การศึกษาความสามารถในการขยายคลองรากฟันของโปรเทเปอร์เน็กส์ในคลองรากฟันจำลองที่มีความโค้งแบบเอส

นายศิรวุฒิ หิรัญอัศว์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาวิทยาเอ็นโดดอนต์ ภาควิชาทันตกรรมหัตถการ
คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

STUDY OF SHAPING ABILITIES OF PROTAPER NEXT IN SIMULATED S-SHAPED CANAL

Mr. Sirawut Hiran-us

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Endodontology
Department of Operative Dentistry
Faculty of Dentistry
Chulalongkorn University
Academic Year 2013

Thesis Title	STUDY OF SHAPING ABILITIES OF PROTAPER NEXT IN SIMULATED S-SHAPED CANAL
By	Mr. Sirawut Hiran-us
Field of Study	Endodontology
Thesis Advisor	Somsinee Pimkhaokham, Ph.D.

Accepted by the Faculty of Dentistry, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Dentistry

(Assistant Professor Suchit Poolthong, Ph.D.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Anchana Panichuttra, Ph.D.)

....Thesis Advisor

(Somsinee Pimkhaokham, Ph.D.)

....Examiner

(Uraiwan Chokechanachaisakul, Ph.D.)

....External Examiner

(Associate Professor Mettachit Nawachinda)

ศิรวุฒิ หิรัญอัศว์ : การศึกษาความสามารถในการขยายคลองรากฟันของโปรเทเปอร์เน็กส์ในคลองรากฟันจำลองที่มีความโค้งแบบเอส. (STUDY OF SHAPING ABILITIES OF PROTAPER NEXT IN SIMULATED S-SHAPED CANAL) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ดร.สมสินี พิมพ์ขาวขำ, 79 หน้า.

บทนำ : การศึกษานี้มีจุดประสงค์ที่จะประเมินความสามารถในการขยายคลองรากฟันของไฟล์นิกเกิลไทเทเนียมสามระบบโดยเปรียบเทียบค่าการวัดหกค่าได้แก่ การเบี่ยงเบนของคลองรากฟัน ตำแหน่งรูเปิดปลายราก มุมความโค้ง รัศมีความโค้ง ความผิดปกติของรูปร่างคลองรากฟันและเวลาที่ใช้ในการขยายคลองรากฟัน วิธีการวิจัย : แบบจำลองคลองรากฟันที่มีความโค้งแบบเอส 30 อันถูกยึดไว้กับแท่นยึดเพื่อถ่ายภาพก่อนการขยายคลองรากฟัน จากนั้นนำมาเตรียมไกลด์พาธด้วย ตะไบมือชนิดเคเบอร์ 10 และเครื่องมือพาธไฟล์เบอร์ 13, 16 และ 19 จากนั้นทำการสุ่มแบบจำลองออกเป็น 3 กลุ่ม กลุ่มละ 10 อันโดยแบ่งออกเป็นกลุ่ม โปรเทเปอร์ยูนิเวอซัล, โปรเทเปอร์เน็กส์ และ ไอเรซ และทำการขยายคลองรากฟันจนถึงขนาดเบอร์ 25 ตามคำแนะนำของบริษัทผู้ผลิต จากนั้นนำภาพก่อนและหลังขยายคลองรากฟันมาซ้อนทับกันเพื่อประเมินการเบี่ยงเบนของคลองรากฟันและตำแหน่งของรูเปิดปลายรากที่แปดระดับ ทำการวัดมุมและรัศมีความโค้งทั้งบริเวณโค้งบนและโค้งล่างจากภาพก่อนและหลังขยายคลองรากฟัน ภาพหลังขยายคลองรากฟันจะถูกนำมาขยายเพื่อระบุความผิดปกติของรูปร่างคลองรากฟันที่เกิดขึ้นในคลองรากฟัน บันทึกเวลาที่ใช้ในการขยายคลองรากฟัน ผลการทดลอง : การเบี่ยงเบนของคลองรากฟันเกิดขึ้นน้อยที่สุดในกลุ่มไอเรซและมากที่สุดในกลุ่มโปรเทเปอร์ยูนิเวอซัล โดยการเบี่ยงเบนทั้งหมดจะเกิดขึ้นที่โค้งในของความโค้ง ตำแหน่งรูเปิดปลายรากฟันมีการขยับไปทางด้านโค้งนอกของความโค้งโดยมีความแตกต่างกันอย่างมากระหว่างกลุ่ม ความผิดปกติของรูปร่างคลองรากฟันเกิดขึ้นน้อยที่สุดในกลุ่มโปรเทเปอร์เน็กส์ และมากที่สุดในกลุ่มโปรเทเปอร์ยูนิเวอซัลซึ่งแตกต่างกันอย่างมีนัยสำคัญ ไม่พบความแตกต่างของมุมและรัศมีความโค้งที่เปลี่ยนแปลงไประหว่างทั้งสามกลุ่ม เวลาที่ใช้ในการเตรียมคลองรากฟันในทั้งสามกลุ่มแตกต่างกันอย่างมีนัยสำคัญ โดยน้อยที่สุดในกลุ่มไอเรซและมากที่สุดในกลุ่มโปรเทเปอร์ยูนิเวอซัล การทดสอบทางสถิติทั้งหมดทำที่ระดับความเชื่อมั่น ร้อยละ 95 บทสรุป : ไอเรซทำให้เกิดการเบี่ยงเบนของคลองรากฟัน การเคลื่อนของตำแหน่งรูเปิดปลายรากและเวลาน้อยที่สุด โปรเทเปอร์เน็กส์ทำให้เกิดความผิดปกติของรูปร่างคลองรากฟันน้อยที่สุด ส่วนโปรเทเปอร์ยูนิเวอซัลทำให้เกิดการเบี่ยงเบนของคลองรากฟัน การเคลื่อนของตำแหน่งรูเปิดปลายรากและเวลามากที่สุด การเปลี่ยนแปลงของมุมและรัศมีความโค้งในแต่ละระบบไม่แตกต่างกัน

ภาควิชา ทันตกรรมหัตถการ ลายมือชื่อนิสิต ....

สาขาวิชา วิทยาเอ็นโดดอนต์ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ปีการศึกษา 2556

5575823432 : MAJOR ENDODONTOLOGY
KEYWORDS: PROTAPER NEXT / SHAPING ABILITY / S-SHAPED

SIRAWUT HIRAN-US: STUDY OF SHAPING ABILITIES OF PROTAPER NEXT IN SIMULATED S-SHAPED CANAL. ADVISOR: SOMSINEE PIMKHAOKHAM, Ph.D., 79 pp.

Introduction: The aim of this study was to determine the shaping abilities of three nickel-titanium (NiTi) endodontic file systems by comparing six parameters: canal deviation, apical foramen position, angle of curvature, radius of curvature, aberrations and instrumentation time. Methods: Thirty simulated S-shaped canal blocks were placed in a customized stand for imaging, and the glide paths were prepared using #10 K-files and #13, 16 and 19 PathFiles. The blocks were then randomly assigned into three groups (n=10): ProTaper Universal, ProTaper NEXT, and iRace. Each system was used per its manufacturer's recommendation up to apical size #25. Pre- and post-operative images were superimposed and used to determine canal deviation at eight levels and any shifting in apical foramen position. Angle and radius of curvatures were measured both coronal and apical curvatures from pre- and post-operative images. The post-operative images were magnified to identify canal aberrations. Instrumentation times were recorded. Results: The iRace system resulted in the least canal deviation, while the ProTaper Universal system produced the most. All canal deviations were to the inner side of the curvatures. The apical foramen position was shifted to the outer side of the curvatures with marked differences among the groups. The ProTaper NEXT system produced the least canal aberrations and the ProTaper Universal system produced the most which was significant difference. There were no significant difference of changing of angle and radius of curvature among groups. There were significant difference of instrumentation time among three groups, iRace system required the least instrumentation time, while the ProTaper Universal system required the most. A 0.05 significance level was set for statistical analysis. Conclusion: The iRace system showed the least canal deviation at most canal levels, shifting in apical foramen position and instrumentation time while the ProTaper NEXT system produced the least canal aberrations. ProTaper Universal showed the most canal deviation at most canal level, shifting in apical foramen position and instrumentation time. Percent difference of angle and radius of curvatures were not significant difference among three groups.

Department: Operative Dentistry Student's Signature ....
Field of Study: Endodontology Advisor's Signature ....
Academic Year: 2013

ACKNOWLEDGEMENTS

Author owned many thanks to many people who helped and support author during working on this thesis.

My deepest thanks to thesis's advisor, Dr. Somsinee Pimkhaokham for guiding and correcting many documents of mine with attentions and care.

This thesis was supported and facilitated with many people included Dr. Jirapat Sawasdichai, residency training program in Endodontics, Department of Operative Dentistry, Chulalongkorn University, Dr. Daisuke Tokita, Dr. Kana Miyara, Dr. Yoshiko Iino, graduate student, Department of Pulp Biology and Endodontics, Division of Oral health sciences, Medical and Dental Sciences Track, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University (TMDU) and Dr. Arata Ebihara, research associate, Department of Pulp Biology and Endodontics, Division of Oral health sciences, Medical and Dental Sciences Track, Graduate school of Medical and Dental Sciences, Tokyo Medical and Dental University (TMDU).

Special thanks should be given to Professor Hideaki Suda for his comments and kindly supported of his laboratory in Department of Pulp Biology and Endodontics, Division of Oral health sciences, Medical and Dental Sciences Track, Graduate school of Medical and Dental Sciences, Tokyo Medical and Dental University (TMDU), Tokyo, Japan.

Financial issue was supported by grant of Graduate school, Chulalongkorn University, Bangkok, Thailand and JASSO scholarship, Ministry of Education, Culture, Sports, Science and Technology, Japan.

Last but not least, author would like to thank all thesis committee (Assistant Professor Anchana Panichuttra, Associate Professor Mettachit Nawachinda, Dr.Uraiwan Chokechanachaisakul) for their useful comments and kind supports.

CONTENTS

Page

Page

CONTENT OF TABLES

Page

CONTENT OF FIGURES

Page

CHAPTER I

INTRODUCTION

Background and Rational

Root canal preparation is one of the most important step in root canal therapy. The goals of root canal preparation (1) is consisted of

1. To remove all tissue debris from root canal system.
2. To create sufficient space for irrigation and root canal medication.
3. Shaping the canal to receive a three-dimensional hermetic filling of entire space.
4. Conform to the general shape and direction of the original canal.
5. Leaving the original foramen in its natural position.

One of the challenges in root canal preparation is to shape the canal which have multi-curvatures known as “S-shaped”. From the study that investigated canal curvatures in 433 anterior and posterior human teeth by radiographic imaging, they found 16% of S-shaped canal which was relatively high. Most of the canals always have unseen curvatures which are not shown in radiograph and can be bent at every point with varying degrees (2). Shaping with stainless steel files in multi-curvatures canals leads to many errors during shaping procedures such as misshaped, ledge, zipping, transportation and perforation (3).

To overcome the errors from root canal preparation procedure, the NiTi rotary instrument was developed and introduced to endodontic field. NiTi rotary instrument has been proved of efficacy in shaping the root canal with superior outcome and less errors (4-6).

Recently, the new NiTi rotary instrument system called “ProTaper NEXT” was introduced. This system was developed in a basis of combining benefits from many previous and recent generations of NiTi rotary system, which is comprised of variable taper design, M-Wire alloy, new cross-section design and off-set of the center of rotation (7). The ProTaper NEXT was recently introduced into the market and there is no scientific literatures related to this instrument, so we are interested in investigation of shaping abilities of ProTaper NEXT in the simulated S-shaped canal.

In the era of evidence-based dentistry, using instruments and techniques in endodontic treatment also required scientific supports. ProTaper NEXT was a new release NiTi rotary system which was developed from ProTaper Universal. ProTaper Universal had a long history of wildly used all over the world. But from scientific literatures about shaping ability in S-shaped canal, they showed less effectiveness when compared to other NiTi rotary systems (8, 9). iRace has a metallurgy and design from the same generation of ProTaper Universal, but was introduced later. iRace has number of instruments closed to ProTaper NEXT. According to manufacturer, iRace is effective in curved canal, but no available scientific literatures to support this claim. It is of my interest to study shaping abilities of the new ProTaper NEXT in simulated S-shaped canals and compared the results with other NiTi rotary systems; ProTaper Universal and iRace.

Objectives

To compare shaping abilities of the ProTaper NEXT, ProTaper Universal and iRace rotary systems in simulated S-shaped canal by six different parameters.

Parameters of shaping abilities

1.1. Canal deviations

1.2. Angle of curvatures

1.3. Radius of curvatures

1.4. Canal aberrations

1.5. Positions of apical foramen

1.6. Instrumentation time

Scope of Study

This study was scoped in experimental laboratory study. Prefabricated resin block was used to simulate artificial S-shaped canal instead of human teeth. Investigating the shaping abilities of instruments was done by using superimposition techniques of pre- and post-operative images. Data was analyzed by using Adobe Photoshop and Microsoft PowerPoint programs.

Expected Benefits

The results of this study on the shaping abilities of ProTaper NEXT compared to ProTaper Universal and iRace in simulated S-shaped canal will be beneficial in clinical applications. Instruments required in root canal preparation should produce less canal deviation, preserve original shape and direction, maintain position of apical foramen and less canal aberrations.

CHAPTER II

LITERATURE REVIEW

Origin of S-shaped Canal

One of the classification of root canal curvatures defined by Nagy, which investigated in 433 anterior and posterior human teeth, is a mathematically based classification, which classified into following groups (2).

1. Straight or "I" form which had incidence of 28%
2. Apical curve or "J" form which had incidence of 23%
3. Curve canal along its entire length or "C" form which had incidence of 33%
4. Multi-curved or "S" form which had incidence of 16%

They found 16% of S-shaped canal which was relatively high. Most of the canals always have unseen curvatures which are not shown in radiograph and can be bent at every point with varying degree.

Metallurgy of NiTi Alloys (10)

NiTi alloys used in endedontic are consisted of approximately 56% (wt.) Nickel and 44% (wt.) Titanium. They can exist in two different structures (phases) called martensite (low-temperature phase) and austenite (high-temperature phase). Several properties are different. When martensite phase is heated, it begins to change into austenite phase which has a super-elasticity property. When austenite phase is cooled, it begins to change into martensite phase which can accumulate greater stress without increasing strain. Composition and metallurgical treatments have impacts on transition temperature. In clinical aspect, NiTi alloy has three different forms which are martensite, stress-induced martensite form and austenite from. Martensite from is soft, ductile and can be deformed. Stress-induced martensitie form is highly elastic. Austenite form is quite hard and strong. Conventional NiTi alloys have austenite transforming finish temperature (Af) which is a temperature that the alloy is completely transform into austenite from, near at room temperature. So conventional NiTi alloys are in austenite form in room temperature and became stress-induced martensitic form during clinical use.

Improvement of NiTi Alloys

In Later, NiTi alloy has been improved the quality by many procedures such as electropolish and heat treatment (11). Studies found that heat treatment was effective in increasing the flexibility of NiTi alloys but manufacturers had to perform an appropriate heat treatment, otherwise alloy's properties might not be improved (12, 13). In 2007, M-wire which is NiTi alloys that went through several heat treatment

Profile Vortex, Vortex Blue, WaveOne, Reciproc and recently 2013, ProTaper NEXT. M-wire contains all three crystalline phases, including deformed and microtwinned martensite, R-phase and austenite (14). Files utilizing M-Wire NiTi can feature deeper flutes and smaller core diameters that add to overall flexibility and still demonstrate a greater resistance to cyclic fatigue. Previous study had shown that M-wire reduced cyclic fatigue by 400% comparing files of the same diameter, cross section and taper (15). From other in vitro studies that compared files made by M-wire with files made by conventional NiTi in artificial canals, showed greater resistance to cyclic failure (16) but showed no difference in other study (17). From the studies investigating metallurgical characterization of M-wire concluded that M-wire had higher strength and wear resistant than similar instruments made of conventional NiTi because of its unique nano-crystalline martensitic microstructures (14, 18). These two studies confirmed that improvement of M-wire alloy was caused by presence of stable martensitic structures in body temperatures. In 2008, R-phase was introduced. This alloys was developed by thermal processing of raw NiTi to transform the austenite phase to R-phase. The R-phase is an intermediate phase that can form during forward transformation from martensite to austenite on heating and reverse transformation from austenite to martensite on cooling. CM Wire was introduced in 2010, using a thermomechanical process that controls the memory of the material, making files extremely flexible but without shape memory (11).

Martensitic phase has a unique properties that made it an ideal phase for endodontic such as high fatigue resistance, easily deformed, recover their shape on heating above Af temperatures. New generation of alloys which are M-Wire and CM Wire have increased Af temperatures. CM Wire and M-Wire will be in martensitic phase at body temperature, where as conventional NiTi will be in austenitic phase (11).

Nickel-Titanium Rotary Instruments

In order to shape the curved canal effectively, NiTi rotary instruments were introduced into endodontic as adjuncts. Nickel-titanium alloy has unique properties of shape memory and super-elasticity which means that on unloading period they return to its original shape before deformation (19). The advantage of using of NiTi instruments for preparation curved root canal is the files will not be permanently deformed as easily as conventional alloy. Previous study showed that when apical preparation is greater than ISO #30, NiTi rotary instrument has a better performance in conforming the shape and direction of original canal (20). Although the NiTi rotary instruments may facilitate and improve the quality of root canal preparation, the risks of using these instruments still present. One of the risks is separated instrument, caused by cyclic fatigue which mean that the instruments were exposed to repeated tensile compressive stress. Factors that influence to cyclic fatigue are diameter of instrument, angle and radius of curvatures. Instruments usually separate at the most curved point of the canal (21). This risk can be minimized by creating a smooth glide path before introducing the rotary instrument into the canals (22).

Generations of NiTi Rotary Instrument

Since 1988, NiTi rotary instruments have never stop their evolution in order to maximize the efficacy of root canal preparation. NiTi rotary instruments can be divided into 5 generations. Important feature of first generation was "passive lands", which stabilized files to stay centered in canal curvatures during preparation. Root canal was prepared by planing action form passive radial lands, resulted in slower preparation but reduced errors from preparation procedures. This generation required many number of files to achieve complete preparation of the canals. Files in this generation were Profile, ProSystem GT, Quantec, Guidance and K3. Second generation changed from passive radial lands to active cutting edges which fasten the preparation procedures and required fewer number of instruments. Some instruments (iRace) provided file lines with alternating contact points for reducing taper lock effect caused by fixed taper. Variable taper which has multiple increasing and decreasing percentage tapers on a single file (ProTaper Universal), limited each file's cutting action to a specific region of the canal. Some manufacturer electropolished their files (Mtwo, iRace) to remove surface irregularities caused from grinding process in order to increase the resistance to file separation. Files in this generation were Mtwo, iRace, Race, ProTaper Universal, Pow-R and Sequence. Third generation was focused on metallurgy by utilizing heating and cooling methods to reduce cyclic fatigue and improve safety when working in curved canal. The desired phase-transition point between martensite and austenite can be identified to produce a more clinically optimal metal than NiTi itself. Files made from other NiTi alloys such as M-wire, CM-wire and R-phase were categorized in this generation. Files made by M-wire were WaveOne, Reciproc, Profile Vortex, Vortex Blue, Profile GT Series X and ProTaper NEXT. Files made by CM-wire were Hyflex and Typhoon. Files made by R-phase were Twisted file and K^3XF. Fourth generation was about changing from continuous rotation to reciprocation, which was any repetitive up-and-down or back-and-forth motions. This concept had fulfilled the idea of single-file technique. Files which had up-and-down motions was Self Adjusting file (SAF). Files which had back-and-forth motions were Reciproc, Waveone and Twisted file adaptive. The concept of fifth generation was “the center of mass and/or the center of rotation are off-set”. This produced a mechanical wave of motion that moved along the active length of the file, minimized the engagement between the file and dentin, enhanced removing debris out of a canal and improved flexibility along the active portion of files. Files which had off-set design were Revo-S and ProTaper NEXT. Moreover, some of files were combined good features from several generations. Reciproc and

WaveOne represented the best design features from second and third generations, coupled with a reciprocating motion that move the file in unequal bi-direction angle. These allowed files to more readily progress, efficiently cut and effectively remove debris out of the canal. ProTaper NEXT also included features from second, third and fifth generations which will be explained later.

Shaping in S-shaped Canal

1. Glide path

Glide path is one of a key factor in using the NiTi rotary instruments. Study showed that using of PathFile create glide path in stimulated S-shaped resin block demonstrated significantly less modification of curvature and canal aberrations than stainless-steel hand files (23). Recent study which investigated the glide path preparation with new rotary instrument (Scout Race) compared to PathFile and stainless steel hand files showed that rotary instruments were suitable for adequate glide path preparation and they promoted less deviation from the original canal when compared with hand-operated instruments. Scout Race showed less deviation in most area of the entire canal compared to PathFile (24). Other study which was investigated in human root canal showed that establishing the glide path with either manual instrument or rotary instrument (PathFile or Mtwo) had no any influence on occurrence of apical transportation or produced any canal aberrations (25).

2. Shaping strategies

Shaping in S-shaped canal may lead to many common errors such as ledge, zip and perforation. These errors might be caused by the great taper of conventional NiTi rotary instrument using in canal with high degree of curvatures. Manufacturer has improved their product in the aspects of design, cross-section and metallurgy in order to improve their flexibility. Size and taper of instruments using in S-shaped root canal preparation were investigated. Study of Yoshimine & Ono et al. which compared shaping ability of files (ProTaper Universal, K3, Race) in simulated S-shaped canal by measuring canal deviation at 2 points (most curved points at coronal and apical curvatures), showed that K3 and Race has superior ability than ProTaper Universal. Furthermore, ProTaper Universal showed a tendency to create ledge or zip at the end of the preparation. This study concluded that the 0.06 taper NiTi rotary instruments can prepare the S-shaped canal without creating severe aberrations, if smaller, less tapered files were use before the 0.06 tapered one. Large increase in taper-size may cause a canal aberrations (8). Whereas other study which also compared shaping ability of files (ProTaper Universal, Mtwo, BioRace, BioRace + S-apex) by the same procedures as mentioned by previous study (8). ProTaper Universal resulted in inferior ability than other three groups and created aberrations significantly difference from the BioRace + S-apex, but not significant difference from other two groups. Results from this study suggested that NiTi files with tapers greater than 0.04 and sizes greater than 30 should not be used for apical enlargement of

S-shaped canals (9). Furthermore, working in a complex canal such as multi-curved canal has an adverse effect on cyclic fatigue resistance on instruments. Study showed that number of cycle to failure of instrumentation in multi-curved canal has statistically lower than instrumentation in single curve canal (26).

Methodologies in S-shaped Studies

There were several methodologies in investigation of canal shaping ability which were image superimposition, radiographic subtraction and micro computed tomography. Specimens using in previous studies included human extracted teeth which had advantage from real root canal dentin, instruments could shape the root canal similar to clinical use. Standardization of the samples was a main issue because this method couldn’t establish equality among groups (20, 27-30). Using samples made of resin block might be the best way to standardize the sample among groups, but had limitation of the results interpretation caused by hardness of resin blocks (8, 9, 23, 24, 31). Comparing pre- and post-operative images were investigated by digital imaging which was used with simulated resin blocks. Superimposition of these images provided direct visual comparison and was reproducible (23, 27, 28). Radiographic imaging which was used with human teeth both intra-oral and extracted teeth. Radiographic subtraction technique was used to investigate these images. Position of the film and angle of x-ray beam had to be exactly the same (20, 28). Micro computed tomography which was used with extracted human teeth. This technique provided more reliability in investigating of shaping ability but required more time and technical procedures (29, 30). Studies which investigated the shaping ability in S-shaped canal always used resin blocks and digital imaging in their methodologies due to the standardization of specimens (8, 9, 24, 31, 32). Some studies analyzed canal centering ability or canal transportation at the most curved points which were not represented all difference positions in S-shaped curvature (8, 9), while some analyzed more points along the entire canal. Eight points were chosen in most of later study of S-shaped due to the points were represented all positions along the S-shaped curvature (24, 31). Twelve points were found only in one study, the additional four points were located in straight portion coronal to the S-shaped curvature which may not represent the S-shaped curvature and could interfere with the interpretation of the results (32).

NiTi Rotary Files of Interested

1. ProTaper Universal

ProTaper Universal was the NiTi rotary files in second generation. This system had fewer number of files compared to files in first generation but still made by conventional NiTi. The ProTaper Universal system is comprised of 6 fundamental instruments, which are SX, S1, S2, F1, F2 and F3 which were the fewest number of instruments in the series compared to all other brand in that time. In this study, Files used were SX, S1, S2, F1 (20/.07) and F2 (25/.08). Files were used at 250-350 rpm and torque ranging from 1-4 Ncm. There were several features and benefits of ProTaper Universal which can be listed as following. Multiple tapers: Progressively tapered design which clinically serves to significantly improve flexibility, cutting efficiency and reduce number of recapitulations. This design allows each shaping file to perform its own “crown down” action. Convex triangular cross-section: This feature reduce the contact area between the blade of the file and root canal wall by changing from passive radial land to active cutting edges. Enhancing the cutting action and improving safety by decreasing torsional loads. From the Convex triangular cross-section, the dentin-instrument contact points were three points. Helical angle and pitch: Having a continuously changing helical angle and pitch over their 14 mm of cutting blades were Optimizing its cutting action, effectively allowed debris removal. Prevention of instruments screwing into the canal. Variable tip diameters: Shaping files have variable tip diameter to allow clinicians to safely and efficiently follow the original canal. Modified guiding tip: This allows instrument to better flow the canal and enhance its ability to find its way through soft tissue and loose debris without damaging the root canal walls. Short handle: Improve access to posterior area of the mouth, especially when there is minimal interocclusal space. Shaping technique: After flaring, flattening and finishing the internal axial walls are archived. The SX file is used in brushing manner on the outstroke, to pre-flare the orifice, eliminate triangle of dentin, relocate the coronal most aspect of a canal away from external root concavities. Confirmed a smooth and reproducible glide path with

K-file #15 or established glide path with PathFile. “Float” the S1 file into canal and passively “follow” the glide path until the light resistance, then laterally “brush” and cut dentin on the outstroke, remove the instrument and clean its flutes, before reinserting the instrument, irrigation and recapitulation is mandatory. Continue the S1 until the WL is reached. The S2 is used in the same manner as S1. Use F1 in a non-brushing action until WL is reached then withdraw the file as the shape is cut. Irrigation and recapitulation after remove the instrument is mandatory. The F2 is used in the same manner as F1 (33).

2. iRace

Characteristic, design and metallurgy of iRace (IRA) were correlated to files in second generation. iRace was developed and introduced after ProTaper Universal, so the number of file was less than the ProTaper universal system. This system had fixed taper and made by conventional NiTi. The iRace system is comprised of three fundamental instruments, which are R1, R2 and R3. In this study, Files used were R1 (15/.06) and R2 (25/.04) with a speed of 600 rpm and a torque of 1.5 Ncm. Features of iRace can be listed as following. Round safety tip: Perfect centering of the instrument in the canals, less risk of perforation nor ledge. Alternative cutting edges: For anti-screwing in effect but the cutting efficiency remained. Triangular cross-section with sharp edges: Cut better and faster without any pressure. The small core grant a higher flexibility and allows a better progression in curved canals. More space for debris removal, improving their evacuation without jamming the blade. Triangular cross-section provided three dentin-instrument contact points. Electrochemical polishing: The treatment eliminates surface imperfections, reduces the risk of weak points (micro-cracks). Shiny surface allows better cleaning and disinfection, improve the sterilization process. Enhanced resistance against fatigue and corrosion. Safety memo disc for controlling number of usage. iRace shaping technique: After establishing the glide path. The R1 is used in long back and forth gentle strokes, light touch, 3-4 seconds in a row. Remove the instrument and clean the blade. Irrigation and recapitulation to confirm the patent of the canals. Continue the instrumentation until the working length is reached. The R2 is used as the same manner as R1 (34).

3. ProTaper NEXT

The ProTaper NEXT (PTN) has three significant design features from three different generations, including variable tapers on a single file from second generation, M-wire technology from third generation and fifth generation of the off set design. PTN is consisted of 5 files which are X1, X2, X3, X4 and X5. Most of the cases can be finished the preparation within 2-3 files. For an example, the PTN X1 file has a centered mass and axis of rotation from D1-D3, whereas from D4-D16, the file has an offset mass of rotation. For percentage tapers, starting at 4%, a file has 10 increasing percentage tapers from D1-D11, but D12-D16, there are decreasing percentage tapers to enhance flexibility and conserve radicular dentin during shaping procedures. Both PTN X1 and X2 files have an increasing and decreasing percentage tapered designed on a single file, but PTN X3, X4, X5 files have a fixed taper from D1-D3, then a decreasing percentage tapered design over the rest of their active portions. All files are used at 300 rpm and a torque of 2.0-5.2 Ncm. Ruddles, the co-inventor of PTN preferred a torque of 5.2 Ncm, as this level of torque has been validated as profoundly safe if clinician perform meticulous glide path management procedures and utilize an outward brushing motion, when progressively shaping the canal. The new design of rectangular off-set cross-section was produced only two dentin-instrument contact points. Furthermore, all files are used in exactly the same way and are always the same regardless of the length, diameter or curvature of a canal as following: After flaring, flattening and finishing the internal axial walls are archived. The SX file is used in brushing manner on the outstroke, to pre-flare the orifice, eliminate triangle of dentin, relocate the coronal most aspect of a canal away from external root concavities. Confirm a smooth and reproducible glide path with K-file #15 or establish glide path with PathFile. The X1 file is used in brushing manner on the outstroke, after every few millimeters of file progression, remove the instrument and clean its flutes, before reinserting the instrument, irrigation and recapitulation is mandatory. Continue the X1 until the WL is reached. The X2 is used in the same manner as X1 (7).

CHAPTER III

RESEARCH METHODOLOGY

Target Population

Multi-curved root canal

Sample

Endo Training-Bloc-S, 0.02 Taper (Dentsply Maillefer, Ballaigues, Switzerland)

Independent Variable

Type of rotary files

Dependent Variables

Canal deviations, angle of curvature, radius of curvature, canal aberrations, positions of apical foramen, instrumentation time

Confounding Factors

Errors in blocks from manufacturer, errors in files from manufacturer, human errors in shaping root canal and data analysis.

Materials

1. Stereomicroscope (Keyence VH8000, OSK, Japan)
2. Endodontic motor (X-smart Plus, Dentsply Maillefer, Tulsa, OK)
3. Computer
4. Computer software (Adobe Photoshop Version7, Microsoft PowerPoint 2013, SPSSVersion17; SPSS Inc, Chicago, IL)
5. Timer
6. Endo Training-Bloc-S, 0.02 Taper (Dentsply Maillefer, Ballaigues, Switzerland)
7. ProTaper Universal rotary files (Dentsply Maillefer, Tulsa, OK)
8. ProTaper NEXT rotary files (Dentsply Tulsa Dental Specialties)
9. iRace rotary files (FKG Dentaire, SA, Switzerland)
10. PathFile (Dentsply Maillefer, Tulsa, OK)

11. Glide (Dentsply Maillefer, Tulsa, OK)

12. K-file #10 (Dentsply Maillefer, Tulsa, OK)

13. Max-i-probe 30-G side vented (Dentsply Maillefer, Tulsa, OK)

14. Syringe

15. Erythrosine dye (Faculty of Dentistry, Chulalongkorn University)

16. Tap water

Methods

This study was divided into two parts. First part was experimental part which was comprised of imaging, sampling the samples, glide path preparation and root canal preparations. Second part was analytical part which was comprised of measuring and analysis of the six parameters. First investigator was focused on first part and blinded second investigator who focused on second part.

1. Pre-operative imaging

Thirty Endo training-Bloc-S, 0.02 Taper, each with a 20- degree apical curvature (3.5 mm radius of curvature), 30-degree coronal curvature (5 mm radius of curvature) were used in this study as samples representing for stimulated S-shaped canals. All samples were fixed in customized stand for precise reposition and marked in 4 positions as reference points for facilitating the image analysis procedures. Before starting the procedures, a preview of pre-operative image was recorded and calibrated the magnification (15X). This magnification calibration was applied to the rest of imaging procedures. Pre-operative images were taken by stereomicroscope in a view that showed both of apical and coronal curvatures. Pre-operative images were taken two times for each samples either with erythrosine dye or without erythrosine dye.

2. Glide path preparation and samples grouping

All canals were initiated with K-file #10 to confirm patency and instrumented as in & out motion until a smooth slide path were established. PathFiles #13, 16, 19 were used to establish glide path at the working length (16 mm) in a sequence according to manufacturer's recommendation. After each instrument, canal was flushed with tap water via Max-i-probe 30-G side vented and recapitulated with K-file #10 to remove debris and root canal obstructions and keep the patency of the root canal. Samples were randomly divided into three groups. PTU (ProTaper Universal group), PTN (ProTaper NEXT group) and IRA (iRace group) with 10 samples each.

3. Root canal preparation and intra- and post-operative imaging

Root canal preparation in PTU and PTN groups began with SX file at 13 mm depth for coronal flaring. In PTU group, canals were prepared with S1, S2, F1 and F2 respectively according to manufacturer's recommendation. In between each instrument and at the end of the canal preparation, block was repositioned into fixed customized stand. Intra- and post-operative images of canal with or without erythrosine dye injection were taken for further investigations.

In PTN group, canals were prepared with X1, X2 respectively according to manufacturer's recommendation. Intra- and post-operative images were also taken in the same way as PTU. In IRA group, canals were prepared with R1 and R2 respectively according to manufacturer's recommendation. Intra- and post-operative images were also taken in the same way as PTU. During the procedure, Glyde was used as lubricant during each instrument. Irrigation with tap water via Max-i-probe 30-G side-vented and recapitulation with K-file #10 were done every time after each instrument reached the working length and before continued to the next instrument. Irrigant used in all groups were limited to 5 ml. All procedures were performed by single operator who is competent in using all rotary file systems. All the rotary file was discarded after single use.

Table 1 Glide path preparation protocol

Files	Action	Length	Stroke (times)	IR (ml)	Recap (times)	IR (ml)	Irrigants remaining in syringe (ml)
K #10	WW	WL	5	0.5	-	-	5.0
K #10	In & Out	WL	5	0.5	-	-	4.5
K #10	In & Out	WL	5	0.5	-	-	4.0
PF #13	In & Out	WL	5	0.5	5	0.5	3.0
PF #16	In & Out	WL	5	0.5	5	0.5	2.0
PF #19	In & Out	WL	5	0.5	5	0.5	1.0
PF #19	In & Out	WL	5	0.5	5	0.5	0.0

Start with 5.5 ml tap water in syringe

Table 2 PathFiles setting

Files	Torque (Ncm)	Speed (rpm)	Length (mm)	Action
13	4	300	WL	In & out
16	4	300	WL	In & out
19	4	300	WL	In & out

Table 3 ProTaper Universal preparation protocol

Files	Action	Length	Stroke (times)	IR (ml)	Recap (times)	IR (ml)	Irrigants remaining in syringe (ml)
Sx	Brush	13mm	5	0.5	5	0.5	4.0
S1	Brush	WL	5	0.5	5	0.5	3.0
S2	Brush	WL	5	0.5	5	0.5	2.0
F1	In & Out	WL	3	0.5	5	0.5	1.0
F2	In & Out	WL	1	0.5	5	0.5	0.0

Start with 5.0 ml tap water in syringe

Table 4 ProTaper Universal setting

Files	Torque (Ncm)	Speed (rpm)	Length (mm)	Action
SX	4	300	13	Brush
S1	3	300	WL	Brush
S2	1.5	300	WL	Brush
F1	2	300	WL	In & out
F2	3	300	WL	In & out

Table 5 ProTaper NEXT preparation protocol

Files	Action	Length	Stroke (times)	IR (ml)	Recap (times)	IR (ml)	Irrigants remaining in syringe (ml)
Sx	Brush	13mm	5	0.5	5	1.0	3.5
X1	Brush	WL	5	1.0	5	1.0	1.5
X2	Brush	WL	1	0.5	5	1.0	0.0

Start with 5.0 ml tap water in syringe

Table 6 ProTaper NEXT setting

Files	Torque (Ncm)	Speed (rpm)	Length (mm)	Action
SX	4	300	13	Brush
X1	4	300	WL	Brush
X2	4	300	WL	Brush

Table 7 iRace preparation protocol

Files	Action	Length	Stroke (times)	IR (ml)	Recap (times)	IR (ml)	Irrigants remaining in syringe (ml)
R1	In & out	WL	5	1.0	5	2.0	2.0
R2	In & out	WL	1	1.0	5	1.0	0.0

Start with 5.0 ml tap water in syringe

Table 8 iRace setting

Files	Torque (Ncm)	Speed (rpm)	Length (mm)	Action
R1	1.5	600	WL	In & out
R2	1.5	600	WL	In & out

Determination of Parameters

Canal deviation analysis

Pre- (without dye) and post-operative (with dye) images were superimposed by overlapping four reference points using computer software (Adobe Photoshop Version 7). Measurement were performed both in left and right side of curvatures at 8 levels, which level 0 was located at apical foramen and level 1-7 were located at every 1 mm coronally. Canal deviations were measured by the difference between left and right values of canal in the same level which were distance from wall to wall of pre- and post-operative images (Fig 1). If the difference between left and right was equal to 0, that point were judged as nondeviation .

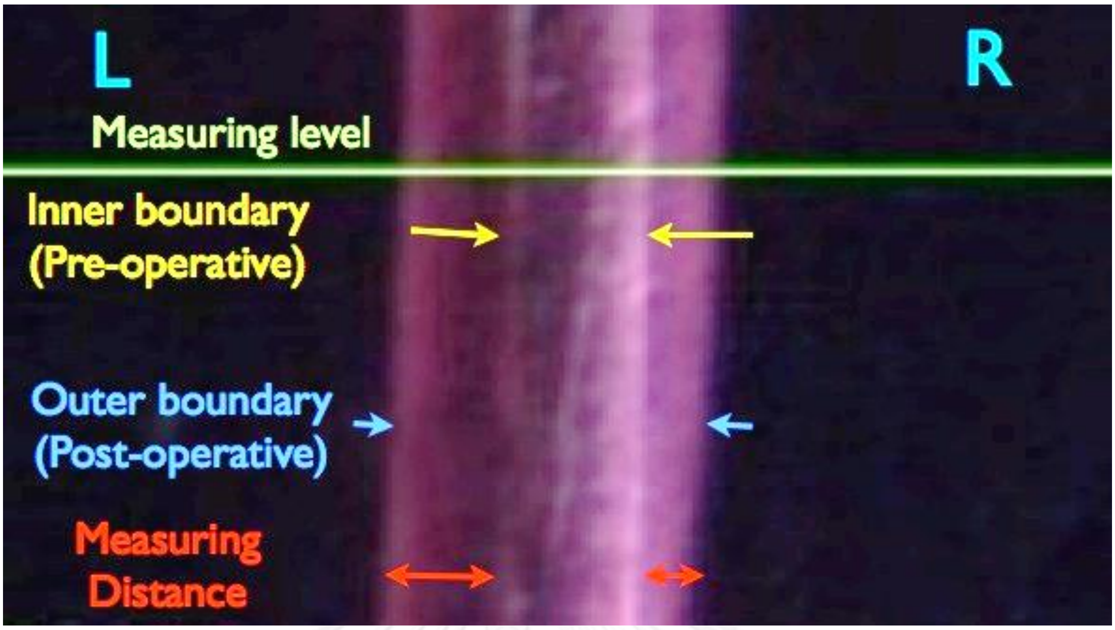

Fig. 1 Measuring left and right values in each level

Position of apical foramen assessment

After the pre- and post-operative images were superimposed. The position of the apical foramen were assessed in the same way as canal deviation analysis but focused on level 0.

Angle of curvature analysis

Angle of curvatures (21) were measured from pre- and post-operative images. Percentage of difference in angle values between pre- and post-operative images was calculated.

Radius of curvature analysis

Radius of curvatures (21) were measured from pre- and post-operative images. Percentage of difference in radius between pre- and post-operative images was calculated.

Canal aberrations assessment

After completed the preparation, samples were reposition in fixed customized stand and taken aberration images under 30X magnification to identify any canal aberrations such as ledge, zip, transportation, broken instrument under 200% magnification by computer software (Adobe Photoshop Version 7).

Instrumentation time assessment

Time consuming of root canal preparation were recorded since the first rotary file was introduced into the canal until the last instrument had reached the working length. Time using for establishing glide path was excluded but irrigation and recapitulation were included.

Statistical Analysis

All data were analyzed by statistics calculated by Statistical Package for Social Sciences (SPSS) software. Type of statistics was defined in each parameter as following.

Canal deviations

Data were tested with Shapiro-wilk test, which showed no normal distribution of data. Difference between left and right values from on each levels of three rotary systems were compared with Kruskal wallis test and identified the significant pairs with Mann whitney u test. A 0.05 significance level was set for statistical analysis.

Positions of apical foramen

Data were tested with Shapiro-wilk test, which showed no normal distribution of data. Difference between left and right values from on level 0 of three rotary systems were compared with Kruskal wallis test and identified the significant pairs with Mann whitney u test. A 0.05 significance level was set for statistical analysis.

Angle of curvatures

Data were tested with Shapiro-wilk test, which showed no normal distribution of data. Percentage difference of angle of curvature between pre- and post-operative images were compared among three systems with Kruskal wallis test and identified the significant pairs with Mann whitney u test. A 0.05 significance level was set for statistical analysis.

Radius of curvatures

Data were tested with Shapiro-wilk test, which showed normal distribution of data. Percentage difference of radius of curvature between pre- and post-operative images were compared among three systems with ANOVA and identified the significant pairs with post hoc (Bonferroni) test. A 0.05 significance level was set for statistical analysis.

Canal aberrations

Total number of aberrations were tested among three rotary systems with Chi-square test and exact monte carlo test. A 0.05 significance level was set for statistical analysis.

Instrumentation time

Data were tested with Shapiro-wilk test, which showed normal distribution of data. Instrumentation time was compared among three systems with ANOVA and identified the significant pairs with post hoc (Bonferroni) test. A 0.05 significance level was set for statistical analysis.

CHAPTER IV

RESEARCH RESULTS

Canal Deviation and Positions of Apical Foramen Results

In order to analyze canal deviation, pre- and post-operative images were superimposed. Pre-operative images without dye (Fig. 2) and post-operative images with dye (Fig. 3) which produced the optimal clear cut of root canal outline for measuring procedures were chosen (Fig. 4). After glide path preparation, images were not recorded and not included in the analysis because canals were eventually prepared in all dimension with NiTi rotary files.

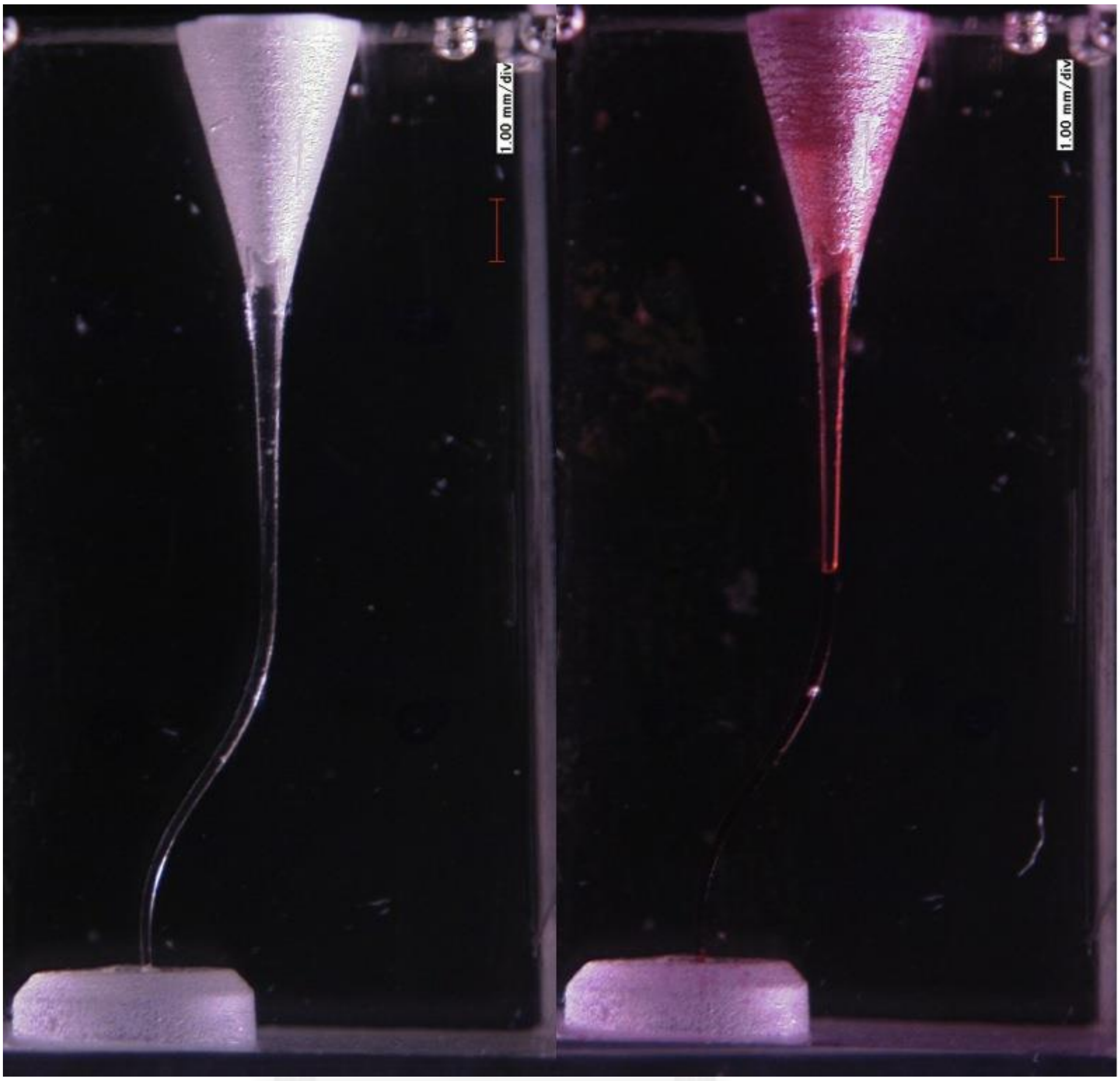

Fig. 2 Pre-operative images without and with dye

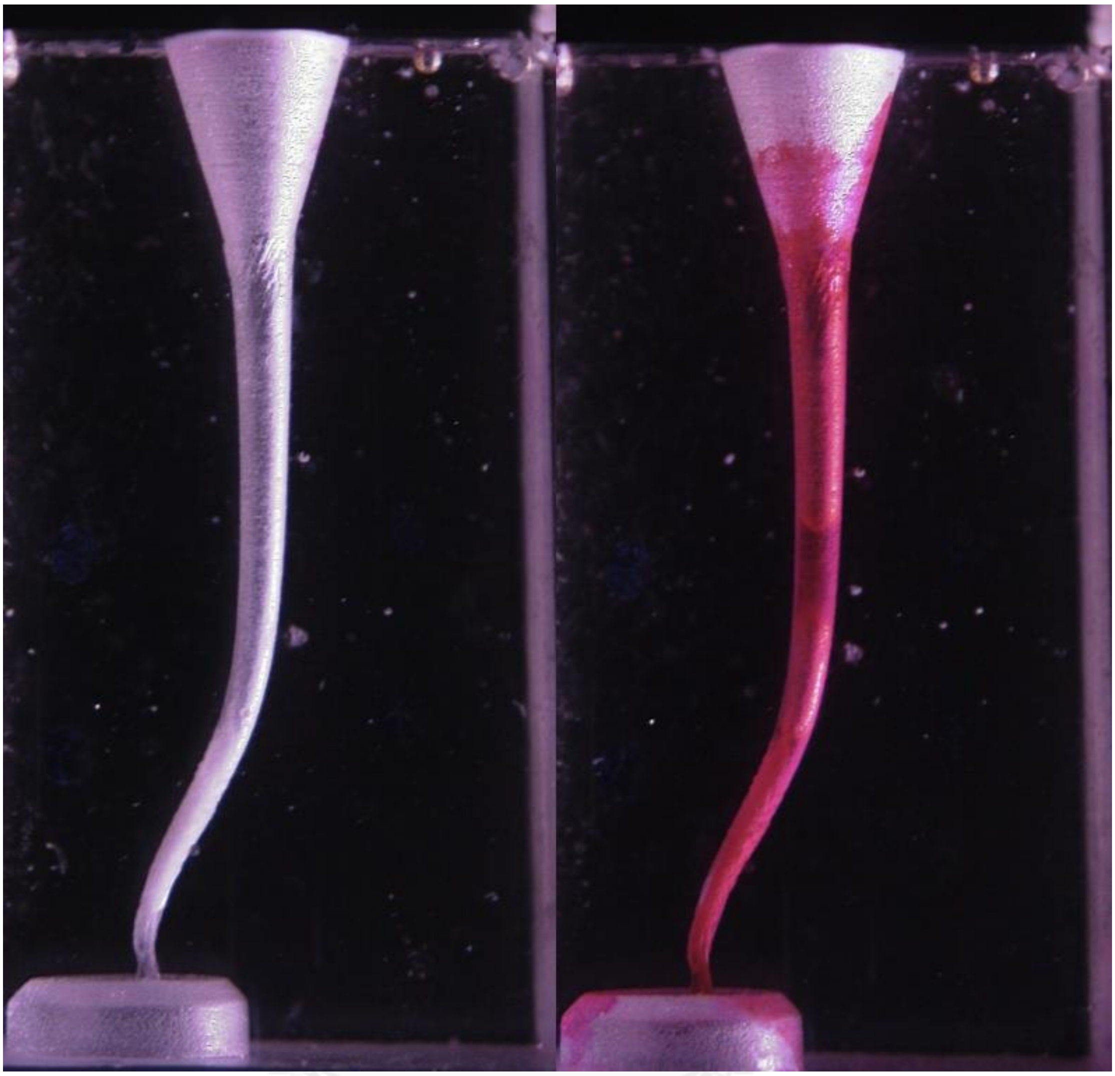

Fig. 3 Post-operative images without and with dye

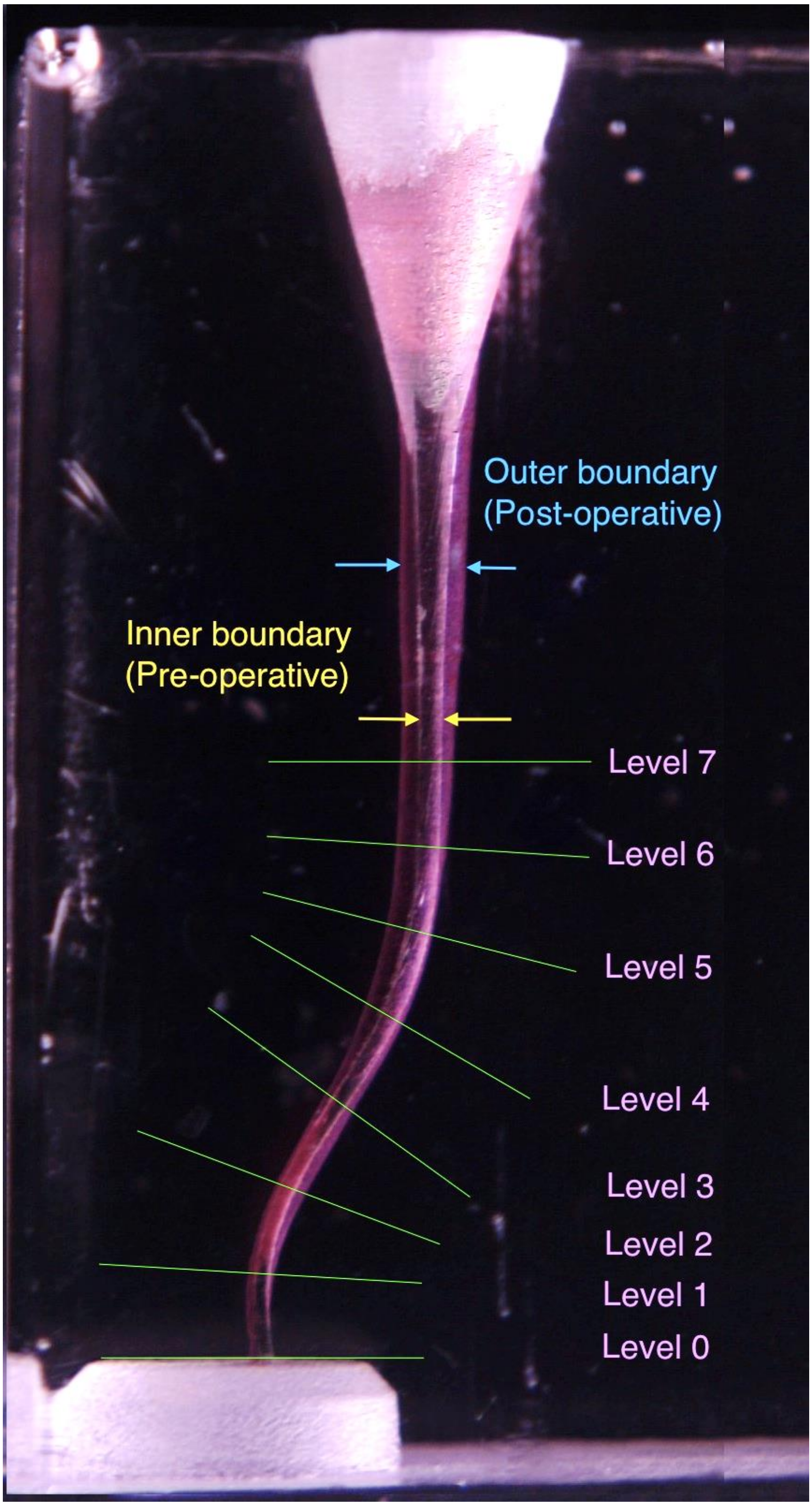

Fig. 4 Canal deviation & position of apical foramen analysis

Table 9 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper Universal group

PTU1	Left	Right	Diff	PTU2	Left	Right	Diff
Level 7	0.248	0.182	0.066	Level 7	0.204	0.204	0
Level 6	0.270	0.129	0.141	Level 6	0.248	0.144	0.104
Level 5	0.304	0.069	0.235	Level 5	0.307	0.078	0.229
Level 4	0.235	0.078	0.157	Level 4	0.229	0.100	0.129
Level 3	0.125	0.163	-0.038	Level 3	0.100	0.182	-0.082
Level 2	0.056	0.138	-0.082	Level 2	0.028	0.154	-0.126
Level 1	0.129	0.060	0.069	Level 1	0.129	0.034	0.095
Level 0	0.160	0.000	0.16	Level 0	0.150	0.000	0.15

PTU3	Left	Right	Diff	PTU4	Left	Right	Diff
Level 7	0.232	0.188	0.044	Level 7	0.270	0.194	0.076
Level 6	0.295	0.122	0.173	Level 6	0.304	0.122	0.182
Level 5	0.279	0.129	0.15	Level 5	0.351	0.044	0.307
Level 4	0.269	0.194	0.075	Level 4	0.292	0.041	0.251
Level 3	0.000	0.270	-0.27	Level 3	0.182	0.154	0.028
Level 2	0.034	0.210	-0.176	Level 2	0.069	0.179	-0.11
Level 1	0.116	0.072	0.044	Level 1	0.132	0.078	0.054
Level 0	0.144	0.000	0.144	Level 0	0.216	0.000	0.216

Table 10 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper Universal group

PTU5	Left	Right	Diff	PTU6	Left	Right	Diff
Level 7	0.238	0.210	0.028	Level 7	2.233	0.210	2.023
Level 6	0.266	0.154	0.112	Level 6	2.547	1.321	1.226
Level 5	0.285	0.094	0.191	Level 5	2.484	0.912	1.572
Level 4	0.213	0.113	0.1	Level 4	1.698	1.321	0.377
Level 3	0.088	0.160	-0.072	Level 3	0.692	1.761	-1.069
Level 2	0.028	0.172	-0.144	Level 2	0.000	1.321	-1.321
Level 1	0.060	0.088	-0.028	Level 1	0.346	0.346	0
Level 0	0.229	0.000	0.229	Level 0	0.943	0.000	0.943

PTU7	Left	Right	Diff	PTU8	Left	Right	Diff
Level 7	2.327	1.950	0.377	Level 7	2.264	2.107	0.157
Level 6	2.673	1.352	1.321	Level 6	2.704	1.384	1.32
Level 5	2.862	0.732	2.13	Level 5	2.830	1.101	1.729
Level 4	2.327	1.069	1.258	Level 4	1.855	1.478	0.377
Level 3	1.384	1.667	-0.283	Level 3	0.566	2.547	-1.981
Level 2	0.409	1.447	-1.038	Level 2	0.346	2.075	-1.729
Level 1	0.943	0.660	0.283	Level 1	0.943	0.849	0.094
Level 0	1.667	0.000	1.667	Level 0	1.069	0.000	1.069

Table 11 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper Universal group

PTU9	Left	Right	Diff	PTU10	Left	Right	Diff
Level 7	1.887	2.484	-0.597	Level 7	2.547	1.950	0.597
Level 6	2.390	2.013	0.377	Level 6	3.208	1.101	2.107
Level 5	2.264	1.258	1.006	Level 5	3.176	0.755	2.429
Level 4	1.792	1.509	0.283	Level 4	2.453	1.289	1.167
Level 3	0.629	1.918	-1.289	Level 3	1.195	1.887	-1.221
Level 2	0.000	2.044	-2.044	Level 2	0.409	1.635	1.541
Level 1	0.440	1.226	-0.786	Level 1	3.208	0.346	2.862
Level 0	0.881	0.000	0.881	Level 0	2.547	0.000	2.547

Table 12 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper NEXT group

PTN1	Left	Right	Diff	PTN2	Left	Right	Diff
Level 7	0.254	0.172	0.082	Level 7	0.223	0.172	0.051
Level 6	0.298	0.078	0.22	Level 6	0.266	0.107	0.159
Level 5	0.266	0.038	0.228	Level 5	0.245	0.056	0.189
Level 4	0.232	0.063	0.169	Level 4	0.150	0.069	0.081
Level 3	0.113	0.110	0.003	Level 3	0.063	0.141	-0.078
Level 2	0.034	0.160	-0.126	Level 2	0.022	0.132	-0.11
Level 1	0.107	0.066	0.041	Level 1	0.088	0.044	0.044
Level 0	0.176	0.000	0.176	Level 0	0.116	0.000	0.116

PTN3	Left	Right	Diff	PTN4	Left	Right	Diff
Level 7	0.326	0.154	0.172	Level 7	0.254	0.204	0.05
Level 6	0.354	0.078	0.276	Level 6	0.310	0.094	0.216
Level 5	0.345	0.063	0.282	Level 5	0.301	0.047	0.254
Level 4	0.207	0.103	0.104	Level 4	0.245	0.078	0.167
Level 3	0.069	0.188	-0.119	Level 3	0.082	0.166	-0.084
Level 2	0.000	0.179	-0.179	Level 2	0.000	0.191	-0.191
Level 1	0.072	0.072	0	Level 1	0.072	0.075	-0.003
Level 0	0.107	0.000	0.107	Level 0	0.188	0.000	0.188

Table 13 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper NEXT group

PTN5	Left	Right	Diff	PTN6	Left	Right	Diff
Level 7	0.254	0.210	0.044	Level 7	0.254	0.188	0.066
Level 6	0.288	0.122	0.166	Level 6	0.295	0.122	0.173
Level 5	0.310	0.056	0.254	Level 5	0.298	0.075	0.223
Level 4	0.172	0.138	0.034	Level 4	0.182	0.100	0.082
Level 3	0.041	0.197	-0.156	Level 3	0.053	0.182	-0.129
Level 2	0.000	0.197	-0.197	Level 2	0.000	0.210	-0.21
Level 1	0.056	0.082	-0.026	Level 1	0.034	0.107	-0.073
Level 0	0.172	0.000	0.172	Level 0	0.110	0.000	0.11

PTN7	Left	Right	Diff	PTN8	Left	Right	Diff
Level 7	0.226	0.210	0.016	Level 7	0.260	0.204	0.056
Level 6	0.254	0.129	0.125	Level 6	0.310	0.107	0.203
Level 5	0.241	0.110	0.131	Level 5	0.266	0.060	0.206
Level 4	0.179	0.119	0.06	Level 4	0.169	0.113	0.056
Level 3	0.069	0.154	-0.085	Level 3	0.031	0.169	-0.138
Level 2	0.000	0.188	-0.188	Level 2	0.031	0.119	-0.088
Level 1	0.022	0.107	-0.085	Level 1	0.082	0.028	0.054
Level 0	0.129	0.000	0.129	Level 0	0.107	0.000	0.107

Table 14 Distance measuring from superimposed pre- and post-operative images (mm) in ProTaper NEXT group

PTN9	Left	Right	Diff	PTN10	Left	Right	Diff
Level 7	0.276	0.176	0.1	Level 7	0.266	0.176	0.09
Level 6	0.298	0.088	0.21	Level 6	0.301	0.072	0.229
Level 5	0.313	0.028	0.285	Level 5	0.266	0.038	0.228
Level 4	0.229	0.069	0.16	Level 4	0.169	0.100	0.069
Level 3	0.091	0.119	-0.028	Level 3	0.055	0.157	-0.102
Level 2	0.000	0.191	-0.191	Level 2	0.000	0.144	-0.144
Level 1	0.034	0.132	-0.098	Level 1	0.082	0.056	0.026
Level 0	0.160	0.000	0.16	Level 0	0.132	0.000	0.132

Table 15 Distance measuring from superimposed pre- and post-operative images (mm) in iRace group

IRA1	Left	Right	Diff	IRA2	Left	Right	Diff
Level 7	0.182	0.132	0.05	Level 7	0.204	0.160	0.044
Level 6	0.210	0.053	0.157	Level 6	0.261	0.085	0.176
Level 5	0.216	0.050	0.166	Level 5	0.213	0.072	0.141
Level 4	0.135	0.097	0.038	Level 4	0.169	0.075	0.094
Level 3	0.031	0.091	-0.06	Level 3	0.047	0.088	-0.041
Level 2	0.000	0.113	-0.113	Level 2	0.034	0.125	-0.091
Level 1	0.050	0.050	0	Level 1	0.028	0.056	-0.028
Level 0	0.034	0.000	0.034	Level 0	0.063	0.000	0.063

IRA3	Left	Right	Diff	IRA4	Left	Right	Diff
Level 7	0.201	0.122	0.079	Level 7	0.210	0.122	0.088
Level 6	0.232	0.078	0.154	Level 6	0.235	0.060	0.175
Level 5	0.216	0.028	0.188	Level 5	0.210	0.053	0.157
Level 4	0.210	0.034	0.176	Level 4	0.163	0.085	0.078
Level 3	0.088	0.100	-0.012	Level 3	0.025	0.135	-0.11
Level 2	0.044	0.100	-0.056	Level 2	0.000	0.138	-0.138
Level 1	0.056	0.044	0.012	Level 1	0.072	0.050	0.022
Level 0	0.078	0.000	0.078	Level 0	0.016	0.000	0.016

Table 16 Distance measuring from superimposed pre- and post-operative images (mm) in iRace group

IRA5	Left	Right	Diff	IRA6	Left	Right	Diff
Level 7	0.223	0.132	0.091	Level 7	0.204	0.138	0.066
Level 6	0.223	0.072	0.151	Level 6	0.216	0.088	0.128
Level 5	0.251	0.000	0.251	Level 5	0.185	0.066	0.119
Level 4	0.194	0.025	0.169	Level 4	0.147	0.091	0.056
Level 3	0.075	0.088	-0.013	Level 3	0.044	0.125	-0.081
Level 2	0.022	0.122	-0.1	Level 2	0.000	0.122	-0.122
Level 1	0.060	0.038	0.022	Level 1	0.056	0.066	-0.01
Level 0	0.072	0.000	0.072	Level 0	0.000	0.000	0

IRA7	Left	Right	Diff	IRA8	Left	Right	Diff
Level 7	0.182	0.160	0.022	Level 7	0.176	0.154	0.022
Level 6	0.210	0.078	0.132	Level 6	0.182	0.100	0.082
Level 5	0.223	0.056	0.167	Level 5	0.229	0.044	0.185
Level 4	0.166	0.063	0.103	Level 4	0.188	0.050	0.138
Level 3	0.056	0.100	-0.044	Level 3	0.088	0.066	0.022
Level 2	0.056	0.094	-0.038	Level 2	0.056	0.107	-0.051
Level 1	0.050	0.028	0.022	Level 1	0.094	0.034	0.06
Level 0	0.038	0.000	0.038	Level 0	0.091	0.000	0.091

Table 17 Distance measuring from superimposed pre- and post-operative images (mm) in iRace group

IRA9	Left	Right	Diff	IRA10	Left	Right	Diff
Level 7	0.223	0.144	0.079	Level 7	0.226	0.122	0.104
Level 6	0.238	0.094	0.144	Level 6	0.260	0.085	0.175
Level 5	0.232	0.025	0.207	Level 5	0.273	0.025	0.248
Level 4	0.226	0.053	0.173	Level 4	0.194	0.047	0.147
Level 3	0.069	0.097	-0.028	Level 3	0.082	0.063	0.019
Level 2	0.028	0.119	-0.091	Level 2	0.038	0.100	-0.062
Level 1	0.088	0.044	0.044	Level 1	0.072	0.016	0.056
Level 0	0.107	0.000	0.107	Level 0	0.094	0.000	0.094

Distribution of data was analyzed by Shapiro-wilk test. All data was normal distributed except level 1, 2, 3, 4, 5, 6 of PTU and level 3 of PTN. Data in this parameter was not normal distributed, so non-parametric statistic (Kruskal wallis test) was used to compare difference among groups in each levels and identified the significant pairs with Mann whitney u test.

Table 18 Mean deviations ± standard deviation (mm). Measuring in 8 levels. Identified the significant difference pairs.

Distance in mm / Levels	PTU (A) Mean ± SD	PTN (B) Mean ± SD	IRA (C) Mean ± SD	Pairs with significant difference
Level 7	0.081 ± 0.304	0.073 ± 0.043	0.060 ± 0.057	-
Level 6	0.706 ± 0.722	0.198 ± 0.043	0.137 ± 0.080	B-C
Level 5	0.988 ± 0.896	0.228 ± 0.046	0.164 ± 0.079	A-C, B-C
Level 4	0.407 ± 0.442	0.098 ± 0.050	0.095 ± 0.05	A-B, A-C
Level 3	-0.575 ± 0.673	-0.091 ± 0.049	-0.036 ± 0.060	A-C, B-C
Level 2	-0.799 ± 0.760	-0.162 ± 0.042	-0.080 ± 0.060	A-B, A-C, B-C
Level 1	0.080 ± 0.423	-0.012 ± 0.056	0.080 ± 0.034	-
Level 0	0.728 ± 0.648	0.139 ± 0.032	0.057 ± 0.036	A-B, A-C, B-C

plus value mean canal was deviated to left side

minus value mean canal was deviated to right side

Significant difference ($p<0.05$)

All three rotary systems generated deviations at every canal level evaluated (Table 18). The PTU group showed the greatest canal deviation at all levels (ranging from 0.080–0.988) and were significantly different from the IRA group at levels 0, 2, 3, 4 and 5 and the PTN group at levels 0, 2 and 4. The IRA group demonstrated the least canal deviation at all levels, except at level 1 (ranging from 0.036–0.164 mm), which were significantly different compared to the PTN group at levels 0, 2, 3, 5 and 6. At levels 1 and 7, the differences in deviation among three groups were not significant.

The apical foramen of all samples (level 0) were shifted to the left side (outer curve of the apical curve), with the PTU, PTN, IRA groups shifting 0.728, 0.139, 0.057 mm, respectively. The differences among three groups were significant (Table 12).

Angle of Curvatures Results

Pre- and post-operative images were measured the angle of curvatures both coronal and apical curves. Using Microsoft PowerPoint software to create lines and circles according to the method described by Pruett et al. (21) (Fig. 5).

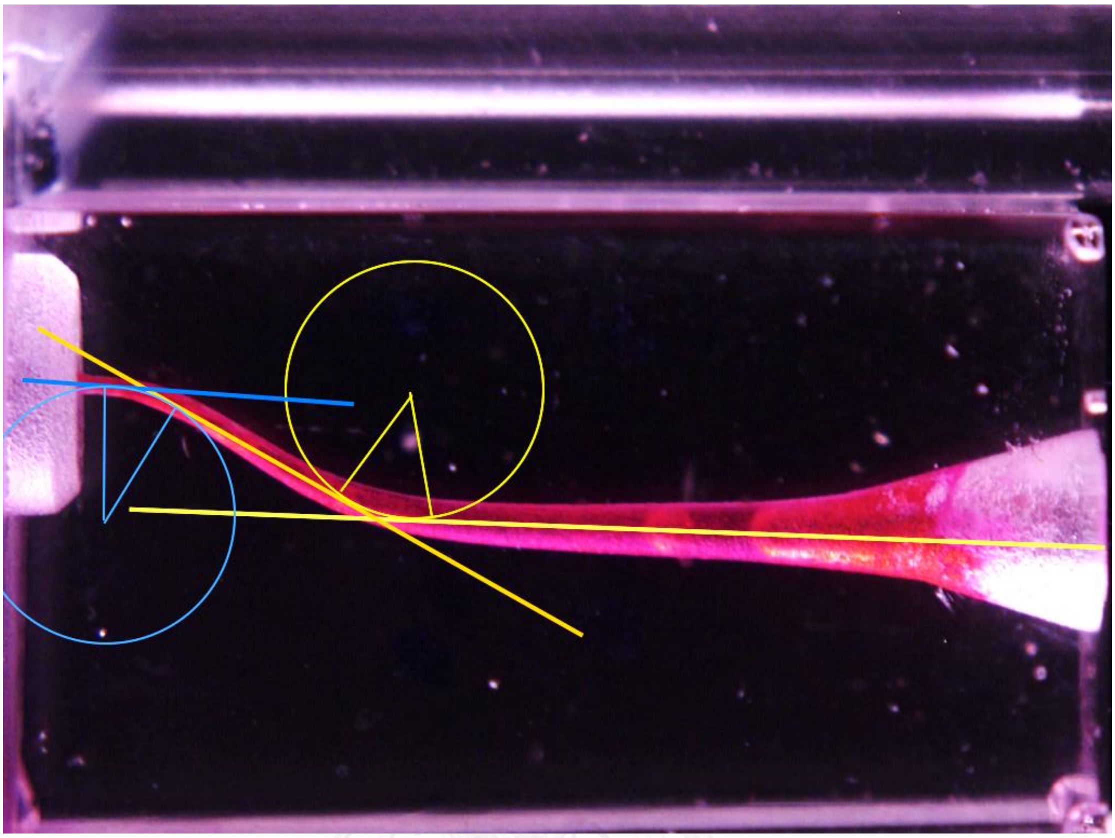

Fig. 5 Measuring Angle and radius of curvatures by Microsoft PowerPoint software

Table 19 Angle of curvatures of ProTaper Universal (degrees)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	33	29	12.12	33	33	0.00
2	33	33	0.00	31	33	-6.45
3	33	30	9.09	40	38	5.00
4	29	28	3.45	28	40	-42.86
5	31	29	6.45	37	41	-10.81
6	30	29	3.33	24	28	-16.67
7	33	30	9.09	33	34	-3.03
8	33	30	9.09	27	28	-3.70
9	33	27	18.18	32	32	0.00
10	34	28	17.65	35	32	8.57

minus value of percent difference mean the angle of curvatures were increased

plus value of percent difference mean the angle of curvatures were decreased

Table 20 Angle of curvatures of ProTaper NEXT (degrees)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	33	33	0.00	29	35	-20.69
2	33	32	3.03	33	35	-6.06
3	35	31	11.43	33	30	9.09
4	35	25	28.57	37	33	10.81
5	30	30	0.00	33	28	15.15
6	31	33	-6.45	34	26	23.53
7	33	31	6.06	30	30	0.00
8	35	33	5.71	25	30	-20.00
9	32	31	3.13	32	32	0.00
10	33	36	-9.09	35	36	-2.86

minus value of percent difference mean the angle of curvatures were increased

plus value of percent difference mean the angle of curvatures were decreased

Table 21 Angle of curvatures of iRace (degrees)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	30	27	10.00	26	27	-3.85
2	32	25	21.88	33	32	3.03
3	34	27	20.59	32	29	9.38
4	38	35	7.89	38	32	15.79
5	30	33	-10.00	35	28	20.00
6	33	31	6.06	35	27	22.86
7	32	28	12.50	24	28	-16.67
8	32	31	3.13	26	26	0.00
9	31	32	-3.23	33	32	3.03
10	34	30	11.76	33	30	9.09

minus value of percent difference mean the angle of curvatures were increased

plus value of percent difference mean the angle of curvatures were decreased

Distribution of data was analyzed by Shapiro-wilk test. All data was normal distributed except apical curvature of PTU. One of data in this parameter was not normal distributed, so non-parametric statistic (Kruskal wallis test) was used to compare difference among groups both in coronal and apical curvatures and identified the significant pairs with Mann whitney u test.

Table 22 Mean difference of angle of curvatures ± Standard deviation (%). Measuring both coronal and apical curvatures.

	PTU	PTN	IRA
Coronal	8.84 ± 5.95	4.24 ± 10.43	8.06 ± 9.81
Apical	-6.99 ± 14.55	0.90 ± 14.33	6.27 ± 11.83

All instruments modified the curvatures in some degree except PTU in samples 1 and 9 in apical curvature and PTN in samples 1 and 5 in coronal curvature which angle of curvatures were unchanged. There were no statistically significant differences among three groups both in coronal and apical curvatures.

Radius of Curvatures Results

Pre- and post-operative images were measured the radius of curvatures both coronal and apical curves. Using Microsoft PowerPoint software to create lines and circles according to the method described by Pruett et al. (21) (Fig. 5).

Table 23 Radius of curvatures of ProTaper Universal (mm)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	3.03	4.89	-61.39	2.47	2.11	14.57
2	3.32	5.12	-54.22	2.49	2.11	15.26
3	3.43	5.12	-49.27	1.76	2.11	-19.89
4	2.57	4.12	-60.31	1.77	1.88	-6.21
5	2.93	4.57	-55.97	1.98	2.23	-12.63
6	2.96	3.86	-30.41	1.98	2.2	-11.11
7	3.12	3.56	-14.10	1.95	1.76	9.74
8	3.27	3.42	-4.59	1.99	1.61	19.10
9	4.27	3.42	19.91	1.91	1.66	13.09
10	4.15	3.32	20.00	2.04	1.55	24.02

minus value of percent difference mean the radius of curvatures were increased

plus value of percent difference mean the radius of curvatures were decreased

Table 24 Radius of curvatures of ProTaper NEXT (mm)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	2.82	3.06	-8.51	2.18	1.72	21.10
2	3.06	4.55	-48.69	2.43	1.71	29.63
3	3.2	5.36	-67.50	1.79	1.71	4.47
4	1.76	4.78	-171.59	1.77	1.4	20.90
5	2.7	5.89	-118.15	1.75	1.76	-0.57
6	2.35	4.05	-72.34	1.2	2.03	-69.17
7	2.61	5.87	-124.90	1.59	1.64	-3.14
8	3.19	4.89	-53.29	1.58	2.17	-37.34
9	3.46	4.17	-20.52	1.04	2.29	-120.19
10	3.5	5.42	-54.86	1.8	1.98	-10.00

minus value of percent difference mean the radius of curvatures were increased

plus value of percent difference mean the radius of curvatures were decreased

Table 25 Radius of curvatures of iRace (mm)

Sample	Coronal curves			Apical curves		
	Pre	Post	%difference	Pre	Post	%difference
1	2.82	4.51	-59.93	1.85	2.89	-56.22
2	2.93	4.3	-46.76	1.88	2.29	-21.81
3	3.1	4.49	-44.84	2.47	2.19	11.34
4	3.32	6.45	-94.28	3.01	2.32	22.92
5	2.96	6.58	-122.30	1.98	1.76	11.11
6	3.02	3.66	-21.19	2.69	1.75	34.94
7	2.95	5.26	-78.31	1.33	2.45	-84.21
8	3.32	4.54	-36.75	1.29	1.64	-27.13
9	3.62	4.36	-20.44	1.98	1.88	5.05
10	3.5	4.26	-21.71	1.55	1.55	0.00

minus value of percent difference mean the radius of curvatures were increased

plus value of percent difference mean the radius of curvatures were decreased

Distribution of data was analyzed by Shapiro-wilk test. All data was normal distributed, so parametric statistic (ANOVA test) was used to compare difference among groups both in coronal and apical curvatures and identified the significant pairs with post hoc (Bonferroni) test.

Table 26 Mean difference of radius of curvatures ± Standard deviation (%). Measuring both coronal and apical curvatures.

	PTU	PTN	IRA
Coronal	8.84 ± 5.95	4.24 ± 10.43	8.06 ± 9.81
Apical	-6.99 ± 14.55	0.90 ± 14.33	6.27 ± 11.83

All instruments modified the radius of curvatures in some degree. There were no statistically significant differences among three groups both in coronal and apical curvatures.

Canal Aberrations Results

After instrumentations were completed, blocks were evaluated under stereomicroscope (30X magnification) to identify aberrations which were ledge and elbow (Fig. 6). In samples with aberrations, the intra-operative images were examined to identify the instrument that caused the aberration (Fig. 7).

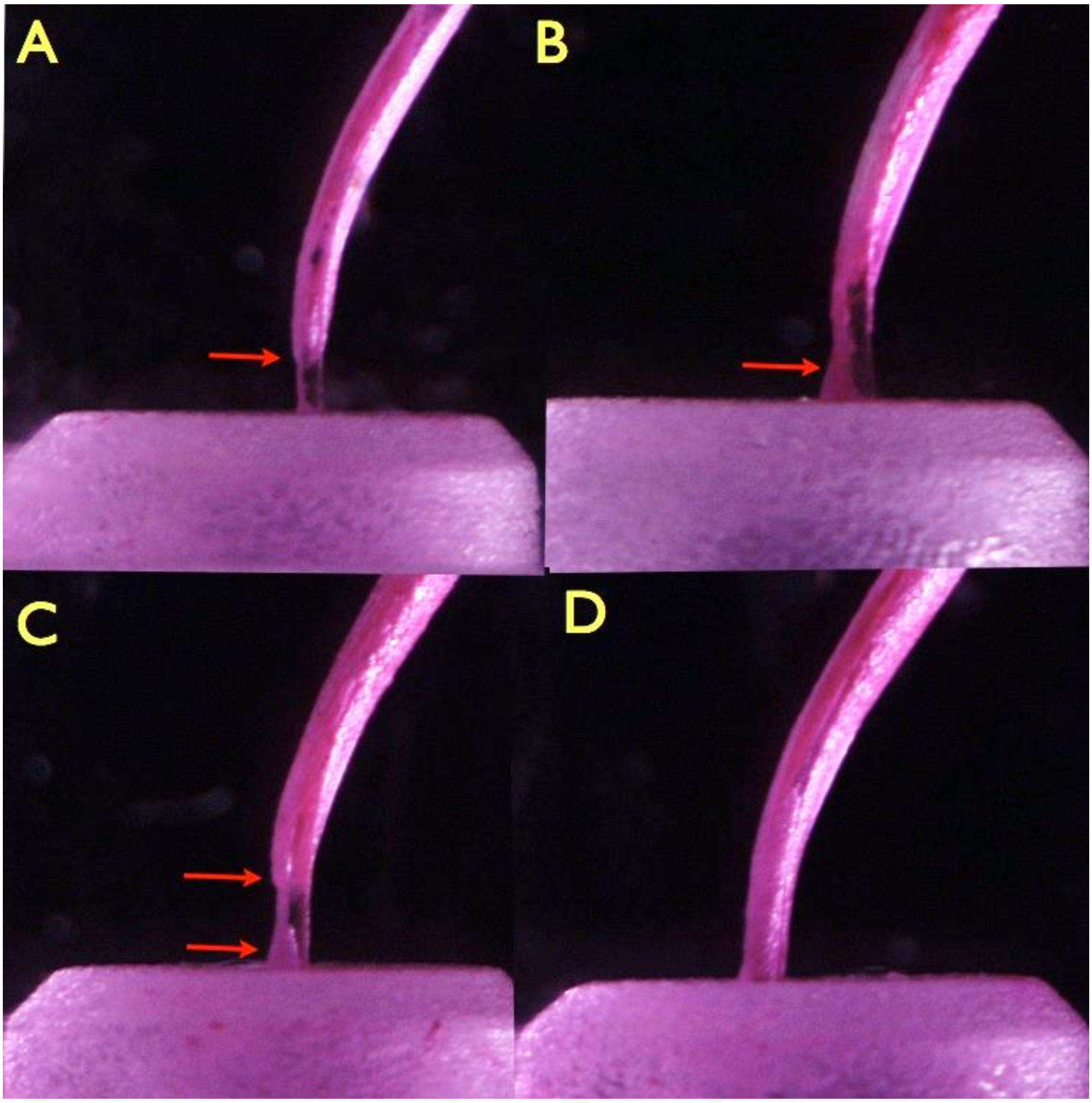

Fig. 6 (A) Ledge, (B) Elbow, (C) Ledge and elbow, (D) No errors

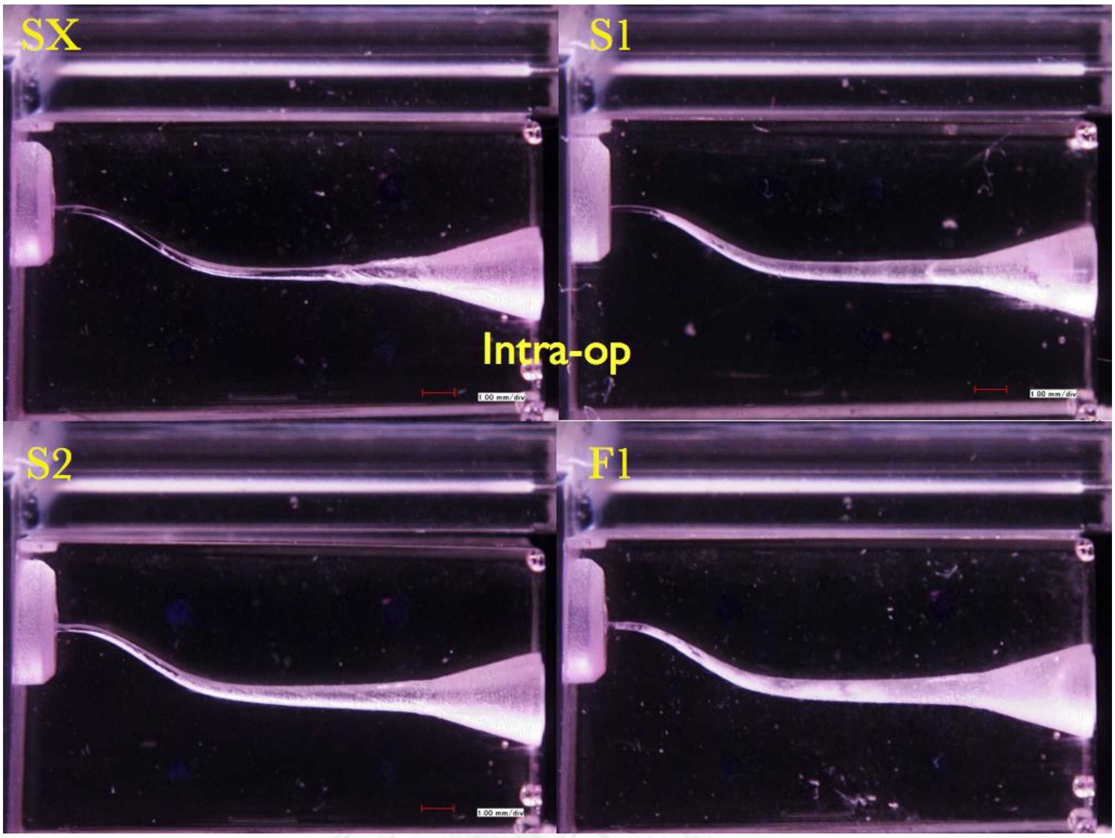

Fig. 7 Intra-operative images

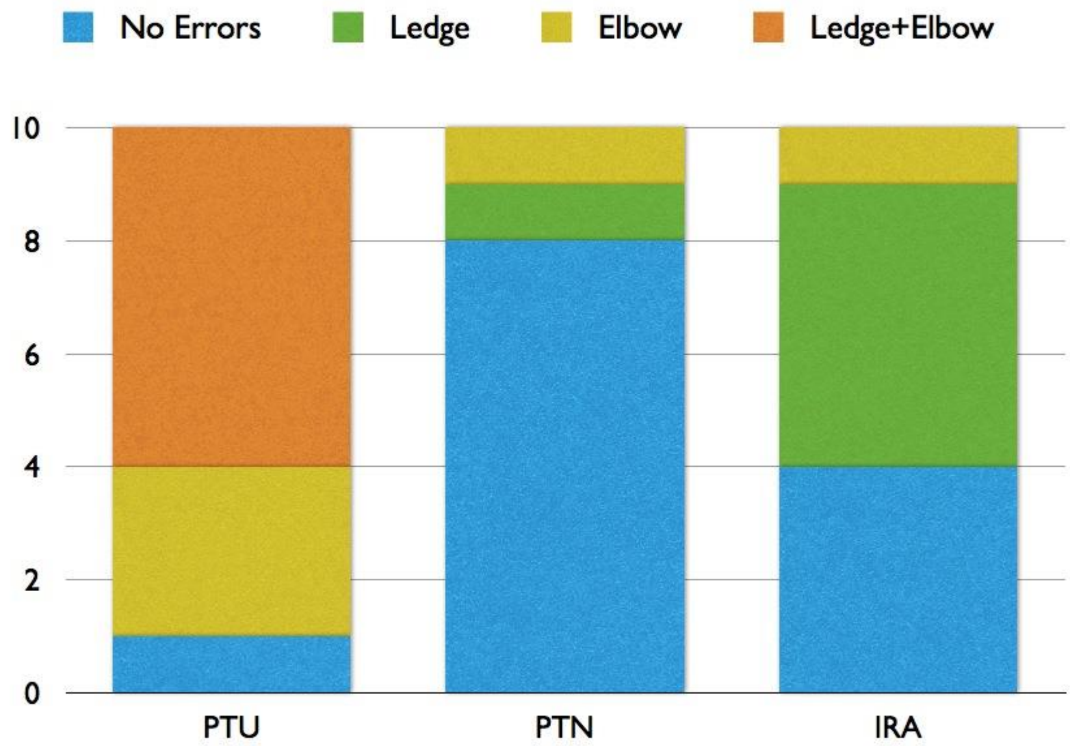

Fig. 8 Chart presented aberrations in each rotary system

The PTU group had a significantly higher incidence of aberrations than the PTN group (Fig. 8). In the PTU group, 9/10 samples demonstrated aberrations, with six samples demonstrating both elbows and ledges. F1 files initiated aberrations in four samples and F2 files initiated aberrations in five samples (Table. 27). In the PTN group, 2/10 samples had aberrations that were initiated with X2 files (Table. 28). The IRA group had 6/10 samples with aberrations that were initiated with R2 files with five samples presenting with ledges (Table. 29). All systems generated canal without (Fig. 9) and with errors (Fig. 10).

Table 27 Aberrations in ProTaper Universal

Sample	Errors		Beginning of error	
	Elbow	Ledge	F1 20/.07	F2 25/.08
1	/	/		/
2	/	/		/
3	/	/		/
4	/	/	/	
5	/		/	
6				
7	/		/	
8	/	/		/
9	/		/	
10	/	/		/
Total	**9**	**6**	**4**	**5**

Table 28 Aberrations in ProTaper NEXT

Sample	Errors		Beginning of error	
	Elbow	Ledge	X1 17/.04	X2 25/.06
1				
2		/		/
3				
4	/			/
5				
6				
7				
8				
9				
10				
Total	1	1	0	2

Table 29 Aberrations in iRace

Sample	Errors		Beginning of error	
	Elbow	Ledge	R1 15/.06	R2 25/.04
1				
2		/		/
3		/		/
4		/		/
5				
6		/		/
7				
8		/		/
9	/			/
10				
Total	**1**	**5**	**0**	**6**

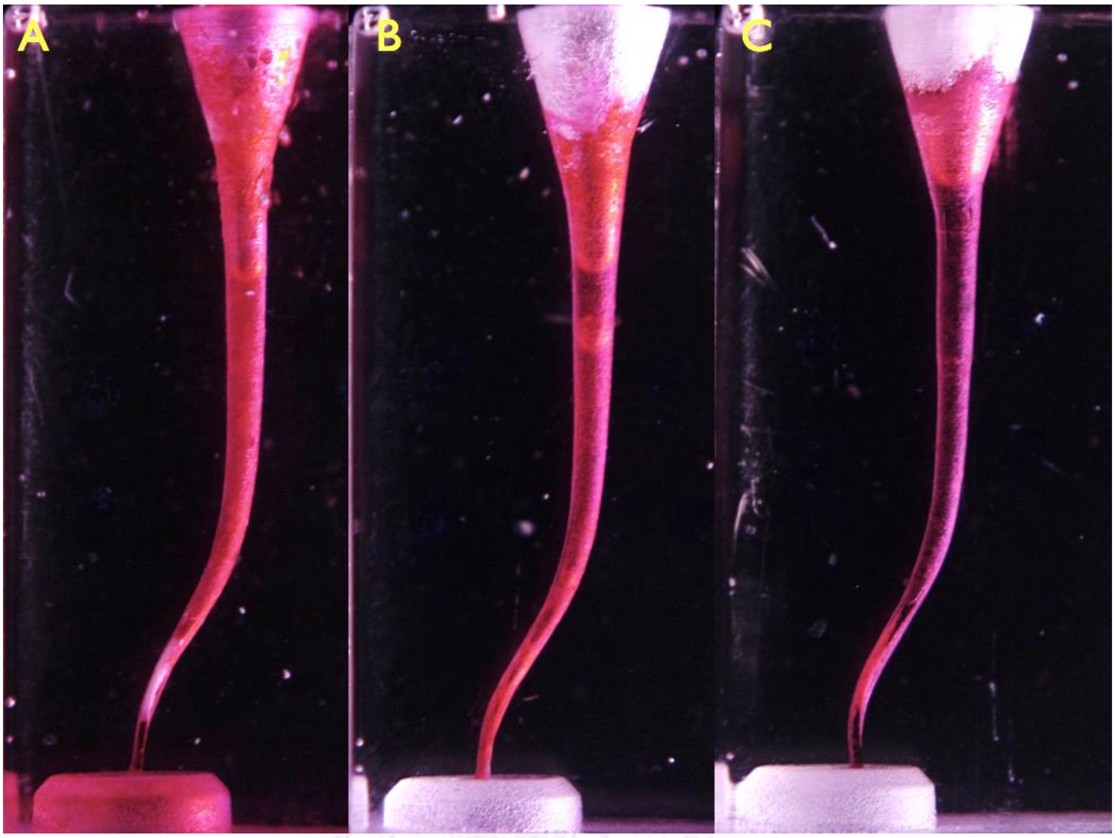

Fig. 9 Samples without errors. (A) PTU, (B) PTN, (C) IRA

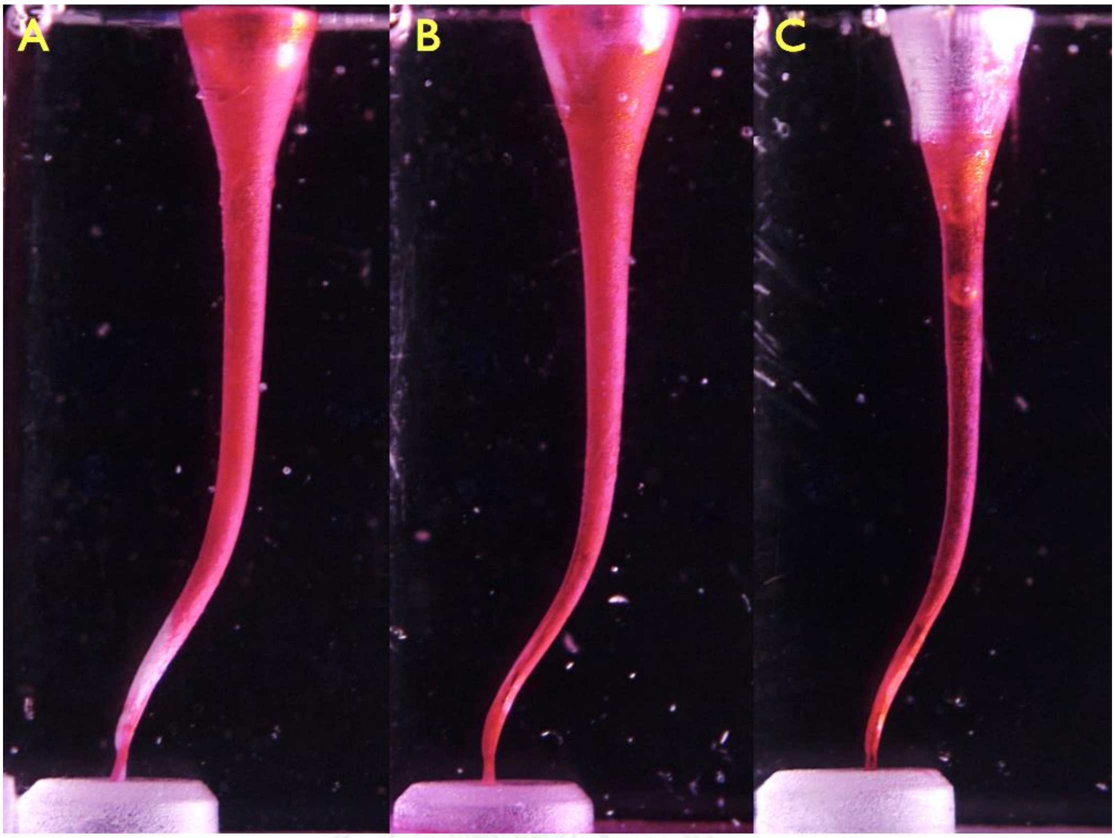

Fig. 10 Samples with errors. (A) PTU, (B) PTN, (C) IRA

Instrumentation Time Results

The instrumentation times were including irrigation and recapitulation.

Table 30 Instrumentation time (seconds)

Sample	PTU	PTN	IRA
1	115.3	81.2	60.2
2	123.8	81.6	62.5
3	121.2	80.0	65.0
4	127.0	81.6	68.9
5	109.2	77.1	65.3
6	113.8	79.1	65.0
7	118.4	76.4	76.0
8	112.7	82.3	75.3
9	110.5	79.0	71.6
10	112.3	77.1	69.6
Average	116.4	79.5	67.9

The instrumentation times, including irrigation and recapitulation, were 1.94 ± 0.10, 1.32 ± 0.04, 1.13 ± 0.09 minutes for the PTU, PTN and IRA systems, respectively. The IRA system required the least time, while the PTU system required the most.

CHAPTER V
DISCUSSION

The present study investigated the abilities of three NiTi rotary systems, ProTaper Universal (PTU), ProTaper NEXT (PTN) and iRace (IRA), to maintain canal/apical foramen position, or to produce canal aberrations, when shaping simulated S-shaped canals. We found that the systems had differences in canal shaping ability. Based on these results, the null hypothesis was rejected. Shaping abilities of three rotary systems were different.

This study used a technique of superimposition the pre- and post- operating images which provided reproducibility and direct visual comparison of the results. A number of studies investigating the shaping abilities of endodontic files used in S-shaped canals have employed the technique of superimposing the pre- and post-operative images in their analysis due to resin blocks couldn’t investigate by mean of x-ray subtraction technique or micro-computed tomography (8, 9, 24, 31). This method provides reproducibility and direct visual comparison of the results. Sample standardization in studies of S-shaped canals is important. Using simulated canal models may be the best way to achieve the sample standardization. The instruments used in the present study were only used once, which prevented any degradation in the instruments' performance that may have occurred with multiple uses. There were no declaration of single used from previous studies (8, 9, 31, 32). Quality of images might be improved by injection of various dye (Methylene blue (9, 31), ink (24)) corresponded to previous studies. This study was taken both with and without dye images in order to maximize the quality of images during analytical procedures.

Number of samples in this study was ten for each system. This number is the least number available in the literatures (8, 9). This study used file only once, this made each sample much more reliable. Non of previous studies had a single used declaration before. The results would be stronger if the number of sample was increased, but the limitation of this issue was limited budget.

Previous studies used various irrigants which were tap water (8, 9, 24), sterile water (31) and distilled water (32). All of irrigants were used for debriding and removing root canal contents. Irrigation volume in each system was controlled equally due to difference in volume may produce difference of debris remaining in root canal which could interfere with the files while working in the canal.

Glide path could be established by many instruments which were hand files, rotary instruments (PathFile, ScoutRace, iRace ISO10, Mtwo). This study used the rotary instruments to create glide path due to previous study showed that making glide path with rotary instrument resulted in less modification of curvature and canal aberrations than stainless steel hand file (23). PathFile was investigated its ability by many studies which provided less deviation (23, 25). ScoutRace had only one study which compared the ability in simulated s-shaped canal with PathFile, the results showed that ScoutRace had superior ability than PathFile. This study was focused on shape of the root canal after preparation which was not associated with shape from glide path procedure. Because canals were prepared in all dimension. Another reason was an availability of the PathFile.

The apical size at the end of preparation was aimed at #25 due to previous study suggested that NiTi files with tapers greater than 0.04 and sizes greater than 30 should not be used for apical enlargement of S-shaped canals (9). If the apical size was aimed at #30, the tapers of file in most systems would be too greater than 0.04.

Points measuring in canal deviation analysis in this study were eight points (24, 31) which represented every curvature along the entire canals. Measuring only two points (8, 9) in the most curved points of each curvature may not reflect all entire S-shaped canal. Measuring twelve points (32) would include a straight portion of the canal which might interfere with the true results. In our study, shaping the S-shaped canals with the PTU files resulted in the greatest canal deviation, which is in accordance with previous studies (8, 9). (Table. 18) The deviation in the PTU group was significantly different from the other two systems at levels 2, 3, 4, 5, which are the curved portion of the simulated canal. The observed canal deviation might be caused by the large tapering of the PTU system files (F1: 20/0.07, F2: 25/0.08), which reduces their flexibility. The PTN system treated canals deviated less than the PTU system treated canals at levels 2 and 4, but deviated more than the IRA system treated canals at levels 2, 3, 5 and 6. The IRA system produced the least canal deviation at levels 2, 3, 4, 5, 6. The PTN and IRA systems utilize fewer files than the PTU system, which may result in less canal deviation because each file would create some of deviation. In addition, the PTN and IRA systems use taper sequences that are different from each other. The PTN system uses SX (19/0.04), X1 (17/0.04), X2 (25/0.06) files at a rotation speed of 300 rpm, while the IRA system employs R1 (15/0.06) and R2 (25/0.04) files at a rotation speed of 600 rpm. In the PTN group, the deviation at levels 3-7 may have been caused by the use the of SX file, which has progressive tapering. Although there are differences in taper sequences between the systems, the tapering of the IRA and PTN files do not exceed a 0.06 taper, which is the maximum taper recommended for use in S-shaped canals (9). The rotation speed of the IRA system is twice that of the PTN system. Therefore, iRace stayed inside the root canal shorter than other systems, which may be one factor why the least deviation was seen for this system. Speed of rotation may influence the deviation result, because more speed allowed the instruments to get in and leave canal as fast as it could, so the chance of deviation was reduced. Higher speed system may provide some advantage in this issue but higher speed would shorten the time for number of cycle to failure which resulted in separated instrument. All canal deviations were to the inner side of the canal curvatures, which corresponds to previous studies (8, 9). All canal deviations were caused by rotary files in each system. PathFile were not associated with the deviations, because all dimension of canal were prepared by rotary file in each system.

In endodontic treatment, it is desirable that the apical foramen position should be maintained at its original position (1). The present study revealed that none of the rotary systems used could maintain the original foramen position. This may due to the path of the canals that have double curves that go in different directions. However, the files have shape-memory effects to maintain their original shape. The rotary files were forced to go to the right side due to the apical curvature, so the tip of files moved to the left side. From the results, the difference among three groups were statistical significant. This may be cause by the difference of taper size of instruments PTU (0.08), PTN (0.06) and IRA (0.04). The greater percentage tapered, the greater diameter and less flexibility of files became. So the greatest tapered produced shift of apical foramen position the most.

Angle and radius of curvatures were proposed by Pruett in 1997 (21). This parameters were introduced in order to establish standard value for communicating between practitioners about degree of difficulty in each case. Almost two decade since this parameters were introduced, there was no study use this parameters for determining shaping ability of files before. This was the first study that used these two value as parameters in shaping ability. Raw data showed wide range of value and extremely high standard deviation. This may cause by errors from method of measuring angle and radius of curvatures. Slightly line shifting of the lines resulted in huge change of the parameter values. In order to solve this issue, increasing sample size until the standard deviation was reduced is expected. But limitation of this issue was the budget, because this study used the rotary file only once and discarded. From this study, we realized that angle and radius of curvatures might not be a suitable parameter for determining of shaping ability of files due to its sensitive measuring.

Previous studies (8, 9, 31) investigated the aberrations from root canal preparation procedures in many aspects which comprised of ledge, zip, elbow, perforation and broken instruments. In the present study, all aberrations were presented which included ledge and elbow. The PTU system created aberrations in nine samples. These might be explained by the "jump in taper" of the PTU file tips (S2: 20/0.04 to F1: 20/0.07), as was suggested by Yoshimine, Ono et al. (8). Furthermore, cross-section of PTU created three dentin-instrument contact point which increased chance of creating aberrations. Conventional NiTi provided less flexibility, this may be the other explanation of the aberrations. Aberrations were found in six samples treated with the IRA system. These may have been caused by the lower flexibility of the conventional NiTi alloy, the triangular cross-section which increased number of contact points between files and canal walls and the use of the single length technique which may have failed to establish a canal with pre-coronal flaring. Even the taper size of iRace was not exceeded the suggestion from previous study (8), but the order of files taper was not increasing in order, this might be another explanation of the results. The PTN system produced the least aberrations, which was significantly different from the number observed in the PTU group. The reduced number of aberrations by this system might have resulted from the gradual increase in file taper (SX: 19/0.04, X1: 17/.04, X2: 25/0.06) and the pre-coronal flaring that results from the crown-down technique. The M-wire technology improves flexibility along the active portion of the PTN files. Moreover, the new off-set rectangular design of PTN's cross section provided only two dentin-instrument contact points and created a mechanical wave of motion which might reduce the chance of creating aberrations. Crown-down preparation technique in PTN allowed files to move freely in the canal, reduced chance of aberrations. All the aberrations were caused by rotary files in each system which could be confirm by investigating intra-operative images. PathFiles were not associated with the aberration, because all aberrations were found in late stage of preparation.

The instrumentation times among three groups were significant difference. The iRace system resulted in the least instrumentation time because it uses the fewest files while ProTaper universal resulted in the most instrumentation time because it uses most files.

From six parameters in this study, we found that only four parameters (Canal deviations, apical foramen position, aberration and instrumentation time) were suitable for determining shaping ability of rotary files. The results of canal deviation could show the relative values of deviation among three systems. However, there are no study that can define the amount of deviation that has clinical significance. Therefore this parameter could tell that each system has more or less deviation than the others, but it doesn’t mean that which systems is good or bad in clinical use. Instrumentation time was one of the parameters that could be used for determining shaping ability. This aspect might be one of the important parameters for clinicians when they decided which systems they should use for their clinical practices. Canal aberrations are also the important parameter. The aberrations such as ledge might prevent the shaping and cleaning procedures beyond that point which may reduce the success rate of the treatment especially in cases associated with periapical lesion (35). Elbow may compromise the apical seal due to improper shape of apical stop which should be ideally as small as practical and provide continuous tapering funnel shape from apical to coronal (1).

Limitations

We should note that the use of rotary files in shaping canals in resin blocks as performed in our study may be different from shaping performed in root canal dentin, so care must be taken in the interpretation of the results. Number of sample was limited by budget due to all instruments were single used.

The interpretation of the results might be better, if the analysis was performed by two blinded investigators to confirm and increase the reliability of the results.

Conclusion

Under the conditions of this study, the iRace system generated the least mean canal deviation at most canal levels evaluated, the least apical foramen position shifted and the least in instrumentation time. The ProTaper NEXT system resulted in the least canal aberrations. The ProTaper Universal system demonstrated the most canal deviation, shifting apical foramen position, aberrations and instrumentation time. The changing of angle and radius of curvatures among three systems were not significant differences. Our findings suggest that, after a smooth glide path has been established with rotary files, the shaping strategy in S-shaped canals should use a step increase in file taper (0.02-0.04-0.06), without a jump in taper, finish with a #25 tip size file.

REFERENCES

1. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am. 1974;18(2):269-96. Epub 1974/04/01.
2. Nagy CD, Szabo J. A mathematically based classification of root canal curvatures on natural human teeth. J Endod. 1995;21(11):557-60. Epub 1995/11/01.
3. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. J Endod. 1975;1(8):255-62. Epub 1975/08/01.
4. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14(7):346-51. Epub 1988/07/01.
5. Glickman GN, Koch KA. 21st-century endodontics. J Am Dent Assoc. 2000;131 Suppl:39S-46S. Epub 2000/06/22.
6. Park H. A comparison of Greater Taper files, ProFiles, and stainless steel files to shape curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2001;91(6):715-8. Epub 2001/06/13.
7. Ruddle CJ, Machtou P, West JD. The shaping movement: fifth-generation technology. Dent Today. 2013;32(4):94, 6-9. Epub 2013/05/11.
8. Yoshimine Y, Ono M, Akamine A. The shaping effects of three nickel-titanium rotary instruments in simulated S-shaped canals. J Endod. 2005;31(5):373-5. Epub 2005/04/27.
9. Bonaccorso A, Cantatore G, Condorelli GG, Schafer E, Tripi TR. Shaping ability of four nickel-titanium rotary instruments in simulated S-shaped canals. J Endod. 2009;35(6):883-6. Epub 2009/06/02.
10. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. J Endod. 2011;37(7):997-1001. Epub 2011/06/22.
11. Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod. 2013;39(2):163-72. Epub 2013/01/17.
12. Kuhn G, Jordan L. Fatigue and mechanical properties of nickel-titanium endodontic instruments. J Endod. 2002;28(10):716-20. Epub 2002/10/26.
13. Zinelis S, Darabara M, Takase T, Ogane K, Papadimitriou GD. The effect of thermal treatment on the resistance of nickel-titanium rotary files in cyclic fatigue.

Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(6):843-7. Epub 2007/04/13.

14. Alapati SB, Brantley WA, Iijima M, Clark WA, Kovarik L, Buie C, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod. 2009;35(11):1589-93. Epub 2009/10/21.

15. Johnson E, Lloyd A, Kuttler S, Namerow K. Comparison between a novel nickel-titanium alloy and 508 nitinol on the cyclic fatigue life of ProFile 25/.04 rotary instruments. J Endod. 2008;34(11):1406-9. Epub 2008/10/22.

16. Larsen CM, Watanabe I, Glickman GN, He J. Cyclic fatigue analysis of a new generation of nickel titanium rotary instruments. J Endod. 2009;35(3):401-3. Epub 2009/03/03.

17. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M, et al. Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod. 2008;34(8):1003-5. Epub 2008/07/19.

18. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. J Endod. 2012;38(1):105-7. Epub 2011/12/14.

19. Lee JH, Park JB, Andreasen GF, Lakes RS. Thermomechanical study of Ni-Ti alloys. J Biomed Mater Res. 1988;22(6):573-88. Epub 1988/06/01.

20. Esposito PT, Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. J Endod. 1995;21(4):173-6. Epub 1995/04/01.

21. Pruett JP, Clement DJ, Carnes DL, Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997;23(2):77-85. Epub 1997/02/01.

22. Patino PV, Biedma BM, Liebana CR, Cantatore G, Bahillo JG. The influence of a manual glide path on the separation rate of NiTi rotary instruments. J Endod. 2005;31(2):114-6. Epub 2005/01/27.

23. Berutti E, Cantatore G, Castellucci A, Chiandussi G, Pera F, Migliaretti G, et al. Use of nickel-titanium rotary PathFile to create the glide path: comparison with manual preflaring in simulated root canals. J Endod. 2009;35(3):408-12. Epub 2009/03/03.

24. Ajuz NC, Armada L, Goncalves LS, Debelian G, Siqueira JF, Jr. Glide path preparation in S-shaped canals with rotary pathfinding nickel-titanium instruments. J Endod. 2013;39(4):534-7. Epub 2013/03/26.

25. Vanessa de Oliveira Alves CEdSB, Rodrigo Sanches Cunha, Sergio Luiz Pinheiro, Carlos Eduardo Fontana, Alexandre Sigrist de Martin. Comparison among Manual

Instruments and PathFile and Mtwo Rotary Instruments to Create a Glide Path in the Root Canal Preparation of Curved Canals. J Endod. 2012;38(1):117-20.

26. Al-Sudani D, Grande NM, Plotino G, Pompa G, Di Carlo S, Testarelli L, et al. Cyclic fatigue of nickel-titanium rotary instruments in a double (S-shaped) simulated curvature. J Endod. 2012;38(7):987-9. Epub 2012/06/19.

27. Glosson CR HR, Dove SB, del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine driven and K-Flex endodontic instruments. J Endod. 1995;21(3):146-51.

28. Schafer E, Erler M, Dammaschke T. Comparative study on the shaping ability and cleaning efficiency of rotary Mtwo instruments. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. Int Endod J. 2006;39(3):203-12. Epub 2006/03/02.

29. Yang G, Yuan G, Yun X, Zhou X, Liu B, Wu H. Effects of two nickel-titanium instrument systems, Mtwo versus ProTaper universal, on root canal geometry assessed by micro-computed tomography. J Endod. 2011;37(10):1412-6. Epub 2011/09/20.

30. 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(8):1121-5. Epub 2012/07/17.

31. Burroughs JR, Bergeron BE, Roberts MD, Hagan JL, Himel VT. Shaping ability of three nickel-titanium endodontic file systems in simulated S-shaped root canals. J Endod. 2012;38(12):1618-21. Epub 2012/11/14.

32. Ersev H, Yilmaz B, Ciftcioglu E, Ozkarsli SF. A comparison of the shaping effects of 5 nickel-titanium rotary instruments in simulated S-shaped canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;109(5):e86-93. Epub 2010/04/27.

33. Ruddle CJ. The ProTaper endodontic system: geometries, features, and guidelines for use. Dent Today. 2001;20(10):60-7. Epub 2001/10/23.

34. SA FD. FKG Swiss Endo Catalog. Switzerland2013.

35. Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod. 1990;16(10):498-504. Epub 1990/10/01.

APPENDIX

VITA

Mr. Sirawut Hiran-us was born on 20th March 1986. He got his bachelor degree of Doctor of Dental Surgery from Faculty of Dentistry, Chulalongkorn University in Class of 2009. He served the government as lecturer and dentist at Sirindhorn College of Public Health, Supahnburi in year 2010–2011. From 2011 to present, he is a dentist at private dental clinic, Bangkok. His recent award was second place of Dentsply Asia University Endodontic Case Contest 2013.