Performance and Preference of Rotary Files by Pre-Doctoral Dental Students at Marquette School of Dentistry

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PERFORMANCE AND PREFERENCE OF ROTARY FILES BY PRE-DOCTORAL DENTAL STUDENTS AT MARQUETTE SCHOOL OF DENTISTRY

by

Morgan McCall, D.M.D.

A Thesis Submitted to the Faculty of the Graduate School, Marquette University, in Partial Fulfillment of the Requirements for the Degree of Master of Endodontics

Milwaukee, Wisconsin

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ABSTRACT

PERFORMANCE AND PREFERENCE OF ROTARY FILES BY PRE-DOCTORAL DENTAL STUDENTS AT MARQUETTE SCHOOL OF DENTISTRY

Morgan McCall, D.M.D.

Marquette University, 2024

Introduction: The aim of this study was twofold: 1) objectively evaluate root canal shaping and procedural mishaps using different NiTi rotary systems in the hands of unexperienced pre-doctoral dental students; 2) to gain an understanding of which rotary file system students subjectively prefer.

Methods: Second year dental students (n=94) enrolled in preclinical endodontics received instructional videos and didactic lectures on the use of three different rotary filing systems: Vortex Blue, EndoSequence, and ProTaper Universal. Students completed root canal treatment using each file system on 3D printed premolars. The quantitative evaluation was completed after each project by two calibrated examiners using digital radiographs. Parameters evaluated included distance from apex, shape, and mishaps. The qualitative evaluation of the study was conducted at the end of the semester. The students completed surveys assessing their file preference based on ease of use, efficiency, and total number of procedural mishaps.

Results: Quantitative analysis showed that there was a significant difference in the mean score when comparing the shape and location from apex between ProTaper Universal and Vortex Blue (p=.044) with Vortex Blue having the higher mean average score. There was no significant difference when comparing either of these systems to EndoSequence. Qualitative analysis demonstrated students had a significantly more challenging time negotiating canals using EndoSequence when compared to ProTaper Universal (p=0.0005) or Vortex Blue (p=0.0254). Students reported significantly more procedural mishaps using ProTaper Universal compared to Vortex Blue (p=0.0144) but there was no significance when comparing either of these systems to EndoSequence. Further qualitative analysis identified 59% of students prefer incorporating Vortex Blue into their future practice; 50% found it was the most intuitive to use, and 53% found it had the best cutting efficiency.

Conclusions: In the hands of predoctoral dental students, Vortex Blue rotary files produced a significantly higher mean score when compared to ProTaper Universal. Students also experienced significantly fewer mishaps when comparing ProTaper Universal to Vortex Blue. Overall, Predoctoral dental students preferred using Vortex Blue rotary files and would consider implementing this system into their future practice.
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INTRODUCTION

There are many rotary file systems with limited evidence-based studies identifying which file system should be taught to pre-doctoral dental students. Students are eager to learn innovative technology that will also provide the most efficient instrumentation technique available. However, teaching the finesse and tactile sensation required to be successful with these instruments is a significant challenge faced by dental educators. With the drastic changes in instrumentation techniques over time, it is important to educate the future of the profession on current instrumentation techniques that are clinically safe, technically intuitive, and efficient. (Unal et al.) The step-back technique introduced by Clem in 1969, has stood the test of time. A survey in 2005 demonstrated that 83% of dental schools in the United States teach the step-back technique and 89.6% of these schools teach cold lateral obturation. (Hulsmann; Cailleteau and Mullaney) Although the step-back technique has endured the evolution various endodontic instrumentation techniques, it comes with its own disadvantages. These include higher risk of transportation, difficulty maintaining the original anatomy of the root canal system, and not to mention significant time consumption. (Hamid et al.)

The introduction of nickel-titanium instruments in 1988 revolutionized endodontic techniques. (Walia, Brantley and Gerstein) The use of rotary nickel-titanium files have reduced some inherent challenges found with the use of stainless steel hand files. (Cheung and Liu; Sonntag et al.) Some studies have even demonstrated a higher frequency of procedural errors with stainless steel files when compared with nickel-titanium rotary instruments. (Cheung and Liu) Although others suggest that file separation occurs more
frequently with rotary instruments. (Sonntag et al.) Regardless of the type of mechanical route taken to negotiate the root canal system, Schilder’s design principles continue to guide our instrumentation techniques. (Hulsmann)

Schilder’s objectives include a continuous tapering funnel from access cavity to the apex, the apical foramen should remain in its original position, and the apical opening should be kept as small as practical. (Hulsmann) Although the biological goals of endodontic therapy have remained constant over time, the mechanical processes to reach these goals has evolved. With the evolution of nickel-titanium files comes increased risk for procedural mishaps due to the files increased flexibility, torsional, and cyclic fatigue presenting challenges to the novice clinician who may lack the appropriate tactile sense required to successfully negotiate canals with a nickel-titanium rotary file. With the potential risk for increased procedural errors, it has become a challenge for dental schools to decide if and when to introduce rotary instrumentation to dental students. With the plethora of different file systems on the market, it is difficult to determine which system will provide the highest clinical satisfaction, consistent quality outcomes, and the fewest number of procedural mishaps. To aid in bridging the gap in evidence-based research on this topic, the aim of this study was twofold: 1) objectively evaluate root canal shaping and procedural mishaps using different NiTi rotary systems in the hands of unexperienced pre-doctoral dental students; 2) to gain an understanding of which rotary file system students subjectively prefer.
LITERATURE REVIEW

The Endodontic Market Today

General dentists perform almost 70% of the root canal treatments in the United States with estimated success rates reported at 64.4%. (Savani et al.; Ng et al.) With the popularity of nickel titanium (NiTi) rotary instruments increasing at an exceptional rate, it is important to incorporate the use of rotary files systems into the endodontic curriculum of dental schools. (Spangberg) With more than 150 types of NiTi rotary systems on the market, it can be overwhelming for a general practitioner to decide which system they should incorporate into their practice and what will work best in their hands. (Liang and Yue) By providing a solid foundation of just a few possibilities of the different available rotary systems, novice providers will be able to make informed decisions about the file system they should incorporate into their practice. It is important to emphasize that dental schools should be the primary educators introducing different instrumentation techniques to dental students. Too often dental sales representatives introduce recent graduates to new technology and share the technological aspect leaving out the biological rationale for its use. (Spangberg) During the predoc endodontic curriculum it must be emphasized that the appropriate file system should be selected based on the experience of the operator, canal morphology, and instrument properties. (Liang and Yue) Its imperative for a novice user planning on completing endodontic procedures to have a comprehensive understanding of the properties of the different file systems and the effects the different files may have on individual clinical cases. (Gavini et al.)

Patients have placed a higher value of their natural dentition over time. With more of the population wanting to retain their natural teeth, the number of endodontic
procedures completed by the general dentist will continue to increase. (Hanni et al.) Educating the predoctoral dental students on how to prevent procedural mishaps along with and providing the rationale for choosing different file selections may potentially decrease the number of procedural errors during root canal instrumentation. (Madarati, Watts and Qualtrough) Overall, if dental schools provide the educational foundation of these new file systems along with their limitations, future providers will be able to provide predictable, successful outcomes. (Gavini et al.; Madarati, Watts and Qualtrough)

**Implementation of Engine Driven Techniques**

General dentists complete a majority of non-surgical root canal procedures and will continue to face technological advances in instrument design and function. (Hanni et al.) Estimated total success rates of primary endodontic treatment completed by pre-doctoral students is 68.4% with little to no improvement over decades. (Ng et al.)

Studies have shown that even with the use of NiTi rotary files, adequate obturation using the cold lateral technique were observed 30.1% of the time in some schools. (Moussa-Badran et al.) Although it is easy to discuss the importance of the implementing rotary techniques into the dental school curriculum, implementing and teaching rotary instrumentation comes with its own set of challenges.

Teaching endodontic procedures in the predoctoral simulation lab requires additional resources to include supplies and equipment. The additional expense of several different file systems and obturation units adds to an already overwhelming tuition expense. Teaching multiple file systems in an already condensed course may not allow the student sufficient time to master one technique. It is critically important that the instrumentation techniques taught in the predoc simulation lab are standardized and
similar to the patient clinic. Making the transition from the predoc simulation lab to the patient clinic seamless. (Hanni et al.; Tavares, Tavares and Florio) Limiting the students’ exposure to stainless steel hand files and step-back instrumentation restricts the student’s perception of current endodontic procedures and advancements. In addition, students report they find NiTi rotary instruments intuitive to use, more efficient and safer when compared to stainless steel hand-files. (Martins et al.) Completing an increased number of procedures using file systems that have gained the students confidence will lead to higher levels of achievement. (Martins et al.; Hulsmann; Davey, Bryant and Dummer)

Teaching clinical endodontics within one semester may not be adequate to allow the students the opportunity to gain an increased level of confidence required to feel confident when they transfer to patient care. (Martins et al.) A recent survey demonstrated that students believe there is not enough time devoted to their endodontic education within the dental school curriculum. (Davey, Bryant and Dummer) Without constant reinforcement and sense of achievement, students may lack the confidence and skill level to treat endodontic patients after they graduate. Although the implementation of these courses may seem initially daunting, other dental schools have described how they have successfully integrated these rotary file systems into their programs. (Hanni et al.) Reporting the challenges, successes and future considerations amongst dental educators will enhance the endodontic educational experience for predoc dental students. (Dummer)

NiTi Rotary vs. Stainless Steel Hand instruments
NiTi rotary files are composed of 56% (wt) of nickel and 44% (wt) of titanium. (Walia, Brantley and Gerstein) The NiTi files transition from three different metallurgical phases during use including the austenite, martensite, and R phase. (Gavini et al.) Whereas stainless steel files are composed of slightly varying range of Iron, Chromium, Nickel, Molybdenum, and Silicon. (Darabara et al.) Stainless steel hand files come with a constant 0.02 taper while NiTi rotary files can be manufactured with a constant or variable taper ranging from 0.02 to 0.06. Stainless-steel hand files are twisted from blanks while NiTi rotary files can be are typically machined from the NiTi blanks. (Darabara et al.) NiTi rotary files can be processed with additional treatments such as thermomechanical processing or electropolishing which can give it advantageous properties that will be discussed in further detail below. (Shen, Zhou, Zheng, et al.)

It is important to make clear distinctions between the benefits and drawbacks of stainless-steel hand instruments when compared to rotary NiTi instruments. Studies have demonstrated that NiTi rotary instruments have produced fewer procedural errors when compared to stainless-steel files in the hands of novice users. (Cheung and Liu) For example, NiTi rotary instruments have unique shape memory and super-elasticity characteristics. (Thompson) Due to these properties, stress applied to these files does not result in the same level of stress that is observed in stainless-steel files. (Shen, Zhou, Zheng, et al.) When stainless steel hand files are bent, they are permanently deformed and will maintain that bent shape. NiTi files are more flexible than stainless steel files and revert to their original shape with ease even after pre-curving by the provider. (Wu et al.) These characteristics allow the NiTi files to remain better centered in the canal and respect the canal’s original anatomy to a greater extent compared to the stainless-steel hand-
files. (Zmener and Balbachan; Esposito and Cunningham) A major disadvantage in stainless steel files was identified by Weine who demonstrated that every hand-file has a tendency to become straightened within the canal regardless of whether or not the file was pre-curved by the provider. (Weine, Kelly and Lio) Hand-files continuously straightening throughout the instrumentation process can lead to clinical mishaps such as perforations, ledging, or apical “zips”. (Weine, Kelly and Lio) Although these mishaps are still possible when using NiTi rotary files, different manufacturing processes and treatments can minimize these risks. (Gavini et al.) It has been demonstrated that novice users have been able to conserve more dentin with less transportation using NiTi rotary instruments when compared to preparations using stainless-steel files. (Gluskin, Brown and Buchanan)

A distinct advantage stainless-steel instruments is providers can visualize the deformation of the file prior to separation and can discard appropriately. (Pruett, Clement and Carnes) In comparison, file separation of a NiTi rotary instrument may occur with no physical signs of deformation upon inspection. (Pruett, Clement and Carnes; Madarati, Watts and Qualtrough) There is currently no consensus of recommended number of uses before a provider should discard NiTi rotary files. (Parashos, Gordon and Messer) Although many companies advertise their files as a single use, this may not be feasible when practitioners are attempting to keep their overhead to a minimum. Some concerns with a variable taper are the aggressive cutting at the larger diameters of the rotary file. NiTi instruments with larger diameters can potentially be expected to separate at fewer cycles than smaller diameter instruments. (Pruett, Clement and Carnes; Plotino, Grande, Bellido, et al.) This is also relatively dependent on the practitioner’s experience and the
ability of the practitioner to recognize when a file is beginning to bind. The ability to recognize this tactile sensation takes time to develop and may be lacking in novice users. However, a recent survey of members of the American Association of Endodontists reported that these instruments were reused by 74% of the respondents (Logsdon et al.). It further demonstrated that a majority of these providers will discard the instrument after its third use (Logsdon et al.). The number of uses of a file is an important determinate in how many potential defects may be present on the file (Parashos, Gordon and Messer). Although trained specialists reuse these files, they may have more insight and appreciation into the limitations of a NiTi rotary file compared to a novice user.

**ProTaper Universal**

ProTaper Universal files (Dentsply Sirona, Charlotte, NC) are designed with a modified triangular cross section along with a variable taper over the length of their cutting flutes (Wu et al.; Koch and Brave). They are designed specifically so that each file in the sequence is preparing a designated area of each canal (Wu et al.). This variable taper creates a more flexible file with a reduced cross-section area (Wu et al.; Gavini et al.). The file system is designed so the provider uses three shaping files (coronal enlargement) and three different sized finishing files (apical enlargement), used in a sequential order according to the manufacturer. The variable taper design of ProTaper instruments mitigates torsional load, file fatigue, and therefore, separation (Wu et al.; Blum et al.).

ProTaper Universal has enhanced its design to make the files more user friendly and decreasing the risk of potential mishaps. Decreasing the taper of the finishing files to enhance tactile sensation during use, smoother transitions from the shaping to finishing
files, increased flexibility, and strategic changes in the cross-sectional shapes of the
finishing files are some of the file enhancements. (Wu et al.) Although the overall
incidence of separated files reported for ProTaper systems is relatively low, it has been
shown that a majority of the separations occurred using the larger files in the
system. (Wolcott et al.) This file is used in a sequential order recommended by the
manufacturer. The provider should start with the shaping files S-1 and S-2 followed by
the sequential order of the finishing files F-1, F-2, F-3 etc.

**EndoSequence**

EndoSequence files are manufactured using NiTi and instead of heat treatment,
these files are electropolished which can significantly decrease risk of crack formation
during instrumentation. (Koch and Brave) Not only does electropolishing decrease risk of
separation, it also increases the cutting efficiency of the file’s edges. (Koch and Brave)
Due to the high cutting efficiency, providers must be attentive to clean the flutes between
uses. (Koch and Brave) EndoSequence has similar file designs to ProTaper Universal in
that it has a triangular cross-section with alternate contact points. (Gavini et al.) This
design aids in keeping the file centered in the canal while reducing the torque required to
run the file due to the decreased resistance during instrumentation. (Koch and Brave)
Although the electropolishing is intended to extend the life of a the file, EndoSequence is
advertised as a single use file system. (Koch and Brave) EndoSequence presents as a
flexible file with adequate shape memory. (Koch and Brave) EndoSequence also presents
with a precision tip, meaning, it is a non-cutting tip that will become active at D-1 which
creates a level of safety in terms of perforation. (Koch and Brave) This file has both
variable pitch and variable helical angles with a constant taper and a lack of radial lands
all of which prevents providers from being ‘pulled down into the canal’. (Koch and Brave) Users have reported a distinct ‘clicking’ noise when using EndoSequence in the canal which is not an abnormal trait for a file of this design, but if clicking becomes ‘clacking’, the provider must be more aware of the amount of pressure they are placing on the file. (Koch and Brave) The EndoSequence file system should be used in a crown-down manner where the provider begins with the larger file and incrementally crown-down until working length is reached.

**Vortex Blue**

Vortex Blue is designed with a constant taper with a triangular cross-section. (Nguyen et al.) These files are manufactured using a new treatment that creates a blue colored file because of the presence of a titanium oxide layer. (Plotino, Grande, Cotti, et al.; Tabassum, Zafar and Umer) The treatment involves repeatedly heat-treating and cooling the files which creates a 60-80nm thick titanium oxide layer, giving the files their distinct blue color. (Gavini et al.; Tabassum, Zafar and Umer) This propriety treatment has been advertised to increase fatigue resistance, cutting efficiency, and flexibility. (Gao et al.; Gavini et al.; Shen, Zhou, Coil, et al.) The heat treatment used by Dentsply Sirona creates a more ductile file, which can be viewed as a “safety factor” since a clinician may be able to clinically see its distortion more evidentially prior to separation compared to less ductile systems that can separate with no warning. (Gao et al.) Practitioners do not need to use as much apical pressure while using Vortex Blue files due to its increased flexibility compared to other systems composed of M-Wire. (Gao et al.) Less force needed to advance the file in the canal can lead to lower risk of separation when using this system. Although these files are advertised as a single use file, previous studies have
shown that the risk for fracture after three uses is low. (Shen, Zhou, Coil, et al.) The Vortex Blue file system should be used in a crown-down manner where the provider begins with the larger file and incrementally crown-down until working length is reached.

**Methods of Evaluating Instrumentation**

Different methods have been employed to evaluate the impact that endodontic instrumentation has on the canal morphology and overall success. Studies may use resin blocks, standardized plastic teeth, extracted teeth, or live patients to evaluate the impact of endodontic instrumentation. (Munoz, Forner and Llena; Pettiette et al.; Gekelman et al.) Some researchers have opted to complete retrospective studies where periapical images of treatments within dental schools have been examined from start to finish to evaluate the success of the treatment. (Hamid et al.) With this type of evaluation researchers can see the number of appointments students needed to complete treatment, if they had adequate length, taper, and density, and what catastrophic events occurred during treatment. (Hamid et al.) An advantage to this method also allows the researcher to see if healing has occurred when comparing pre-op and post-op radiographs. (Hamid et al.)

Other studies have utilized XCP precision instruments during patient treatment to evaluating the changes in canal morphology during treatment. (Pettiette et al.) This allows the patient to bite down in a reproducible manner to obtain radiographs in a consistent orientation throughout treatment. Specific measurements are then taken of multiple angles of the canal before and after treatment and compared to evaluate the changes in canal curvature. (Pettiette et al.)
Others have focused more on the physical changes the instrumentation has on the tooth morphology. This has been done through different methods such as evaluation of periapical radiographs to computed tomography. Micro-computed tomography has advantages because there is no need to prepare samples or need for alteration of the tooth in question. (Peru et al.) Preparing teeth by sectioning to evaluate the canal morphology can be damaging to the sample making an accurate evaluation difficult. (Peru et al.) After a 3-D scan is obtained the pre-operative scan can be imposed over the post-op scan and the changes in anatomy can clearly be evaluated by researchers after instrumentation is completed. (Gekelman et al.) A disadvantage to micro-computer tomography is the high cost when compared to obtaining routine periapical imaging.

This study utilized the periapical radiographs obtained after obturation in the MUSoD simulation lab of standardized teeth that were instrumented by pre-doctoral students using several rotary file systems. Evaluation of the obturation periapical imagines provided a cost-effective way to evaluate the instrumentation by dental students using different rotary file systems. This method allows examiners to see if students can successfully obtain adequate length and taper when using different endodontic instrumentation techniques. It also enables researchers to examine any catastrophic mishaps that may occur during instrumentation.
MATERIALS AND METHODS

Ninety-four second year dental students enrolled in preclinical endodontics received instructional videos and didactic lectures on the basic use of three different rotary filing systems: Vortex Blue (Dentsply Sirona, Charlotte, NC) EndoSequence (Brasseler USA, Savannah, GA), and ProTaper Universal (Dentsply Sirona, Charlotte, NC). Two examiners were calibrated by reviewing a standardized rubric and using this rubric to grade mock cases to ensure examiners were in agreement. Each student received three 3D printed maxillary first premolars (B22X Kilgore Dental, Kilgore, TX), with two canals. Teeth were mounted in the ModuPro Endo model using the associated ModuPro Fixing Gel (Acadental, Inc. Overland Park, KS). Pre-op periapical radiographs were exposed using a Nomad (Dexis, Quakertown, PA) and Shick digital sensors (Dentsply Sirona, Charlotte, NC). Students were instructed to measure the teeth initially in hand using a ruler to establish an estimated working length, teeth were isolated with a rubber dam using single-tooth isolation, the teeth were accessed, and working length was confirmed with a #10 file and PA radiograph, a glide path was created to a size #20/.02 file and the canals were then instrumented using the assigned rotary file system. Canals were irrigated throughout the procedure with water and EndoGel (DC Dental, Baltimore, MD) was used on the rotary files during instrumentation. The students were instructed to use a crown-down technique when using the Vortex Blue and EndoSequence file systems. Canals were instrumented using file specific orifice openers; Vortex Blue and EndoSequence the orifice openers were a size #25/.08 and #25/.04 respectively. Orifice opening was followed by a crown-down technique starting with a size #40/.04 file until a master apical file size of #35/.04 was created. Patency was maintained throughout and
recapitulation between files to prevent canal blockage. ProTaper Universal was used according to manufacturer’s recommendations starting with SX followed by S1, S2, and F1 until apical prep size of F2 (0.25v) was created. After instrumentation, the canals were dried with paper points and obturated using Kerr EWT sealer (Kerr Dental, Brea, CA) and corresponding 0.02 MAF gutta-percha followed by #20/.02 accessory cones using and #25 hand NiTi spreader (Premier Dental, Plymouth Meeting, PA). and cold lateral compaction A stainless steel plugger (tip size?) heated by a bunsen burner was used to sear off the coronal gutta percha at the cemento-enamel junction. The quantitative evaluation was completed after each project. Straight and shift shot PA radiographs were obtained after final obturation and graded by two calibrated examiners. Each of the following parameters were evaluated including distance from apex, shape, and procedural mishaps. The categories ‘Location from Apex’ and ‘Shape’ were assigned a numerical grade based on a standardized rubric while mishaps were recorded as either being present or absent (see figure 1). Two canals were evaluated, if there was a discrepancy between individual canals, the lower numerical value was assigned to the final grade. The qualitative electronic questionnaire was then given to the students at the end of the semester.

**LOCATION FROM APEX**
- 0: >2 mm from apex, over-extruded GP
- 1: Flush, 1-2 mm from apex
- 2: 0.5-1 mm from apex

**SHAPE**
- 0: Single cone, no or minimal taper, separated file affecting length
- 1: Single cone, few accessory cones, minimal taper, separated file not affecting length
- 2: Well-tapered with coronal flare

**MISHAPS:**
- Yes
- No

**Figure 1:** Quantitative rubric used for grading criteria.
Did you feel you were having a difficult time negotiating the canal with ProTaper Universal?
   a. Yes
   b. No

Did you feel you were having a difficult time negotiating the canal with Vortex Blue?
   a. Yes
   b. No

Did you feel you were having a difficult time negotiating the canal with EndoSequence?
   a. Yes
   b. No

Regarding the number of files, you had to use for ProTaper Universal, did you think there were:
   a. Too Many files
   b. An acceptable amount of files

Regarding the number of files, you had to use for Vortex Blue, did you think there were:
   a. Too Many files
   b. An acceptable amount of files

In regard to the number of files you had to use for EndoSequence, did you think there were:
   a. Too Many files
   b. An acceptable amount of files

Did you receive additional help from faculty or residents during the root canal instrumentation?
   a. Yes
   b. No

If you selected yes in the previous question, what kind of help did you receive?
   a. Hands on help only
   b. Verbal instruction only
   c. Hands on help and verbal instruction

Did you research any of the file systems outside of class lectures and demonstrations before completing this lab?
   a. Yes
   b. No

If you selected yes to the previous question, what type of additional aid did you use?
   a. Literature
   b. Videos
   c. Other resources not listed above _____ (please describe)

Did you encounter any of the following mishaps using ProTaper Universal (please circle all that apply)?
   a. Separated instrument
   b. Perforation
   c. Ledge formation

Did you encounter any of the following mishaps using Vortex Blue (please circle all that apply)?
   a. Separated instrument
   b. Perforation
   c. Ledge formation

Did you encounter any of the following mishaps using EndoSequence (please circle all that apply)?
   a. Separated instrument
   b. Perforation
   c. Ledge formation

Which sequence of the file system was the most intuitive to use (In other words – which file system was the clearest to you?)
   a. ProTaper Universal
   b. EndoSequence
   c. Vortex Blue
   d. Hand filing with the sequential step back technique

Which file system do you think has the best cutting efficiency?
   a. ProTaper Universal
   b. EndoSequence
   c. Vortex Blue
   d. Hand filing with the sequential step back technique

Which system would you prefer to incorporate into your future practice?
   a. Traditional hand filing (Step back preparation)
   b. EndoSequence
   c. ProTaper Universal
   d. Vortex Blue

Would you prefer to practice with only one rotary system or be exposed to multiple rotary systems in the sim lab?
   a. Only one system
   b. Multiple systems

Figure 2: Qualitative questionnaire provided to students.
STATISTICAL ANALYSIS

A comprehensive statistical approach was conducted to characterize and compare the variables of interest. The presentation and analysis of these variables were completed as follows: Numeric variables were summarized using essential descriptive statistics, including mean, standard deviation, and range. Categorical variables were summarized using frequency and percentage distributions. To assess the association between categorical variables across groups chi-square tests and, where applicable, Fisher's exact tests were employed. When comparing the means of numeric variables ANOVA repeated measure was used. A significance level (alpha) of 0.05 was applied consistently across all statistical comparisons. This threshold was used to determine whether observed differences were statistically significant. All statistical analyses were performed using SAS version 9.4, developed by SAS Institute in Cary, NC. This rigorous statistical methodology ensures that the data analysis is both comprehensive and reliable, allowing for meaningful insights and valid conclusions to be drawn from the study's findings.
RESULTS

Quantitative Analysis

The mean average scores for ProTaper Universal, Vortex Blue, and EndoSequence were 6.22, 6.87, and 6.77 respectively (Figure 3). The total mean score difference between ProTaper Universal and Vortex Blue was significant (p=0.044) but there was no significant difference in mean score when comparing either ProTaper Universal or Vortex Blue to EndoSequence. Separated files were recorded as being present if observed in the PA radiograph. Vortex Blue Quantitative analysis of procedural mishaps demonstrated the following separation rates for each system: ProTaper Universal (7.4%); Vortex Blue (0%); EndoSequence (3.2%). This distribution of the percentages of the broken files is different for three groups (p=0.0197).

![QUANTITATIVE ANALYSIS](image)

**Figure 3:** Mean average score assigned to each file system.

Qualitative Analysis

One student chose to not participate in the questionnaire so only 93 (98.9%) responses were recorded. Students were surveyed if they felt they were having a difficult time negotiating the canal with each system. For ProTaper Universal, 9.7% of students
believed it was difficult to use this system while 90.3% did not have trouble negotiating the canal. While using Vortex Blue, 7.5% of students found it difficult to negotiate canals while 92.4% did not. Lastly, 10.8% of students found negotiation difficult with EndoSequence while 89.2% did not. Overall, students had a significantly more difficult time negotiating canals using EndoSequence when compared to either ProTaper Universal (p=0.0005) and Vortex Blue (p=0.0254).

Regarding the number of files used for each system, each student was asked if they thought there were ‘too many files’ or ‘an acceptable number of files’. For ProTaper Universal, Vortex Blue, and EndoSequence 92.5% 97.8% and 93.5% of students believed that there were an acceptable number of files in each system respectively. Students were asked to report if they received any additional help from faculty or residents during the root canal instrumentation. 79.6% of students stated that they did receive additional help while 20.4% did not receive additional help. A follow up question was asked regarding what type of additional help students received during the projects. 48.4% of students received verbal instruction only while only 1.1% received hands on help only. 33.3% reported receiving hands-on help in addition to verbal instruction. The survey identified that 75.3% of students researched the files systems outside of class and lectures. However, only 34 students specified what type of additional aid they used outside of the formal class setting with instructional videos being the most frequent answer (73.5%) followed by miscellaneous resources (23.5%), and literature (2.9%). Overall, 50.5% of students thought that Vortex Blue was the most intuitive to use followed by ProTaper Universal (26.9%) then EndoSequence (12.9%). Although hand-filing was not a part of this study’s focus, 5.4% of students believed this method was more intuitive over the use
of rotary files. Most students felt as though Vortex Blue had the best cutting efficiency (53.8%), followed by ProTaper Universal (29.0%) and EndoSequence (17.2%). No students believed that hand-filing with the sequential step-back method had adequate cutting efficiency. Once the students had been exposed to each file system 59.1% would prefer to incorporate Vortex Blue into their future practice followed by 24.7% who would prefer to use ProTaper Universal, and 15.1% who would prefer EndoSequence. Only one student in this survey (1.1%) would prefer to incorporate hand-filing into their future practice. Being introduced to multiple file systems can be overwhelming for novice practitioners and 20.4% of students prefer only learning one system while 79.6% enjoyed learning multiple systems at once. Students were asked to report the total number of mishaps they encountered with each file system. This included ledge formation, file separation, and perforation. For ProTaper Universal, 8.6% of students reported a separated instrument, 9.7% reported perforation, and 9.7% reported a ledge formation. For Vortex Blue, 4.3% of students reported a separated instrument, 6.5% reported perforation, and 6.5% reported a ledge formation. Lastly, for EndoSequence 2.2% reported a separated instrument, 7.5% reported perforation, and 4.3% reported ledge formation. There was a significant difference in reported total procedural mishaps between ProTaper Universal and Vortex Blue (p=0.0144) and no significant difference between Vortex blue and ProTaper when compared to EndoSequence. When analyzing the file separation rates individually, students reported a 9%, 4%, and 2% rate for ProTaper Universal, Vortex Blue, and EndoSequence respectively. This distribution of percentages of the separated files was the same across the three groups and was not statistically significant (p=0.1218).
Figure 4: Qualitative questionnaire results.
Regarding the number of files, you had to use for Vortex Blue, did you think there were:

- Too Many files: 2
- An acceptable amount of files: 91

Regarding the number of files, you had to use for EndoSequence, did you think there were:

- Too Many files: 6
- An acceptable amount of files: 87

Did you receive additional help from faculty or residents during the root canal instrumentation?

- Yes: 74
- No: 19

If you selected yes in the previous question, what kind of help did you receive?

- Hands on help only: 1
- Verbal instruction only: 45
- Hands on help and verbal instru...: 31

**Figure 4:** *Qualitative questionnaire results continued.*
Did you research any of the file systems outside of class lectures and demonstrations before completing this lab?

- Yes: 23
- No: 70

If you selected yes to the previous question, what type of additional aid did you use?

- Literature: 1
- Videos: 25
- Other resources not listed above: 8

Did you encounter any of the following mishaps using ProTaper Universal (please circle all that apply)?

- Separated instrument: 8
- Perforation: 9
- Ledge formation: 9

Did you encounter any of the following mishaps using Vortex Blue (please circle all that apply)?

- Separated instrument: 4
- Perforation: 6
- Ledge formation: 6

Figure 4: Qualitative questionnaire results continued.
Did you encounter any of the following mishaps using EndoSequence (please circle all that apply)?

- Separated instrument: 2
- Perforation: 7
- Ledge formation: 4

Which sequence of the file system was the most intuitive to use (in other words – which file system was the clearest to you?)

- ProTaper Universal: 25
- EndoSequence: 12
- Vortex Blue: 47
- Hand filing with the sequential s...: 5

Which file system do you think has the best cutting efficiency?

- ProTaper Universal: 27
- EndoSequence: 16
- Vortex Blue: 50
- Hand filing with the sequential s...: 0

**Figure 4:** *Qualitative questionnaire results continued.*
Which system would you prefer to incorporate into your future practice?

- Traditional hand filing (Step bac... 1
- EndoSequence 14
- ProTaper Universal 23
- Vortex Blue 55

Would you prefer to practice with only one rotary system or be exposed to multiple rotary systems in the sim lab?

- only one system 19
- Multiple systems 74

Figure 4: Qualitative questionnaire results continued.
DISCUSSION

Though some may suggest that traditional hand instrumentation is the safest instrumentation technique to introduce to predoctoral dental students during their second year of dental school, others will argue that novice users can achieve better results with greater efficiency using motor driven instrumentation techniques. (Sonntag et al.; Georgelin-Gurgel et al.; Friedlander and Anderson; Sattapan et al.; Peru et al.) Research also suggests the importance of teaching rotary instrumentation to predoctoral dental students while they are unbiased more receptive and malleable to learning new techniques. (Baumann and Roth) The efficiency of rotary instrumentation also allows students to complete procedures at a faster rate with fewer appointments, providing better access to care for the patients in the dental community. (Martins et al.)

Others have demonstrated that dental students produce better results with higher dentin conservation and less transportation of curved canals when compared with hand-files. (Peru et al.) Students in previous studies have also reported that NiTi rotary instruments are more efficient, safer, and easier to use compared to the stainless-steel hand-files. (Martins et al.) These results are consistent with the qualitative data obtained in this study as only five students (5.34%) reported they preferred to use traditional hand instruments.

Not discussed in this research is the use of reciprocating file systems. Many dental schools have introduced reciprocating file systems into their curriculum for several reasons. Reciprocating files mimic the motion of a hand file with a backward and forward motion. (Grande et al.) This motion aides with increasing the cyclic fatigue cycle of the file leading to higher resistance to fracture. (Grande et al.) Whereas it’s been
demonstrated that students first learning endodontic instrumentation have decreased fracture rates when using reciprocating files,(Hamid et al.) the use of reciprocating files have also been shown to decrease the overall chair time for the patient. Reciprocating files were not included in this study, and this may be considered a limitation. A repeat of this study in the future with their incorporation should be considered. The limitations of this study did not allow for further research comparing reciprocation to rotary instrumentation.

**QUANTITATIVE DATA DISCUSSION**

The data collected in this study provides qualitative and quantitative evidence of a preferred rotary file system and the file system that produced the fewest procedural errors. Instrumentation success was evaluated by reviewing periapical images. Success was based on the incidence of separated files, distance from apex, and overall canal shape. Regarding separated instruments, Vortex Blue had no separated instruments observed by examiners. There were three separated instruments reported by the examiners in the EndoSequence group and seven separated instruments in the ProTaper Universal group. Previous studies have reported Vortex Blue rotary files are more resistant to cyclic fatigue when compared to ProTaper Universal.(Nguyen et al.) The quantitative findings from this study are in agreement. Although the electropolishing feature of EndoSequence files is to prevent crack propagation, previous studies have shown that all EndoSequence files showed some sort of crack formation and plastic deformation after use.(Herold, Johnson and Wenckus) The students may have used these files numerous times throughout the course which could explain why EndoSequence also had a higher rate of file separation. A possible explanation of the higher separation rates
for ProTaper Universal could be due to the variable taper design while EndoSequence and Vortex Blue are constant tapers. A study by Parashos demonstrated that triangular variable taper files had higher rates of unwinding, torsional fracture, and flexural fracture when compared to constant taper files. (Parashos, Gordon and Messer) Since ProTaper Universal is variable taper, it may have had a higher incidence of torsional fatigue where the apical portion of the final is engaged and the more coronal aspect of the file continues to rotate. This could have caused a higher fracture rate in the apical portion for this system. An additional cause for these differences could be due to the different file sequences used for each system. The ProTaper Universal sequence has students begin with the S-1 and S-2 shaping files. These files are designed to instrument the coronal 2/3 of the canal. Although it is not explicitly recommended to take the shaping files to working length, students who experienced separated files may have sent the initial shaping files to working length. The apical prep size for the S-1 and S-2 are a size #17 and a size #20 respectively. Identifying which files were separated by a periapical image is close to impossible, but there is a high probability that these are the files that students separated due to their smaller sizes making them more delicate. In addition, with the aggressive cutting of variable taper files students may have felt that they needed to push harder on the file to get it to working length. Students have not developed the tactile sense required to gauge the amount of pressure to put on the file as its traversing down the canal. (Herold, Johnson and Wenckus) In comparison, students may not feel the need to push harder with EndoSequence and Vortex Blue since the coronal aspect of the canal is enlarged in a crown down fashion to minimize the stress on the file as it extends apically. Overall, Vortex Blue had a significantly higher mean score compared to
ProTaper Universal during the evaluation of the periapical radiographs (p=0.044). This could potentially be due to the higher number of separated files observed when evaluating the ProTaper Universal system. The separated instruments may have impacted the distance from the apex in addition to the shape of the canal preparation. There was no statistically significant difference in overall mean score when either ProTaper Universal or Vortex Blue to EndoSequence.

**QUALITATIVE ANALYSIS DISCUSSION**

Students completed a short questionnaire after all the projects for the semester were completed. Students were asked if they had a difficult time negotiating the canals for each individual system. The results demonstrated that students felt they had a much more difficult time negotiating canals with EndoSequence when compared with ProTaper Universal or Vortex Blue. The results were statistically significant for both ProTaper Universal (p=.0005) and Vortex Blue (p=.0254) when compared to EndoSequence. There was no statistical significance when comparing ProTaper Universal to Vortex Blue in regard to difficulty negotiating the canals. A possible explanation for these results could be found in the flexibility of the files. Although EndoSequence claims that the electropolishing of its files can increase flexibility, when compared to two file systems that have additional heat treatments, this system may feel stiffer in the hands of the dental students.

Students were also surveyed on the total number of mishaps they encountered such as ledge formation, perforation, and file separation. Students reported a significantly higher number of total mishaps when using ProTaper Universal compared to Vortex Blue (p=0.0144). There were no significant differences when either ProTaper
Universal or Vortex Blue were compared to EndoSequence in the total number of mishaps. Due to the delay in receiving the survey, students may have guessed how many files they think they separated when using one system over another. As mentioned before, Vortex Blue has been shown to have higher cyclic fatigue compared to ProTaper Universal which also would contribute to the number of separated files reported within the survey. (Nguyen et al.)

Perforations were another procedural mishap the students were asked to report. Some students believed a perforation consisted of an over-extended gutta percha cone through the apical foramen. This may have led to higher reports of ‘perforations’ for some systems when compared to others.

Overall, students reported that they preferred to use Vortex Blue over the other file systems and that they would be interested in implementing this system into their future practice. This could be due to the lower number of procedural mishaps reported and that they reported this file to have a higher cutting efficiency when compared to ProTaper Universal and EndoSequence. Whether a pre-doctoral student can truly appreciate different cutting efficiencies of file systems after limited exposure is debatable.

**LIMITATIONS**

Limitations with the study design are comprised of several factors contributing to potential bias. The expectation for a second-year dental student to learn three different rotary file systems after limited exposure may be overwhelming and confusing for students. However, a majority of students did report they prefer to be introduced to several file systems while in the simulation lab. If given sufficient time, exposure to
different file systems may have resulted in different outcomes. However, due to time constraints within the semester, it was not possible to assign additional projects using different rotary systems. The Vortex Blue rotary file system was assigned as the system of choice for two additional projects throughout the semester resulting in increased familiarity and better outcomes. In addition, Vortex Blue was assigned as the required file system for one of the competency exams, highlighting a potential limitation in the experimental design.

The periapical radiographs from the competency exam were used for evaluation of this research. Although each project assigned through the semester affected the student’s overall course grade, students tend to work differently under the stress of an official competency exam, contributing to further limitations of this study.

Using a 2-D periapical radiograph of the final obturation as the evaluation method led to the following biases: A well-obturated canal was able to mask the presence of a separated file which may contribute to the different separation rates of each system. Magnification is often times required to identify a fractured instrument. (Parashos, Gordon and Messer) Students in this study did not have access to any type of endodontic operating microscope. Instruments can leave such small fragments in the canal that they are easily bypassed before the provider can even recognized that a fragment was left behind. (Parashos, Gordon and Messer)

Distance from the apex may have been the result of the obturation technique versus a function of the instrumentation technique. Students remove the coronal gutta percha by heating a plugger with a heat source (Bunsen burner). As a result of the uncontrolled heat, students tended to pull their cones coronally during the obturation.
Since obturation is technique sensitive, future studies may consider using a master apical file radiograph as their evaluation of cleaning and shaping for each rotary system to avoid adding an additional bias. A future repeat of this study should consider incorporating these scans to gain a greater insight into which system produced greater conservation of dentin and less transportation. A repeat study may also be completed on extracted teeth as another concern is the deformation of the plastic once heat is generated by each file system which may have altered the results of this study to an extent.

The questionnaire (Figure 2) requested a yes/no response regarding separated files. No distinctions were made between a separated hand-file and separated rotary file. Students may not have been properly instructed to discard overused files which could result in file separation.

There was also a potential that some rotary files were reused more than others since the students had a limited supply or they would have to purchase new files at their own expense. Novice users may not be able to recognize or appreciate when files are beginning to unwind leading to higher risks of separation.

Instructor intervention was not recorded, thereby some students may have received more assistance from instructors than others. Instructor intervention was not standardized. Forty-five students reported receiving verbal instructions only while thirty-one students reported hands-on and verbal instruction while completing their projects.

Another possible limitation to this study was the questionnaire was presented to the students at the end of the semester after completion of all projects. The time lapse of one week between the completion of the course and the questionnaire may have negatively impacted the questionnaire results because of inaccurate recalled data.
The final limitation to this study was the lack of standardized working lengths resulting in working length variation and variation in distance from the apex, again not necessarily a function of the instrumentation technique. Students were instructed to pre-measure the standardized tooth prior to mounting it in the ModuPro model. If a student miscalculated the initial working length from the beginning, their final obturation radiograph would be inaccurate resulting in overfilled or underfilled canals. A shorter working length observed on the periapical image could have caused students to report ‘ledges’ when reporting the total number of procedural mishaps during the qualitative analysis. Therefore, an underestimated working length may have impacted the results although it was not directly related to the file systems used.

Regardless of file design and instrumentation techniques, the provider’s clinical experience and overall knowledge of appropriate case selection may be more significant in the prediction of the risk of file separation. (Herold, Johnson and Wenckus) Without the proper introduction in the dental school setting, students may rely on outside continuing education courses to learn how to use NiTi rotary instruments. Many of these courses may be financially driven and lack information on appropriate case selection, leading new users to adopt a specific brand and use it for all of their clinical cases.
CONCLUSION

In the hands of predoctoral dental students, Vortex Blue rotary files produced the best results when compared to ProTaper Universal when graded by the examiners and had the least number of separated instruments. Qualitative analysis demonstrated that students had a more difficult time negotiating canals using EndoSequence when compared to Vortex Blue or ProTaper Universal. There were significantly fewer total mishaps reported when comparing Vortex Blue to ProTaper Universal (p=0.0144). Overall, predoctoral dental students preferred using Vortex Blue rotary files and would consider implementing this system into their future practice.


Munoz, Estefania, Leopoldo Forner, and Carmen Llena. Print.


