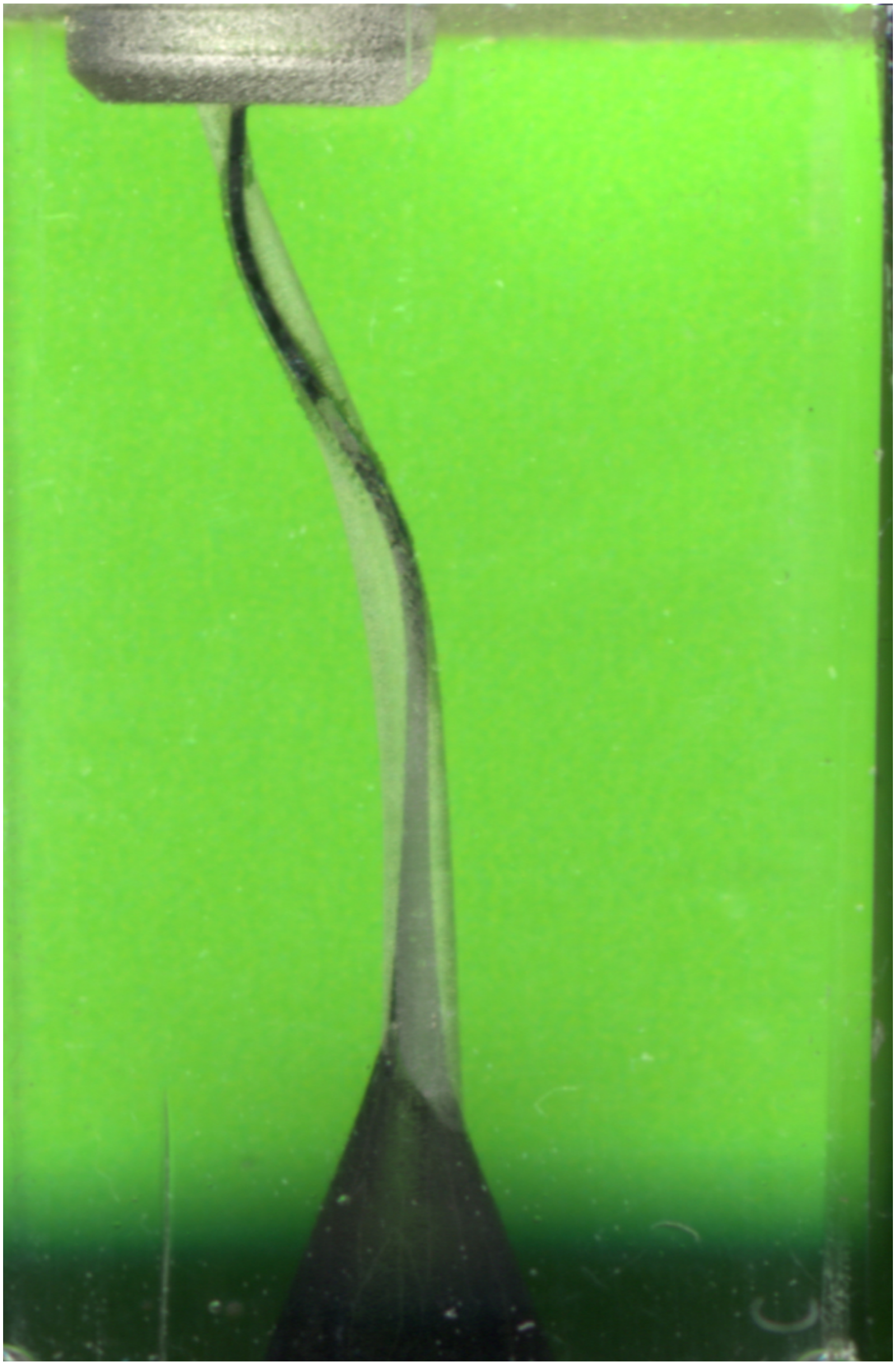

Figure 10- Pre and Post instrumentation image Superimposed (Vortex Blue)

Figure 11- Pre and Post instrumentation images superimposed (EndoSequence)

Figure 12- Pre and Post instrumentation images superimposed (HyFlex CM)

DISCUSSION

Understanding materials properties and its influence on instrument performance is critical for the clinician. During the past decade many different rotary systems have been introduced to endodontics, each with their distinctive characteristics but all with the same purpose of avoiding procedural errors.

Numerous approaches to modify the way the instruments are manufactured which results in variation in the physical properties have been done by manufacturers. Recently thermomechanical treatment processes has been attempted to improve flexibility and fatigue resistance. Studies evaluating the influence of this property on the shaping ability of files manufactured by this procedure are limited, with variation in assessment criteria. In this study 3 systems were chosen that are different in their NiTi processing. No studies have compared EndoSequence, Vortex Blue and HyFlex CM rotary file systems in terms of transportation and canal volume change at three canal levels. Thus this study was a comparison between the 3 file systems using simulated canals in resin blocks; it does not reflect the action of the instruments in natural root canals because of the differences in the surface texture and hardness as well as cross-section (45). However, investigators promoted those studies comparing the effects of root canal instrumentation on canal anatomy should also consider details of preoperative geometry that is why similarity was an essential factor for the design of the study (86-88). Clear resin blocks allow a direct comparison under identical conditions of the shapes acquired with different instruments (45, 64).

Numerous techniques can be used to evaluate the shaping ability of NiTi instruments, which includes serial sectioning technique, micro-computed tomography, and radiographic or image technique. Each of these methods has distinct advantages and disadvantages. For example, serial sectioning is a complicated, invasive and a physical sectioning of the teeth before preparation can result in loss of material and can cause tissue damage; plus it is restricted to predetermined levels (89, 90). A noninvasive method for the analysis of canal geometry and efficiency of shaping, can be achieved by the use of the computed tomography imaging technique; however it is not cost effective (91). The radiographic method is noninvasive but only is used to record two-dimensional changes(89). However, Katz and Tomase demonstrated that apical transportation shows the greatest changes in the mesiodistal dimension (92). Consequently, the radiographic (image) method was used in this study.

The ink adhered to the root canals and irrigation without instrumentation could not remove it. Comparisons between the three experimental groups indicated that all the instruments were able to remove most of the ink. In all three experimental groups, cleaning capacity was apparently better in the coronal and middle thirds of the canal than in the apical third. This correlates with the study done by Peters et al in 2001 where they compared four preparation techniques on canal volume and surface area finding that all instrumentation techniques left 35% or more of the canal surface area unchanged (93).

The most important aspect in evaluating the shaping ability of the instruments are preservation of the original path and a central position of the file (1). In the present study, the use of HyFlex CM resulted in significantly less canal curvature changes compared with Vortex Blue and EndoSequence. No significant differences were noted between Vortex Blue and EndoSequence. Even if some articles report an increased flexibility of º Vortex Blue vs. traditional NiTi, data from the present study does not support those findings. The only significant difference between the 2 files was at the 8 mm level where Vortex Blue demonstrated less transportation than EndoSequence.

HyFlex CM files have been said to have higher resistance to cyclic fatigue and flexibility than conventional superelastic NiTi files (94). Vortex Blue and HyFlex CM files may have the mutual advantage of greater torsional strength and high deformation (95). During the experimental phase of this study, there were four file separations using this system, which were not included in the data because the purpose of the study was to measure the shaping ability not cyclic fatigue. Also, it is important to mention that in this study almost all of the HyFlex CM instruments were plastically deformed following canal preparation. This is in agreement with the study done by Peter et al in 2012 in as far as about 82 % of HyFlex CM instruments were permanently deformed following preparation of simulated curved canals in resins blocks (96). This may be one of the reasons why some authors recommend single use for smaller HyFlex CM instrument (95). On the other hand, the manufacturer of HyFlex CM files states that permanently deformed instruments will regain their original shape when sterilized at approximately 134 ºC.

The advantage of HyFlex CM from Vortex Blue and Endosequence files showed by this study includes creating less aberration without significant shaping errors, which can be attributed to the increased flexibility of these instruments(94). This result is comparable with a study done by Zhao et al in 2013 where HyFlex CM instruments showed good shaping ability in curved canals (97). The reason could be the processing;

Hayashi et al stated that additional heat treatment of NiTi instruments is very effective in increasing the flexibility of NiTi rotary (98). Previous studies support the increased flexibility of these types of instruments (9, 99, 100).

The apical transportation for all of the tested instruments had comparable scores with no statistical differences. Some of the potential factors that could contribute to these results were standardized by matching the size and taper of the final apical file. In this study the final apical size was set to size 30. It has been shown that debridement is optimized by larger apical preparations, usually to size 35 (54). On the other hand, studies have showed that when the apical size is maintained to 30 there is less evidence of aberrations in the apical area. Also, the use of a small taper may help to optimize shaping results in curved canals (1, 54).

Considering the two dimensional assessment method employed and the variations in material properties between dentin and resin, complete extrapolation of the results to the clinical practice may not be wise and confirmation of these results using three dimensional technologies in a clinical setup is necessary.

SUMMARY AND CONCLUSIONS

Within the limitation of this in vitro study, it can be concluded:

1. In overall shaping abilities, the HyFlex CM file system performed better than the Vortex Blue file system and the EndoSequence file system in a majority of the defined areas measured.
2. The flexibility of thermomechanically treated files is beneficial in preparing canals with multiple curvatures.

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