Torsion and Bending Properties of EdgeEndo Files

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TORSION AND BENDING PROPERTIES OF EDGEENDO FILES

by

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ABSTRACT

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Introduction: One important step of root canal therapy is the process of cleaning and shaping each canal. This process involves using endodontic rotary files combined with chemical irrigants to remove pulpal remnants and infected dentin from the canal while eliminating pathogenic bacteria. It is essential to maintain proper canal anatomy while cleaning and shaping. The challenge for the practitioner is to select a rotary file system that will be flexible enough to maintain canal anatomy but strong enough to prevent breakage under normal use. File flexibility allows for better maintenance of canal anatomy. A file's resistance to torsional fatigue reduces the chance of file breakage. The purpose of this study was to compare the torsion and bending properties of a brand new file system (EdgeFiles by EdgeEndo, Albuquerque, NM) marketed as being twice as strong but half the price compared to other marketed files

Materials and Methods: Thirty files of each type were used. Ten different files systems were evaluated. Size 30 files of .04 taper EdgeFile X7, EdgeFile X5, EndoSequence (Brasseler), Vortex Blue (Dentsply), GT Series X (Dentsply), K3XF (SybronEndo), HyFlex CM (Coltene/Whaledent, Inc.), and .06 taper EdgeFile X3 (EdgeEndo), ProTaper Universal (Dentsply), ProTaper Gold (Dentsply). Testing was done with a torsiometer following ISO 3630-1. Twelve of each file type were evaluated for bending and 18 of each type were evaluated with torsion. Results were separated into 3 different groups due to differences in file design. Group 1 included X3, Protaper Universal, and Protaper Gold. Group 2 included X5 and GT series X. Group 3 included X7, EndoSequence, Vortex Blue, K3XF, and HyFlex CM.

Results: In Group 1, X3 showed the most flexibility followed by ProTaper Gold then ProTaper Universal. For strength, ProTaper Gold had the highest resistance to torsion followed by ProTaper Universal then X3. In Group 2, X5 showed more flexibility while GTX had higher strength. In Group 3, HyFlex CM showed the most flexibility followed by X7, then EndoSequence, Vortex Blue, and finally K3XF. For strength, K3XF was highest. X7 and Vortex Blue had similar values which were higher than HyFlex CM followed by EndoSequence.

Conclusion: An overall conclusion could be made that strength and flexibility have a relatively inverse relationship in each group. The stronger files tend to be less flexible

and the more flexible files tend to be more susceptible to torsional failure. ProTaper Gold and X7 had the best combinations of strength and flexibility.

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INTRODUCTION

The main objective of root canal therapy is the treatment or prevention of apical periodontitis. One of the most important steps in this process is efficient chemo-mechanical debridement of the canal [1]. The purpose of debridement is the removal of remaining tissues, microorganisms, and dentin debris from the root canal system which, if not properly removed, could lead to persistent apical pathology [1, 2]. Mechanical debridement is performed with endodontic files while chemical debridement is simultaneously completed with irrigants.

There are a number of procedural errors which could negatively affect the overall prognosis of a root canal treated tooth. These errors include instrument breakage, canal transportation, ledges, and perforations. Each of these errors can leave uncleaned walls or tissue remnants within the canal and allow bacteria to survive. Instrument breakage can block the canal and prevent further debridement [3]. Canal transportation can leave canal walls untouched [3]. Ledges can prevent complete shaping of the canal [4]. Perforations can leave unclean canal space and increase post-operative pain [5].

Endodontic technology has greatly improved in the last three decades. One significant advance is the introduction of nickel-titanium (NiTi) rotary files. NiTi files were first proposed for endodontic use in 1988 [6]. NiTi possesses unique characteristics which make the alloy suitable for endodontic rotary use due to the molecular crystalline phase transformation of austenitic and martensitic phases [7]. This allows for external forces to induce greater strain on the alloy without increasing stress thus causing the NiTi to return to its original shape after stress is no longer applied [8]. This characteristic is referred to as “superelasticity”. When used in endodontic files, NiTi can reduce file breakage and still maintain canal anatomy compared to conventional stainless steel files [6, 7].

Manufacturers are continuously developing new products which take advantage of the superelasticity of NiTi. The goal of many file developers is to produce something that is strong enough to resist the forces of torsion while maintaining enough flexibility to follow canal anatomy. EdgeFile (EdgeEndo, Albuquerque, NM, USA) is made of an heat treated nickel-titanium alloy brand named Fire-Wire [9]. The manufacturer claims that their files can be used in place of competitors at half the cost [10].

EdgeEndo produces 3 different file systems (X3, X5, and X7) which, according to the manufacturer, can be used with the same hand piece, speed, and torque as their specified competitor’s recommended settings. X3 files can be used with the same settings as ProTaper and ProTaper Next (Dentsply Tulsa Specialties, Tulsa, OK, USA) rotary file systems [9]. X5 files are compatible with GT and GT Series X (Dentsply) rotary file systems [11]. X7 files are compatible with Vortex, ProFile (Dentsply), K3 (SybronEndo, Orange CA), EndoSequence (Brasseler USA, Savannah GA), TF (SybronEndo) and other similar 04/06 taper rotary file systems [12]. If the competitor’s settings are unavailable then the settings should be 300-500 rpm and 300g/cm for all 3 file systems [9, 11, 12].

There are many published articles which compare the torsional resistance and bending properties of numerous files systems. To this date, according to our knowledge, there are no published studies in which EdgeEndo EdgeFiles have been used. The purpose of this study was to compare the angular deflection (bending) and resistance to fracture in torque in these files. Due to similarities in file design and system use, three different comparisons will be made. Group 1 will compare X3, ProTaper, and ProTaper Gold. Group 2 will compare X5 with GT Series X. Group 3 will compare X7, Vortex Blue, EndoSequence, K3XF, and HyFlex CM. ISO 3630-1 guidelines will be followed for resistance to fracture in torque and bending [13].

LITERATURE REVIEW

Root canal therapy is the process of accessing a tooth pulp chamber and preparing it by means of chemomechanical debridement so it can be sealed with a permanent biocompatible material. The main objective of this process is the treatment or prevention of apical periodontitis [1].

Dental pulp is a highly vascularized, highly sensitive tissue located within the central aspect of the tooth. When the pulp has been irritated it performs three basic reactions to protect itself from the irritation: (1) decrease dentin permeability, (2) form tertiary dentin, and (3) induce inflammatory and immune reactions [14]. There are a number of sources of pulpal irritation that can cause inflammation [14]. The primary source of irritation arises from bacteria and bacterial byproducts which navigate to the pulp via decay and/or microleakage [15]. In 1965, Kakehashi et al. did a study in rats where they found that bacteria are the primary cause of inflammation. In 1981, Moller et al. did a similar study in monkeys where they found that bacteria-free pulp chambers did not cause periapical inflammation when compared to infected pulp chambers. Sundqvist found that in humans, traumatized teeth with intact crowns and necrotic pulps did not show radiographic or clinical signs of periraducular pathology [16].

The major aim of root canal therapy is to prevent or treat apical periodontitis. This is done by cleaning and shaping of the canal via mechanical and chemical processes [1]. In 1974, Schilder introduced 5 mechanical objectives aimed at successfully preparing the root canal [1]:

1. Continuously tapering funnel preparation from the access cavity to the apical foramen
2. Root canal preparation should maintain the path of the original canal
3. Conical canal preparation should exist in multiple planes to improve flow of irrigants
4. The apical foramen should remain in its original position
5. The apical opening should be kept as small as possible

In 1955, Stewart found that as the canal space was enlarged through shaping, the number of microorganisms in the canal was reduced [17]. In 1981, Bystrom and Sundqvist found that mechanical preparation alone will not completely remove bacteria from within the canal wall, thus supplemental chemical debridement and irrigation is equally essential [18].

The ideal mechanical and chemical objectives of irrigation are (1) flush out debris, (2) lubricate the canal, (3) dissolve organic and inorganic tissue, and (4) prevent the formation of a smear layer during instrumentation [19]. The ideal biologic function of irrigants is to (1) have a high efficacy against anaerobic and facultative microorganisms in their planktonic state and in biofilms, (2) inactivate endotoxin, and (3) be nontoxic when they come in contact with vital tissues, and (4) not cause an anaphylactic reaction [19]. Sodium Hypochlorite (NaOCl) is currently the most commonly used irrigating solution due to its efficacy and fits most of the requirement for an ideal irrigant as listed earlier [20].

A recent meta-analysis by Ng et al. found that the four greatest factors leading to endodontic success are: (1) the absence of pretreatment periapical lesions, (2) root canal fillings with no voids, (3) obturation within 2 mm of the apex, and (4) an adequate coronal restoration [21]. In 1994, Ingle used radiographs to determine that 58% of treatment failures were due to incomplete obturation [22]. Incomplete obturation is often associated with procedural errors such as loss of length, canal transportation, and perforations [23]. Therefore, the primary goal for the clinician is to improve their clinical skills to avoid these errors while choosing instruments that will help to reduce their incidence.

The search for ideal endodontic instruments has been a long and detailed process. In 1746, Fouchard used piano wires for root canal therapy [24]. In 1838, Edward Maynard used watch springs to develop the original version of the endodontic hand instrument but it was not until 1875 that the first commercially produced endodontic instrument was available [25] . Though these instruments were innovative and creative, proper cleaning and shaping was still a great challenge and the percentage of root canal failures remained high [26]. One significant addition to the endodontic community, and still in use today, was the development of the K-file (Kerr) in 1915 [25].

In 1921, Hess published an article where he used a novel method to evaluate nearly three thousand teeth. His findings revealed that root canal anatomy is much more complex than what was thought at the time [27]. Canal complexity, and the challenges associated with negotiating and shaping these canals, has continually inspired manufacturers to develop new products.

The first known rotary instruments were developed by Oltamare. He used a fine needle with a rectangular cross-section mounted in a dental handpiece [25]. In 1889, Rollins developed the first endodontic handpiece for root canal preparation. To prevent file fracture, the rotational speed was limited to 100 r.p.m. [25]. In 1958, endodontic handpieces became popular with the introduction of the Racer-handpiece as well as the Giromatic in 1964 [25]. These products still had limitations, namely that they required the use of stainless steel files which have limited flexibility and rotational abilities.

Even though files have been used for many decades, it was not until 1961 that the first hand filing technique was described in publication by Ingle. He described the method as the standardized technique where he used hand files sequentially from smaller to larger size with each file going to working length [28]. The step-back technique, introduced by Clem in 1969, was similar to the standardized technique but included a sequential stepping with each file inserted 0.5 mm to 1.0 mm shorter than the previous to produce an increased taper [29]. In 1976, Walton histologically showed the step-back technique to be more effective than the standardized technique alone [30].

Since the first published technique in 1961, at least sixteen different techniques have been published [25]. The main objective of each of these techniques is to efficiently remove debris and microorganisms from the root canal system while maintaining appropriate canal anatomy and reducing the amount of procedural errors that occur. Though many studies have been performed to compare techniques there are no definitive conclusions regarding which technique is most effective [31, 32].

Regardless of which technique is used for canal shaping, procedural errors still occur. One common mishap is file fracture, where the apical portion of the file separates in the canal. File fracture with hand files occurs between 1% and 6% of the time. Fracture of rotary files occurs between 0.4% and 5% of the time [3, 33]. When instrument fragments remain in the canal it can prevent access to apical portions, thus preventing further cleaning and shaping in those areas [34]. Interestingly, current studies do not show a significantly higher rate of failing root canal treatments with separated files when the treatment has been performed by specialists [33]. Regardless of prognosis or outcome, this mistake is still perceived by most clinicians as an untoward event and avoiding this mishap is preferred [35].

One common endodontic procedural error is canal transportation. Canal transportation is defined as “the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation” [36]. There are a number of procedural errors which can be defined as types of canal transportations. These errors include ledging, zip formations, elbow formations, perforations, stripping, and others [29].

Ledge formation is one of the most common types of canal transportation [37]. Ledge formation occurs when instrumenting a curved canal because the rigid file attempts to work in a straight line and removes excess structure from the outer part of the curve. These can be difficult to bypass and often become blocked, resulting in an unfilled apical portion of the root [25]. When it occurs, ledge formation can lead to an unfavorable treatment outcome [38]. Jafarzdeh and Abbott described 14 possible causes of ledge formation [39]:

1. Not extending the access cavity sufficiently to allow adequate access to the radicular part of the root canal

2. Loss of instrument control if endodontic treatment is attempted via a proximal surface cavity or through a proximal restoration
3. Incorrect assessment of the root canal direction
4. Incorrect root canal length determination
5. Forcing the instrument into the canal wall
6. Using a noncurved stainless steel instrument that is too large for a curved canal
7. Failing to use the instruments in sequential order
8. Rotating the file excessively at the working length
9. Inadequate irrigation or lubrication during instrumentation
10. Over-relying on chelating agents
11. Attempting to retrieve separated instruments
12. Removing root filling materials during endodontic retreatment
13. Attempting to negotiate calcified root canals
14. Inadvertently packing debris in the radicular portion of the canal during instrumentation

File design plays a role on canal shaping and can contribute to ledge formation [40]. Files with greater flexibility may result in fewer undesirable changes in the shape of curved canals [41]. File manufacturers have aimed to develop files that help to avoid ledging and other types of transportation by following canal shapes with less iatrogenic error [42].

One significant innovation in the field of endodontics has been the development of nickel-titanium (NiTi). NiTi was first designed in 1959 and subsequently used in orthodontic arch wires. It was not until 1988 when Walia et al. proposed it for use in endodontics [6]. Walia et al. designed a #15 hand file and fabricated it using 0.02-inch orthodontic arch wires. They then tested the mechanical properties of this file and compared it with the traditional stainless steel hand files [6].

Until the advent of rotary, endodontic filing was performed by hand. In 1992, McSpadden produced the first known commercially available NiTi rotary instrument [43]. These instruments had a high fracture rate due to their 0.02 taper. In 1994, Johnson introduced a NiTi rotary instrument with a 0.04 and a 0.06 taper. This taper allowed for less file breakage while increasing efficiency when compared to hand filing with stainless steel files [43].

The early generation of NiTi files has inspired several different variations and the market is changing as manufacturers are striving to improve upon recent technologies. This has been bolstered by recent studies which have shown that NiTi files have improved flexibility resulting in a better ability to stay centered in the canal while producing less aberrations when compared to stainless steel [44].

The mechanical properties of NiTi give it unique abilities. When Nickel-Titanium is present in a one to one atomic ration it will have superelastic and shape memory effects [7]. NiTi has a low modulus of elasticity resulting in superior flexibility which ultimately leads to less instrument fracture [6, 45]. This is why NiTi can be used in a rotary driven handpiece. The advent of rotary handpieces and NiTi instruments has significantly reduced the amount of time it takes to prepare the canal and has allowed more respect to canal anatomy [44, 46].

NiTi possesses two stable main phases: austenite and martensite. These phases allow it to have both superelasticity and shape memory [47]. When external stresses are applied to NiTi, the austenite crystalline form transforms into a martensitic crystalline structure which can handle greater stresses without increasing the metallic strain. This transformation elasticity is what provides superelasticity [7].

There have been multiple attempts to improve the NiTi alloy and some reports indicate that new NiTi alloys may be five times more flexible than those currently used [48]. Some studies have found surface irregularities in NiTi files. These irregularities include milling marks, metal flash, and rollover [49, 50]. There is some speculation that fractures in NiTi instruments originate at these imperfections [51].

Electropolishing is a currently used strategy to remove these surface irregularities. Anderson et al. found extension of fatigue life for electropolished instruments [52]. Cheung found no change in fatigue resistance of electropolished instruments [53]. One study found improved corrosion susceptibility for RaCe instruments, but a different study found similar corrosion susceptibility for RaCe and non-electropolished ProFile instruments [54, 55]. Another example of a commonly used electropolished file is by EndoSequence (Brasseler USA, Savannah, GA).

Another effort to improve the properties of NiTi is the process of heat-treatment. With thermal processing, the transition temperature of the NiTi can be adjusted. This results in increased flexibility and higher resistance to cyclic fatigue. M-wire, produced in 2007 by Dentsply Tulsa Dental, is a heat-treated alloy. This has resulted in a file that is stronger and more flexible than its non-heat-treated counterparts [56]. Some examples of this file type are the newly introduced blue and gold alloys (Dentsply Tulsa Dental Specialties, Tulsa, OK). Another example is the Controlled Memory (CM) alloy (Coltene Endo, Cuyahoga Falls, OH).

File breakage usually occurs from cyclic fatigue or torsional overload. Breakage from cyclic fatigue occurs due to metal fatigue. As a file rotates freely in a curved canal, the inside portion of the file is compressed and the outer portion is stretched. This process is repeated upon each rotation [42]. NiTi instruments can withstand several hundred flexural cycles before fracturing but fractures still occur after a low number of cycles [57, 58].

Torsional overload occurs when the tip of the instrument is engaged in the canal and becomes locked while the shank continues to rotate. When enough torque is applied to the file, fracture occurs [59]. This can also occur when instrument rotation is slowed due to increased surface area contact [42]. Although they are considered separate elements, both cyclic fatigue and torsion should be analyzed together, especially in curved canals [59]. Working with an instrument with high torque may lower the file’s resistance to cyclic fatigue and studies have shown that cyclic prestressing can reduce a files torsional resistance [60].

Canal anatomy can have an effect on file separation as well. As mentioned earlier, cyclic fatigue can have a lateral aspect but it can also have an axial aspect as well. As the instrument rotates in a curved canal it can be bound and released by canal irregularities [61].

Torque applied to portion of a file during root canal therapy depends on multiple factors but the most important factor is the contact area between the dentin and the file [62]. The amount of surface area contacting a file varies due to file design, file taper, and clinical technique. Using the crown-down approach is recommended to reduce the amount of surface area contacted. This will prevent much of the file to contact less of the walls, thus reducing the amount of torsion applied which ultimately reduces the risk of file fracture [62].

There have been numerous studies on several different file systems and shaping techniques. Ideally, these studies should be done in vivo and there are some that have been performed that way. But, due to the high amount of variation involving canal anatomy and operator technique, many in vivo studies are not a reliable option [63]. A number of different models have been used to assess certain instrument properties. The properties have mostly included torque at failure and cyclic fatigue at failure among others.

According to ISO standards, torque at failure is measured with the apical 3 mm of the instrument tightly held in the testing device while the handle is rotated [13]. Many NiTi instruments have been tested this way [64].

Studies have shown that files with greater flexibility show improved shaping of the canal due to greater centering ability while minimizing aberrations in the canal [65]. Flexibility is also important because it lowers the bending stress of a file and reduces the risk of flexural fatigue [57]. Bending tests are used to demonstrate the amount of flexibility a file has. According to the ISO specification a torsiometer is used to evaluate bending properties [13]. Three mm of a file tip is inserted into the chuck of a torsiometer perpendicular to the axis of the motor. The file is then rotated by the opposite chuck which is controlled by the motor. As the motor rotates to 45 degrees, angular deflection of the file occurs. The bending moment is recorded after the 45 degree angle is achieved [66].

There is a constant search for a file with enough flexibility and strength to properly maintain canal anatomy, resist cyclic fatigue, and resist breakage from torsion. Benchtop testing can effectively help the clinician in determining which instrument will accomplish the above goals.

MATERIALS AND METHODS

Ten different file systems were selected for use in this study. Files were sorted into 3 different groups based on similar design and/or method of use [9, 11, 12]. Group 1 compares X3, ProTaper, and ProTaper Gold. Group 2 compares X5 with GT Series X. Group 3 compares X7, Vortex Blue, EndoSequence, K3XF, and HyFlex CM. File sizes for Group 1 are 30/.06. File sizes for Groups 2 and 3 were 30/.04.

Both torsion and bending were evaluated independently using a torsiometer (Sabri Dental Enterprises, Downers Grove, IL). Eighteen files of each type (n=18) were used for torsion, and 12 of each file type (n=12) were used for bending. Both torsion and bending were performed per ISO 3630-1 guidelines described for root canal files by using a torsiometer at room temperature (22˚C) [13].

For torsion, the tip of each file was inserted into a fixed chuck which measures applied forces via a connected torque-sensing load cell. The shaft of the file was then inserted into an opposing chuck connected to a variable speed motor so that the axis of the file was parallel to that of the motor. The shaft was then rotated clockwise at a speed of 2 revolutions per minute until the file separated. The torsional load and degrees of rotation were noted and the maximums at failure were recorded.

To test flexibility/stiffness the bending test was performed. In this test, the tip of each file was inserted into the above listed chuck but at an angle perpendicular to the rotating axis of the motor. The rotating pin, attached to the opposing chuck controlled by the motor, was made to slightly touch the file without applying forces. The motor was then activated, rotated 45 degrees, and then stopped. The forces applied to the torque-sensing cell were recorded.

All data were statistically analyzed by ANOVA with SPSS (SPSS Inc., Chicago, IL) and statistical significance was set at $P<.05$.

RESULTS

Bending

For bending, the amount of force applied was measured in g/cm. Table 1 shows Groups 1, 2 and 3. Note that a higher applied force represents more stiffness and thus less flexibility. In each table grouping, files are listed in order from most flexible (top) to least flexible (bottom).

Torsion

For torsion, two variables were recorded and statistically analyzed: torque (g/cm) and angle of rotation (degrees) at the point of file separation. Table 2 shows mean torque values for Groups 1-3. Files are listed in order from highest to lowest torsion applied. This means that the files are listed from strongest (top) to weakest. The stronger a file is, the more force is required before file separation occurs.

Rotation

Table 3 shows angle of rotation at file separation. Files are listed from highest rotation (top) to lowest degrees of rotation.

Group 1	**Bending (g/cm)**
X3	76±7
ProTaper Gold	126±10
ProTaper Universal	161±15
Group 2	**Bending (g/cm)**
X5	32±5
GT Series X	89±7
Group 3	**Bending (g/cm)**
HyFlex CM	21±2
X7	32±5
EndoSequence	46±5
Vortex Blue	56±5
K3XF	66±8

Table 1 – Bending moment

Group 1	Torque (g/cm)
ProTaper Gold	167±12
ProTaper Universal	164±15
X3	120±9
Group 2	**Torque (g/cm)**
GT series X	116±19
X5	77±11
Group 3	**Torque (g/cm)**
K3XF	117±10
X7	98±7
Vortex Blue	94±10
HyFlex CM	65±4
EndoSequence	58±4

Table 2 - Torsion

Group 1	**Angle of Rotation (degrees)**
ProTaper Universal	523±35
ProTaper Gold	429±42
X3	349±50
Group 2	**Angle of Rotation (degrees)**
X5	602±82
GT series X	455±54
Group 3	**Angle of Rotation (degrees)**
HyFlex CM	834±90
K3XF	538±68
EndoSequence	502±52
Vortex Blue	490±36
X7	466±46

Table 3 - Rotation

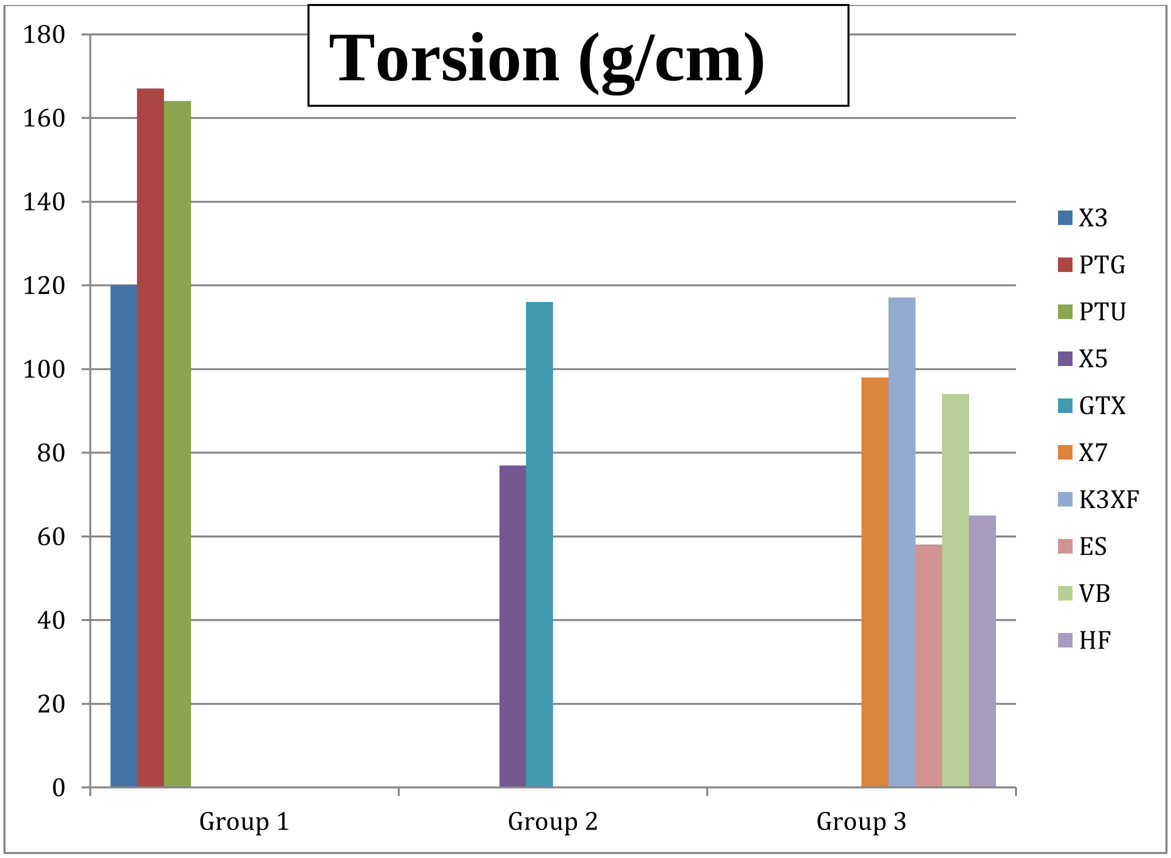

Figure 1 – Torsion comparison chart

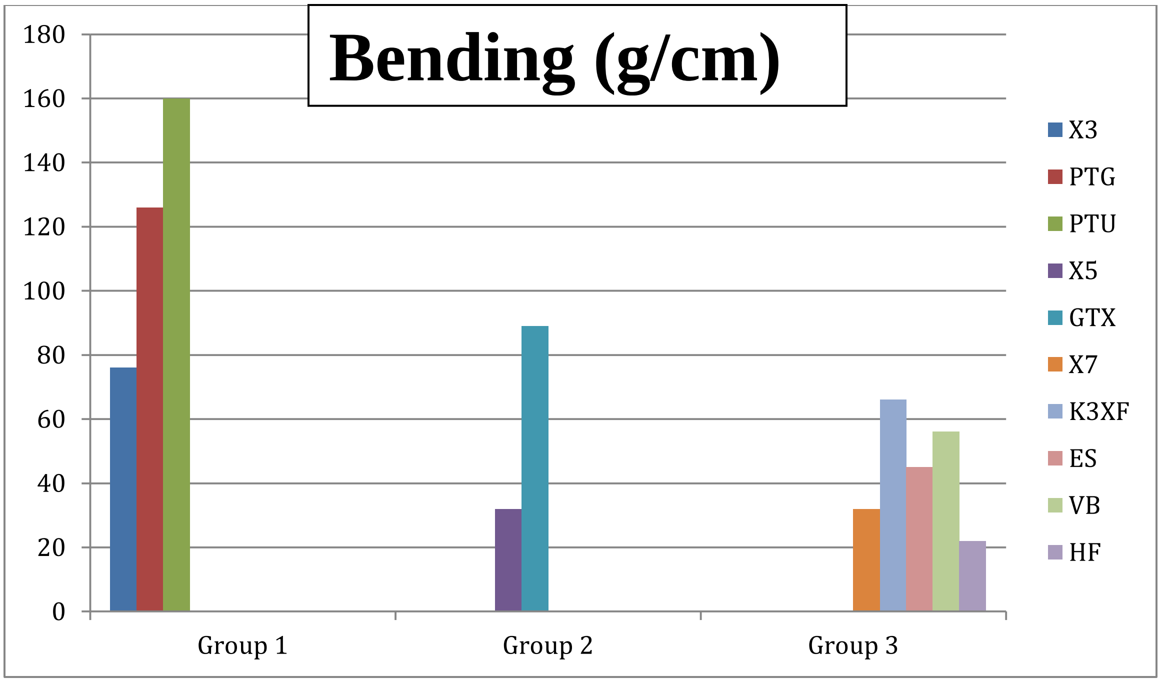

Figure 2 – Bending comparison chart

DISCUSSION

Over the past few decades file manufacturers have made great strides in file development due to nickel-titanium and its properties. It is important for the clinician to both understand the differences between each file system and choose a file or file system that possesses the characteristics they need to perform effective root canal preparation.

Even though NiTi rotary instruments have increased flexibility and strength when compared to stainless steel instruments, a high risk of fracture remains as a problem during endodontic therapy [3]. Studies have shown that instrument fracture has been attributed to torsional failure and cyclic fracture [58]. One study found that a high prevalence of torsional failure occurred in NiTi rotary files when compared to fracture from cyclic fatigue (55.7% vs 44.3%) [67].

New systems of NiTi rotary instruments have been developed that advertise as having greater strength and increased flexibility. A file that has greater flexibility and increased strength will have less chance of file breakage while properly maintaining canal anatomy.

This study compared the torsion and bending properties of the newly developed EdgeFile with other currently available files on the market. There are a number of factors which have an influence on torsional behavior and flexibility of a file. These factors include cross-section, alloy composition, electropolishing, and thermomechanical processing [8, 52, 66, 68]. Benchtop studies of bending demonstrate a file's flexibility. File flexibility indicates the mechanical behavior of endodontic instruments while preparing curved canals [41].

Flexibility can be just as important as strength because files that are stronger usually tend to sacrifice some flexibility. Thus, a purpose of this study would be to determine which file has the ideal amount of strength without compromising flexibility

In Group 1 of this study, ProTaper Gold demonstrated a significantly higher resistance to file separation in terms of rotation to failure due to torsion than ProTaper Universal which was stronger than EdgeFile X3. ProTaper Gold was not the most flexible but did show significantly more flexibility than ProTaper Universal. EdgeFile X3 was the most flexible among the 3 systems. Of the 3 file systems in Group 1, ProTaper Gold had the best combination of strength and flexibility

In group 2, GT Series X was significantly stronger than EdgeFile X5 but the bending moment of X5 was much lower than that of GTX (32 g/cm and 89 g/cm, respectively), thus X5 is much more flexible but not as strong.

In group 3, K3XF was the strongest, then X7 and Vortex Blue showing similar results, followed by HyFlex CM and EndoSequence having the lowest resistance to file separation. HyFlex CM had the most flexibility followed by X7, EndoSequence, Vortex Blue, then K3XF. Interestingly EdgeFile X7 was the 2nd most flexible file and the 2nd strongest file. Thus, X7 had the best combination of strength and flexibility of the files studied in Group. It can be concluded that EdgeFiles have somewhat similar properties as the other files tested. Other properties, such as cyclic fatigue and clinical outcomes, should be tested as well.

SUMMARY AND CONCLUSIONS

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

1. For Group 1 flexibility: EdgeFile X3 > ProTaper Gold > ProTaper Universal.
2. For Group 1 strength: (ProTaper Gold , ProTaper Universal) > EdgeFile X3
3. For Group 2 flexibility: EdgeFile X5 > GT series X
4. For Group 2 strength: GT series X > EdgeFile X5
5. For Group 3 flexibility: HyFlex CM > EdgeFile X7 > EndoSequence > Vortex Blue > K3XF
6. For Group 3 strength: K3XF > (EdgeFile X7, Vortex Blue) > HyFlex CM > EndoSequence

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