Investigating Torsional Force and Angle of Rotation to Fracture of XP-3D Shaper NiTi Rotary Files

BY

DORIS BASALI

B.S. Georgetown University, 2012
D.D.S. New York University, 2016

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Master of Science in Oral Sciences
in the Graduate College of the
University of Illinois at Chicago, 2019

Chicago, Illinois

Thesis Committee

Satish Alapati, BDS, MS, PhD, Chair, Advisor
James Bahcall, DDS, MS
Bradford Johnson, DDS, MHPE

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
A_f	Austenite Finish Temperature
A_s	Austenite Start Temperature
CBCT	Cone Beam Computed Tomography
M_f	Martensite Finish Temperature
MR	Martensite Reorientation
M_s	Martensite Start Temperature
NaOCl	Sodium Hypochlorite
NiTi	Nickel-Titanium
SD	Standard Deviation
SE	Superelasticity
SIM	Stress-Induced Martensite
SS	Stainless Steel
TFF	Torsional Force to Fracture

SUMMARY

Heat treatment of nickel-titanium rotary file instruments has been demonstrated to be more efficient for conventional root canal therapy. This *in vitro* study compared the torsional force to fracture (TFF) and angle of rotation to fracture (ARF) of XP-3D Shaper conforming Nickel Titanium (NiTi) rotary files in as-received condition and after 1 and 3 simulated clinical uses. Simulated root canals (30-degree curvature) in clear resin blocks were used. 25 mm length XP-3D Shaper files were tested (n=10 per test group). TFF and ARF were recorded with torsiometer (Sabri Dental Enterprises). As per ISO-3630-1, TFF was obtained by measuring peak torque in gram-centimeters (g-cm), and ARF in degrees of rotation until instrument separation. The data was analyzed using ANOVA and Tukey's Post-Hoc tests ($p<0.05$). SEM analysis of the separated portion was also performed. The XP-3D Shaper demonstrated no significant difference ($p>0.05$) in TFF between as-received and 1 use, as-received and 3 uses, and 1 use and 3 uses. There was a significant ($p<0.002$) decrease in ARF between the XP-3D Shaper as received and 1 use, as-received and 3 uses, and between 1 use and 3 uses. There is no significant difference ($p>0.05$) in TFF between the XP-3D Shaper files as-received, after 1 use, and after 3 uses. There is a significant difference ($p<0.002$) in ARF between the XP-3D Shaper files as-received, after 1 use, and after 3 uses. The possible explanation for these results could be due to the non-linear file design in combination with the heat treatment of the nickel-titanium.

I INTRODUCTION

1.1 Background

The three major components of endodontic treatment are accessing the canals, cleaning and shaping, and obturation of canals. Much research has been performed in order to enhance all three aspects of practice in order to maximize the ultimate success of root canal treatment. For example, investigators have been studying the mechanical preparation aspect of cleaning and shaping by developing and studying many different file systems. Mechanical preparation via manual and rotary instrumentation is intended to remove tissue, infected tooth structure, debris, and bacterial contents of the root canal. These cleaned and disinfected canals are subsequently prepared for obturation.

Stainless steel hand instruments were the first file types initially introduced to endodontics in order to complete the mechanical preparation phase of root canal therapy. As the stainless steel material is particularly rigid, they can potentially create certain complications during instrumentation. For example, according to authors including Weine et al, using large sizes of stainless steel files can cause potential iatrogenic complications such as ledges, transportation, and zipping of the canals. This could compromise the mechanical debridement of the canals and possibly the success of the cases by preventing thorough cleaning and shaping of critical apical portions of the canals. In addition, such errors affecting the apical anatomy of the root canals could lead to complications in later portions of treatment, such as adequate obturation of canals.

In 1988, Walia et al. developed a novel file material for cleaning and shaping the canals with less potential for adverse events. Interestingly, he developed this idea after studying the material as used for orthodontic tooth movement. In the initial development of the material, "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." The material was made of 508 Nitinol and current versions are approximately 54% nickel and 46% titanium (Zhou). They also possess unique characteristics that could be potentially beneficial for endodontic instrumentation such as superelasticity (SE), which is the ability of NiTi to be reversibly deformed and return to its original characteristics. In the case of NiTi specifically, it has been found that the material could be reversibly deformed up to 8% while still ultimately maintaining its original properties (Thompson).

Thus, a major advantage to using NiTi files in endodontic instrumentation is the flexibility of the files which is due to a combination of its inherent low elastic modulus and superelasticity (Zhou). Other advantages are that NiTi files are more efficient, stay centered within the canal, may minimize debris extrusion, may minimize apical transportation, and may reduce ledging and zipping.

One unfortunate result of increased stresses placed on the files is possible instrument separation. According to a retrospective study by Iqbal et al, there is approximately a 1.68% incidence of instrument separation of NiTi rotary instruments. This was found to be approximately seven times higher than the incidence of instrument separation of stainless steel hand files. In addition, separation of the instruments was most frequently found in the apical one-third of root canal spaces.

File separation during clinical treatment generally occurs due to one of two reasons: torsional stress or cyclical fatigue (Sattapan). Torsional stress occurs when the file binds at some portion of the canal but the remainder of the file continues to rotate within the canal, ultimately causing file separation. Cyclic fatigue occurs as the file freely rotates within the curved canal and separates at the point of maximal flexure (Bahcall). In general, separation occurs significantly more frequently due to torsional stress than due to cyclic fatigue.

Some potential factors affecting the prognosis following instrument separation include the pre-operative diagnosis (Spili), the timing of the incident during treatment (Spili), the ability to bypass or remove the separated instrument fragment (Crump), the quality of the obturation following separation (Fu), and the presence of perforations created during attempts to remove the instrument fragment (Fu). Spili et al. also found that file separation during root canal treatment can potentially decrease the prognosis up to 5-7% depending on various factors. As a result, it is imperative to avoid iatrogenic errors such as file separation during root canal therapy.

1.2 Significance of study

According to Schilder and other authors of classic endodontic literature, "cleaning and shaping of root canals is the single most important phase of endodontic treatment" and "root canal systems much be cleaned and shaped- cleaned of their organic remnants and shaped to receive a three-dimensional hermetic filling of the entire root canal."

Adequate mechanical debridement as well as chemical debridement is necessary in order to clean the root canal system to the minimum threshold that will allow for successful treatment. Decreased outcomes may result from improper cleaning and shaping techniques. While the mechanical debridement is dependent on the file systems used, chemical debridement refers to the introduction of irrigants in order to kill microorganisms and dissolve tissue within the canals. Irrigant delivery to the critical apical portion of the root canal is invariably dependent on the size and shape of the mechanical preparation (Haapasalo). Effective irrigant placement and flow are aided by maintaining proper shape and taper during the instrumentation process. In addition, obturation can be negatively affected if instrumentation is not completed appropriately. Thus, it is evident that proper mechanical instrumentation can significantly affect future steps of root canal treatment and ultimately the overall success of the treatment.

While iatrogenic file separation occurs in a small percentage of cases, it has been postulated that file separation can lead to decreased outcomes. While treatment can still be successful if a file is removed, several factors can potentially affect the prognosis as previously mentioned. While there are many literature references regarding instrument separation due to cyclic fatigue, quality research regarding file separation due to torsional stress is lacking (Bahcall). Thus, the significance of this study is to review the effect of thermomechanical changes to specific endodontic rotary files and evaluate how these changes affect file separation due to torsional stress.

1.3 Specific Aims

This objective of this *in vitro* study was to compare the torsional force to fracture (TFF) and angle of rotation to fracture (ARF) of XP-3D Shaper conforming Nickel Titanium (NiTi) rotary files in as-received condition and after 1 and 3 simulated clinical uses.

1.4 Hypothesis

H(o): The null hypothesis is that there is no difference in Torsional Force to Failure (TFF) and Angle of Rotation to Failure (ARF) between as-received and 1-use, as-received and 3-uses, and 1-use and 3-uses files.

II REVIEW OF LITERATURE

2.1 Historical Overview of Endodontic files

For many years, hand instrumentation was the standard way to instrument root canal systems. Stainless steel hand files are useful due to their strength, ability to hold their shape, and flexibility in smaller diameter sizes. Iqbal et al also found that stainless steel hand files were approximately seven times less prone to fracture as compared to their NiTi rotary counterparts. For this reason, they are often used at the start of the root canal instrumentation procedure in order to minimize iatrogenic complications during subsequent stages of instrumentation. Another goal of using hand files to initiate treatment is to create a guide path for the NiTi rotary files to follow. Stainless steel hand files come in many different variations and cross sections for various purposes. For example, K files have been made with square, triangular, and rhomboid cross sections. The most commonly used original K type files are triangular in cross-section and therefore more flexible than other cross sections (Roane). These files range in sizes which correspond to tip diameter, per ISO guidelines.

When using hand files, it is important to consider their physical characteristics as they can ultimately affect clinical outcomes in a variety of ways. For example, hand files are recommended when tactile sensation is needed during treatment as this can aid in the negotiation of calcified canals, curved canals, or when attempting to bypass ledges, files or other iatrogenic errors. In addition, the combination of adequate rigidity and flexibility of hand files is advantageous in the instrumentation of many difficult to navigate canals. Conversely, larger size hand files tend to be particularly stiff and if used inappropriately, can cause iatrogenic errors such as formation of ledges, formation of apical elbows, or apical transportation. According to Weine, such iatrogenic errors “would be difficult to seal with any canal filling used.” Thus, as most canals, particularly in posterior teeth, are curved in some way, it is recommended to avoid the larger sizes of hand files in most cases. They could cause straightening of naturally curved canals, often at the expense of the outer wall of the canal (Weine). In addition, due to the inherent rigidity of the larger files, by straightening the canals there was a tendency to miss tissue and debris within the canals, also potentially leading to decreased outcomes.

Several clinicians have presented root canal instrumentation techniques in order to alleviate some of the iatrogenic errors occurring during treatment. For example, Goerig promoted step down technique to "simplify apical instrumentation because immediate direct line access to the apical third of the tooth is used." In addition, Torabinejad introduced passive step back and Morgan and Montgomery introduced crown down technique in order to enhance coronal flaring. In order to minimize straightening of canals, Abou-Rass proposed anti-curvature filing in order to file the bulkier root structure away from the curvature and thinner danger zone. In clinical practice, this technique did not resolve the issues created by larger hand files. Another technique proposed to resolve this issue was the balanced force technique, as proposed by Roane. According to Roane, the concepts "use force magnitudes in order to create control over undesirable cutting associated with canal curvature. Rotation is promoted as the means of maintaining magnitude as a control and counterclockwise direction of rotation produces finite operator control." While ultimately this technique also did not solve the issues created by larger hand files, it did help clinicians navigate smaller canals and is therefore still used in certain cases to this day.

In general, the use of hand files and the development of various techniques in order to work with them have been instrumental to achieving endodontic success and developing the techniques we use today. It is still standard amongst general dentists and endodontists alike to create a guide path using the hand files and possibly further instrument using hand files depending on the specific canal anatomy. In more recent years, rotary NiTi files have become the gold standard of canal instrumentation and have generally been successful in minimizing certain iatrogenic errors, particularly straightening of canals, during instrumentation.

2.2 Nickel Titanium Rotary Instruments

2.2.1 Properties and phases

Nickel-Titanium is an alloy that has been used in dentistry for many years, initially in orthodontics until being introduced to endodontics by Walia et al in 1988. Using the 56% nickel and 44% titanium combination structurally leads to an equiatomic ratio of each metal in the alloy (Shen) in order to give the structure of NiTi many unique characteristics including its superelasticity. This is ideal for mechanical instrumentation, as the rigidity of stainless steel files was found to create iatrogenic complications. One possibly negative outcome of Walia's original investigations into NiTi was that early files made from NiTi tended not to hold a pre-curved formation as well as stainless steel files although he also found that they tend to stay better centered in the canal more than stainless steel.

Superelasticity is a result of the two stable crystalline phases of NiTi: Austenite and Martensite. Martensitic-Phase (M-Phase) metal is straight and soft at or below room temperature. Austenitic- Phase (A-phase) metal's working phase is at 35 degrees C. In certain variations of the material, when the NiTi file is subjected to thermomechanical changes it can develop a quality known as shape memory which is defined as the ability of NiTi to be deformed when it undergoes a strain and then return back to its original for after heating again (Zhou). NiTi's ability to elastically deform up to 8% is a characteristic of its unique microstructural crystalline phase. For example, if the shape of a file with the shape memory ability is altered during clinical use, it should theoretically return to its normal pre-use shape following sterilization.

The ability of the alloy to transform between phases based on stress, heat, and strain are the main reason it is so useful as an endodontic instrument (Zhou). As figure 1 shows, superelasticity takes place at the austenite finish temperature (A_f) which is roughly at body temperature. As the material cools, it converts to martensite by losing its austenite microcrystalline structure. According to Hargreaves, in the martensitic phase, the alloy has less superelasticity and can therefore deform significantly easier when stressed although in this phase it possesses the characteristic of shape memory. The schematic shown in Figure 2 explains the phase changes of NiTi in response to heating, cooling, and strain.

There are eight phases of the stress strain curve of NiTi as described in Figure 3. These phases range from the least amount of strain on the alloy to the greatest strain on alloy. The first stage is the elastic deformation stage of the austenite form of the alloy and is characterized by a low strain on the alloy. In the second stage, there is a plateau of the stress value indicating the transformation from the austenite to the intermediary R phase of the material. The R-phase microstructure is in the form of a rhombohedral design and due to its unique ability to possess both shape memory and superelasticity it has garnered interest for future endodontic file designs (Zhou). While the third stage shows the R phase, at stage four there is a stress induced martensite (SIM) stage indicating material changing from the R-phase to martensitic phase of the alloy. At the fifth stage is when the martensitic alloy is undergoing elastic deformation as a result of increased stresses and strains placed on the material and stage six is the martensitic reorientation (MR) phase. Stage seven shows the non-linear deformation stage of reoriented martensite and stage eight is the plastic deformation stage of reoriented martensite. According to Zhou, the progression from stages six to eight may ultimately lead to failure of the alloy. Obviously, as stress increases on the alloy its tendency to go towards plastic deformation will increase. In addition, superelasticity is associated with the SIM stage, while shape memory is associated with the MR stage (Zhou).

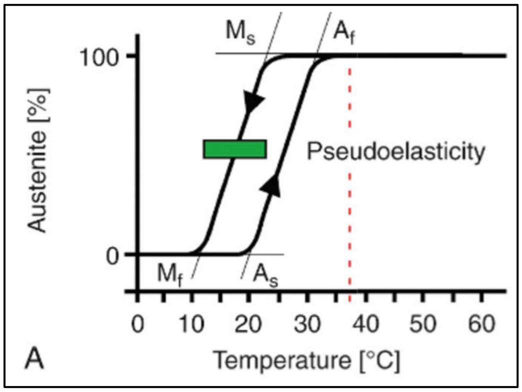

Figure 1. Superelastic Behavior of nickel-titanium- temperature (Hargreaves et al. 2016, Chapter 6 pg. 222)

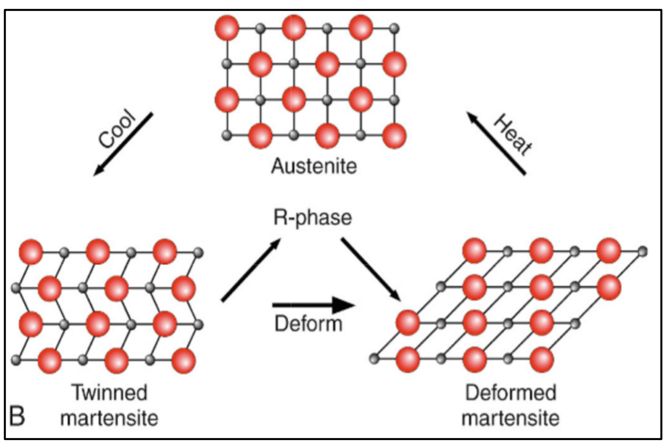

Figure 2. Superelastic Behavior of nickel-titanium-strain (Hargreaves et al. 2016, Chapter 6 pg. 222)

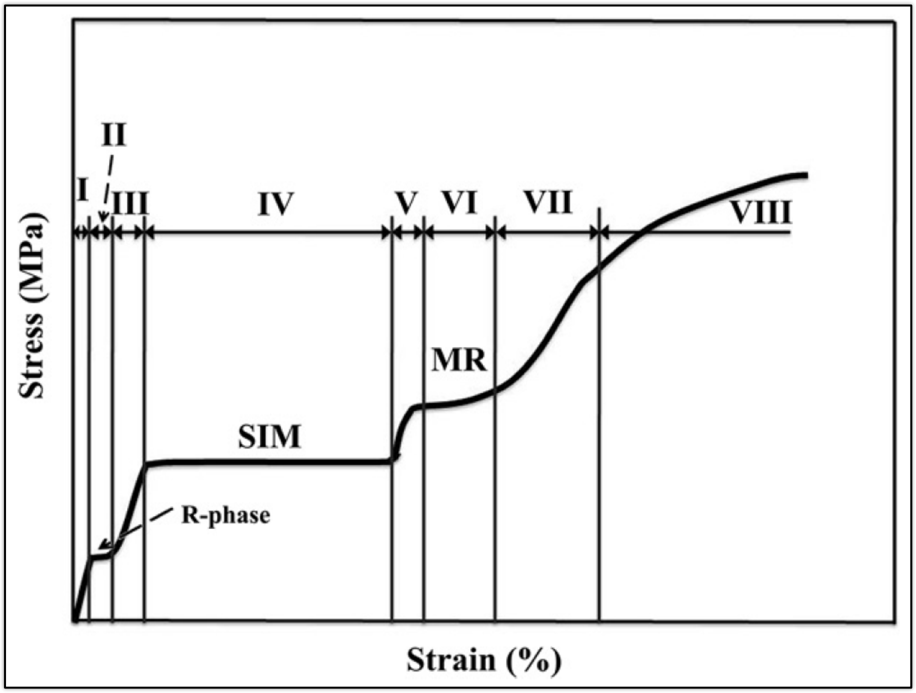

Figure 3. Stress-Strain Curve of nickel-titanium.
SIM: Stress-Induced Martensite
MR: Martensite Re-Orientation
(Zhou et al. 2013)

2.2.2 Alterations of Nickel-Titanium

While the introduction of standard nickel titanium instruments was crucial to the advancement of endodontic practice, much more research has been performed regarding ways to enhance these files by various methods. Ultimately, the goal is to maintain or increase the efficiency, flexibility, and other positive aspects of the files while further decreasing potential iatrogenic errors associated with the files such as separation, ledging, and zipping. While these potential errors are inherently decreased with NiTi technology, they are still present and can still continue to negatively affect treatment prognosis (Panitvisai). Thus, much research has been performed on thermomechnical processing of endodontic files in order to enhance the technology of the files. For example, different manufacturers have developed various propriety heat treatment mechanisms to develop unique characteristics in files. For example, Alapati et al learned that when alloys were heat treated at higher temperatures ranging from 400 ˚C to 600˚C they maintained their austenitic phase longer than warranted. Subsequently, it was suggested that for future development, heat treatments at lower temperatures are required to increase the martensitic phase of NiTi and therefore provide increased elasticity. In addition to heat treatment, another example of alteration of NiTi technology is electropolishing. In this process, an electrical current is passed through the file within a bath of electrolytes ultimately coating the instrument and reducing surface defects. The goal of this process is to increase resistance to corrosion as well as to cyclic and torsional stresses (Gutmann).

More recently, recent technologies have led to the creation of NiTi files with non-linear file designs. These are files with adaptive cores and a non-linear design and envelope of motion with the goal of three-dimensional shaping of canals. Additionally, they have unique design characteristics that enable them to touch major portions of root canal space which traditional files are unable to instrument. Maintaining natural anatomy is one of the unique characteristics of these instruments. The offset contact with dentin is also less likely to cause torsional stresses and thereby possibly reduces incidence of fracture. However, one main drawback to these types of files is determining the true length of the file. Lack of adjusting true length during instrumentation could cause over preparation of the apical portion. One another important issue is lack of understanding of the envelope of motion of these files may result in excessive flare. Hence, a better nomenclature and instrument description with these new files is warranted.

2.3 XP-3D Shaper™

Brasseler has created a proprietary heat treatment model that has been implemented to create their XP-3D Shaper files. The technology uses their MaxWire® Technology to "adapt to the canal's natural anatomy by expanding once exposed to body temperature (Brasseler). It is an ISO #30 file with a 1 degree taper and the advantages of this file design include the superelasticity and extreme flexibility and resistance to cyclic fatigue, the ability to transform to its austenitic serpentine shape at body temperature, and the ability to expand to the natural anatomy of the canals. Figure 4 shows the file's shape variations in the martensitic and austenitic phases.

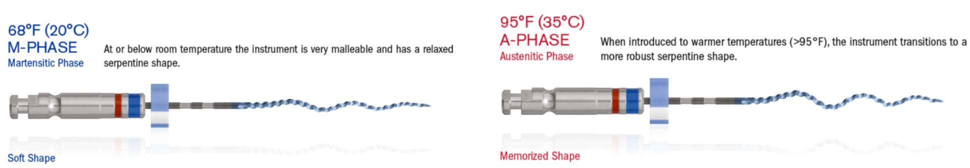

Figure 4. XP-3D shaper file in martensitic and austenitic phases

Another proprietary technology used in the file is the Booster Tip™ which contains six cutting edges and rapidly transitions from an ISO size #15 to size #30 within 1 mm from the tip and therefore allows the file to function as a scouting and shaping file. In addition, the Adaptive Core™ Technology which "allows the smaller central core of the file to move freely and adapt to the canals and natural morphology (Brasseler)."

2.4 Torsional Stress Testing and the Torsiometer Machine

Torsional stress in endodontics occurs when the tip of a rotating instrument binds at some point within the canal wall and then separates as the motor continues to spin. In order to test torsional stress to fracture, a Torsiometer Machine was used (Sabri Dental Enterprises, Inc., Downers Grove, IL) (Figure 5). The machine is made up of two individual pieces including a testing apparatus and a mechanical value readout unit. The shank end of the file is locked from one side in the testing apparatus while the file tip is locked 3mm from the tip at the other side. In a clockwise direction, the device rotates the tip of the file at two revolutions per minute while the shank remains in a stationary position, allowing the file to be twisted under a torsional load.

Upon separation of the file, the unit stops rotating and disengages the free end while the torque value (g-cm) and angle of rotation (°) to fracture are computed and displayed.

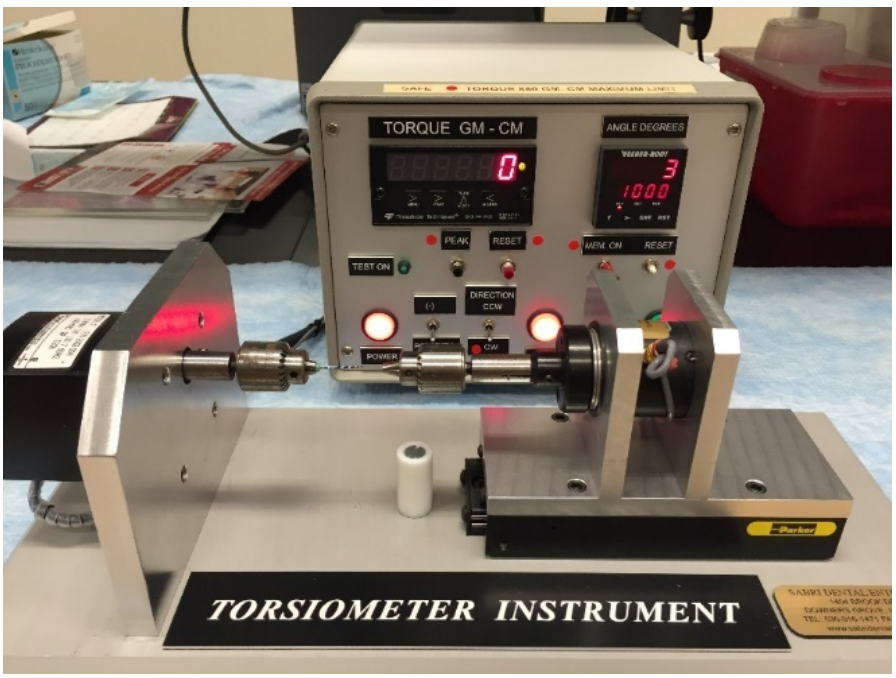

Figure 5. Torsiometer Instrument. Testing apparatus appears in foreground while readout machine is present in the background.

III MATERIALS AND METHODS

3.1 Overview

This *in vitro* study was conducted in the labs of Drs. Satish Alapati at the University of Illinois at Chicago College of Dentistry (801 S. Paulina St, Rooms 536 Chicago IL, 60612) by the primary investigator.

3.2 Study Design

Torsional stress resistance to fracture of XP-3D shaper NiTi files was performed on 25-mm length files. The central core of XP-3D Shaper is a size No. 30 with a 1-degree taper. Files were tested the Torsiometer instrument in as-received condition, and after 1 and 3 simulated clinical uses. Each experimental group had 10 files, totaling 30 files per group.

3.3 Endo-Bloc Instrumentation

XP-3D Shaper files were used in a manner simulating clinical use using clear resin endo-blocs (Endo-training block A0177, DENTSPLY Maillefer, Ballaigues, Switzerland). Files were randomly assigned to the as-received, 1 use, or 3 use group. Files in the as-received group were tested the Torsiometer instrument without undergoing any clinical simulation. The files allotted in the 1 use group were clinically simulated to reach working length in one individual bloc. The files in the 3-use group were clinically simulated to reach working length in three separate root canals by being used in three separate endo-blocs.

The endo-blocs used have a canal that measures 16 mm in length with a 30-degree apical curvature. The blocs were standardized initially to a guide path using size #15 SS K in order to clinically simulate creating a guide path using hand files prior to initiating rotary instrumentation. Following guide path preparation, size 20/08 Vortex Orifice Opener ((Tulsa Dentsply) was set to one-half the working length and was used to open the orifice of the endo-bloc. Following orifice opening, the XP-3D shaper file was used per manufacturer's instructions. The canals contained 1 ml of 5.25% NaOCl. Using long gentle strokes of 5-7 mm, the file was progressed down to working length using rotary instrumentation (Figure 5) (Tulsa Dentsply Torque Control Motor model E3) at 800 rpm with a torque level of 1Ncm. Once working length was reached, the canal was re-irrigated and the instrument was worked in long gentle strokes to working length for 10 strokes in order to reach a preparation size of #30/04.

The set of files in each experimental group were randomly allocated either to prepare one or three endo-blocs. Each file was coated with RC Prep™ (Premier Hannover, Germany) prior to usage and 5.25% NaOCl (1.0 mL) was used for irrigation after each rotary file.

After files were subjected to their clinical use capacity, they were further tested on the Torsiometer instrument. As per ISO-3630-1, TFF was obtained by measuring peak torque in gram-centimeters (g-cm), and ARF in degrees of rotation until instrument separation and values were recorded for all 30 instruments.

FIGURE 6. Illustration of instrumentation using XP-3D shaper file (Brasseler USA)

3.4 Statistical Analysis

GraphPad Prism software (GraphPad Software, La Jolla California USA) was used to analyze the TFF and ARF data collected during experimental testing. Statistical significance was determined using ANOVA and Tukey's Post Hoc tests. Significance was set to $p < 0.05$. Data is presented as means ±SE and considered significant for $P < 0.05$.

IV RESULTS

In this *in vitro* study, 30 total XP-3D Shaper files were subjected to the Torsiometer instrument: 10 as-received, 10 after 1 simulated clinical use, and 10 after 3 simulated clinical uses.

4.1 Torsional Force to Fracture

The values obtained for torsional force to fracture are shown in TABLE I.

TABLE I:
TORSIONAL FORCE TO FRACTURE (G-CM)

	VXP3DS	1XP3DS	3XP3DS
1	41	43	42
2	42	40	46
3	39	47	39
4	45	39	41
5	52	40	36
6	46	38	37
7	42	42	40
8	39	41	38
9	41	40	39
10	44	39	40

When comparing the torsional force to fracture between groups, the XP-3D Shaper demonstrated no significant difference ($p>0.05$) in TFF between as-received and 1 use, as-received and 3 uses, and 1 use and 3 uses (Figure 6).

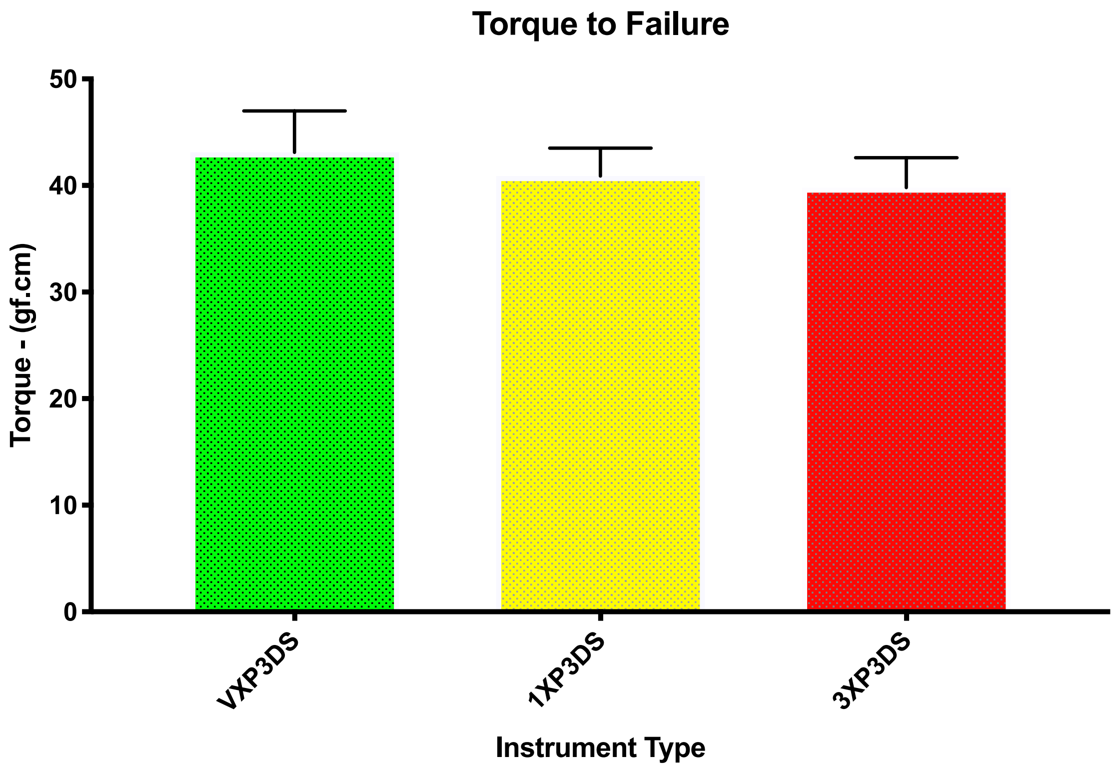

Figure 7. Graph comparing TFF between groups

4.2 Angle of Rotation to Fracture

The values obtained for angle of rotation to fracture are shown in TABLE II.

TABLE II
ANGLE OF ROTATION TO FRACTURE (DEGREES)

	VXP3DS	1XP3DS	3XP3DS
1	1507	889	769
2	1880	824	794
3	1609	940	732
4	1890	927	841
5	1870	970	699
6	1652	942	722
7	1668	897	763
8	1699	861	812
9	1745	907	801
10	1772	877	718

When comparing angle of rotation to fracture between groups, there was a significant ($p<0.002$) decrease in ARF between the XP-3D Shaper as received and 1 use, as-received and 3 uses, and between 1 use and 3 uses.

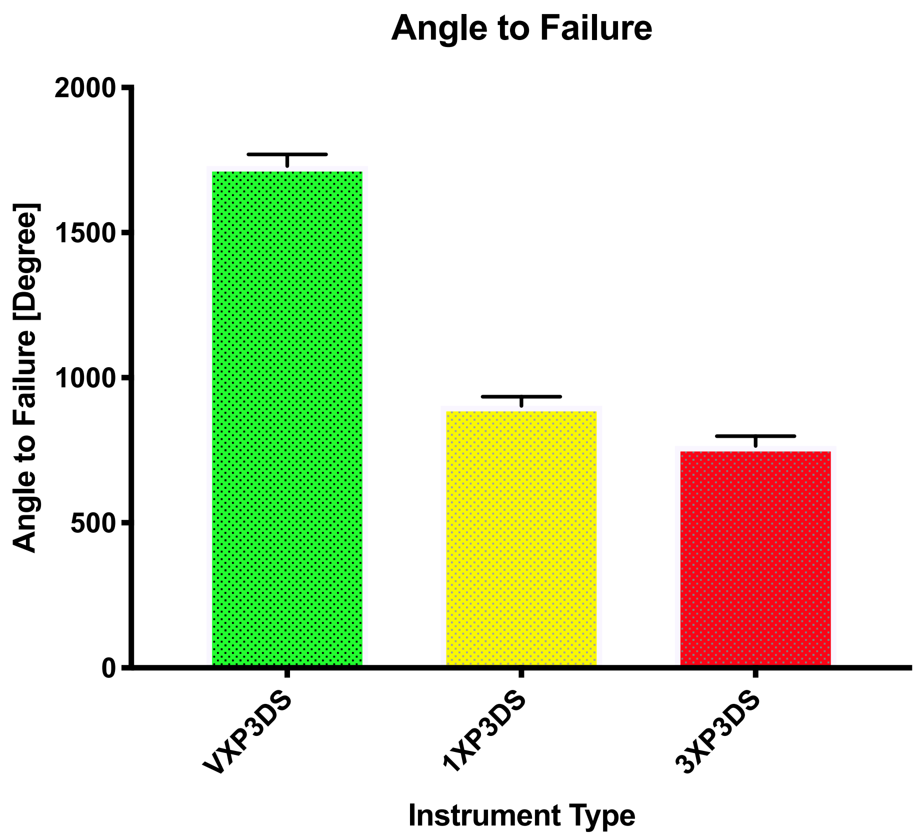

Figure 8. Graph comparing ARF between groups

V DISCUSSION

In this *in vitro* study, Brasseler XP-3D Shaper files were compared regarding their torsional force to fracture and angle of rotation to fracture in as-received, and after 1 and 3 simulated clinical use conditions.

In this study, we focused on the mechanism of torsional stress rather than cyclic fatigue as it relates to file fracture as it is less frequently studied and has not yet been studied in relation to these files. Torsional stress occurs when an instrument binds at the tip while the remainder of the instrument continues to rotate, thus fracturing the bound portion.

Due to complex root anatomy systems, it is extremely important to radiographically assess teeth pre-operatively as well as possible. As cone beam computed tomography (CBCT) becomes more widespread and standard during care, evaluation of canal anatomy prior to treatment is becoming more common and even expected. Due to this technology, clinicians are better able to evaluate the curvature of canals and effectively anticipate their treatment protocol. For example, in severely curved cases, practitioners may be more inclined to use files with certain technologies such as heat treatment or non-linear file design in order to minimize chances of file separation or other iatrogenic errors. In addition, as evidenced by this research, it would be prudent of clinicians to use files only a single time to decrease incidence of fracture.

In this study, files were tested for torsional force properties per ISO 3630-1 guidelines by using a Torsiometer (Sabri Dental Enterprises, Inc, Downers Grove, IL). The results of this study ultimately conclude that there is no significant difference between usage groups in regard to torsional force to fracture. Empirically, however, during the study it was seen by the primary investigator that there was a slight trend of decrease in TFF with increased usage, although not statistically significant. In regards to angle of rotation to fracture, there was a significant difference between usage groups. Specifically, with increased usage, there was a significant decrease in angle of rotation to fracture of the files. Thus, more iatrogenic complications were found in cases with more simulated clinical uses. Empirically, it was also noted that with increased use, more effort and passes were required to get the file to working length in the endo-blocs.

During the study, it was found that with increased usage, there was slightly more unwinding of files, which was also correlated with decreased angle of rotation to fracture. Thus, unwinding can be an indicator of a deformed file that may be more susceptible to fracture than its intact counterpart.

In general, the most clinically relevant finding of this study was the increased susceptibility to fracture with increased simulated clinical usage of the files. As a result of using a file multiple times, it is possible that there may be increased incidence of fracture and potentially decreased results. Thus, it is necessary for a practitioner to be prudent when deciding whether to re-use a file, particularly in cases where significant stresses and increased workload have been placed on the file. In these cases, it may be wise to discard files after a single use rather than risk iatrogenic errors during treatment.

VI CLINICAL RELEVANCE AND LIMITATIONS

As it would be unethical to conduct such a study clinically, we attempted to simulate clinical conditions as closely as possible during the experimental process. For example, the acrylic endo-blocs used possess a similar physical structure and hardness compared to natural dentin. In addition, the irrigation protocol during instrumentation while conducting the study was consistent with standard clinical practice. One limitation of the study is that we were unable to control for body temperature during instrumentation and torsional force testing. We considered the use of devices such as a water bath or hair dryer, however we found that it was not possible to keep environmental temperatures consistent throughout the experimental process. Ultimately, it would not be acceptable to conduct such an experiment in a clinical setting and every effort was made to simulate clinical conditions.

Ultimately, the main clinical significance of this study is results suggest that after a single use, the susceptibility of the XP-3D Shaper file to fracture increases. In practice, clinicians should be wary when using files multiple times, particularly when excessive force has been placed on the file during treatment. As torsional force and angle of rotation are not quantified during treatment, it is generally up to the clinician's discretion when to avoid re-using a file. In addition, appropriate motion of the files, for example, a pecking motion as described by Dederich et al, should be used in order to avoid binding and placing excessive stresses on the files. A final clinical application of the study is the observation that after use, unwound files were more prone to fracture. During treatment, clinicians should take care to inspect files before and after use and discard if files are observed to be physically deformed in some way.

VII FUTURE RESEARCH DIRECTIONS

Future research aspirations would be to better simulate clinical conditions by controlling for body temperature during testing. In addition, it would be helpful to consider whether sterilizing the files between uses, to better mimic clinical use, would have any effect on the results. Finally, future projects could evaluate the file fragments using a scanning electron microscope as well as direct scanning calorimetry to evaluate the samples microscopically and thermoanalytically.

VIII CONCLUSIONS

There is a trend of decreased ARF in XP-3D Shaper files with increased usage however there is no significant difference ($p>0.05$) in TFF of the XP-3D Shaper files with increased usage. This implies that with increased use files are more susceptible to fracture and overuse of files should therefore be avoided. The possible explanation for these results could be due to the non-linear file design in combination with the heat treatment of the nickel-titanium.

CITED LITERATURE

Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. *JADA* 1980; 101:792-794.

Alapati SB, Brantley WA. Iijima M, Clark W, Phil D, Kovarik L, Buie C, Liu J, Johnson WB. Metallurgical Characterization of a New Nickel-Titanium Wire for Rotary Endodontic Instruments. *J Endod* 2009; 35:1589-1593.

Alapati SB, Brantley WA. Iijima M, Schricker SR, Nusstein JM, Li UM, Svec TA. Micro-XRD and temperature-modulated DSC investigation of nickel-titanium rotary endodontic instruments. *Dent Mater* 2009; 25:1221-1229.

Alapati SB, Brantley WA, Svec TA. SEM observation of nickel-titanium rotary endodontic instruments that fractured during clinical use. *J Endod* 2005; 31: 40-3.

Alves-Claro AP, Clar FA, Uzumaki ET. Ear resistance of nickel-titanium endodontic files after surface treatment. *Journal of Materials Science. Materials in Medicine* 2008; 19: 3273-7.

Bahcall J. Remedying and Preventing Endodontic Rotary Nickel-Titanium (NiTi) File Breakage. Compend 2013; 34:2-5.

Brantley WA, Svec TA, Iijima M. Differential scanning calorimetric studies of nickel-titanium rotary endodontic instruments. *J Endod* 2002; 28:567-72.

Capar ID, Kaval ME, Ertas H, Sen BH. Comparison of Cyclic Fatigue Resistance of 5-Different Rotary Pathfinding Instruments Made of Conventional Nickel-Titanium Wire, M-wire, and Controlled Memory Wire. *J Endod* 2015; 41:535-538.

Council on Dental Materials, Instruments and Equipment. Revised American National Standards Institute/American Dental Association Specification no. 28 for root canal files and reamers, type K (revised 1988).

Dederich DN, Zakeriasen KL. The effects of cyclic axial motion on rotary endodontic instrument fatigue. *Oral Surg Oral Med Oral Pathol* 1986; 61(2): 192-6.

Diemer F, Calas P. Effect of Pitch Length on the Behavior of Rotary Triple Helix Root Canal Instruments. *J Endod*; 2004:716-718

Fu M, Zhang Z, Hou B. Removal of broken files from root canals by using ultrasonic techniques combined with dental microscope: A retrospective analysis of treatment outcome. *J Endod* 2011; 37: 619-622.

Gao Y, Gutmann JL, Wilkinson K, Maxwell R, Ammon D. Evaluation of the Impact of Raw Materials on the Fatigue and Mechanical Properties of ProFile Vortex Rotary Instruments. *J Endod* 2012; 38:398-401.

Gutmann JL, Gao Y. Alteration in the inherent metallic and surface properties of nickel-titanium root canal instruments to enhance performance, durability and safety: a focused review. *Int Endod J* 2012; 45:113-128.

Hargreaves KM, Berman LH. Cohen's Pathways of the Pulp. 11th ed. St. Louis, Mosby Elsevier, 2016.

International Organization for Standardization. Dentistry – Root-canal Instruments – Part 1: General requirements and test methods. ISO 3630-3631, 2008.

Iqbal MK, Kohli MR, Kim JS. A retrospective clinical study of incidence of root canal instrument separation in an endodontic graduate program: A Penn Endo database study. *J Endod* 2006; 32: 1048-43.

Johnson E, Lloyd A, Kuttler S, Namerow K. Comparison between a novel nickel-titanium alloy and 508 nitinol cyclic fatigue life of ProFile 25/.04 rotary instruments. *J Endod* 2008; 34:1406-1409.

Kazemi RB, Stenman E, Spangberg LS. A Comparison of stainless steel and nickel-titanium H-type instruments of identical design: torsional and bending tests. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; 90:500-506.

Kramkowski TR, Bahcall J. An *in vitro* comparison of torsional stress and cyclic fatigue resistance of ProFile GT Series X rotary nickel-titanium files. *J Endod* 2009; 35:404-407.

Lee DH, Park B, Saxena A, Serene TP. Enhanced surface hardness by boron implantation in Nitinol alloy. *J Endod* 1996; 22:543-546.

Morgan LF, Montgomery S, An evaluation of the crown down pressureless technique. *J Endod* 1984; 10: 491-498.

Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of secondary root canal treatment: a systematic review of the literature. *Int Endod J* 2008; 12:1026-46.

Panitvisai P, Parrunit P, Sathorn C, Messer H. Impact of a Retained Instrument on Treatment Outcome: A Systematic Review and Meta-analysis. *J Endod* 2010; 36:775–780.

Parashos P, Gordon I, Messer HH. Factors influencing defects of rotary nickel-titanium endodontic instruments after clinical use. *J Endod* 2004; 30: 722-5.

Parashos P, Messer HH. Rotary NiTi instrument fracture and its consequences. *J Endod* 2006; 32: 1031-43.

Park SY, Cheung GS, Yum J, Hur B, Park JK, Him HC. Dynamic torsional resistance of nickel-titanium rotary instruments. *J Endod* 2010; 36:1200-1204

Peters OA. Current Challenges and Concepts in the Preparation of Root Canal Systems: A Review. *J Endod* 2004; 30:559-567.

Peters OA, Barbakow F. Dynamic torque and apical forces of Profile .04 rotary instruments during preparation of curved canals. *Int Endo J* 2002; 35:379-389.

Peters OA, Gluskin AK, Weiss RA, Han JT. An *in vitro* assessment of the physical properties of novel HyFlex nickel-titanium rotary instruments. *Int Endod J* 2012; 45:1027-34.

Pettiette MT, Metzger Z, Phillips C, Trope M.. *J Endod* 2009; 25:230-234.

Plotino G, Grande NM, Cotti E, Testarelli L, Gambarini G. Blue Treatment Enhances Cyclic Fatgiue Resistance of Vortex Nickel-Titanium Rotary Files. *J Endod* 2014; 40:1451-1453.

Roane JB, Sabala CL, Duncanson MG. The "Balanced Force" Concept for Instrumentation of Curved Canals. *J Endod* 1985; 11:203-211.

Sattapan B, Nervo GJ, Palamara JE. Defects in rotary nickel-titanium files after clinical use. *J Endod* 2000; 26: 161-65.

Sattapan B, Palamara J, Messer H. Torque During Canal Instrumentation Using Rotary Nickel-Titanium Files. *J Endod* 2000; 26: 156-60.

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

Schilder H. Filling root canals in three dimensions. *Dent Clin NA* 1967; 11:723-44.

Shen Y, Zhou H, Zheng Y, Peng B, Haapasalo M. Current Challenges and Concepts of the Thermomechanical Treatment of Nickel-Titanium Instruments. *J Endod* 2013; 39(2):163-172.

Spili P, Parashos P, Messer HH. The impact of instrument fracture on outcome of endodontic treatment. *J Endod* 2005; 31:845-50.

Tepel J, Schafer E. Endodontic hand instruments: cutting efficiency, instrumentation or curved canals, bending and torsional properties. *Endod Dent Traumatol* 1997; 13:201-210.

Testarelli L, Plotino G, Al-Sudani D, Vincenzi V, Giansiracusa A, Grande NM, Gambarini G. Bending proeprties of a new nickel-titanium alloy with a lower percent by weight of nickel. *J Endod* 2011; 37:997-1001.

Thompson SA. An overview of nickel-titanium alloys used in dentistry. *Int Endod J* 2000; 33:297-310.

Torabinejad M. Passive step-back technique. *Oral Surg Oral Med Oral Pathol* 1994; 77: 398-401.

Turpin YL, Chagneau F, Vulcain JM. Impact of two theoretical cross-sections on torsional and bending stresses of nickel-titanium root canal instrument models. *J Endod*; 26: 414-417.

Vinothkumar TS, Miglani R, Lakshminarayananan L. Influence of deep dry cryogenic treatment on cutting efficiency and wear resistance of nickel-titanium rotary endodontic instruments. *J Endod*; 33:1355-8.

Walia H, Brantley WA, Gerstein. An Initial Investigation of the Bending and Torsional Properties of Nitinol Root Canal Files. *J Endod 1988*; 14: 46-51.

Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. *J Endod*; 1975; 1:255-262.

Xu X, Eng M, Zheng Y, Eng D. Comparative Study of Torsional and Bending Properties for Siz Models of Nickel-Titanium Root Canal Instruments with Different Cross-Sections. *J Endod* 2006; 32:372-375.

Yamamura B, Cox TC, Heddaya B, Flake NM, Johnson JD, Paranjpe A. Comparing Canal Transportation and Centering Ability of EndoSequence and Vortex Rotary Files by Using Micro-Computed Tomography. *J Endod* 2012; 38:1121-1125.

Ye J, Gao Y. Metallurgical Characterization of M-Wire Nickel-Titanium Shape Memory Alloy Used for Endodontic Rotary Instruments during Low-cyclic Fatigue. *J Endod* 2012; 38:105-107.

Zhou H, Peng B, Zheng YF. An overview of the mechanical properties of nickel-titanium endodontic instruments. *Endo Topics* 2013; 29:42-54.

Zhou H, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Mechanical Properties of controlled memory and superelastic nickel-titanium wires used in the manufacture of rotary endodontic instruments. *J Endod* 2012; 38:1535-154

VITA

Doris Basali

Education and Professional Experience:

Georgetown University- B.S. Biology of Global Health

New York University College of Dentistry- DDS

Ohio State University- General Practice Residency Certificate

University of Illinois in Chicago- Certificate in Endodontics, MS Oral Sciences