RANYA ELEMAM

ASSESSMENT OF THE ROOT CANAL TRANSPORTATION AFTER PREPARATION WITH NEWLY INTRODUCED ENDODONTIC FILES

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RESUMO

Introdução: A instrumentação dos canais radiculares é um passo essencial no tratamento endodôntico pois determina a eficácia de todos os procedimentos subsequentes. A fase da instrumentação deveria manter a posição do forâmen sem quaisquer desvios do trajeto original, o que se revela desafiante em canais curvos. As avaliações da performance das limas endodônticas tem passado sempre pela sua capacidade de se moldarem à anatomia radicular, sem desvios, principalmente nos canais curvos. O transporte do canal é um dos parâmetros mais utilizados para avaliar a performance das limas. A fadiga das limas endodônticas é uma das propriedades mecânicas possíveis para esta avaliação. A correlação entre a fadiga e a ocorrência de fractura da lima permitem uma melhor compreensão das características dos instrumentos

Objetivo: **1).** Avaliar o uso frequente dos sistemas ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Suíça) na capacidade de moldar o canal radicular. **2).** Avaliar o sistema de limas BT-Race (FKG, La Chaux-de-Fonds, Suíça) na sua capacidade de moldar o canal radicular após repetidas utilizações. **3).** Observar alterações morfológicas das limas ProTaperNext antes e após várias utilizações, através da microscopia eletrônica de varrimento (MEV).

Metodologia: **1).** Trinta e seis canais radiculares em blocos de acrílico (Dentsply-Maillefer) foram dividos em seis grupos experimentais (n = 36). Seis novos conjuntos de instrumentos PTN (Dentsply Maillefer, Ballaigues, Suíça) foram utilizados seis vezes para instrumentar os blocos de acrílico. A lima 15K foi inserida com o comprimento de trabalho (CT), seguido-se a lima ProGlider para criar um "glide path". A utilização sequencial das limas PTN através da técnica crown-down foi usada para atingir o tamanho (30/07) a nível apical. Foram realizadas fotografias macroscópicas dos blocos foram realizadas antes e após a instrumentação, estratificadas com o "software" Paint Shop Pro 9 de JascSoftware®. O transporte do canal foi medido utilizando CAD Solidwork2014 em onze locais. **2)** Os trinta e seis canais radiculares em blocos de acrílico foram divididos em seis grupos. A irrigação fez-se com utilização de álcool etílico a 99%. Os canais foram preparados usando uma técnica crown-down até atingir um tamanho final apical de 35 / 0,04. Imagens pré e pós-instrumentação foram tiradas com lentes de aumento macroscópico, estratificadas com o "software" Paint Shop Pro 9 e o transporte do canal foi medido utilizando CAD Solidwork2014 em onze locais. **3)** Dezoito canais simulados em blocos de acrílico (Dentsply-Maillefer, Ballaigues, Suíça) com um grau de curvature de 60º foram divididos em três grupos experimentais. Seis novos conjuntos de instrumentos PTN (Dentsply Maillefer, Ballaigues, Suíça) foram utilizados três vezes para instrumentar os blocos de acrílico. Uma lima 10K foi inserida no comprimento de trabalho (CT), seguida pela ProGlider para criar um "glide path". A instrumentação com PTN foi utilizada, de acordo com a instrução do fabricante, com irrigação com álcool etílico a 99% ao longo do procedimento. Todos as limas foram fotografados na mesma posição antes e depois das três preparações dos canais, usando uma alta resolução de MEV (FEI Quanta 400FEG ESEM / EDAX Genesis X4 M). Todas as limas foram analisadas através do software SPSS V.22 usando - General Linear Model 2 way ANOVA, com correção de Bonferroni para comparações múltiplas. O valor de p foi ajustado para 0,05

Resultados: **1).** As limas PTN induzem transporte; o menor valor de deslocamento do centro de canal ocorreu aos 4 milímetros (0,015 ± 0,014), enquanto o maior se verificou aos 6 milímetros (0,077 ± 0,035). **2)** Não houve diferença estatisticamente significativa no transporte de canal após seis utilizações das limas PTN. 3) As limass BT-Race transporte induzido; a menor quantidade de transporte canal centro foi visto no 2 mm (0,030 ± 0,020), enquanto que a maior quantidade foi visto observado a no 6 milímetros (0,102 ± 0,042). Não houve diferença estatisticamente significativa no canal de transporte resultou da utilização de arquivos PTN após seis usos. **3).** As limas BT demonstraram maior transporte em todos os locais (apical, médio e coronal), independentemente do número de utilizações. **4).** Foi observado um defeito, "metal strip" na superfície do metal de um instrumento X1, pré-operatóriamente. Dois pequenos defeitos, microfissuras, foram observados em duas limas X2, no pós-operatório e uma aresta de corte romba foi observada em três limas X1, tanto antes como depois da utilização. Uma lima PTN fraturou.

Conclusão: **1)** As limas PTN respeitam a anatomia dos canais e podem ser usadas, de modo seguro, para preparar canais de dentes mono e multirradiculares. **2)** As limas BT-Race respeitam a morfologia dos canais e são seguras para usar repetidamente com uma pequena incidência de transporte dos canais. **3)** Um pequeno número de defeitos apareceu na superfície das limas PTN. A mesma lima PTN pode ser usado com segurança 3 vezes para preparar canais de dentes multirradiculares em situação clínica.

Palavras-chave: instrumento rotativo de níquel-titânio; capacidade de dar forma; Transporte; Protaper Next; BT-race; MEV; análise de superfície

ABSTRACT

Introduction: Root canal instrumentation is an essential step in root canal treatment since it determines the efficacy of all subsequent procedures. Instrumentation step should maintain the foramen position without any deviations from the original path of the canal which is challenging in curved canals. Evaluations of the performance of endodontics files always examined their ability to shape the curved root canals without errors. Canal transportation is one of the most common parameters used to evaluate files performance. File fatigability is a mechanical property of the endodontic files that is valuable to evaluate. The link between fatigability and file failure improves the understanding of file characteristics.

Aim: The aims of the thesis are: **1).** To evaluate the frequent use of ProTaper Next (*PTN; Dentsply Maillefer, Ballaigues, Switzerland*) systems on shaping ability of root canal. **2).** To evaluate the repeated use of BT-Race (*FKG, La Chaux-de-Fonds, Switzerland*) file system on shaping ability of root canal. **3).** To observe the morphological alterations of ProTaperNext files before and after continuous use by scanning electron microscopy (SEM).

Methodology: **1).** Thirty-six root canals in clear resin blocks (*Dentsply-Maillefer*) were allocated into six experimental groups (n = 36). Six new sets of PTN instruments (*Dentsply Maillefer*, *Ballaigues, Switzerland*) were used six times to shape the resin blocks. A #15 K-file was inserted to the working length (WL), followed by ProGlider to create a glide path. Sequential use of PTN instrumentation in a crown-down technique was used to reach size (30/07) apically. Macroscopic photos of the blocks were taken before and after instrumentation, layered by Paint Shop Pro 9 from JascSoftware®. Canal transportation was measured using CAD Solidwork2014 in eleven locations. **2).** Thirty-six canals in resin blocks were allocated into six groups. 99% ethyl alcohol used for irrigation. canals were prepared using a crown-down technique to a final apical size of 35/.04. Pre- and post- instrumentation images were taken using macroscopic magnifier, layered by Paint Shop Pro 9 software, and canal transportation was measured using CAD Solidwork2014 in eleven locations. **3).** Eighteen simulated root canals in clear resin blocks (*Dentsply-Maillefer, Ballaigues, Switzerland*) with 60º degree of canal curvature were allocated to three experimental groups. Six new sets of PTN instruments (*Dentsply Maillefer, Ballaigues, Switzerland*) were used three times to shape the resin blocks. A #10 K-file was inserted into the working length (WL), followed by ProGlider to create a glide path. PTN instrumentation was used according the manufacture instruction with 99% ethyl alcohol for irrigation throughout the procedure. All files were photographed in the same position before and after three canals preparations using a high-resolution SEM (FEI Quanta 400FEG ESEM / EDAX Genesis X4 M). All data were analyzed by SPSS software V.22 using - General Linear Model 2 way ANOVA, with Bonferroni correction for multiple comparisons. p value was set to 0.05.

Result: **1).** PTN files induce transportation; the lowest value of canal center displacement was seen at 4mm (0.015±0.014), whereas the highest amount at the 6mm (0.077±.035). **2)** There was no statistically significant difference in canal transportation after utilizing PTN files after six uses. **2).** BT-race files induced transportation; the least amount of canal center transportation was seen at the 2 mm (0.030±0.020), while the greatest amount was seen at the 6mm (0.102±0.042). There was no statistically significant difference in canal transportation resulted from utilizing PTN files after six uses. **3).** BT files demonstrated greater transport at every location (apical, middle, and coronal) regardless of times of use. **4)**. A metal strip appeared on one X1 instrument surface pre-operatively. Two small microcrack defects were observed on two X2 files postoperatively, and a blunt cutting edge was observed on three X1 files before as well as after use. One PTN file fractured.

Conclusion: **1)** PTN files respect the canal anatomy and can be used to prepare single and multiple canals in a single furcated tooth safely.**2)** BT-Race file respects the canal morphology well and were safe to use repeatedly with few incidences of transportation. **3)**

Small number of changes appeared on PTN surfaces. The same PTN file can be used safely 3 times to prepare multi-rooted canals in a clinical situation.

Keywords: Nickel-titanium rotary instrument; Shaping ability; Transportation; Protaper NEXT; BT-race; SEM; surface analysis.

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SYMBOLIC AND ABBREVIATIONS

ANOVA	Analysis of Variance
BT-Rac	Booster Tip- Reamer with Alternating Cutting Edges
CAD	Computer-Aided Design.
CBCT	Cone-beam computed tomography
CM-wire	Controlled memory
CT	Computed tomography
DICOM	Digital Imaging and Communications in Medicine
HF	Hyflex
IR	iRace
ISO	International Standards Organization
K File	Kerr File
LSD	Least Significant Difference

MCT	Micro-computed tomography
mm	Millimeter
N	Newton
Ncm	Newton centimeter
NiTi	Nickle Titanium
PRM	“Revolutions” per minute
PTN	ProTaper Next
PTU	ProTaper Universal
R-Phase	Rhombohedral phase
SAF	Self-adjusting file
SEM	Scanning Electron Microscope
SPSS	Statistical package for the social sciences
SS	Stainless Steel
WL	Working Length

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CHAPTER 1

General Introduction

It has been well-known that bacteria and by-products are significant etiological factors in the initiation and progression of pulpal inflammation and apical periodontitis[1]. Therefore, a critical objective of root canal treatment is the elimination of bacteria and their substrates from the root canal system. Mechanical preparation in endodontic therapy involves the application of irrigants and medicaments to form a bacteria-free canal while shaping the canal for root filling processes.

The mechanical preparation or root canal instrumentation is the most perplexing step during root canal therapy procedure; it is challenging and time consuming.[2] It is considered an essential part of root canal treatment procedures as it determines the efficacy of subsequent phases.[3] Objectives of ideal root canal instrumentation procedures include well shaped root canal that is continuously tapered , maintaining the original shape, free of any iatrogenic damage to the canal system and /or to the root structure while maintaining the original foramen position (i.e. no transport).[4] The ability to keep the instruments centered is crucial to achieve those objectives and deliver an accurate enlargement to the root canal without any unnecessary weakening to the root structure.

Endodontic instruments that enlarge and prepare root canals must meet the basic requirements of effect transport and centering in order to ensure successful root canal treatment.[3, 5, 6] Teeth and corresponding root canal anatomy varies in cross-section, shape, thickness of dentin, and foramen size. These anatomical variation increases the possibility of procedural errors in curved canals,especially transportation, since most endodontic instruments are straight and capable to create lateral forces in curved canals.[7] The instrumentation objectives were achieved only minimally when using stainless steel files since they are very rigid and their rigidity increases with larger instrument sizes.[7] However, nickel-titanium (Ni-Ti) instruments, with their unique property of super elasticity, allow entering in curved canals with less stress.[8] The elasticity permits bending to follow the anatomical curvature of the canal, [9] which reduces stress and torsion forces within the canal leading to minimal transportation.[8]

When Transportation occurs, it has two components - direction and deviation. *Direction* is an excessive dentine removal in a single direction off the main tooth axis of the canal.[10] *Deviation* is any undesirable departure from natural canal path, which is the distance (in millimeters) from the before- and after - instrumented canal as a function of file action.[11] Root canal transportation is defined according to the Glossary of Endodontic Terms of the

American Association of Endodontists as: "the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of the file to restore themselves to their original linear shape during the canal preparation".(12) Centering is a measure of deviation, and represents the ability of the instrument to stay centered in the canal.(13)

1.1 HOW TRANSPORTATION OCCURS

All root canal instruments tend to straighten inside the canal regardless the alloy of the file used (3, 5, 14-16). The cutting edges are forced against the outer side of the curved canal wall (convexity-side) in the apical third of the canal and against the inner side wall at the middle or coronal thirds of the canal (concavity-side), which causes an asymmetrical dentin removal (3, 16). As a result, the apical canal areas appear over prepared in the direction of the convexity of the canal, and , greater amounts of dentin are removed at the concavity along the coronal plane leading to canal transportation or straightening (3, 16) (Figure 1).

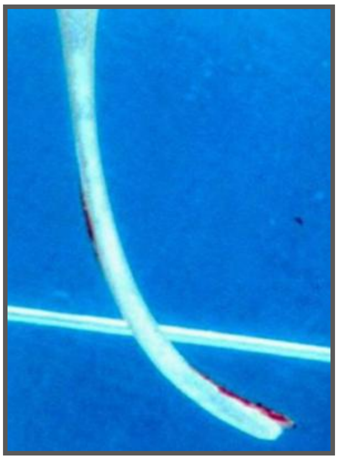


Figure 1: Simulated canal after preparation with stainlesssteel K-files showing the characteristic patterns of canal transportation. In red color(17).

1.2 CONSEQUENCES OF ROOT CANAL TRANSPORTATION

Deviation of the original path of the canal may result in damage of the apical foramen and loss of apical stop (5). As a consequence, this will lead to extrusionof debris, irrigants, or filling materials and subsequently an irritation of the periapical tissues (17).

Transported root canal has the outer aspect of the curvature over prepared thus inducing an elliptical shape at the apical endpoint called zipping [17]. It is also called ‘hourglass shape,’ a ‘teardrop,’ or a ‘foraminal rip’ [5, 16, 18].The incidence of the zipping has an undesirable effect on the apical seal of root canal specially if cold lateral compaction technique was used [19] (Figure 2) .

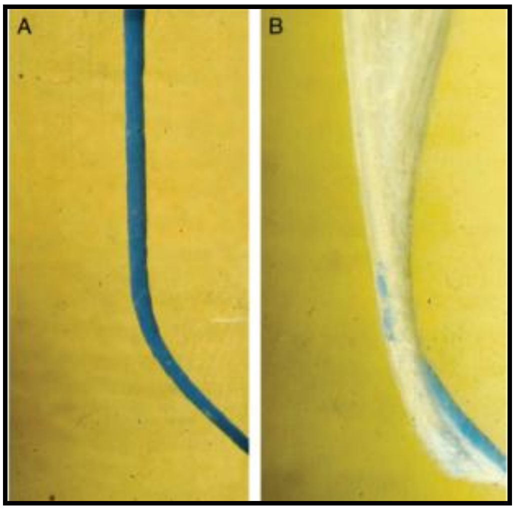


Figure 2: (A, B) Simulated root canals in plastic blocks before and following preparation clearly demonstrate the genesis of straightening and creation of zip and elbow [5].

The narrow area of the root canal that exist between the extreme material removal area alongside the outer wall apically and the over increase of the inner wall of the curvature coronally is called elbow. It usually exists at the point of maximum curvature (Figure 2). This lead to less taper of the canal and inadequate cleaning and obturation of the apical part of the root canal [5, 18].

Apical perforation is another consequence which occurs due to the sharp cutting tips of the used instruments [3, 5].

Strip perforation occurs in the middle or the coronal third of the canal, and manifests as a perforation that is most often the result of over preparation along the inner side of the wall of the curvature [5, 20].

Ledging is similarly a result of canal deviation when the working length cannot be reached [17]. It occurs in the middle or the apical part of root canals as a raised area at the beginning of the outer side of the curvature [5].

1.3 FACTORS INFLUENCING THE INCIDENCE OF CANAL TRANSPORTATION

Degree and radius of root canal curvature both induce a stress on the instruments. The more severely curved and the shorter the radius of curvature, the greater the risk of transportation [21].

File design, specifically those instruments that have a modified non-cutting tips are better in maintaining the original canal path compared with instruments with conventional tips [22]. Cross-section, depth of flutes, core diameter, and spirals per unit length also influence the ability of the instrument to maintain the original canal curvature [23].

Instruments which are made from stainless steel produce more transportation than instruments made from nickel titanium (NiTi). However, NiTi files which are thermo-mechanically proceeded cause minor canal transportation. Yet, the newer generation of NiTi instruments, such as those made of new alloys (CM-wire, M-wire), demonstrate negligible transportation [22].

Numerous innovative nickel-titanium (NiTi) rotary systems claiming improvements in shaping ability performance are currently available. However, centering ability during instrumentation to avoid transport is a persistent concern. An instrument that is capable of producing optimally centralized preparation is not yet available [24-28]. The search for the instrument most effective in shaping the toot canal without transportation may partially explain the recent dramatic influx of new files with varied materials and designs on the market [14]. Some studies which investigated rotary endodontic files showed that NiTi maintained original canal shape better than stainless steel files [29-31]. This was attributed to the unique property of super elasticity of NiTi files which allowed placing them in curved canals with less lateral forces and less transportation [8]. Objective evaluation of the transport efficacy of endodontic files is important to clinicians and researchers, and is the subject of the review of literature in section 2.2.

CHAPTER 2

Literature Review

2.1 HISTORY OF NICKEL-TITANIUM (NITI) INSTRUMENTS

NiTi instruments are made of NiTi alloy which contains 56% nickel and 44% titanium. They were first introduced by Walia et al. in 1988 [32]. Their first application in endodontic design was commercially available in the 1990's [33, 34]. Two of the main characteristics of this alloy are shape memory and superior elasticity. These files had two or three times more elastic flexibility and greater clockwise and anti-clockwise torsion fracture resistance than stainless steel files [32]. The first generation group of the Ni-Ti files systems had passive cutting radial lands, constant tapers of their active cutting blades and several files within the system. Those features allowed the file to stay centered in the canal. GT files (*Dentsply Tulsa Dental Specialties, Tulsa, OK, USA*) is an example of this group [33].

The advance of Ni-Ti files has significantly enhanced the quality of root canal shaping, and has decreased the occurrence of iatrogenic errors during root canal preparation [3]. In the early 1992, NiTi files were introduced to students in the college of dental medicine at the University of South California, which led to a surge of development [32]. NiTi instruments now are available in a variety of forms (files, pluggers, spreaders, etc). The second generation of Ni-Ti rotary files was available in market in 2001 [34]. In contrast to the first group, this group have active cutting edges and less numbers of instruments to prepare the root canal. Types in this group include the EndoSequence (*Brasseler USA*), and BioRaCe (*FKG Dentaire SA, La Chaux-de-Fonds, Switzerland*), ProTaper (*Dentsply Tulsa Dental Specialties, OK, USA*).

Currently, with over two decades of use, the design of the NiTi instruments has undergone significant modifications. Improvements in Ni-Ti metallurgy that resulted in third generation where manufacturers emphasized on using heating and cooling methods which significantly enhanced the files cyclic fatigue and reduce fragility of Ni-Ti instruments in curved canals [35]. Types in this group are the Twisted File (*Axis|SybronEndo, Orange, USA*); HyFlex (*Coltène, Whaledent AG, Altstatten, Switzerland*); and GTX (*Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA*), Vortex (*Dentsply Tulsa Dental Specialties, Tulsa, OK*), and WaveOne (*Dentsply Tulsa Dental Specialties, OK, USA*). Reciprocation technology is another innovation which has been added to the advanced group of NiTi files and has led to the introduction of a fourth generation of instruments [36]. This generation of instruments is based on the single-file technique. Example to this group; WaveOne (*Dentsply Tulsa Dental Specialties, OK, USA*) and Reciproc (*VDW, GmbH, Munich, Germany*) Self-adjusting file (*SAF; ReDent-Nova, Raanana, Israel*) [36, 37]. The fifth generation of shaping files designed in an approach that the center of mass and/or the center of rotation are offset to reduce the engagement between the file and dentin and improves flexibility [27]. Types of files with this technology are Revo-S, One Shape® (*Micro-Mega®, Besançon, France*), and the PTN ProTaper Next (PTN) file (*Dentsply Tulsa Dental Specialties/ DentsplyMaillefer*).

M-wire NiTi is considered one of the most advanced modifications of nickel–titanium alloy which is made by thermal treatment process to NiTi wire blanks [38]. The M-wire alloy is a mixture of nearly equal amounts of R-phase (i.e., pre-martensitic or an intermediate phase between austenitic and martensitic phase) and austenite NiTi; a conventional super elastic NiTi which has an austenite structur [35, 39]. M-wire NiTi contains substantial amounts of martensitic that does not undergo phase transformation resulting in a metallurgical microstructure that exhibits alloy strengthening [40]. It has been claimed that these instruments improve file flexibility and resistance to cyclic fatigue while retaining cutting efficiency [41].

NiTi rotary instruments provide significant advantages in clinical endodontic care for their flexibility and time-saving properties. However, the variety of their designs and cross-sectional configurations distinct to each instrument may lead to clinical challenges depending on the case encountered.

Many characteristics need to be investigated during development of a new instrument, such as cleaning ability, shaping ability, safety aspects and effects on root canal configuration [3, 5, 42-49]. Also, within the limitations of all performed studies, the selection of the appropriate rotary instrument systems may vary depending on the individual clinical case. The practitioner must be well informed about the property of each system and make the choice of the system and sequence according to the root canal anatomy. Most of these studies outcomes must on the other hand be interpreted with caution because they are limited to the present investigation realized with simulated canals and must be supported by further research[50].

2.2 HOW INSTRUMENTS ARE EVALUATED FOR THEIR EFFICACY

Many evaluation parameters were used in the literature when shaping ability of instruments was investigated. These parameters included change in the root canal cross-sectional area, degree of canal transportation, centering ability, minimum remaining dentine thickness in the mesial and furcal directions, taper and flow of"the prepared root", smoothening of the canal walls, change in curvature angulation, centering ratio, working time, fracture of instruments, canal aberrations, and working length [(51)]. Yet, transportation and centering ratio are used most frequently.

The literature consistently reports a three step process for shaping ability evaluation:

1) images of the canals are taken before (pre-image or un-instrumented) and after (post-image or instrumented),

2) the pre- and post-images are superimposed, and

3) measurements are taken of the difference between the pre/ post-image using a mathematical equation.

A summary of the literature from 2010-2015 relevant to the three steps evaluation of two parameters (transportation and centering ability) follows.

<u>STEP 1</u>. Scanning and imaging: Different modalities are used to capture pre/post images. These include digital microscope software[(11)], periapical radiographs[(40, 52-55)], digital camera [(41, 56-58)], digital camera attached to stereomicroscope[(59, 60)], stereoscopic magnifier [(61)], and standardized digital radiograph [(41, 62-64)]. Various types of computed tomography (CT) were found to be the most accurate since it is non-destructive and produces more accurate images than other imaging techniques [(28, 65-67)]; cone-beam CT [(27, 68-71)], and spiral CT [(72, 73)]. It was acknowledged in the literature that the superior methods that were used to assess shaping ability of endodontic rotary files were MCT and CBCT.

MICRO-COMPUTED TOMOGRAPHY (MCT)

MCT is the compact form of the ordinary computed tomography (CT), but with higher resolution that permits accurate evaluation of any changes in prepared root canals [(74)]. MCT improves the image resolution by generating 3-dimensional images without destroying the sample [13, 72, 75]. Also, the device permits quantitative and qualitative evaluations of root canals, providing their anatomical details and variations and allows comparison of pre- and post-preparation images of root canals [76]. It has become a significant educational and research tool for pre-clinical teaching in endodontics [77]. For these reasons, the current generation of MCT instruments is considered a superior technique to evaluate the quality of root canal preparation techniques [78].

CONE-BEAM COMPUTED TOMOGRAPHY (CBCT)

Cone-beam computed tomography (CBCT) is a non-invasive technique whose images are highly accurate compared to conventional methods because of the details of the images it produces [72, 74, 79]. It has been used in clinical endodontic practice and in researches that assess the root canal morphology, fractures, and changes in prepared root canals[10, 80]. CBCT has a low radiation amount and less resolution compared to CT, which may cause problems when enhancing data during imaging and for research[80].

STEP 2. Pre/Post images superimposition: Different software programs facilitate the process. The most common are Adobe Photoshop [11, 24, 41, 56-58, 60, 81-83] and AutoCAD [52, 62]. Other applications used are: Image Tool software (*University of Texas Health Science Center, San Antonio, TX, USA*)[61]; magnetic optical disc[72]; DiCom software[84]; Image Tool software (*University of Texas Health Science Center, San Antonio, TX, USA*) [61]; and NTT (*New Net Technologies Ltd, Naples, FL*) using a Dell Precision T5400 workstation (*Dell, Round Rock, TX*) [69].

STEP 3. Measurements: Most studies measured the transportation in a cross sectional view [27, 28, 56, 65, 68, 84] (Figure 3) while few preferred a perpendicular plane [11, 83] (Figure 4).

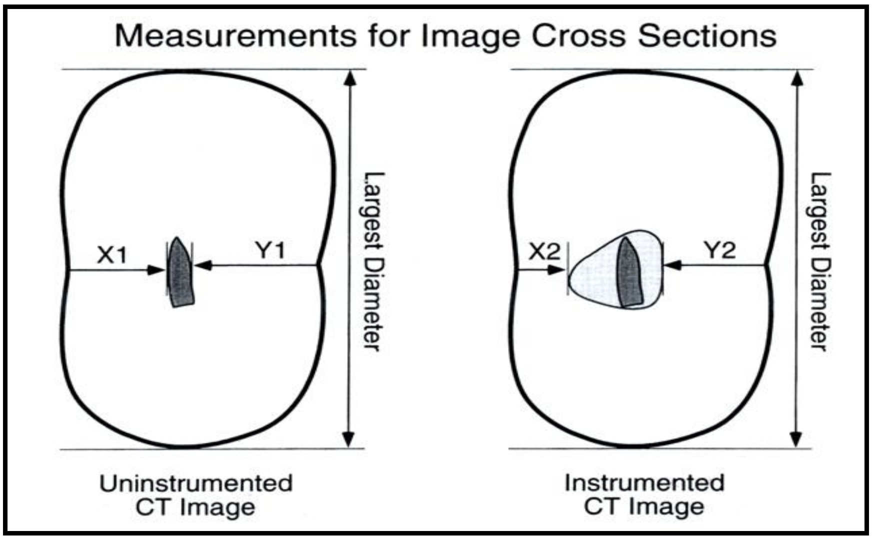


Figure 3: Root canal cross sections showing calculation of transportation based on Gambill's formula. Un-instrumented image (left): original canal space represented by dark shaded area. Instrumented image (right): light shaded area represents canal shape after in instrumentation. X1: the shortest distance from the outside of the curved root to the periphery of the uninstrumented canal, Y1 the shortest distance from the inside of the curved root to the periphery of the uninstrumented canal, X2 the shortest distance from the outside of the curved root to the periphery of the instrumented canal, and Y2 the shortest distance from the inside of the curved root to the periphery of the instrumented canal[(13)].

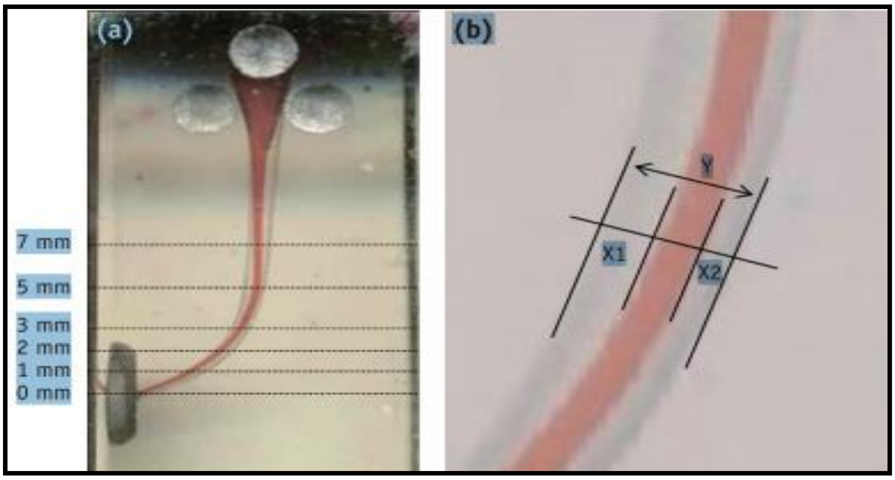


Figure 4: (a) The picture indicates the points at which the canal width was measured after superimposition of pre- and post-operative images; (b) X1 represents the maximum extent of canal movement in one direction and X2 is the movement in the opposite direction, Y is the diameter of the final canal preparation[(24)].

2.3 APPLYING THE 3 STEPS TO TRANSPORTATION

IMAGING AND SUPERIMPOSITION

Many of the imaging software programs summarized previously have applications for measurement as well, which may explain the popularity of Adobe Photoshop and AutoCAD. These applications use the superimposed photos [24, 41, 52, 57, 62-64, 81, 82, 85]. If the files (initials and finals) or marked centers were not superimposed, transportation was assumed. Then the distance between these files or the non-corresponding marks were measured in millimeters which showed deviation of the original canal path in the apical third. Image 1.38x software (*National Institutes of Health, Bethesda, MD*) [11, 83, 86], Image tool 3.0 software (*Uthscsa, San Antonio, TX, USA*) [55], ImageJ analysis software (*ImageJ v1.44, U.S. National Institutes of Health, Bethesda, MD, USA*) were also used to measure apical transportation [41, 63], and recently a use of ImageJ software (National Institute of Health, public domain) [83].

MEASUREMENT OF TRANSPORTATION

Most studies used Gambill's equation 1 (ANNEX I) [27, 28, 53, 65, 68, 69, 71, 80, 84], that measures the difference between X1,X2 minus Y1,X2 in pre-and post-instrumented images . A result of zero value indicates no canal transportation, a positive value represents mesial movement, whereas a negative value represents distal movement or movement toward the furcation [28, 65, 68].

Javidi *et al.* [56] used the Garip method (ANNEX I) [87], that is a ratio of X_1,X_2 divided by Y_1,Y_2. A proportion above one indicates that canal is transported to the inner wall of the root canal curvature and a value below one shows transportation to the outer wall of the root curvature [56]. If the value equals one, the canal centering has not changed. Al-Manei *et al* calculated the transportation by subtracting the dentinal thicknesses of the un-instrumented root canal from those of the instrumented canal in the furcal and mesial directions[88]. Zhao *et al* [86] calculated canal transportations by comparing the changes of the centers in micrometers before and after instrumentation at selected locations in the canals (ANNEX I). Others evaluated transportation using software by calculating the canal curvature using Cunningham's method (ANNEX I) [58], and Schneider's method (ANNEX I) [58].

MEASUREMENT OF CENTERING

The centering ratio is the difference between the instrumented and non-instrumented canal, which measures the ability of instrument to stay centered. As with transportation, different formulae are used to calculate the centring ratio. Many review papers adopted Gambill's equation [27, 28, 61, 66, 69, 71, 72, 84] (ANNEX I) with results equal 1 indicating a perfect center of instrument in the canal [13]. Zang's formula (ANNEX I) [89] is a ratio of mesial to distal surface between the instrumented and uninstrumented canal. When this value was closer to zero, it was considered that the instrument had a lower capacity to maintain itself in the central axis of the canal [68]. Calhoun and Montgomery formula (ANNEX I) [90], is similar to the Garip (ANNEX I) method with the denominator, Y as the instrumented value only. A smaller value indicates better centering of the instrument in the canal.

OTHER METHODS

Methodologies that were used to evaluate the performance of root canal instrumentation include: silicon impression, muffle system, and radiograph superimposition techniques. Many of these techniques were demonstrated in endodontic research. Yet, limitations are well-recognized prompting the search for new methods with improved capacities that permit both quantitative and qualitative three-dimensional assessments of the root canal [91]. For these reasons, the three are given only cursory description:

Silicon Impression material - Goldman and Davis *et al*.[92] injected a silicone impression material into instrumented root canals of extracted teeth. The materials proved the ability to assess flow, taper, and smoothness of the walls. To use the silicon in the small unprepared canals properly, a low viscous silicone is applied with a vacuum technique. Although the low viscous type of silicones was able to display details, this method did not give details on the status of the original root canals before preparation due to the difficulty to introduce the silicone into the narrow unprepared canals [93]. Measurements of transportation taken through this method are compared by digitalized photographs from each impression. Barthel etal[93] stated that the poly vinyl siloxane impression was an ideal type of material to take repeated impressions of the root canal without damaging of tooth structure. This study advised that this technique of evaluating instrumentation of root canals might be a valid tool to compare new incumbents or instrumentation techniques [93]. The 3D internal impression models of prepared canals were also assessed under stereomicroscope to measure the efficiency in preparing canals [20, 94].

Muffle system - An *in vitro* method used to evaluate the change in canal diameter. It is also known as Bramante et al method named after the establisher of this technique [47].

The double radiographic superimposition technique, used first by Iqbal et al [95], does not require modification [96] and it can measure the apical transportation in two dimensional views (2D) mesiodistal and buccolingual of the longitudinal shape of the root canal. However, the real value of canal transportation extended to the 3rd plane was not normally evaluated by this measure [97]. In addition, the cross section of the root canal is impossible to be observed [96]. Measurement of apical transportations can be very challenging because of the fact that there is no gold standard method for their assessment, and all used different methods have limitations [98].

2.4 FEATURES OF TWO INSTRUMENTS EXAMINED IN THE THESIS AND STUDIES THAT INVESTIGATING SOME PROPERTIES OF BOTH FILES

2.4.1 PROTAPER NEXT (PTN) FILE

2.4.1.1 FEATURES

ProTaper Next (*Dentsply Maillefer, Ballaigues, Switzerland*) follows the distinctive features of the most recent generation of NiTi endodontic rotary files (5th generation). It is a successor of ProTaper Universal system (PTU) (*Dentsply Maillefer,Ballaigues, Switzerland*) [99]. PTN is similar to PTU in clinical strategy, such as technique of shaping root canals and the variable taper along the active cutting blades [100]. The two files have different alloy properties and cross-sectional designs (Figure 5).

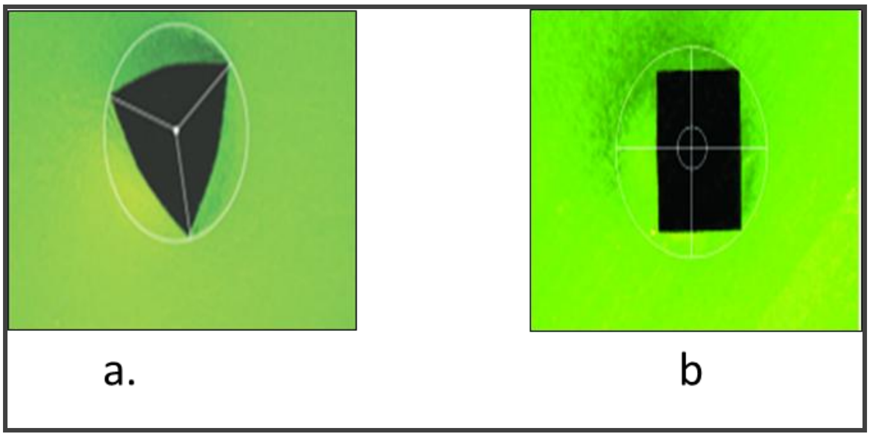


Figure 5: a - Cross section of (PTU) ProTaper Universal at the middle of the working part/ | b - cross section of (PTN) ProTaper NEXT at the middle of the working part[40].

PTU instruments have a convex triangular cross-sectional design, a non-cutting safety tip and a flute design that combines multiple tapers within the shaft [101]. PTN file is manufactured from M-wire alloy which adds file flexibility and cyclic fatigue resistance while maintaining the cuttin efficiency [67]. PTN has an innovative off-centered rectangular cross section that gives the file a snake-like swaggering movement and greater strength as it advances into the root canal. The manufacturer claims that the rotation of this cross section generates enlarged space for debris removal [102]. The center of rotation is offset to create a mechanical wave of motion alongside the active part of the file [99]. The offset design reduces the binding between the file and the root canal [22, 27]. Similar to the progressively tapered design of any set of ProTaper file, this design aids to minimize the engagement between the file and dentin [24]. The shaft length of the PTN is small, therefore provides better access to the posterior teeth. The recommended speed is 350 rpm with a torque of 2.5 N/cm [103]. The PTN system contains five files (X1, X2, X3, X4 and X5), each coded with a different colored ring on itshandle (i.e,yellow, red, blue, double black, and double yellow, respectively) (Figure 6). The X1 (17/0.04) and X2 (25/0.06), are the shaping and finishing files while X3 (30/0.07), X4 (40/0.06), and X5 (50/ 0.06) are optional [103].

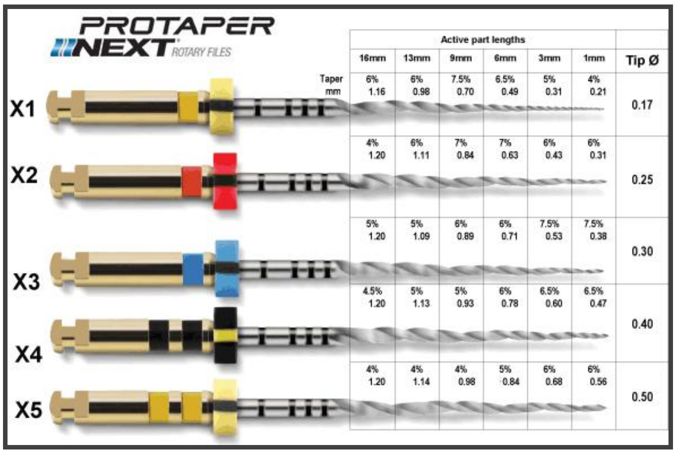


Figure 6: Color coding and dimensions indicate the shape created by each file [(102)].

PTN showed different magnitude of torque and varios amounts of negative force and positive force in all instruments sizes (Figure 7- Figure 9). PTN X1 showed the highest negative force with magnitude 1.37N, Low positive force 0.03N and maximum need of torque amount 1.79 Ncm. The highest torque and the positive force were seen with X2 among all files sizes. X2 showed 4.75N magnitude of positive force 2.11 Ncm of needed torque and only 1.04N nefative force .

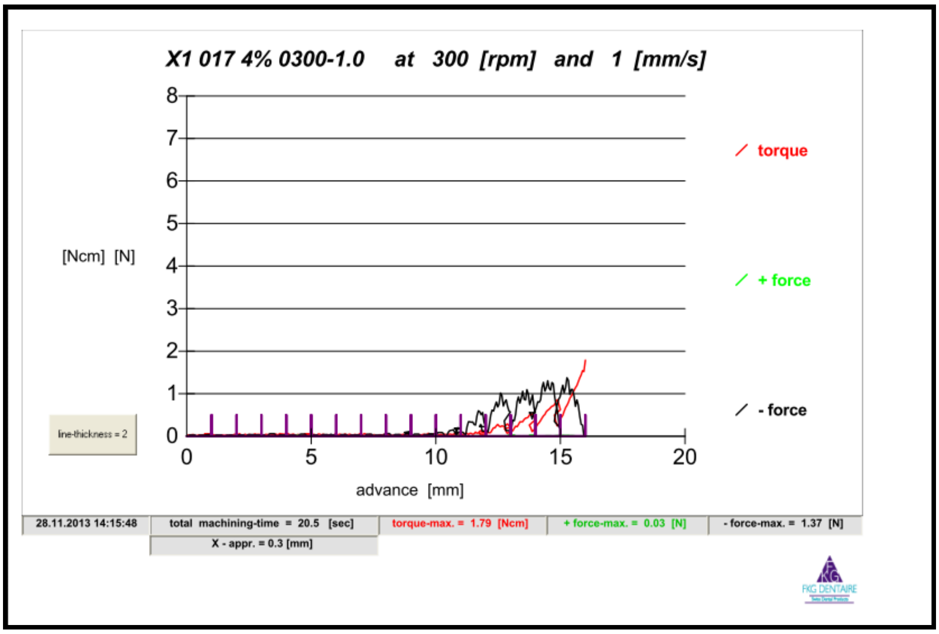


Figure 7: PTNX1 at torque 1.79Ncm and speed 300 rpm.

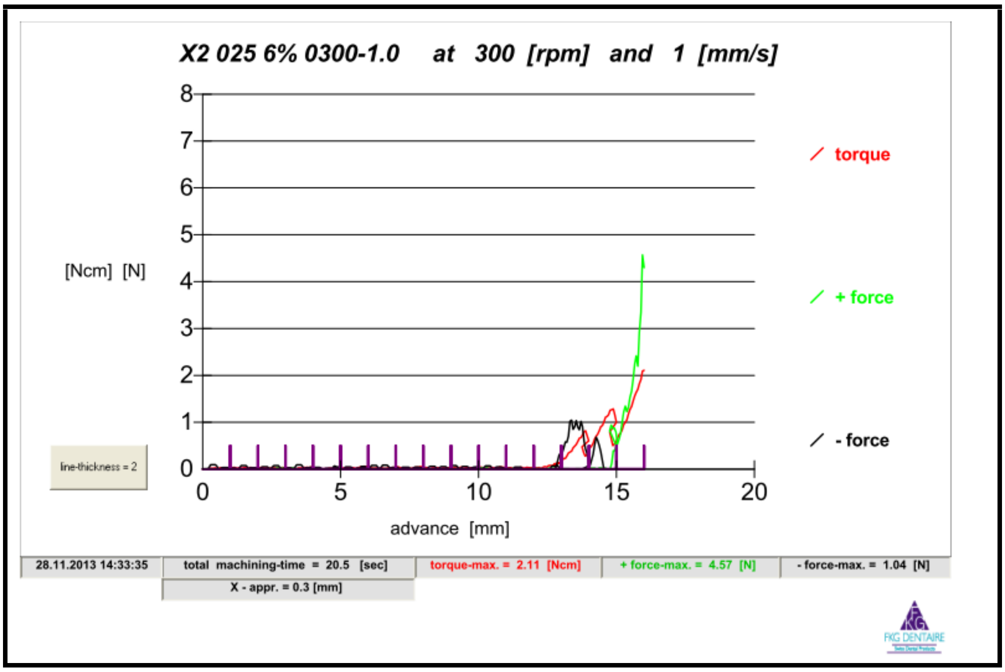


Figure 8: PTNX2 at torque 2.11Ncm and speed 300 rpm.

The PTN x3 revealing the smallest value of the negative force among the rest of files within the system the amount was 0.35N . While the positive force was 4.50N and the maximum needed torque was1.51 Ncm.(Fig9)

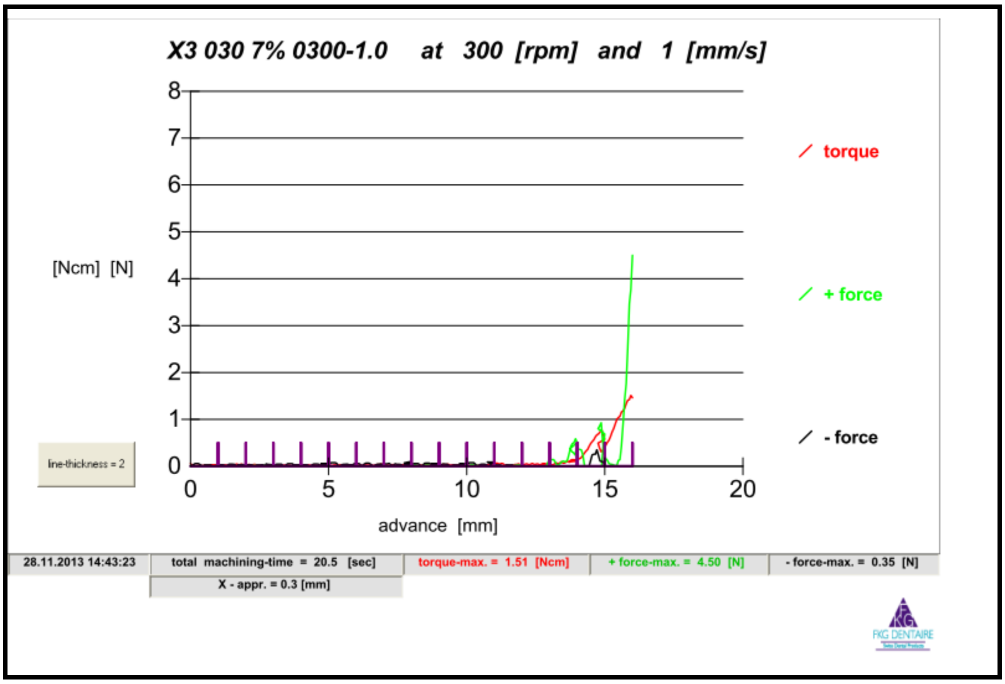


Figure 9: PTNX3 at torque 1.51Ncm and speed 300 rpm.

2.4.1.2 STUDIES THAT INVESTIGATING PTN

SHAPING ABILITY:

Shaping ability of files means the ability of the instrument to shape the root canal, specially curved canals without inducing aberrations. This is normally done by evaluating whether the file straightening the curvature or its centering ability or its capability to maintain the canal centered with less displacement or transportation.

The shaping ability of PTN, PTU, and WaveOne(WO) was compared using both simulated L-shaped and S-shaped root canals [(58)]. Canals were prepared up to size 25 by all file systems; pre-and post-images were taken and then superimposed. The central axis transportation and straightened curvature were evaluated using image analysis program. Findings for L-shaped simulated canals showed that PTN produced the least transportation at apical constriction and the highest transportation value at straight section. PTN and PTU produced less transportation than WO at curved section. PTN preserved the canal curvature best among all groups. For S-shaped simulated root canals, PTN showed the best preservation to the coronal curvature.

A study by Capar *et al*.[(69)] compared canal transportation, canal curvature, centering ratio, surface area, and volumetric changes of curved mesial root canals of 120 mandibular molars after instrumentation with ProTaper next X2, One-Shape (OS), Protaper Universal F2 (PU F2), Reciproc (R) R25, Twisted File Adaptive (TfA), or Waveone Primary[(69)]. The angle of the root curvature ranged from 20°–40°. CBCT images were taken pre- and post-instrumentation. The root canal images were assessed 2, 5, and 8 mm from the apex using the Gambill's formula (ANNEX I). The centering ratio for same levels was evaluated using the Garip method (ANNEX I). Showed result contrast to the study by Wu *et al*.[(58)], they revealed no significant difference in canal transportation and centering ratio between PTU, WO and PTN. They also showed that the six rotary file systems produced similar straightening in root canal curvature and similar canal transportation. The R Files exhibited greater volumetric changes compared with OS, TFA, and PU.

Using CBCT, Elnaghy *et al*. investigated the efficacy of PTN system in dentin removal, canal transportation, and centering ability with and without glide path preparation using either ProGlider (PG) or Path-File(PF) [(71)]. All samples were scanned before and after preparation using CBCT scanner. Root canal transportation and centering ratio were evaluated at 3, 5, and 7 mm from the apex. The volumetric changes were also calculated. The results showed that there was no significant difference in the volume of removed dentin and centering ratio between the tested groups. At 3 mm and 5 mm levels, the PG/PTN group showed a significantly lower canal transportation mean than PF/PTN and PTN only, but there was no significant difference in canal transportation at 7 mm level. The authors concluded that glide path using PG before PTN preparation displayed a better performance and less canal aberrations compared to instrumentation performed with PF/PTN or PTN only. Türker *et al*[63] evaluated the effects of glide path preparation of different path finding systems (K files, Path file or paraglider instrument) on canal transportation induced by PTN [63]. The preparation performed on resin block canals and to evaluate the transportation,a double digital radiograph method was used. It was found that there were no significant differences between the tested groups. It was concluded that PTN file preserved the morphology of root canal well and was safe to use either with or without path finding files.

The root canal shaping properties of PTN, PTU, and WaveOne were compared by measuring the volume of unprepared canal, the volume of dentin removed after preparation, the amount of un-instrumented areas, and the transportation of the coronal, middle, and apical thirds of canals [86]. The preparation time and instrument failure were also calculated. Thirty-six maxillary first molars were scanned using micro-CT pre- and post-operatively with a voxel size of 30 mm. Results found that preparation had increased the volume and surface area of all root canals. PTN system created significantly less transportation than WaveOne and PTU systems in the apical third of the mesial canals). No significant difference was found in apical transportation in distal canals between the three file systems. WaveOne was significantly quicker in preparation than either the PTU or PTN. Bürklein *et al* compared the shaping ability of PTN, Mtwo, PTU, and BT-RaCe [40]. Eighty root canals with curvatures of 25°-39° were prepared to a final apical size of 40. Pre- and post-preparation radiographs were taken. Canal transportation and straightening of the canal curvatures were calculated with a computer image analysis program. Preparation time and instrument failures were also assessed. BT-RaCe files caused significantly more canal straightening compared to Mtwo ($p < 0.05$). None of the other files exhibited significant difference in canal straightening. Also, no significant differences in canal transportation were found between the file systems. PTN files showed significantly faster preparation than other rotary systems.

The shaping ability of PTN, iRaCe and Hyflex CM rotary NiTi files [41] in curved root canals was evaluated. Sixty mandibular molars with angles of curvature of mesio-buccal canals ranging from 25°-35° were used. Pre- and post-operative radiographs were taken. Double-digital standardized radiographic method was used to assess the apical transportation at 0.5 mm from the working length. Curvature straightening, preparation time and instrument failures were measured. It was found that PTN caused significantly more canal straightening than IR and with no significant differences between IR and HF files. No significant differences in apical transportation were found between the three groups. IR and HF were equally fast and significantly quicker than PTN ($p < 0.05$). Comparison of canal transportation and centering ratios caused by PTN and one shape File OS was made using root canals with average curvature of 20 [(85)]. CBCT scan was used to assess canal transportation at 1, 2, 3, 4, and 5 mm sections. Both file systems showed similar results ($p > 0.05$) in terms of canal transportation and centering ratio and they were both safe to be used in curved canals.

A recent study by Dhingra *et al*. evaluated the efficiency of PTN by examining canal transportation and centring ratio [(104)]. CBCT was used for sample scanning. Evaluation of canal transportation and centering ratio were done through Gambill's equation and Garip formula. The results showed insignificant transportation in all samples and more centered preparations. Canal deviation, changes in apical foramen position and instrumentation time were assessed in simulated S-shaped canals prepared using PTN, PTU or iRace files [(105)]. Pre- and post-operative images were taken and superimposed. Deviation was assessed using Adobe Photoshop software. iRace system resulted in the lowest mean canal deviation and induced the least shift in the apical foramen position compared to the other two systems. It also had the lowest instrumentation time.

Ferrara *et al*. compared the shaping ability of Protaper next (PTN) and ProTaper Universal (PTU) in the curved root canals of extracted human molar teeth [(64)]. Thirty root canals of 17 extracted human molars teeth were randomly assigned to two experimental groups (n =15): ProTaper Next and ProTaper Universal (PTU). The final size of all apical foramina was 0.25 mm in diameter. Standardized digital radiographs were used to take before and after instrumentation images. The experiment showed that both files ProTaper Universal and ProTaper Next systems performed similarly,with regard to the straightening of curved root canals and apical transportation. They also showed that preparation using ProTaper Next was significantly faster than ProTaper Universal.

FORMATION OF DENTINAL MICROCRACKS:

Crack is defined as all lines that are seen prolonged from the root canal lumen to the dentin or from the outer root surface into the dentin [(106)]. Both Instrumentation step,as well as rotary nickel-titanium (NiTi) files have the risk to induce crack formation [(107, 108)].

Priya *et al*. investigated generation of microcracks in root canals following instrumentation using Protaper, Protaper Next, Reciproc and One shape NiTi files; with different types of motion (rotary and/or reciprocating) were used. It was found that the least amount of microcracks were formed in canals that were instrumented with PTN files in both rotary and reciprocating motion [(109)]. Similar results were reported by Çiçek *et al.*[(110)] who compared PTN with PTU and WaveOne files. This result was attributed to the less taper of PTN files in comparison with other file systems.

Another study by Karataş *et al.* [(111)] found that PTN and TFA produced significantly less cracks than PTU and WaveOne systems in the apical section (3 mm). However, De-Deus *et al*. [(112)] reported that neither PTN and TFA systems induced any new dentinal microcracks.

EXTRUDED DEBRIS:

During the cleaning and shaping step of root canal procedure, dentin chips, pulp tissue, microorganisms, and irrigants are intended to extrude in coronal direction but some may be outflow apically toward the periradicular tissues [(113)]. This can lead to inflammation, postoperative pain, and delay of periapical healing [(114)]. Therefore, its prevention is necessary to avoid those complications [(113)].

The quantity of extruded debris produced from using PTN and PTU in root canal was measured and compared [(115)]. The study showed that extruded apical debris produced by PTN files was significantly less than that produced by PTU files. The result was explained by the design features of the apical part of PTN files, their off-centered rectangular cross-section, and tapering.

Similarly, Ozsu *et al*. [(116)] reported that PTN extruded less debris than PTU which was attributed to the offset design. They also found that SAF extruded the least amount of apical debris. This result was also reported by Pawar *et al* [(117)], who compared SAF with PTN and WaveOne files.

In contrast to the previous studies, Usun *et al.* [118] reported that PTN created the highest amount of apical debris when compared with Twisted File and WaveOne which produced the least debris.

TORQUE AND FORCE OF PTN:

Determining the appropriate torque magnitude is necessary to limit fracture incidence of rotary endodontic files [119]. Pereira *et al*. [120] used six sets of PTN Instruments (X1–X5) to prepare 36 artificial canals in order to determine the peak torque and forces of the files. They divided the files into 6 groups and applied different settings of rotations per minute and different numbers of in and-out movements to reach full working length in each group as follow: (250 rpm/ 3 ins, 250 rpm/4 ins, 300 rpm/3 ins, 300 rpm/4 ins, 350 rpm/3 ins, and 350 rpm/4 ins). An automated torque bench was used to record the peak torques (Ncm) and both positive and negative forces (N). Overall, the PTN files exhibited significant differences ($p<.01$ or less) in peak torque, positive force, and negative force. X2 revealed the maximum torque with all settings. X5 displayed the utmost positive force in all groups. X1 and X2 presented the highest negative forces in all groups except for 350 rpm/4 ins. Significantly lower torque and positive force were noticed in the group 350 rpm/4 ins for all instruments excluding X4. On the other hand, X1 exhibited a significantly lower negative force for 350 rpm/4 ins. The authors recommended the speed of 350 rpm and with 4 in-and-out movements to generate the minimum torque along both positive and negative forces.

A study by Arias *et al* [100] compared the peak torque and force of PTN with those of PTU instruments. They randomly allocated 12 maxillary incisors and 6 mesial roots of mandibular molars into two equal groups. After a glide path was attained, a total of 12 new sets of each file system were used. The tests were performed in a standardized approach in a torque-testing platform, with peak torques (Ncm) and forces (N) recorded. The results revealed no statistically significant differences in peak torque and force between PTN files when small or large root canals were prepared. Yet, some PTU files demonstrated statistically lower peak torque and force ($P < .01$) for both canal types. It was concluded that PTN instruments had superior consistency in peak torque for small and large canals than PTU files.

A comparison of torsion resistance flexibility and surface micro-hardness of PTN, Twisted Files (TF) and RaCe (RC) file systems on metal blocks was performed [121]. Five millimeters of the tip of each instrument were secured by filling the mold with a resin composite, and moved the files clockwise at 300 rpm. The amount of applied weight before file failure was recorded and the topographic features of the fracture surfaces were illustrated using a scanning electron microscope. The files were evaluated for bending resistance via cantilever-bending test. Vickers micro-hardness was also measured on the cross section of instruments with 300 g load and 15 seconds dwell time. Results revealed that PTN resistance to torsional stresses and wear was the highest. TF showed improved flexibility compared to the other two tested files. The study showed dimples near the center of the fracture surface of all examined files as typical pattern of torsional fracture.

CYCLIC FATIGUE:

Many factors contribute to file fracture, but the two main reasons are torsional and cyclic fatigue[(122)]. Cyclic fatigue is more prevalent in curved root canals, whereas torsional failure might happen even in a straight canal [(123)]. The two failure modes occur in clinical situation, however cyclic fatigue to be the primary cause of instrument fracture [(124)].

Testing cyclic fatigue consider suitable reflect to the mechanical properties of NiTi rotary instruments for a safe, efficient clinical use [(125)].

Elnaghy compared cyclic fatigue resistance of PTN, TF, HyFlex CM and PTU [(126)]. All files were rotated in simulated canals until failure, and the number of cycles to failure (NCF) was recorded. Also, a scanning electron microscope was used to measure the topographic features of the fracture surfaces of all broken files. PTN demonstrated greater resistance to cyclic fatigue as compared to PTU and HyFlex CM. The files fractured approximately 5 mm from the tip of the instrument. The cross-sections of fracture in all files revealed similar fracture patterns (e.g., crack origins, fatigue zone and an overload fast fracture zone).

In support of the previous study, Pérez-Higueras *et al*. found that PTN was significantly more resistant to cyclic fatigue than PTU. They attributed the difference to the key design features of the PTU nickel-titanium alloy and triangular cross-section [(127)].

Different alloys of different manufacturing approaches were tested to check whether different manufacturing methods affected their fatigue resistance [(128)]. The study compared the cyclic fatigue resistance of PTN, HyFlex, OneShape and Revo-S in steel canals. Result exhibited that PTN instruments had similar fatigue resistance to OneShape instruments, whereas Revo-S had the lowest fatigue resistance. HyFlex (CM wire) instrument had the best cyclic fatigue resistance. Cyclic fatigue resistance of PTN and VB were compared with PTU rotary instruments in simulated canals [(129)]. The study showed that PTN X1 and X2 were more resistant than PTU F2–F5. VB 20/04–45/04 were more resistant to cyclic fatigue than PTN X2–X5 and PTU S2–F5.

A study by Pedulla *et al*. compared the effect of different magnitude of torsional preloads on the cyclic fatigue resistance of instruments made of different alloys: PTN X2 (M-wire), Mtwo (conventional NiTi), and HyFlex files (CM-wire) [(130)]. Files were subjected to 20 or 40 torsional preload and were tested for cycle fatigue at each preload. The results showed that torsional preloads lowered the cyclic fatigue resistance of both the conventional and treated (M-wire and CM-wire) NiTi rotary instruments except for HyFlex CM size 25, 0.06 taper with a 25% of torsional preloading.

The failure of rotary file caused by excessive torsional stress can be controlled by creating a manual or mechanical glide path. [(131)] Berutti *et al*. compared the effect of glide path on torque, time required for PTNX1to reach the full WL, by testing with PathFiles, and ProGlider in simulated root canals [(132)]. Results showed that ProGlider performed better than PathFiles in declining the electric power consumption of ProTaper Next X1 and confirmed the ability of ProGlider to reduce stress in Pro-Taper Next X1 during canal shaping.

FRACTURE PATTERNS AND PLACEMENT

Ertas *et al.* [(133)] investigated the fracture incidence of reused ProTaper Next compared to ProTaper Universal rotary instruments and identified the location of separated fragments.

Showed that; the life span of both instruments was the same for preparation of mandibular molar teeth and both fils didn’t fractured in the first time usage. The study also revealed that most fractured ProTaper Next instruments were X1 and ProTaper Universal instruments were F2.

Elnagi *et al.* [(134)] evaluated the topographic features of the fracture surfaces of broken PTN, Twisted Files (TF) and RaCe (RC) files using a scanning electron microscope. They also compared their torsional resistance, flexibility, and surface micro-hardness. The highest torsional resistance and micro-hardness was observed in PTN, followed by RC ($p < .05$). The fracture cross sections of all files exhibited dimpling near the center of fracture surface.

2.4.1.3 SUMMARY

The literature on PTN reveals strong methods (comparative studies, random assignment), a varied testing material (mandibular molars, premolars, and simulation), imaging techniques, instruments, and statistical applications (use of alpha .05 across studies). PTN consistently outperformed comparative instruments on most features examined (e.g., transport, centering, debris, fatigue, etc.).

2.4.2 BT-RaCe

2.4.2.1 Features

BT-Race files (FKG, La Chaux-de-Fonds, Switzerland) offer an assortment of single-use option. They are made from conventional austenite NiTi [40]. The key features of BT-RaCe NiTi file system is its triangular cross-section (Figure 10) and the booster tip (ergo BT), which permits the file to follow curvatures in canals without unnecessary stress on the file or the root wall.

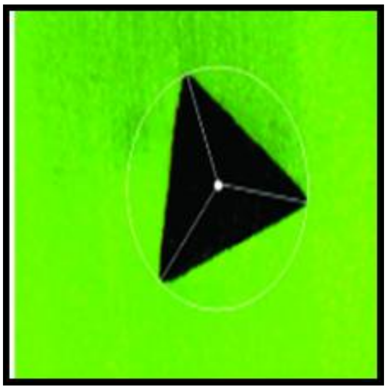


Figure 10: Cross sections of BT-RaCe at the middle of the working part [40].

These characteristics are intended to increase the files flexibility and efficiency. The file holds a reduced diameter feature to facilitate progression of the instruments towards the apical aspect and maintain the original canal morphology [135]. It also has a non-screw in design and electro-polished surface to decrease the effects of torsional and cyclic fatigue. The BT tip of the files is a non-cutting tip from 0 to 0.15 mm diameter. From 0.15 mm upwards, the cutting edges start (Figure 11). This allows files to work safely in narrow canals[136]. The breaking point of the file is located 16 mm from the tip. The manufacturer recommends the creation of a glide path up to at least size 15 with hand files prior to using BT-RaCe instruments. The instrumentation procedure of the file performed with a rotational speed of 800 rpm, and the torque is adjusted to 1.5 Ncm [40].

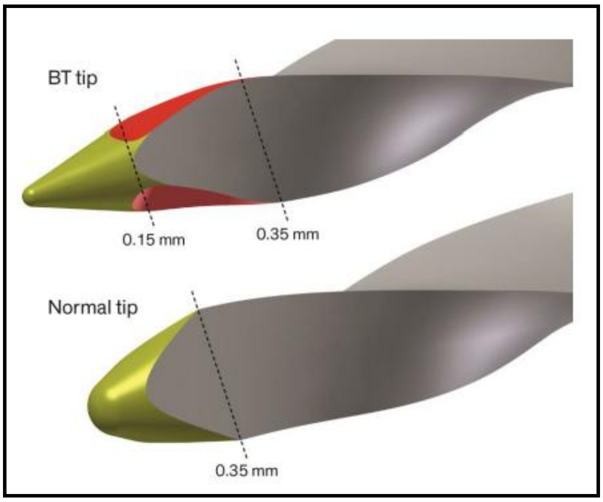


Figure 11: BT tip and Normal tip: localization of the cutting point (136).

BT-RaCe instrument system is available in sequential sizes from 1 to 3 (Figure 12) [136]. These sizes are intended to remove minimal dentin coronally to preserve the root strength as follow:

BT1 (10, 0.06)**:** Has a small apical diameter and large taper to clears the coronal part of the canal. It is the first file of the system, used for exploration, creation of a glide path and conservative enlargement of the coronal third.

BT2 (35,0.00): Has a cylindrical tip size equivalent to ISO 35. The file is flexible due to non-taper design to prepare the apical third of the canal.

BT 3 (35, 0.04)**:** This file is used to link the coronal and apical preparations shaped by the previous two instruments (BT1 and BT2) and provide the final shaping of the canals.

The manufacture also produces larger number of the files called BT-Race XL which are BT40/0.04 and BT50/0.04 which work on different sittings (600-800 RPM) [135].

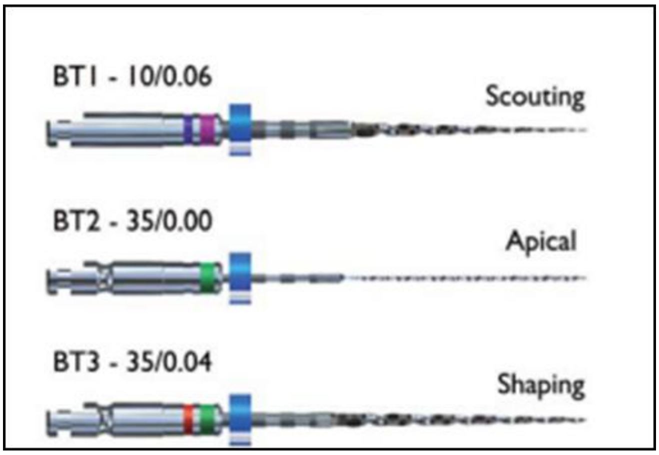


Figure 12: BT-Race sequence [136]

BT-Race file system showed different magnitude of negative and positive forces. Each file for all instruments sizes had different value (Figure 13, Figure 14 and Figure 15). BT1 showed the smallest value of negative force 0.19 N btween all other files within the system. The maximum torque needed to rotate it at 800 rpm was 0.77Ncm and the magnitude of positive force was 0.61N (Figure 13). BT2 showed the highest positive force compared with other files within the system, the amount of positive force for BT2 was 2.16N,the negative force was 0.17N and maximum torque for rotation was 0.20 Ncm(Figure 14). The maximum requested amount of torque needed for rotating BT3 was 0.50Ncm, the amount of positive and negative forces were 0.61N, 0.73N respectively (Figure 15).

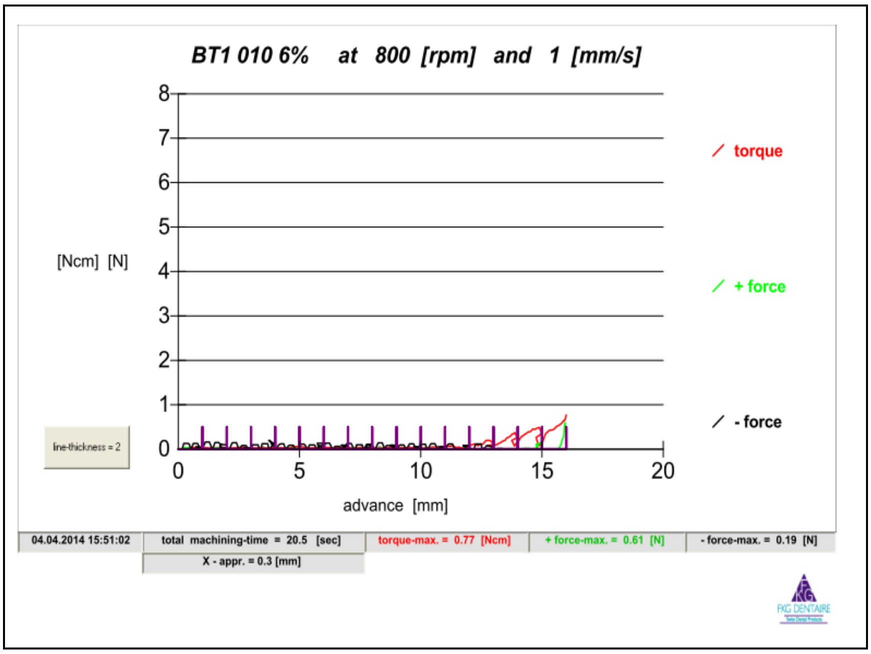


Figure 13: BT1 at torque 0.77Ncm and speed 800 rpm

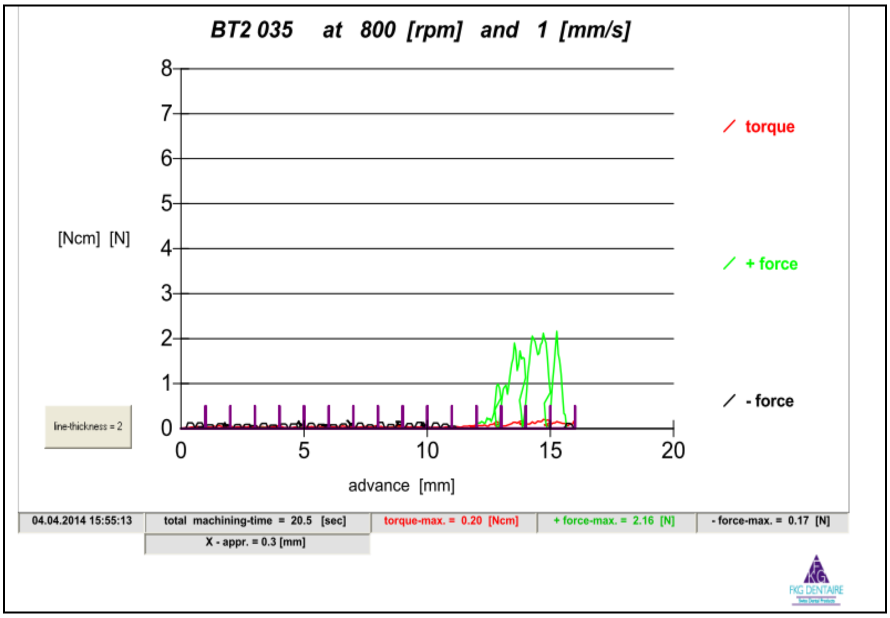


Figure 14: BT2 at torque 0.20Ncm and speed 800 rpm

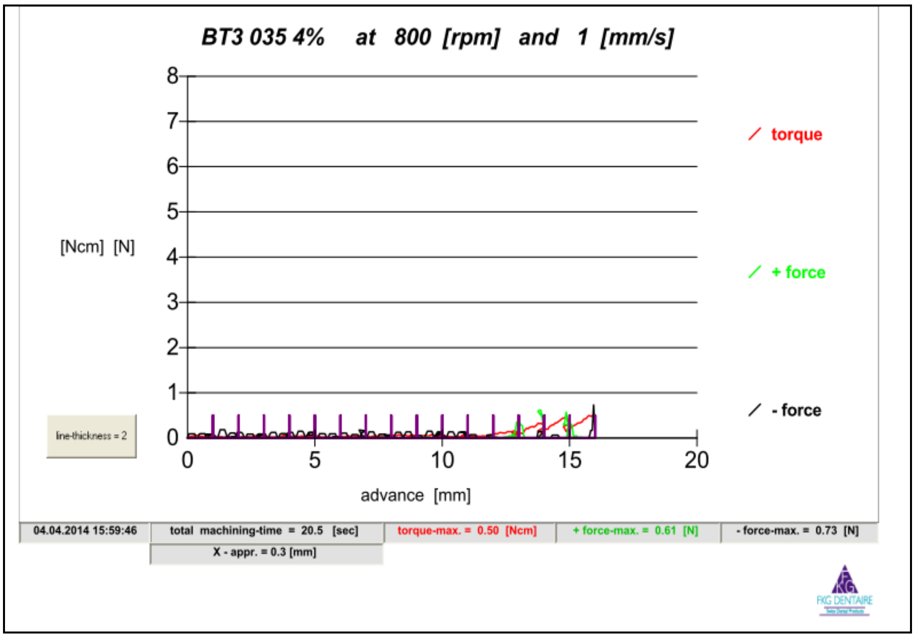


Figure 15: BT3 at torque 0.50Ncm and speed 800 rpm

2.4.2.2 Studies that investigating BT-RaCe

Shaping ability:

To date, there is limited information available regarding the shaping ability of BT-RaCe instruments [40]. Bürklein *et al.* [40] compared shaping ability of four different NI-Ti rotary instruments (Mtwo, ProTaper Universal, ProTaper NEXT and BT-RaCe) using pre- and post-instrumentation radiographs of 80 root canals with curvatures of 25° and 39°. They found that BT-RaCe files resulted in more straightening during instrumentation compared to Mtwo. Straightening did not differ significantly among the other instruments. Also, there was no significant difference between the instruments in canal transportation. Considering preparation time, PTN files was faster than all others tested files. Fracture was noted in only one instrument, the BT-RaCe2. It was concluded that all tested instruments had the ability to maintain root canal curvature. Caution should be taken when using the BT2 instrument due to its unique cylindrical design [40].

2.4.3 Literature review of the topographic changes in PTN endodontic rotary files using scanning electron microscopy(SEM).

Despite the high improvement that NiTi instruments provide to the field of endodontics, the many advantages they ensure and the growing use of them in dental practice, they are prone to fracture without any visible defects [137]. This unpredicted fracture prevalence remains a concern during their clinical use. The potential difficulty in removing fractured pieces of broken files may compromise the outcome of endodontic treatment [138]. Modifications in instrument design, instrumentation protocols, and manufacturing approaches were examined by some researchers in order to understand the mechanisms of failure and extend the life span of the instruments [131].

NiTi failure is mainly due to their fatigability which occurs as a result of stress during instrumentation of the root canal [139]. Generally, fatigability leads to failure of NiTi endodontic instruments due to flexural or torsional fatigue. Flexural fatigue, also called cyclic fatigue [137], occurs when the file is used in a curved canal [75], which is the most destructive form of stresses [140]. On the other hand, torsional fatigue occurs in two forms; dynamic and static fatigue. Dynamic fatigue results from frictional forces that are caused by resistance of dentin to the file's cutting [141]. Static fatigue occurs during root canal preparation when the tip or any other part of the file is locked in but the shaft continues to rotate [141]. Torsional fatigue typically shows plastic deformation followed by fracture [79, 142] or dimples features on the whole fracture surface whereas torsional failure is featured by the presence of circular abrasion characters as well as dimples but near the centre of rotation on the fracture surface [131, 143, 144].

Many factors contribute to NiTi instruments failure; such as root canal anatomy, operator performance and alloy properties [145]. Fracture files or the general conditions of failure occurred more commonly in severely curved root canals than in straight or moderately curved ones [137, 146]. This is due to the overloads which are made on the files that are caused by the sudden changes in canal curvature which on return restrains the spinning of the instrument [147].

Operator factor similarly influences fatigue resistance of NiTi rotary instruments [148]. Education or experience is required to reduce the incidence of rotary NiTi instrument fracture [149-151]. Alloy properties is another factor that is connected with the failure of rotary endodontic instruments [43, 152, 153]. New endodontic instruments have been subjected to new strategies to improve flexibility, resistance to fracture, fatigability and cross-sectional designs compared to conventional NiTi instruments. Manufacturers have also proposed different thermomechanical treatment meyhods. Electro-polishing method is used by some manufacturers to improve the fracture strength of rotary NiTi instruments [154]. M-wire alloy has greater flexibility and fatigue resistance than conventional NiTi instruments [155].

The literature reports contradictory results on the effects of repeated use of NiTi files. Mechanical degradation over time, and canal anatomy have all been found to contribute to file failure after 1-20 uses in moderately and severely curved canals [146, 156]. The number of times NiTi rotary file can be re-used remains uncertain [157-159]. Repeated clinical use of NiTi instruments has always been a concern, not only due to their high inclination to undergo cyclic fatigue and fracture without any visible signs [160] but also for the potential of prion transmission. Health control authorities in many countries limited such instruments to a single use [161]. Single use, yet means that the same endodontic file can be used in 3–4 root canals within one tooth and those canals could be complex or tortuous [125]. The files perform a considerable amount of work within these teeth. Therefore, the objective of this study was to evaluate if the amount of root canal transportation changes upon re-using the file systems six times and recording the surfaces characteristic changes in simulation that corresponds to a clinical situation of treating a molar tooth with three to six canals.

Assessment of topographic changes of the rotary instruments after clinical use is common in endodontic literature. This type of investigation would provide insights into the patterns of file use in clinical practice. It would also have an important impact on understanding file failure and fracture initiation [(74)]. Such studies are crucial in attempts to minimize risk of instruments breakage within canals. A number of studies have already evaluated the deterioration and failure of PTN files and reported that PTN instruments have superior cyclic fatigue resistance compared with previously released endodontics NiTi rotary instruments [(121, 127-130, 133)]. However, to date, apart from Elnagy *et al.* study that examined the fracture cross sections of PTN under SEM [(121)], no evaluation of the surface characteristics of PTN files have been fully performed (before and after use). In addition, no studies have assessed the effect of repeated use of PTN files on the failure pattern to simulate instrumentation of multi-rooted teeth. The link between the metal surface changes and file breakage with repetitive usage could possibly lead to more understanding of the series of changes that occur in an instrument before its ultimate failure, hence, helping to standardize their usage frequency.

The purpose of this study is to observe the morphological alterations of ProTaperNext files before and after continuous use (3 times) using scanning electron microscopy (SEM). Along with other studies, materials and methods used in this study are described in details in Chapter 4. Results are presented in Chapter 5. Discussion and Conclusions are in Chapter 6 and 7, respectively. Implications and recommendation for further research are in Chapter 8.

CHAPTER 3

Aims and Objectives

The purpose of this study is to determine the shaping ability (i.e., transportation) of two of the new generation of NiTi endodontic file systems (PTN and BT-Race) by measuring canal transportation in simulated root canals in resin blocks.

The research questions are:

1. Do the two new rotary file systems PTN and BT induce root canal transportation?
2. Does repetitive use (from one to six times of uses) affect the ability of each file system to induce root canal transportation?
3. The study also aimed to evaluate the surface topographical changes of PTN file system after repetitive uses to simulate multi-rooted teeth under scanning electron microscopy (SEM).

CHAPTER 4

Materials and Methods

The research in this thesis was designed as *In-vitro* investigation, in view of that three *in-vitro* studies were comprised as follow

1. Investigation of toot canal transportation after preparation using PTN
2. Investigation of toot canal transportation after preparation using BT-race
3. Evaluation of the surface topographical changes of PTN file system

Two research techniques were employed to meet the objectives of the current research.

For the first two experiments, CAD software was used for evaluating root canal transportation after using Protaper next file and BT-Race file. The CAD software is commonly used to measure the root canal transportation. It was also used in previous endodontic studies in assessment of root canals and root canal filling (162). It is reliable and easy to use and able to measure the details, thus used in the present experiments.

For assisng the surface changes of PTN file,SEM was used. It has been used in several endodontic studies; to evaluate the cleaning efficiency of various instrumentation technique for their accuracy (163-165) and for visualizing the topographic features that appear on file surfaces for their high-resolution images (74, 79, 97, 126).

4.1 INVESTIGATION OF TOOT CANAL TRANSPORTATION AFTER PREPARATION USING PTN AND BT-RACE

4.1.1 ProTaperNext File System Experiment

Sample preparation

Thirty-six curved root canals in clear resin blocks (Dentsply-Maillefer Ballaigues, Switzerland) were used for this study. Each canal was 16 mm long and had an apical curvature of 60° (Figure 16). The blocks were given numbers from 1to 36 and allocated into 6 groups (n=6).

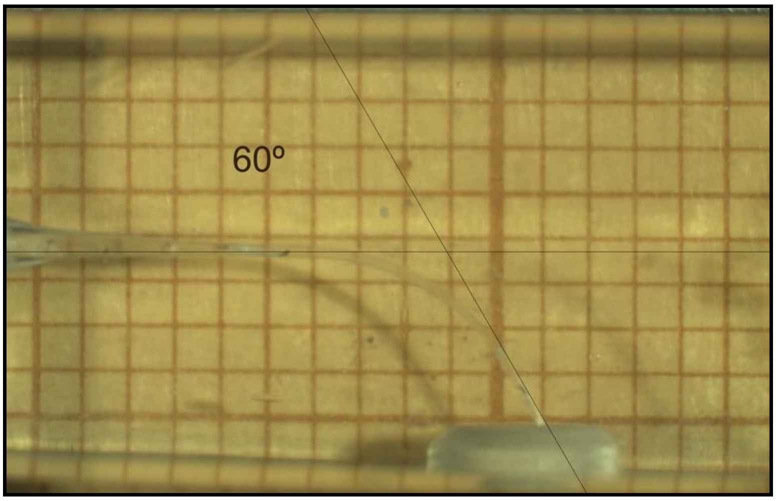


Figure 16: Resin blocks (*Dentsply-Maillefer Ballaigues, Switzerland*)

Six kits of PTN file system were also given numbers from 1 to 6 and each kit was used to prepare the corresponding group number of the resin blocks (i.e. file system 1 used for group 1, file system 2 for group 2 and so forth). Each file was used 6 times; one time in each block within each group. Blocks number (1,2,3,4,5,6) were all prepared by first-use file, first file in each kit. Blocks 7,8,9,10,11,12 were prepared using a file that had been used once (second use file). Block 13,14,15,16,17,18 were prepared by files used three times (Table 1).

Table 1: Sample allocation into groups

File System No	Group1	Group2	Group3	Group4	Group5	Group6
F.S.1	B1	B7	B13	B19	B25	B31
F.S.2	B2	B8	B14	B20	B26	B32
F.S.3	B3	B9	B15	B21	B27	B33
F.S.4	B4	B10	B16	B22	B28	B34
F.S.5	B5	B11	B17	B23	B29	B35
F.S.6	B6	B12	B18	B24	B30	B36
Number of time of uses	1st time	2nd time	3rd time	4th time	5th time	6th Time

F.S.: file system no 1-6
B: Resin block no1-36

ROOT CANAL INSTRUMENTATION

Instrumentation was performed by a single operator. In all canals, working length (WL) was up to the level of the apical foramen using #10 hand K-file (*Dentsply Maillefer Ballaigues, Switzerland*). Glide-path was established using ProGlider (*Dentsply Maillefer,Ballaigues, Switzerland*). The canals then were instrumented using crown-down technique by PTN files that were driven by a WaveOne endodontic motor (*Dentsply/Mailleferm, Ballaigues, Switzerland*) (Figure 17).

Figure 17: WaveOne endodontic motor (*Dentsply/Maillefer,Ballaigues, Switzerland*)

The rotational speed was set at the recommended rotation of 350 rpm and the torque at 2.5 Ncm. Preparation was performed using all three files in a gentle in-and-out motion until the full working length was reached. The instrumentation sequence was as follows: X1 file (size 17, 0.04 taper), followed by X2 file (size 26, 0.06 taper) and finally X3 file (size 30, 0.07 taper). All canals were irrigated frequently with 99% ethyl alcohol using a gauge 30 side-vented needle (Figure 18) and repeatedly recapitulate with size 10 K-File to keep the glide path open.

Figure 18: Gauge 30 side-vented needle

<u>IMAGE PROCESSING (PRE AND POST INSTRUMENTATION IMAGES)</u>

A special setup was prepared to visualise the geometry of the canal. In this setup, macroscopes (x 6 magnifications) with image recording and analysis program (Leica Application Suite © 2008 *Leica Microsystems, Switzerland. Ltd*) was used to enable photographing the resin blocks before and after canal preparation (Figure 19).

Figure 19: Macroscopes (*Leica Application Suite © 2008 Leica Microsystems, Switzerland. Ltd*)

The macroscope was positioned on top of a reference plane. Since the acrylic blocks are transparent, a millimeter reference grid was used to obtain information for geometric corrections during the processing (Figure 20).

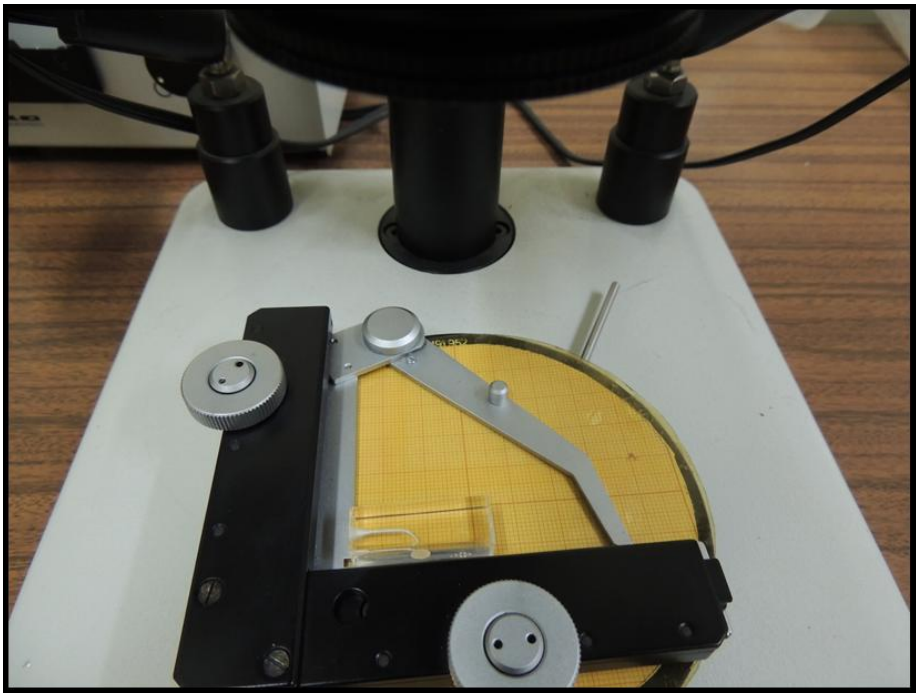


Figure 20: A view shows a millimeter reference grid

Two image projections were recorded for each block according to the setup shown in (Figure 21).

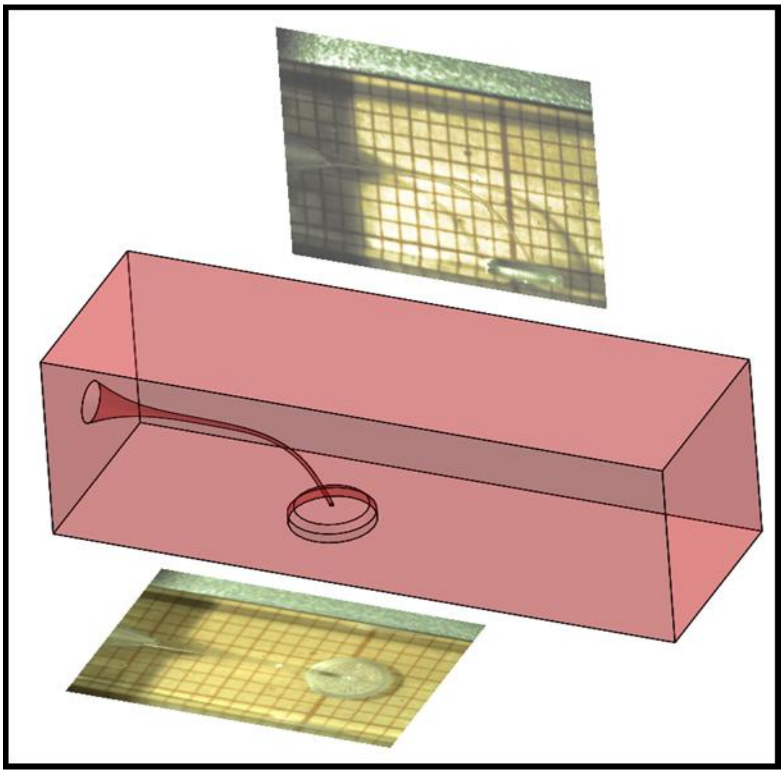


Figure 21: Images recorded for each block

Special care was taken to reduce the effect of geometric aberrations of the optical system and to obtain a smooth illumination field. As the optical system needs a field big enough to focus the canal and reference grid simultaneously, it was operated with small apertures and this adjustment demanded strong illumination. To obtain light enough to record clear images, the use of a pair of lamps was needed and this explains the double shadow in all of the pictures.

All images were processed using Paint Shop Pro 9 (*JascSoftware® U.S.A*) to adjust the illumination and contrast. The functions used were Histogram Equalize and Brightness/Contrast in all images. However, in some cases it was necessary to use high-pass filtering (with the Sharpness function). In effect of image processing can be noticed in the pair of images corresponding to the same recording before and after processing (Figure 22).

(a) (b)

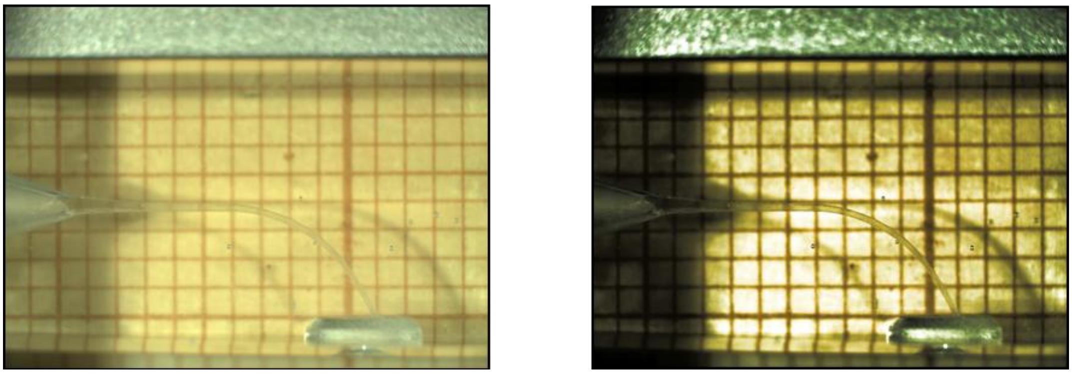


Figure 22: (a) image recorded, (b) image after processing

After improvement of contrast of all images the second step of processing was performed on SolidWorks (*Dassault Systèmes®, Waltham, Massachusetts, USA*). It is a CAD software which was used to extract the geometric data.

At this stage, all images were scaled to the original dimensions by using one of the squares imprinted on the reference plane. Subsequently, it was necessary to introduce a coordinated system parallel to the horizontal and vertical directions as defined by the reference grid. The origin of this system was placed near the exit of the canal since the shape of this geometry was not changed during the file use. The origin and the coordinated axes are illustrated in (Figure 23).

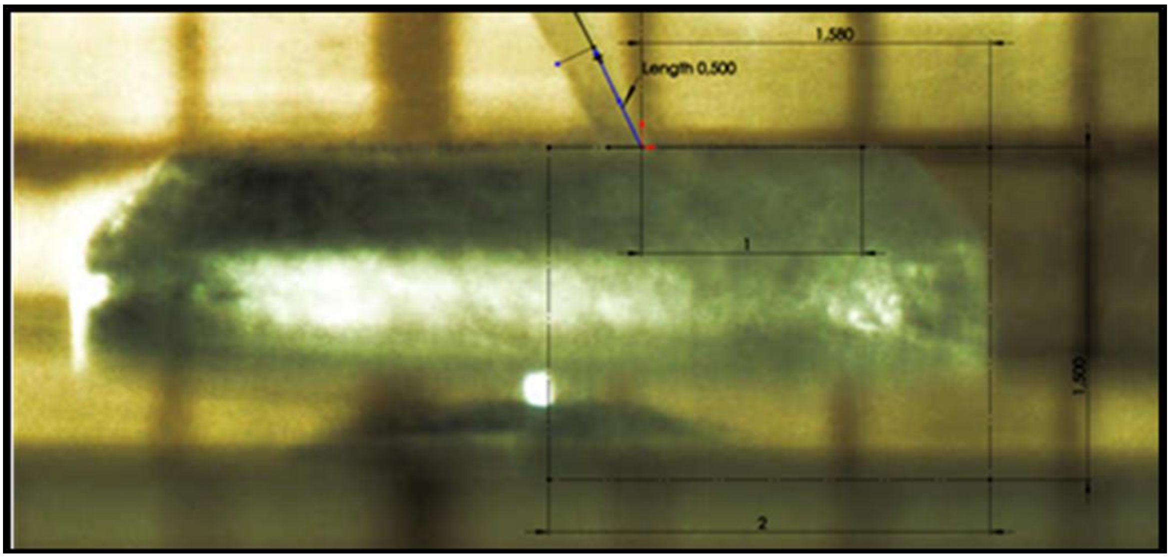


Figure 23: Placement of the original coordinated system near the canal exit.

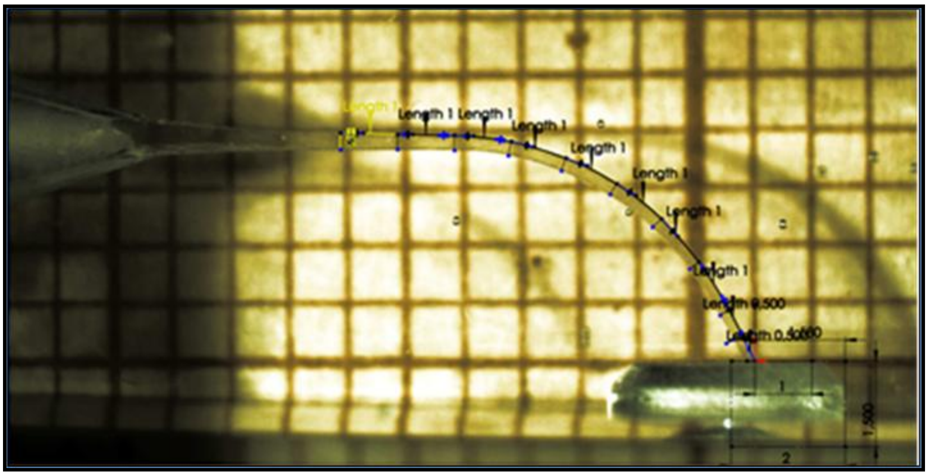


Figure 24: The curve reference and the set of cross sections used to follow the canal opening.

Using only pairs of images recorded before and after instrumentation in the front plane, the first image was used to define a reference curve and a set of cross sections according to a previously defined set of distances from the canal exit. The reference curve followed the original outside curvature of the canal, as shown in (Figure 24)**.**

The total distance evaluated was 9 mm length with the first section placed at the origin. The second and third at 0,5 mm length and the following ones 1 mm apart. This procedure was applied to all pairs of images to extract data about the canal opening. The CAD tools were used to define the reference lines for each cross section which were: a spline to fit the geometry of the outside curvature, and a perpendicular line to define the direction of measurement. The length of the last line was adjusted to fit the original cross section as seen in (Figure 24).

The position of the second image was matched using the reference lines previously defined and was recorded in the CAD draw board as can be seen on (Figure 25).

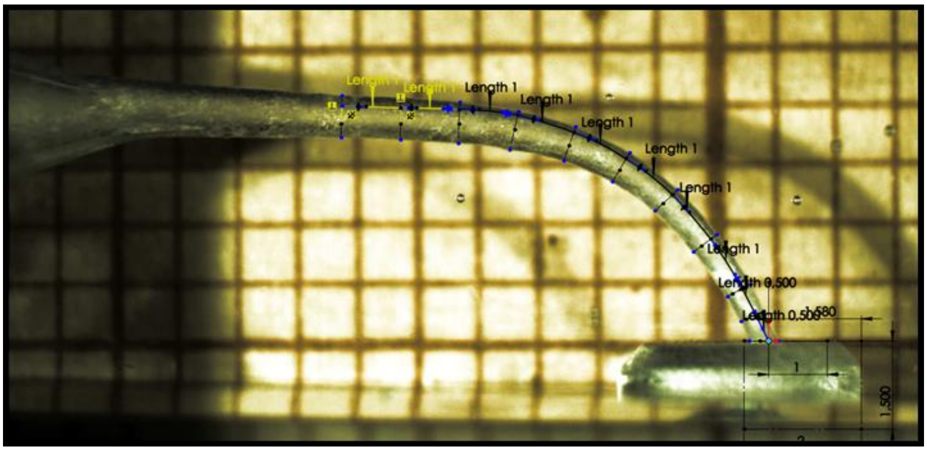


Figure 25: Positioning 2 images (pre and after instrumentation) and measurements on the image were recorded.

A magnified view of the canal in (Figure 25) is presented in (Figure 26) to show how the measurements were performed. The reference line is plotted solid black and changes in the cross sections projection is represented by the dashed lines. The standard reference helped to obtain maximum and minimum deviation from the canal original shape and also to measure the canal transportation resulted after use of each file.

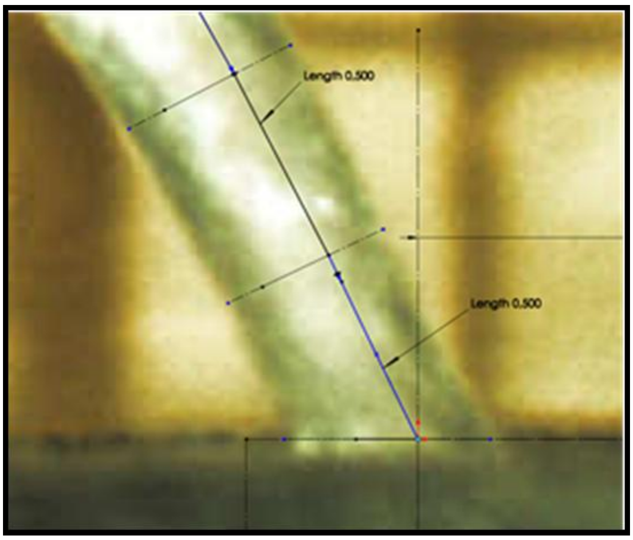


Figure 26: Measurements on the three first cross section. Solid line represents reference and dashed lines represent changes in cross section.

EVALUATION OF CANAL PREPARATION

Transportation was determined by the amount of resin removed from both the inner (concave part) and the outer (convex part) sides of the canal at the selected measuring points and consequently was assessed by subtracting the amount of resin removed at the outer wall of the canal from that removed at the inner wall of the canal.

Calculation:

Transportation of the canal:

$$(\textit{Deviation toward innert side of the canal} - \textit{Deviation toward the outer side of the canal})$$

Transportation of the center:

$$\frac{\textit{Deviation toward inner side of the canal} - \textit{Deviation toward the outer side of the canal}}{2}$$

Direction of transportation: positive results meant that transportation occured mainly in the inner surface of the canal wall curvature and negative results indicated that transportation occured mainly in the outer surface of the canal wall curvature.

4.1.2 BT-RACE FILE SYSTEM EXPERIMENT:

SAMPLE PREPARATION

A total of 36 curved root canals in clear resin blocks (*Dentsply-Maillefer Ballaigues, Switzerland*) were used for this study. Each canal had an angle of apical curvature of 60° and was 16 mm long . The blocks were given numbers from one to thirty-six (B1-B36) and then allocated into six groups (G1-G6). Each group consisted of six blocks. Six kits of BT-Race file system were also given numbers from one to six (F.S.1.-F.S.6). Each kit was used to prepare the corresponding number of the block group. Each file was used six times;one time in each block within each group (Table 1).

INSTRUMENTATION OF THE SAMPLES:

Instrumentation was performed by a single operator. In all canals, working length (WL) was dignified up to the level of the apical foramen using a #10 hand K-file (*Dentsply Maillefer, Ballaigues, Switzerland*) and glide-path was established using a #10 hand K-file (*Dentsply*

Maillefer, Ballaigues, Switzerland). Using crown-down technique, the canals were instrumented by BT-Race files driven by the Rooter Endodontic motor (*FKG, La-Chaux De Fonds, Switzerland*) (Figure 27). The rotational speed was set at the recommended rotation of 800 rpm and torque at 1.5 Ncm.

Figure 27: Rooter Endodontic motor

Preparation was performed using all three files in a gentle in-and-out motion until the full working length was reached. The instrumentation sequence was as follows: BT1 (size 10, 0.06 taper); BT2 (size 36, 0.00 taper); and BT3 (size 35, 0.04 taper). All canals were frequently irrigated with 99% ethyl alcohol using a 30 gauge side-vented needle (Figure 27) and repeatedly recapitulated with #10 K-file to keep the canal patent.

IMAGE PROCESSING AND EVALUATION OF CANAL PREPARATION

Same procedures were performed as in the first experiment.

STATISTICAL ANALYSIS FOR ALL SAMPLES

SPSS software version 22 was used for data analysis, and multivariate statistical analysis (GLM - General Linear Model) was applied. The Bonferroni correction was used of multiple comparisons analysis and a significance level of .05 was used for both experiments data. Eleven locations were considered: 0 mm, 0.05mm, 1mm, 2mm, 3mm, 4mm, 5mm, 6mm, 7mm, 8mm, 9mm for each files used.

A comparison of the amount of canal transportation between the two files was performed by dividing the eleven locations into three areas (apical 0-3mm, middle 4-6mm, coronal 7-9mm).

4.2. STUDYING THE TOPOGRAPHIC CHANGES IN PROTAPERNEXT ENDODONTIC ROTARY FILE BY SCANNING ELECTRONIC MICROSCOPE(SEM)

SAMPLE PREPARATION

Eighteen simulated root canals (16 mm in length and 60º in curvature) in clear resin blocks (*Dentsply-Maillefer Ballaigues, Switzerland*) were used for this study. The blocks were given numbers from one to eighteen and then assembled into three groups (n=6). Six kits of a PTN file system were also given numbers from one to six. Each kit was used to prepare the corresponding block group. The blocks and the file groups are detailed in (Table 2)**.**

Table 2: Sample distribution

File System No.	Group 1	Group 2	Group 3
F.S.1=1 PTNX1-X2	B1	B7	B13
F.S.2=2 PTNX1-X2	B2	B8	B14
F.S.3=3 PTNX1-X2	B3	B9	B15
F.S.4=4 PTNX1-X2	B4	B10	B16
F.S.5=5 PTNX1-X2	B5	B11	B17
F.S.6=6 PTNX1-X2	B6	B12	B18

F.S.: file system no. 1-6
1-6 in front of each system referred to each group number
B: resin block no. 1-18

CANAL INSTRUMENTATION:

All canals were treated by a single operator. For each canal, the working length (WL) was estimated at the level of the apical foramen using a #10 hand K-file (*Dentsply Maillefer, Ballaigues, Switzerland*) and a glide path was established using ProGlider (*Dentsply Maillefer,Ballaigues, Switzerland*). Using WaveOne endodontic motor (*Dentsply/Maillefer, Ballaigues, Switzerland, PTN*) files were used to prepare the canals with crown-down technique. The rotational speed was set, as recommended, at 350 rpm with a torque of 2.5 Ncm. Preparation was performed using two files (X1 and X2) in a gentle in-and-out motion until the full working length was reached. The instrumentation sequence was as follows: X1 file (size 17, 0.04 taper) followed by X2 file (size 26, 0.06 taper). All canals were frequently irrigated with 99% ethyl alcohol using a 30 gauge side-vented needle and repeatedly recapitulated with a size 10 hand K-file to keep the canal patent.

TOPOGRAPHIC EVALUATION:

Before using the files to prepare the canals, they were examined using scanning electron microscopy (SEM). A high resolution FEI QUANTA 400 FEG SEM (*FEI, Hillsboro, Oregon 97124 USA*) (Figure 28) was used for this purpose.

Figure 28: SEM (A high resolution FEI QUANTA 400 FEG SEM (*FEI, Hillsboro, Oregon 97124 USA*)

All instruments were examined in the same position before and after use to observe any surface changes. Photomicrographs were taken at X100, X200, X400, X500, X1000, and X2000 magnification and three views were chosen: apical, middle and a critical point area. The latter was 3-5 mm away from the apical end of the file. The files were cleaned after use by ultrasonic sterilization (*Biosonic UC125 Coltene Whaledent, Langenau / Germany*) (Figure 29) for 30 minutes, and then re-examined.

Figure 29: Ultrasonic sterilization (Biosonic UC125 *Coltene Whaledent, Langenau / Germany*)

EXAMINATION CRITERIA

The criteria used for checking the instruments' surface defects were adopted by Eggert (74) and were as follows: no visible defects, pitting, corrosion, fretting, microcracks, fractures, metal strips, spiral distortion, blunt cutting edges, disruption of cutting edges or fatigue cracks.

CHAPTER 5

Results

5.1 EXPERIMENT (1) PTN

The amount of resin removed during the instrumentation in all the blocks of the sample is listed in (9-ANNEX II). The quantity of canal center transportation obtained at all locations in all blocks is presented in (10-ANNEX II). These quantities were resulted by applying the following formula (Difference between the amount of resins removed at inner side of the canal wall from the amount of resin removed in outer side of the canal wall over 2) on the data presented in (Table 9-ANNEX II)

Total of means and standard deviations for the canal center transportation in all sample are summarized in (Table 3). Regardless of number of file uses, the lowest total mean value of canal center displacement was seen at the 4mm level (0.015±0.014), whereas the highest total mean amount of canal displacement occurred at 6mm location number 8 (0.077±0.035). This is also illustrated in (Graph 4-ANNEX III).

Table 3: Means and standard deviations of canal center transportation induced by PTN files considering locations and number of times of use.

Location mm	First Time (n=6)	Second Time(n=6)	Third Time (n=6)	Fourth Tim(n=6)	Fifth Time(n=5)	Sixth time (n=6)	Total (35)
0	.040±.010	.030±.024	.047±.029	.036±.019	.025±.007	.034±.008	.036±.019
0.5	.014±.012	.024±.016	.034±.020	.024±.013	.022±.020	.022±.006	.023±.015
1	.025±.010	.038±.013	.041±.019	.028±.014	.025±.016	.021±.014	.030±.015
2	.014 ±.013	.023±.020	.031±.021	.021±.010	.020±.012	.021±.009	.022±.015
3	.012±.010	.015±.015	.038±.024	.016±.007	.022±.017	.012±.011	.019±.017
4	.012±.012	.012±.010	.027.±020	.013.±014	.008±.007	.017±.013	.015±.014
5	.071±.021	.058±.014	.040±.025	.059±.018	.036±.012	.060±.027	.055±.022
6	.095±.031	.0920±.033	.07±1.036	.076±.045	.054±.037	.069.±022	.077±.035
7	.044±.025	.048±.030	.032±.027	.037±.030	.020±.029	.030±.016	.036±.026
8	.025±.016	.032±.022	.036±.014	.034±.0292	.034±.014	.011.±005	.028±.019
9	.024±.018	.025±.023	.042±.031	.028±.022	.037±.018	.019±.008	.029±.021

It was very prominent that, in almost all blocks, the transportation occurred more towards the outer aspect of canal wall at the apical level; but towards the inner aspect of the canal wall at the middle and coronal levels. This is presented in (Table 4). This was clear based on interpretation of the obtained signals. Negative value meant that transportation was toward the outerside of the canal wall curvature while the positive value indicated that the transportation was toward the inner side of the canal wall curvature (Table 4).

Table 4: Total Means and directions of transportation of the canal center induced by PTN at the examined locations.

Blocks	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
35 Blocks	-0.034	-0.023	-0.030	-0.022	-0.019	0.015	+0.055	+0.077	+0.036	+0.028	0.029

A General Linear Model (2 way analysis of variance, ANOVA) was used to determine if there were significant differences between the amount of transportation (11 locations in Table 3 first column) and number of times file was used (1-6 uses in Table 3). Post hoc multiple comparison test was performed using Bonferrroni correction.

A statistically significant main effect by transportation location was found (Wilks' lambda = .039, F =48.645, p<.000). Follow up pairwise comparison tests, with Bonferroni correction, revealed significant differences in transport at all 11 locations (p<.05). But significant interaction effects between the number of time of use and PTN file were not found (Wilks' lambda =1.61, F=.933, p> .05).

Additionally to this outcome, our result showed that during the root canal preparation, one file fractured. PTX1 number 6 was broken at the sixth use while preparing block number 30.

it can be concluded that PTN file could induce canal transportation with measurably significant progress from 0 – 9mm. File use (up to 6 consecutive uses) does not adversely impact the ability of PTN file to induce transportation.The amount of transportation does not different upon using PTN file six times.

5.2 EXPERIMENT (2) BT RACE

Amount of the resin removed during instrumentation in all blocks of the sample using BT-RaCe files in both outer and inner side of the canals is listed in (Table -ANNEX II).

Canal transportation values were obtained after applying formula to the data obtained from (Table -ANNEX II), the calculated formaula used as follow (Difference between the amount of resins removed at inner side of the canal wall from the amount of resin removed in outer side of the canal wall over 2). The quantities of canal center transportation resulted at all locations for all sample are listed in (Table -ANNEX II).

Table 5: Means and standard deviations of canal center transportation induced by BT files considering locations and number of time of uses.

Location mm	First Time (n=6)	Second Time (n=6)	Third Time (n=6)	Fourth Time (n=6)	Fifth Time (n=5)	Sixth time (n=6)	Total (35)
0	.086±.062	.073±.041	.072±.050	.114±.070	.103±.031	.021±.016	.08±0.054
0.5	.036±.021	.039±.025	.043±.024	.064±.051	.048±.020	.041±.015	.045±.028
1	.022±.019	.029±.015	.027±.022	.037±.029	.036±.022	.041±.014	.032±.020
2	.029±.018	.030±.030	.034±.021	.02±3.017	.026±.019	.011±.011	.030±.020
3	.040±.035	.027±.022	.048±.024	.036±.016	.040±.023	.035±.005	.038±.022
4	.06±3.048	.055±.025	.067±.035	.070±.029	.080±.043	.039±.018	.063±.035
5	.088±.044	.083±.028	.098±.039	.087±.046	.089±.045	.059±.028	.085±.038
6	.123±.056	.090±.027	.113±.039	.104±.063	.096±.031	.081±.017	.102±.042
7	.078±.032	.049±.023	.057±.040	.064±.051	.042±.020	.051±.022	.057±.033
8	.038±.0324	.039±.025	.039±.012	.035±.019	.022±.012	.019±.012	.032±.020
9	.043±.044	.063±.027	.037±.026	.049±.034	.033±.020	.025±.015	.042±.030

Total of means and standard deviations of canal center transportation collected from all sample are listed in (Table 5). Data showed that the least amount of transportation was seen at the 2 mm (0.030±0.020) followed by 1mm (0.032±0.020) at apical level locations. The greatest amount of transportation was seen at the 6 mm (0.102±0.042) followed by 5 mm (0.085±0.038) level. This also was illustrated (Graph 5-ANNEX III).

BT-Race rotary NiTi files showed transportation in both canal sides. However, there was more transportation toward the inside of the curve in the coronal and middle levels, than toward the outside of the curve at the apical level (Table 6).

Table 6: Direction of the total means of transportation of the canal center induced by BT-Race at the measured locations.

Blocks	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
35 Blocks	-0.080	-0.045	-0.032	+0.030	+0.037	+0.062	+0.085	+0.103	+0.058	0.033	-0.041

A General Linear Model (2 way analysis of variance, ANOVA) was used to determine if there were significant differences between the amount of transportation (11 locations in Table 5 first column) and number of times file was used (1-6 uses in Table 5). Post hoc multiple comparison test was performed using Bonferroni correction. A statistically significant main effect by transportation location was found (Wilks' lambda = 0.114, F =15.589, p<0.00). Follow up pairwise comparison tests, with Bonferroni correction, revealed significant differences in transport at all 11 locations (p<0.05). Significant interaction effects between time and PTN file were not found (Wilks' lambda = 0.083, F=.1.376, p> 0.05).

In addition to all of the above, the result also showed ,one file fractured; BT2 number 4 broke during the sixth time attempting to prepare block number thirty-four.

It was found that BT RaCe file induced transportation with measurably significant progress from 0 – 9mm. File use (up to 6 consecutive uses) did not adversely impact the ability of the BT Race file to induce transportation. The amount of transportation does not different upon using BT-RaCe file six times.

5.3 COMPARISON BETWEEN PTN AND BT

Two sets of repeated measures ANOVA were used to determine whether there was a significant difference between:

1) The amount of transportation at three canal location (apical, middle and coronal) and file type (PTN and BT-RaCe);

2) Number of times file was used and file type.

The summary data are reported below in (Table 7). Post hoc multiple comparison test was performed using Bonferroni correction techniques. Statistically significant main effects by file type were found by transportation (Wilks' lambda =0.469, F= 21.099, *p*<0.00).

Significant main effects by time were not found (Wilks' lambda=0.664, F=1.651, *p*>0.05). Significant interaction between the locations were not found (Wilks' lambda =0.785, F=0.959, *p*>.05).

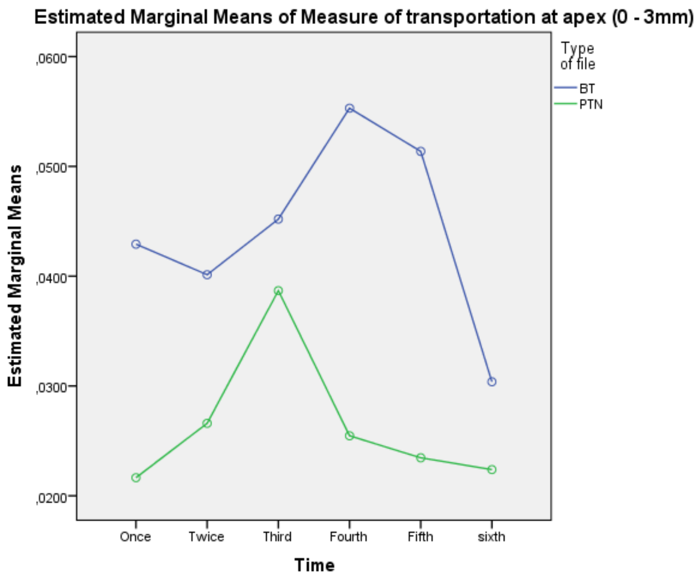
As shown in the graphs1-3 (and able of data output-ANNEX IV), BT files on average demonstrated greater transport at every location (apical, middle, and coronal) regardless of times of use.

Post hoc comparisons (LSD) revealed that the difference is at the coronal aspect of the canal (F = 2.959; *p* = 0.019) at the 6th use for every paired comparison (e.g., 1-6, 2-6, 3-6, etc), except for that between the 5th and 6th.

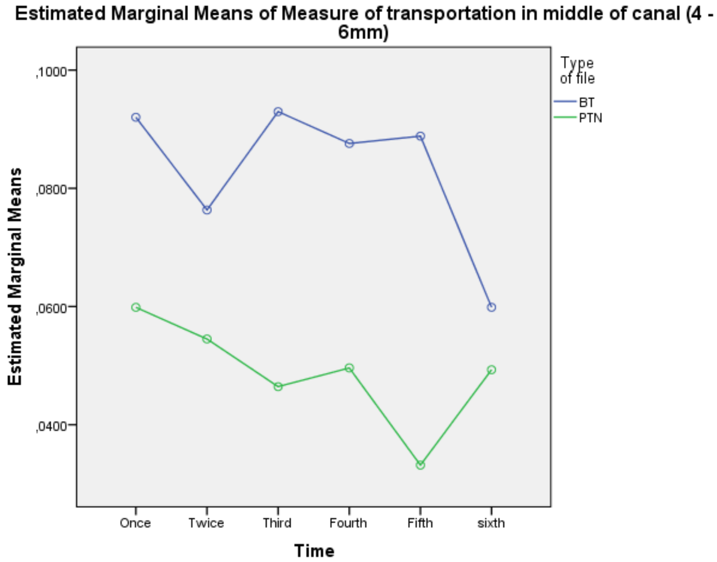
Table 7: Total means and standard deviations of canal transportation induced by PTN files and BT-Race at the three levels of the canals.

Measured Level	Amount of canal transportation (mm)		
	PTN	BR-Race	P value
Apical	0.026±0.013	0.045±0.019	*p* <0.005
Middle	0.049±,018	0.084± 0.036	*p* <0.005
Coronal	0.031±0.014	0.044±0.015	*p* <0.005

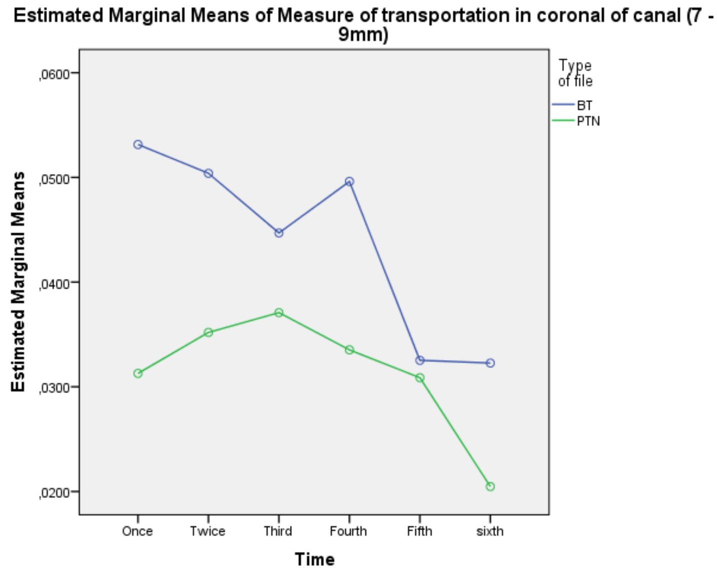
Comparing amount transportation and number of times of file use showed more transportation when PTN file was used for the third time and when BT Race file was used for the fourth time file at apical, middle and coronal levels (Graph 1, Graph 2 and Graph 3).



Graph 1: Measure of transportation in apical part of canal (0 - 3mm).



Graph 2: Measure of transportation in middle part of canal (4 - 6mm).



Graph 3: Measure of transportation in coronal of canal (7 - 9mm).

5.4 EXPERIMENT (3) STUDYING THE TOPOGRAPHIC CHANGES IN PROTAPER NEXT ENDODONTIC ROTARY FILE BY SCANNING ELECTRON MICROSCOPY (SEM)

PTNX1 and PTNX2 of each of the six systems were examined two times; before (B) and after use (A) (a total of 24 files). The files showed no pitting, corrosion, fretting, spiral distortion, disruption of cutting edges or fatigue cracks. However other changes were observed, which listed in (Table 8) and showed by photos below.

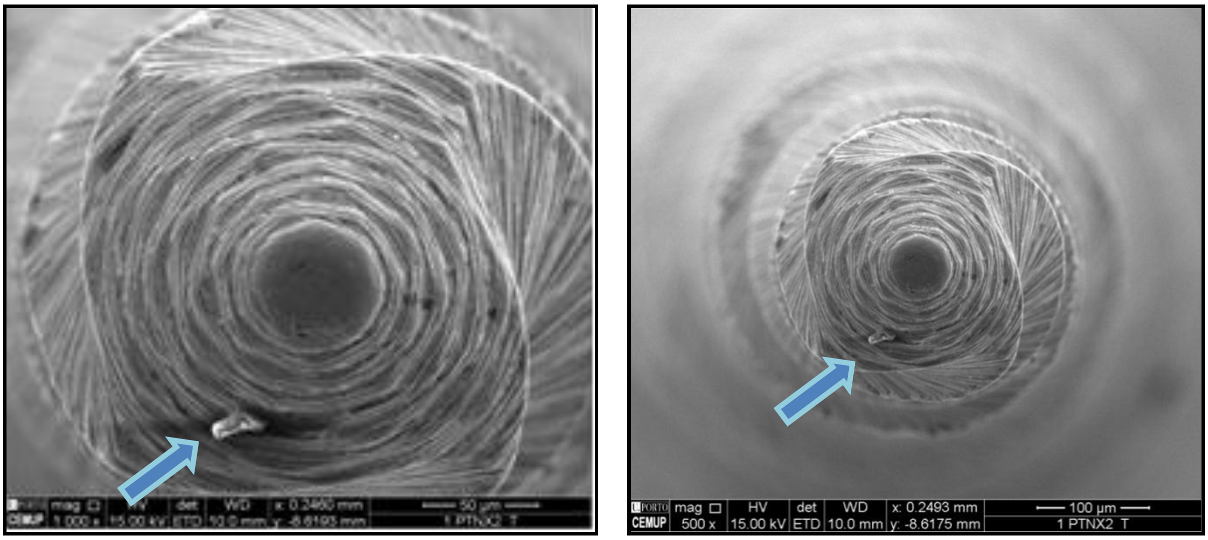
Table 8: Criteria used to evaluate the topographic changes.

Criteria	1PTNX1		1PTNX2		2PTNX1		2PTNX2		3PTNX1		3PTNX2		4PTNX1		4PTNX2		5PTNX1		5PTNX2		6PTNX1		6PTNX2	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
No visible defect	X	X			X	X	X	X	X	X	X	X			X	X			X	X			X	
Corrosion																								
Fretting																								
Micro-cracks				X																				X
Fracture																		X						
Metal flash																								
Metal strips			X																					
Spiral distortion																								
Blunt cutting edges													X	X			X	X			X	X		
Disruption of cutting edge																								
Fatigue cracks																								

PTNX1,2: ProTaper Next ; B: Before use ; A: After use

Among these, 15 files showed no visible defects, and 9 files showed some topographic surface defects.

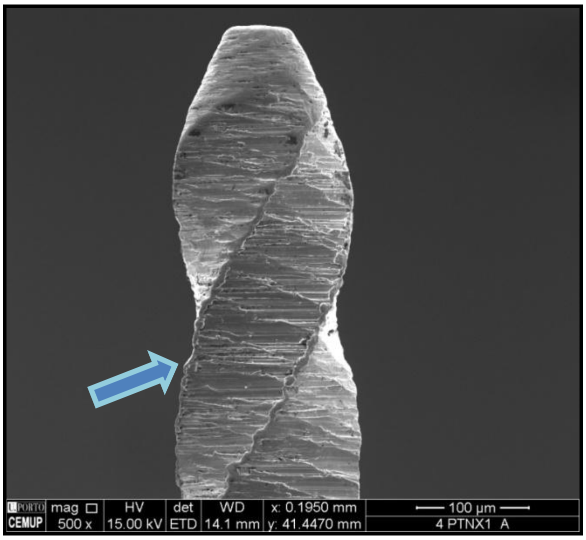
One X2 file had a metal strip on the apical portion (from the top view) before its use (1PTNX2) (Figure 30 a-b).



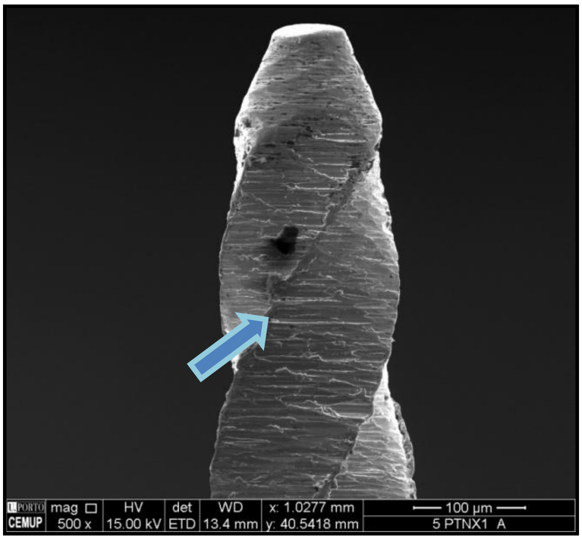
a: 1PTNX2 b: 1PTNX2

Figure 30: Metal strip a: 1PTNX2, b: 1PTNX2

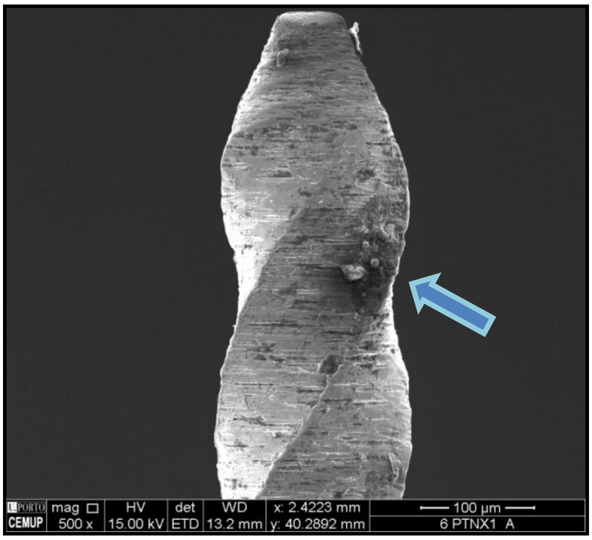
Three X1 files had blunt cutting edges of their apical and middle surfaces before use (4PTNX1, 5PTNX1, and 6PTNX1) (Figure 31, Figure 32).Such defects persisted after usage (Figure 33)



a. 4PTNX1

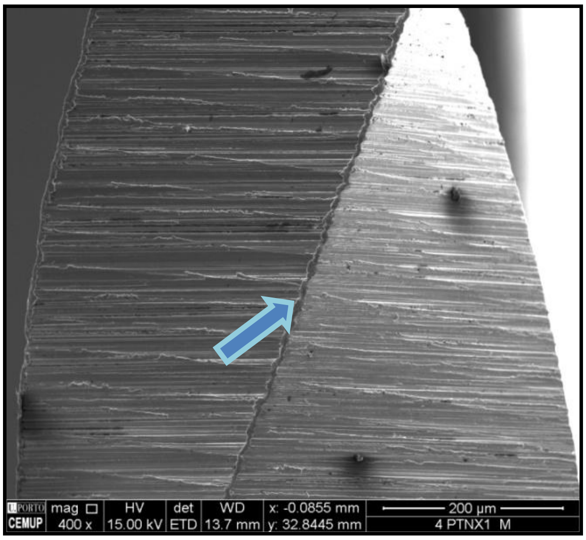


b.: 5PTNX1

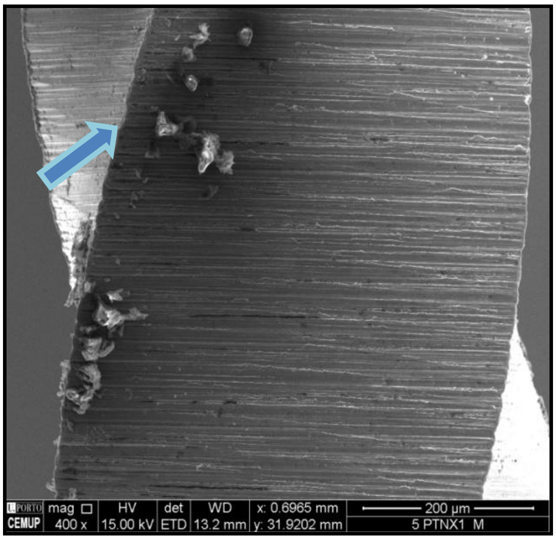


c.: 6PTNX1

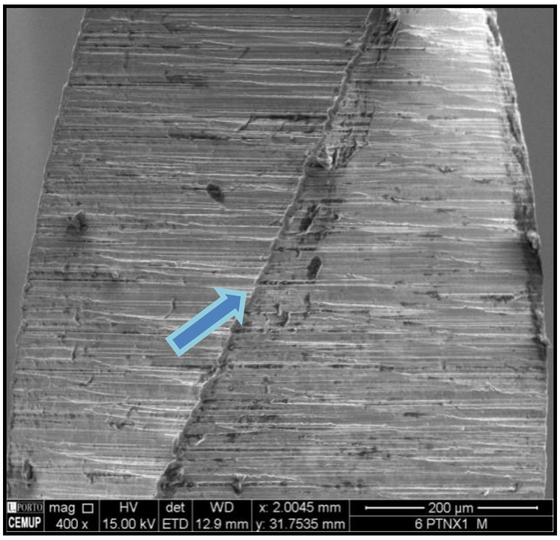
Figure 31: Apical part of 4PTNX1, 5PTNX1, 6PTNX1 showing blunt cutting edges before uses (a-c)



a.: 4PTNX1

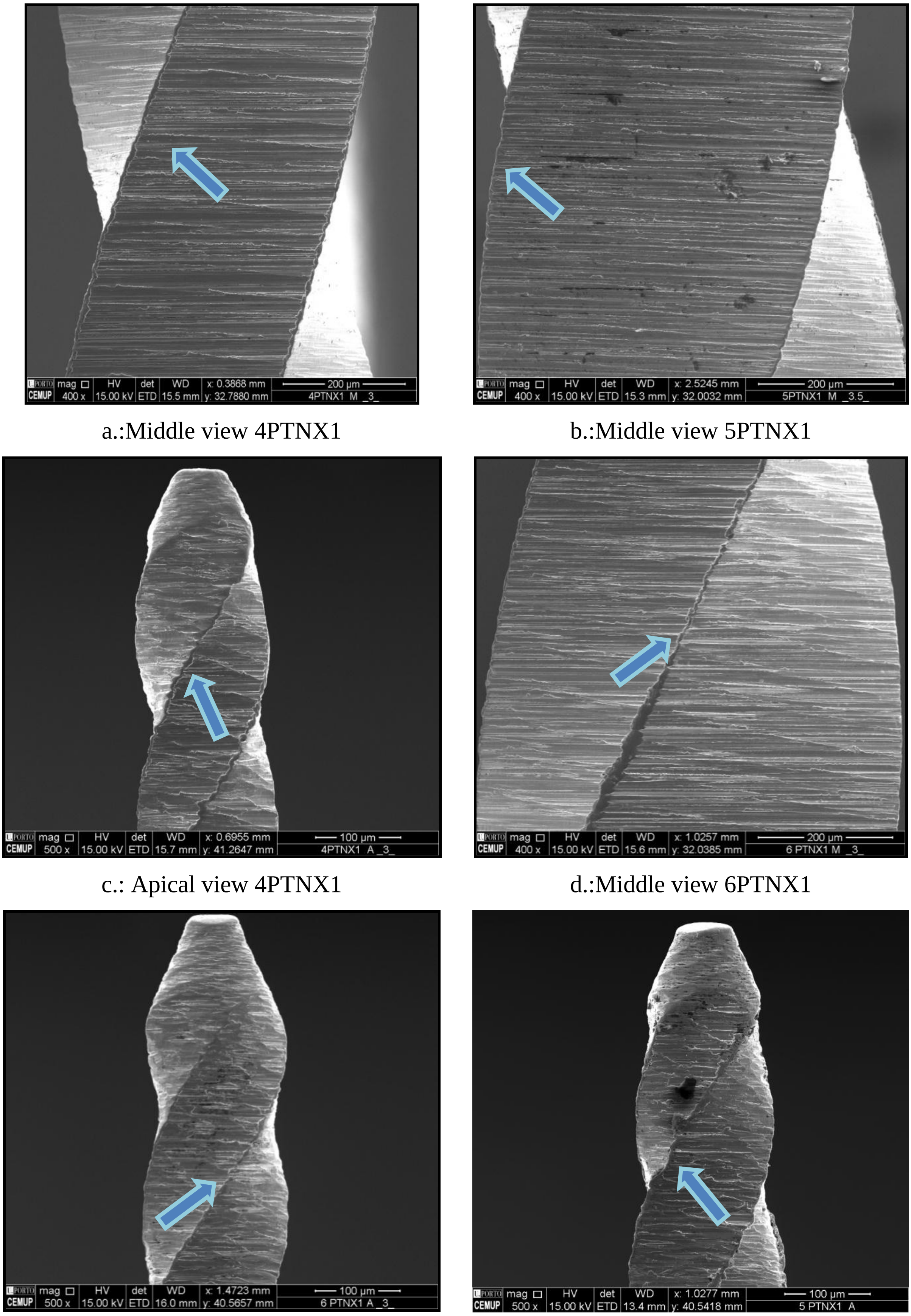


b.: 5PTNX1



c.: 6PTNX1

Figure 32: Middle part of 4PTNX1, 5PTNX1, 6PTNX1 showing blunt cutting edges before uses.(a-c)



a.:Middle view 4PTNX1

b.:Middle view 5PTNX1

c.: Apical view 4PTNX1

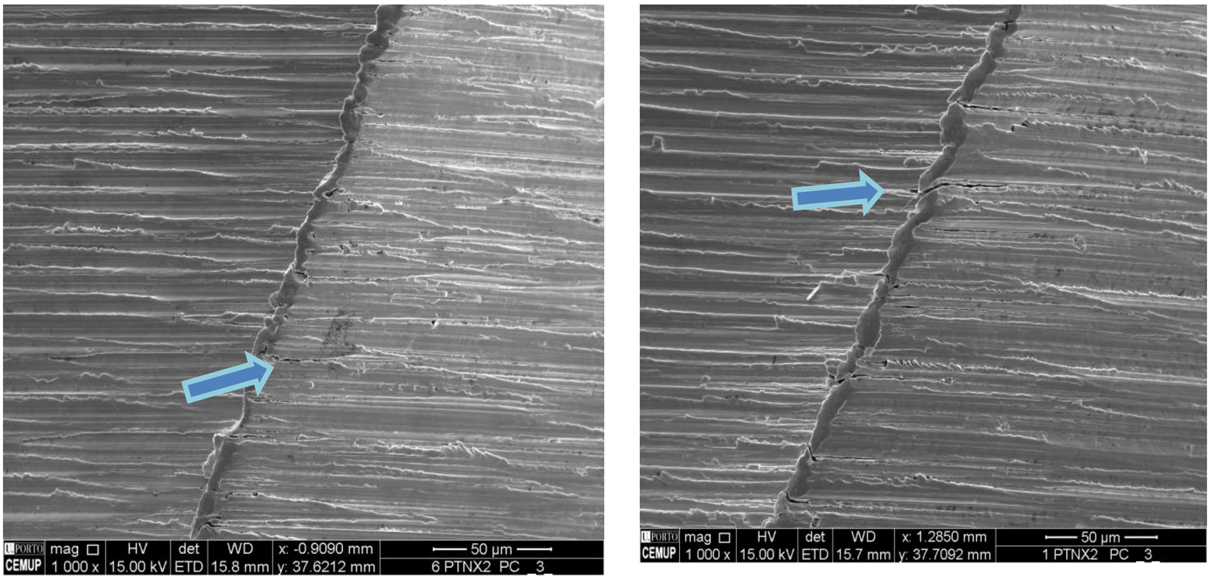
d.:Middle view 6PTNX1

e.: Apical view 6PTNX1

f.: Apical view 5PTNX1

Figure 33: Middle and apical views showing blunt cutting edges after uses (a-f).

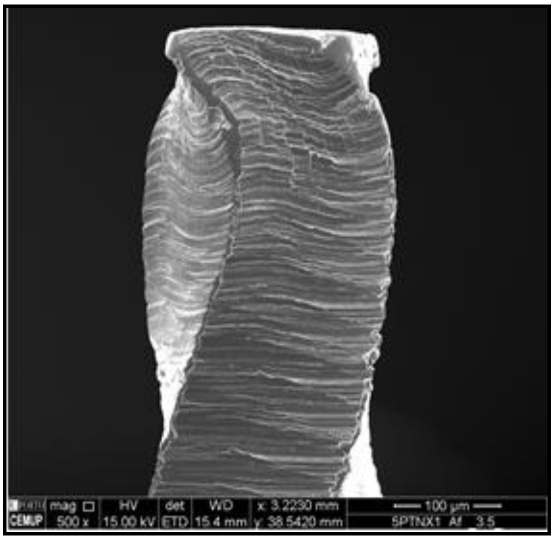
Small micro-cracks were observed on the critical point area under 1000X magnification in two X2 files after use (1PTNX2 and 6PTNX2) (Figure 34).



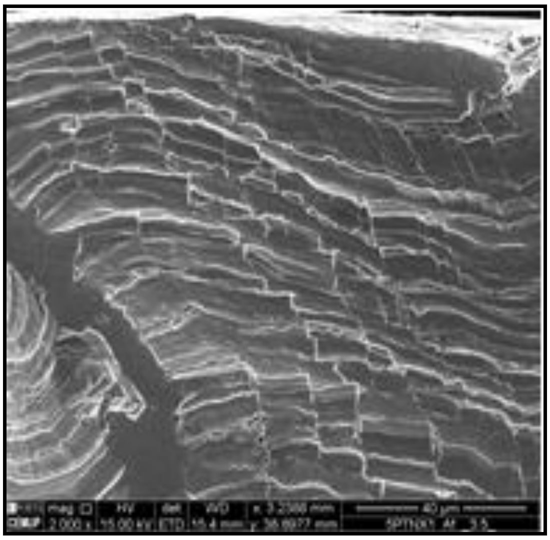
a: 6 PTNX2 b: 1PTNX2

Figure 34: Micro cracks after uses (a: 6 PTNX2; b: 1PTNX2).

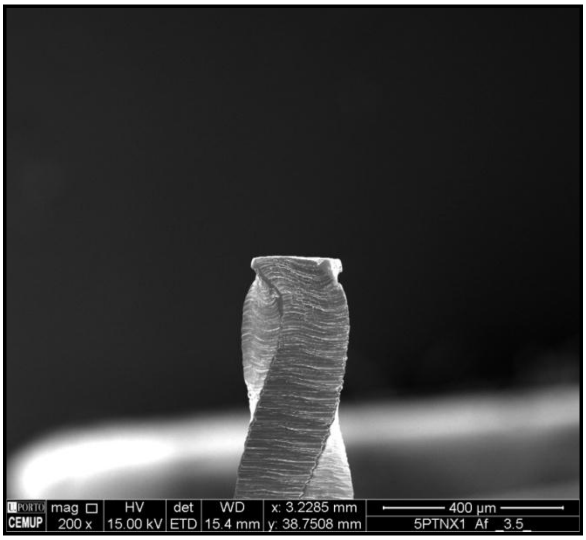
One file had fractures after its third use (5PTNX1) (Fig 35 a-d).



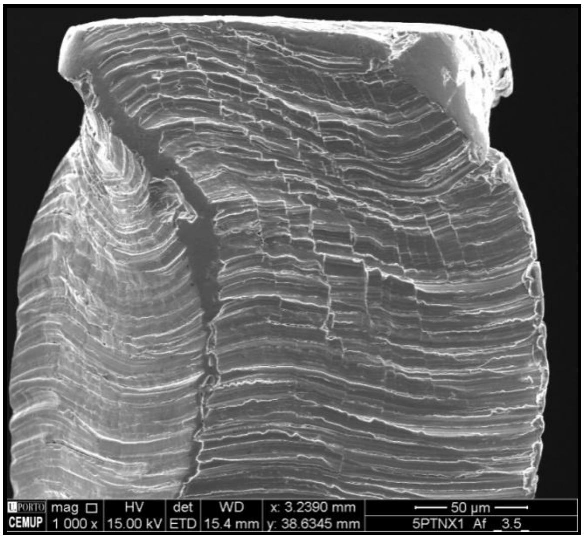
(a)



(b)



(c)



(d)

Figure 35: Apical section of 5PTNX1 showing fracture in critical area (a-d).

5.5 KEY FINDINGS SUMARY

1. In PTN experiment, the lowest total mean value of canal center displacement was seen at the 4mm level (0.015±0.014), whereas the highest total mean amount of canal center displacement occurred at the 6 mm location (0.077±.035).
2. The canal center transportation occurred more towards the outer aspect of the canal wall at the apical level;but towards the inner aspect of the canal wall at the middle and coronal levels after preparation with PTN.
3. There was no statistical significant difference between the amount of transportation after using PTN file 6 times ($p > 0.05$).
4. In BT-Race experiment, the least amount of transportation was seen at the 2 mm (0.030±.020), followed by transportation at the 1 mm (0.032±.020). The greatest amount of transportation was seen at the 6 mm (0.102±.042) followed by transportation at the 5 mm (0.085±.038) level.
5. The canal center transportation occurred more towards the outer aspect of the canal wall at the apical level;but towards the inner aspect of the canal wall at the middle and coronal levels, after preparation with BT-Race.
6. There was no statistical significant different between the amount of transportation after using BT-Race 6 times ($p>0.05$).
7. Small incidence of fracture occurred in both files.
8. Small changes of PTN surfaces were seen; like micro-cracks, metal strip or blunt cutting edges.

CHAPTER 6

Discussion

6.1 SHAPING ABILITY OF PTN AND BT-RACE FILES

The purpose of the present studies was to evaluate the shaping ability of PTN and BT-Race rotary systems after repeated usage in an experimental setting. These two file systems were selected as they represent modern endodontic instrument designs as well as newly introduced advances in NiTi files. Evaluating the changes of the amount of root canal transportation upon re-using the file six times mimic the clinical situation of treating one or two molars. Study results are not intended to endorse NiTi file reuse from patient to patient, and single NiTi use should remain the world standard. Single use minimizes cross contamination and instrument fracture. However, it is important to study the durability of instruments in non-clinical re-use situations to determine their maximum capabilities and performances. The repeating in and out pecking type shaping with the same file in six canals clinically mirrors the situation of treating a molar tooth with three to six canals, or two molars in the same patient.

Shaping ability was evaluated in simulated canals in acrylic resin models under firmly controlled laboratory conditions. The use of acrylic resin blocks as an experimental model for the in-vitro analysis of root canal preparation is accepted in research protocols (6, 166) and they are used in dental education (167). Benefits of the use of resin blocks include:

Their transparency, which facilitates accurate recording of the geometry of root canal both before and after preparations (93).

Blocks are standardised in terms of canal size, shape, and the degree of canal curvature (168)

Blocks are simple experimental models that allow direct comparison of the shaping ability of different instruments (45, 169, 170).

Another important methodological aspect of both studies was the use of CAD solid works software that provided a two-dimensional computer-aided image. The software has been used in previous endodontic studies (162, 171-174) and is recognized to offer an advantage in analyzing the anatomical details of the endodontic space and in the assessment of the root canal filling (162). Without sophisticated imaging software, it would be difficult to reliably measure minute differences of critical interest in the present experiments.

Key findings and recommendations for clinical applications specific to each of the examined files are discussed below.

PTN:

Assessing the effect of repeated use of PTN on the quality of canal preparation in terms of transportation and file fatigue has not been performed before. The present study examined the amount of transportation of the center of the root canal calculated by dividing the value of the difference between the widths of resin removed from the measured locations of the aspect walls by two. Although, most previous research evaluated the transportation of the canal as an entire entity(40, 69, 71, 175), our study results are consistent.

In the present study, all transportation values at apical positions were less than 0.3 mm; in 0 mm= (0.036±0.019), 0.05 mm= (0.023±0.015), 1 mm = (.030±.015), 2 mm= (0.022±0.015) and in 3mm= (0.019±0.017) (Table 3). The findings suggested that the use of PTN would not compromise the apical seal (176). Apical transportation more than 0.3mm will negatively affect the root canal system seal (19).

The direction of canal transportation caused by PTN rotary NiTi instruments was, in general, toward the outer aspect of the canal curve at the apical part of the prepared canal, and toward the inner aspect of the canal curve at the middle and coronal parts. The amounts are more extended at the middle level, which is in agreement with other studies (58, 59, 71, 104). The direction is thought to be due to the file's super elasticity, which allows the instrument to follow the canal curvature (177-179). When rotary files are used to shape curved canals, the shape memory property of NiTi alloy make the files return to their original shape. Therefore, the files are forced to straighten toward the outer side of the curvature removing more resin from this area. The same property decreases their cutting coronally along the inner wall (180)..

Nickel-titanium (NiTi) endodontics files, have improved the technical quality of the cleaning and shaping of root canals, they are capable to preserve the original canal curvature better (177, 181), induceing less procedural error comparing with conventional instruments and even enhance the clinical outcomes, literature showed; success rate with the procedure performed with NiTi higher than those mad with SS (182, 183). Despite the great advantages of rotary NiTi files versus stainless steel, the NiTi may undergo fracture as a result of torsional or flexural fatigue (184). In the present study, only one of PTN NiTi rotary files broke, and the failure occurred when it was used for the sixth time. Failure might be due to the resistance of the resin block material that resulted in an "unwinding" of the instrument flutes to produce a stress point and subsequent fracture of the file [29, 145]. Fracture leads to the assumption that breakage of a repeatedly used file may be avoided when the file is handled carefully. The pressure on the file could also be reduced by creation of a glide path during preparation. Accordingly, the torsional failure and file separation are reduced [185]. Supporting to our study, a CBCT study [71] reported that creating a glide path with ProGlider performed better with fewer canal aberrations when compared with instrumentation performed with ProTaper Next with Path- File or ProTaper Next only[71].

The two research questions regarding PTN were:-

Do PTN rotary file systems induce root canal transportation?

Does repetitive use (1-6) affect the ability of PTN file system to induce root canal transportation?

The PTN file in the present study could induce canal transportation but the amount was very small. This might be due to its cross-sectional design [27, 40, 175], and the type of alloy used for its manufacturing (M-wire) [67, 186]. Use of ProGlider (PG) in this study to create a glide path could be also another reason for the minimal amount of transportation. Supporting to this, Elnagy *et al*. [71] reported that creating a glide path with ProGlider performed better with fewer canal aberrations when compared with instrumentation performed with ProTaper Next with Path-File or ProTaper Next only [71]. This was also supported by another study that suggested creating a glide path would reduce instrument deviation and lessen the amount of resulting canal transportation [38].

The results showed that no statistically significant differences in the amount of transportation was induced by using PTN systems six times. This is contrary to a study examined the effects of multiple clinical uses of ProTaper Universal [187], and reported significant diversity in the amount of transportation between the numbers of file uses. This was explained as a result of reduction in cutting efficiency of the instrument due to a modification of the cutting edge [187]. However, it is important to note that, in the present study the instruments maintained their cutting efficiency throughout the experiments. Files removed the resin materials on both inner and outer sides of the canal walls of the tested simulated canals. Microscopic study to the topographic surface changes is advised in order to determine efficacy after 6 times uses.

BT-RACE:

Examination of the effect of several clinical uses of BT-Race instruments on root canal transportation has not been done before. The present study demonstrated a fracture of BTN file only after the instrument was used six times. Failure may be due to significant amount of work done beyond the recommended single use of file. BT-Race file is ideal for use in one case only, and the manufacture claims that it is ideal for molars with 4/5 canals [(188)]. In addition, the inherent resistance of the resin material of the blocks used might have caused unwinding of the instrument flutes and, consequently, fracture of the files [(29, 145)]. The single fracture might have occurred because the electro-polished surface feature of the file decreased the effects of torsional and cyclic fatigue [(136)]. Burklein *et al*. also reported one BT-Race file fracture (BT2) [(40)] and attributed that to its design. The working part is cylindrical not tapered which make the file lower resistance to fracture compared with tapered instrument, they also explained that , this part of file easily deformed which prevents the file to progress toward the apical direction and lead to ledge formation at the outer aspect of the curved canal apicaly.

The obtained results demonstrated the amount of the apical canal transportation was within the safe ranges of 0.15-0.30 mm. Measurements bigger than 0.30 mm may lead to number of adverse effects on the apical seal [(3, 19)]. The present study showed that transportation of canal center at 0.5 mm was (0.045±0.028). This finding was consistent with the results of a study by Burklein et al who evaluated the shaping ability of BT-Race [(40)] and showed that canal transportation at 0.5 mm was (0.12±0.08), considering that the center and whole canal transportation.

To date, the study by Burklein et al is the only study that evaluated the shaping ability of BT-Race [(40)]. Due to the lack of studies conducted on BT-Race, results were compared to the published data about the predecessor systems manufactured by the same company. Despite the fact that different methodologies were used, the outcomes were consistent with those of the current study. The present study showed that the transportation of the center of the canal at 1 mm was (0.032±.020), at 3 mm was (0 .038±.022) and at 5 mm was (0 .085±.038). Saber *et al* [(175)] measured the transportation induced by iRaCe (*FKG, La Chaux-de-Fonds, Switzerland*) at the apical region (1.5 mm from the apex) and found it to be (0.06±0.01). Maitatin *et al (189)* showed that canal transportation at apical level of 3 mm was (0.10±0.10) and at middle level of 6 mm was (0.15 ± 0.13). The results of the current study showed that the transportation amount almost half that found in those studies[(40, 175, 189)]. In this study; the amount was for transportation of the canal center rather than transportation of the whole canal, thus the comparison showed compatibility with others.

In agreement with other studies, that evaluated other NiTi files (GTX, WO, PTU, FT, PTN) (58, 59, 71, 104), this experiments found that the quantity of canal transportation was more prominent at the middle level. The direction of canal centers' transportation resulted from the use of BT-Race was, in general, toward the outer aspect of the curve at the apical part of the preparation, and toward the inner aspect of the canal curve at the middle and coronal parts. Many studies reported the same finding with the use of other rotary endodontic instruments (6, 60, 190, 191). This was attributed to the file's super elasticity, which allowed the instrument to follow the canal curvature (177-179). The shape memory property of NiTi alloy make the files return to their original shape. Therefore, the files are forced toward the outer side of the canal wall curvature removing more resin from this area. The same property forces the files away from the inner wall coronally resulting in less cutting in thus area (180).

The two research questions regarding BT Race were:-

Do BT-Race rotary file systems induce root canal transportation?

Does repetitive use (1-6) affect the ability of BT-RaCe file system to induce root canal transportation?

The results of this study indicated that: **1)** the file did induced transportation and **2)** showed no significant difference of the amount of root canal transportation upon re-using the file six times. The present study, BT-RaCe instruments maintained their cutting efficiency throughout the experiments. The files effectively removed the resin materials on both the inner and outer sides of the canal walls of the tested simulated canals. The small resulted amount of transportation observed in the current study might be explained by BT-RaCe file flexibility. A previous study found that a small amount of transportation resulted with flexible files(57). It was specified that the centered canal preparation depended on the file design, its flexibility, or the instrumentation technique (192). The file sequences and BT tip of the BT-RaCe instrument allowed adequate apical preparation sizes, ensured that the original canal shape was maintained, and kept the files centered in the canal (136, 188). These factors might have resulted in the small amount of canal transportation reported in the present study. BT-Race file system has a "non-screw-in design" that introduces them into the root canal with low magnitude of positive force and torque, and allows them to be withdrawn smoothly from the canal with low magnitude of negative force and torque. This feature could explain the insignificant changes in the amount of canal transportation when BT Race was used frequently.

Despite the limitations of this study and as the small amount of transportation that was induced by BT-Race file, repetitive use (up to six times) did not affect the shaping ability of BT-Race in curved root canals. A standard protocol for testing the shaping ability of NiTi rotary instruments is required to ensure consistency of methodology and to obtain comparable results when assessing the canal transportation caused by new instruments and techniques.

6.2 COMPARISON BETWEEN PTN AND BT-RACE:

When the two files were compared, this results revealed significant differences in the amount of transportation induced by six times use. The use of PTN file caused less canal transportation than the use of BT-RaCe. This difference between them might be due to the difference in their manufacturing and design features. Bürklein *et al.* (83) evaluated the same instruments but did not find statistical significant differences between them at the level of 0.5 mm from the apex. They used natural dentinal roots with 25°-39° curvature, and the final apical size preparation was 40. Standardized radiograph imaging was used to take photos pre and post to the instrumentations. The approach and methodology used in our study was different which might explain the different findings.

The two files are made of different metal alloys. PTN is constructed from M-wire and BT-race from conventional austenite NiTi. Instruments that are made of new alloys (CM-wire, M-wire) produce almost no transportation (193). This could explain the smaller amount of transportation induced by PTN in comparison with BT Race. In addition, PTN file has a progressive taper at the apical section and a decreasing taper at the coronal section (194), whereas BT-Race has a constant taper (136). It has been claimed that progressive taper increases the flexibility of files (195), which may affect the amount of canal transportation resulted from the use of PTN (177).

While there was a difference between the two files, a similar pattern of transportation was seen at all measured levels. Inclination of transportation was more predominant in third and fourth time of use with both file systems. Operator-related factor cannot explain the finding since only one person shaped all canals.

6.3 STUDYING THE TOPOGRAPHIC CHANGES IN PROTAPER NEXT ENDODONTIC ROTARY FILE BY SCANNING ELECTRON MICROSCOPY (SEM)

The present *in vitro* study evaluated the surface changes of PTN rotary instruments before and after the third use. Scanning electron microscopy (SEM) was used to analyse the changes that occurred on PTN surfaces. The endodontic literature showed that SEM produced high resolution images and allowed characterization of the topographic features that appeared on the file surfaces and on the fractured surfaces of broken instruments [(74, 79, 97, 126)]. It displays more detailed information than light microscopy, and reveals certain distinct features that could even help categorize the type of fracture mechanism involved [(196)]. SEM has been used to observe the dentinal debris and explore patent dentinal tubules [(197)]. In addition, it was proven to be useful in evaluating surface defects without affecting the physical properties of endodontic files [(97)].

This study, three areas were selected for evaluating the surface changes: the middle third, the apical third and the critical area of the file (3-5 mm away from the apical point of the file). The selection of the areas to be evaluated was based on the view of Sattapan *et al.* [(198)], who indicated that these three areas were the most critical because the files tended to fracture close to their tips. Tapering of the file increased towards the handle, so the bulk of the file was much stronger than its tip [(160)].

It was found that before use, the files had a highly smooth surface except for one metal strip observed on the tip of one PTNX2 . The same finding was observed in previous reports [(74, 142)] and was explained as a result of the manufacturing process [(43, 199-202)].

The presnt study, blunt cutting edges were observed in three files before use and stayed unchanged after the third use. Similarly, in testing the Lightspeed file, Eggert *et al*. [(74)] described a remaining blunt cutting edge after use and explained that it meant that the sharp cutting edges were not overused. Kumar *et al.*[(142)] analyzed the ProTaper Universal file (PTU) and found the same defects but only after use. The researchers explained these defects as a result of the safe cutting tip and the anti-screwing design, which required less pressure to avoid such defects [142].

Micro-cracks were detected this study. Similarly, Subha *et al.* showed that ProTaper rotary files exhibited micro-fractures after the third and fourth use compared with K3 and PTU hand files [203]. Micro-cracks or micro-fractures are the results of a rotational bending of the file within the canal due to shear forces on the blades, which later combine to become fatigue cracks [204].

The results of the present study also revealed a fracture on one PTNX1 file (number five), that happened immediately after the third use. Similarly, in a study that examined the separation incidence of PTN, it was reported that most fractured PTN files were X1 files. Those instruments were the first used to penetrate and shape the full working lengths of the canals, and, thus, they were more likely to suffer from fatigue [133]. In the current study, ProGlider was used to create glide paths before using PTNX1 files, which could have made X1 files less subject to fatigue, thus reducing the number of file fractures [132].

On examining the fracture surface at higher magnifications, SEM revealed a strong plastic deformation near the fracture zone. A previous study of PTN reported similar typical dimpling near the center of the fracture surface [121]. Such a defect indicated that the fracture occurred by torsional stress rather than by cyclic fatigue [131, 160, 205]. The same files that broke (5PTNX1 file) had shown few changes before use (blunt cutting edge). Such changes could act as a stress concentration area and led to fracture. The elastic limit of the material was exceeded, which led to plastic deformation followed by fracture [206, 207]. The fracture occurred 4 mm from the apical point. This was comparable to previous works [137, 208] which indicated that instruments did not fracture at the tip of the file but rather at the point of supreme flexure of the shaft or the midpoint [126, 199].

Repeated use of NiTi files can cause plastic deformation of the material [209]. The deformation may be lead to inadequate preparation, insufficient cleansing and shaping of the root canal system and can ultimately lead to the fracture of the files [210].

NiTi alloys have been proven to increase the cyclic fatigue resistance of the instruments [211]. The results of this study showed low occurrence of topographic changes, low fracture incidence and high resistance to cyclic fatigue compared to previous studies [142, 200, 203, 212]. This difference could be due to many factors such; The M-Wire technology provides greater flexibility for the files along with the off-centered rectangular cross-sectional design, improves the file's strength, and gives the system high resistance to cyclic fatigue [213, 214]. The unequal contact between PTN instrument and the root canal wall could also be a feature that enhanced the fracture resistance of PTN file [126].

Although PTN is able to resist high torsional stress, the incidence of its fracture occurred as a result of torsional failure. Therefore, clinicians should consider these findings especially when preparing curved root canals with the same file that have already been used to shape narrow root canals. It is recommended that clinicians use light insertion and avoid forcing the instrument apically during instrumentation.

6.4 STUDY LIMITATIONS:

The major limitation in this study would be the fact that the study is *in-vitro*. *In-vitro* or laboratory research studies, in general, have good internal validity but poor external validity or generalization. As such, the results may not be transferred to clinical performance [215]: However, transferring results interpretation to the clinical setting should be made with caution [216].

In this study, the samples were instrumented similarly to clinical situation and only one operator performed all procedures. This was done to aim at a better standardization. The simulated canals in resin blocks may not match the various anatomical configurations in real tooth structure. Other clinical setup, like the patient factor is also missed. Clinical outcomes could thus not be investigated [217]. However, Ahmad *et al.* [218] examined the cutting proficiency of ultrasonic instrument on curved canals in simulated acrylic resin blocks and natural teeth, and could not find any qualitative or quantitative differences in the way of removal of material along the length of the canal's wall. Khalilak *et al*. compared apical canal transportation in extracted teeth with that in simulated resin blocks [219] and found that the simulated resin blocks and extracted teeth showed similar apical transportation [219]. Both studies concluded that their results could be extrapolated to a clinical situation [218, 219]. Accordingly, the obtained results of the two experiments showed no differences in canal transportation between six time uses in canals in the resin blocks, it would be expected that testing on the harder dentin would eventually generate same results.

Previous studies also noticed that rotary instruments showed wear same in dental root canals as in resin-based root canals [101, 220]. A number of studies reported a lower amount of wear on the K3 instruments when they were used in human dental root canals, compared to when they were used in simulated resin root canals [8, 29]. Accordingly, it can be concluded that if rotary files could withstand the tension generated by cutting acrylic resin in simulated canals after multiple uses, its stability when used in canals of natural teeth would probably be greater. One should be comfortable using resin blocks to standardize the samples as they permit better comparability by having similar baseline shape and material [187]. Regardless, caution should be taken as natural dental canals are anatomically varied which can affect the torsional load of the instruments [221].

In the first two experiments, evaluation of the canal preparations was performed only in the longitudinal plane of the canal. This only represents two-dimensions of the three-dimensional root canal, when the fact that endodontic instrument is preparing the canal in three-dimensions. The third study aimed to evaluate the morphological alterations of PTN file using scanning electron microscopy. This method of evaluation provided a qualitative observation of the surface changes. Quantitative analysis would also be needed by using other experimental methods, such as Electrochemical Impedance Spectroscopy [222] with a focus on the characteristics of the surface titanium oxide layer or Atomic Force microscopy (AFM) [200]. AFM is a scanning probe microscopy technique which is used to reconstruct three-dimensional surface topography images in real time.

Evaluating the morphological changes was only performed on PTN because of lack of funding, which also resulted in evaluating PTN files three times instead of six times. As result of lack of research funding, the six times use needed to confirm whether the small amount of canal transportation was linked to dull cutting surfaces or no.

CHAPTER 7

Conclusion

This thesis provides evidence-based information for the clinical uses of newly manufactured rotary endodontic files. Within the limitation of the present studies, it can be concluded that the newly manufactured PTN and BT-Race rotary files demonstrated good capability to minimize errors during cleaning and shaping of curved canals. The studies also showed that the operator should be aware of the elements that might affect the instrument efficacy (i.e., canal anatomy, operator experience, file design) as it was demonstrated that there was reduction in stress and failure with competent preparation. The AutoCAD software models, used in the experiments provided a cost-effective means of evaluation and are useful in measuring in the third dimension. Other key findings specific to file types are:

PTN files (Dentsply Maillefer, Ballaigues, Switzerland) respected the original canal curvature well and were safe to use repeatedly with few incidences of canal transportation.

BT-Race files (FKG, La Chaux-de-Fonds, Switzerland) respected the original canal curvature well. It can be used to prepare canals in multi-rooted teeth with minimal amount of canal transportation.

In clinical simulation experiments, minimal morphological alterations of PTN rotary files were observed after three uses, and file stability was preserved. Thus, PTN rotary instruments can be used multiple times and safely in curved simulated root canals without fear of failure.

CHAPTER 8

Recommendations for Future Work

The current experiments were performed on a small sample size, and future experiments on a larger sample size are recommended to verify results. There is a difference between statistical significance and clinical significance [(223)]. For this confirmatory experiments may establish clinical relevance and value PTN and BT Race files that the findings of the present studies strongly indicated.

In order to find a cheaper substitute to the CT-Scan, which is considered to be the best for three-dimensional analysis, were offered a design to evaluate canal transportation in the third dimension using the CAD software. It wasn't possible to use that design for the present study as there were costs associated with the manufacturing of the components which were prohibitive. Also, the expertise needed to competently use the software was not available at the time of the study. Therefore, a three-dimensional evaluation of canal transportation resulted from the use of PTN and BT Race is recommended.

SETUP FOR RESEARCH PURPOSE

Here proposed setup, which was implemented to access the geometry of the canal for this thesis using Paint Shop Pro 9 from JascSoftware® and CAD software (Chapter4: Methodology), can be enhanced to allow the three dimensional measurements of canal transportation. This could give a better economic tool that would help the researchers to perform same work with less cost compared to the micro-CT.

It is known that the ideal tool to obtain 3D data is the micro-CT which could be applied on real teeth. However, with micro-CT drawbacks and the limitations of acrylic models that were discussed in Chapter 2, the acrylic blocks could be a good alternative for teaching purposes or testing of the cutting process. Having all this in consideration, an effort was carried out to extract 3D information from the pairs of images (two planes of projection) of each measurement (Figure 37) shows the original canal geometry created with CAD.

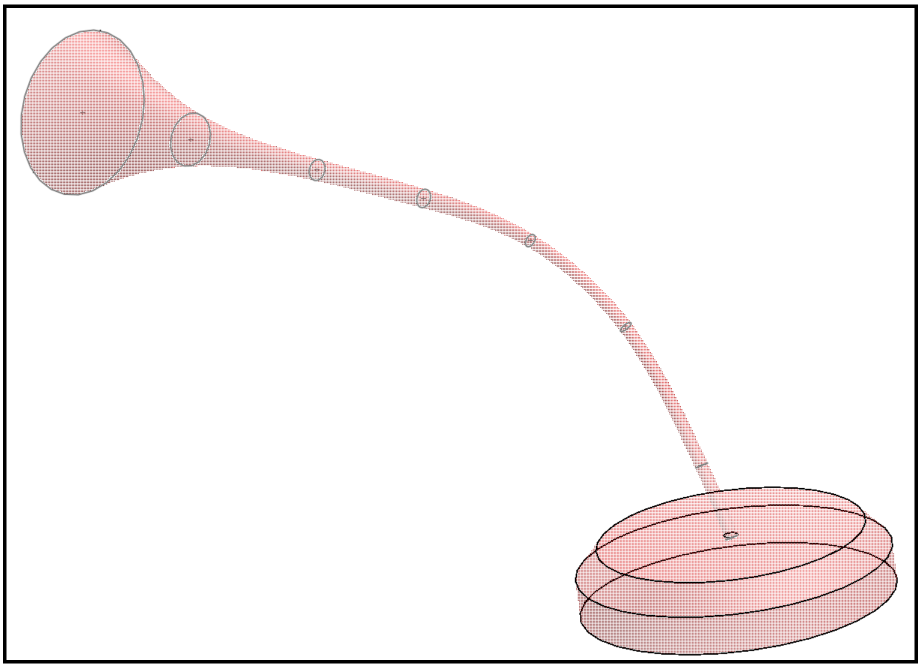


Figure 36: Example of the 3D geometry using the results of each cross section.

As it can be seen in (Figure 36) the selected cross sections start with circular geometry and can be fully characterized by its diameter which, could be extracted through the frontal projection using CAD to simulate the final result of the canal opening. Then, by superimposing it on the original geometry, the two images, which are presented in (Figure 37) and (Figure 38) can be extracted for canal front view and top view.

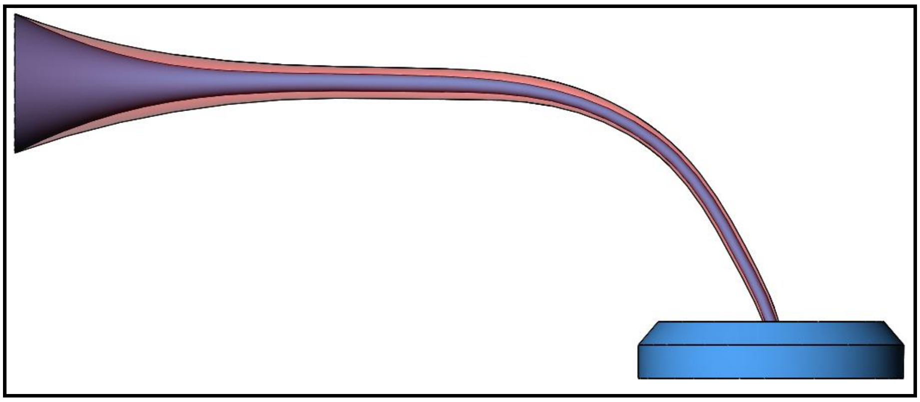


Figure 37: A front view of the original and final geometry of the canal simulated by CAD.

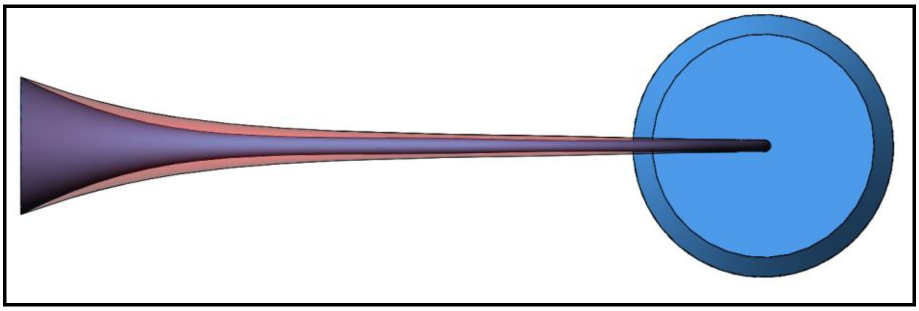


Figure 38: A top view of the original and final geometry of the canal simulated by CAD.

As the file is conical and due to the canal curvature, it is expected that the final geometry, obtained after canal preparation, should have elliptical cross sections. This means that a complete definition of the cross section geometry could be achieved by measuring the maximum and minimum axes of the ellipse. Figure 39 shows the geometry of the canal simulated by CAD. This leads to the conclusion that the final geometry in 3D representation could be reached using the two projections previously referred to.

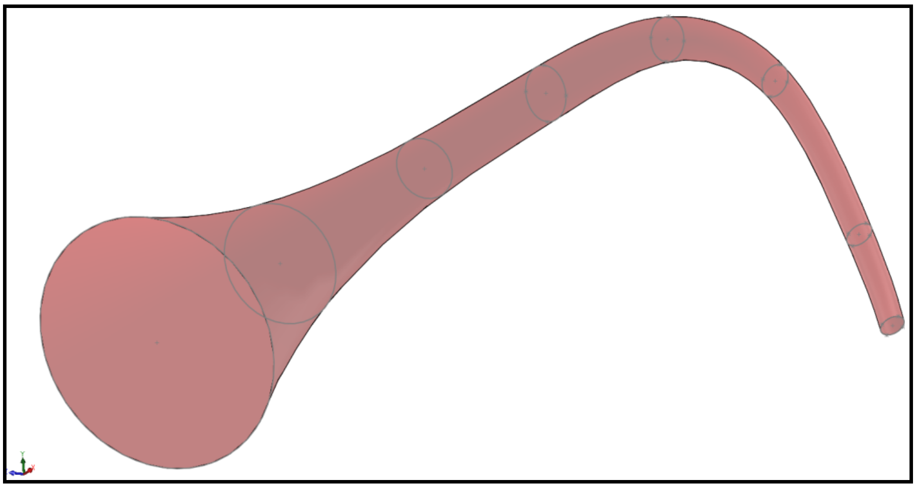
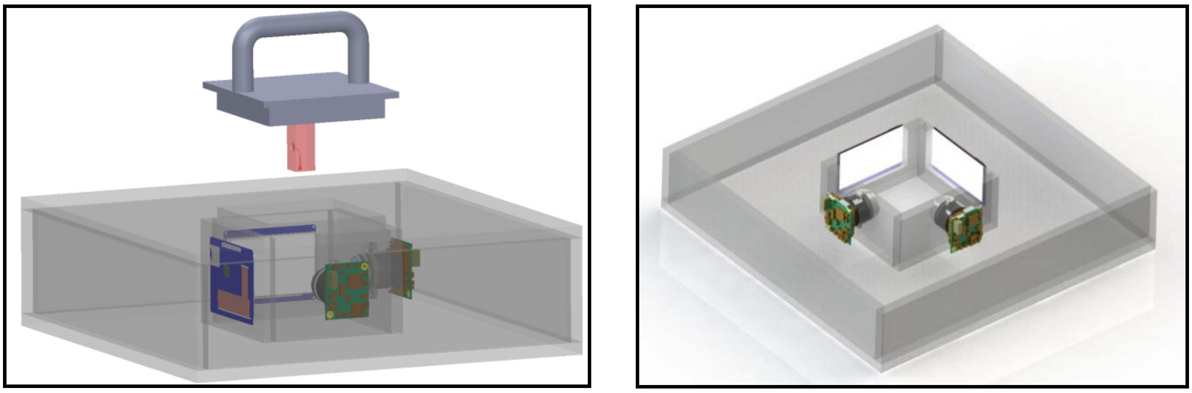


Figure 39: An isometric view of the CAD simulation of the final geometry.

OTHER SETUPS PROPOSAL:

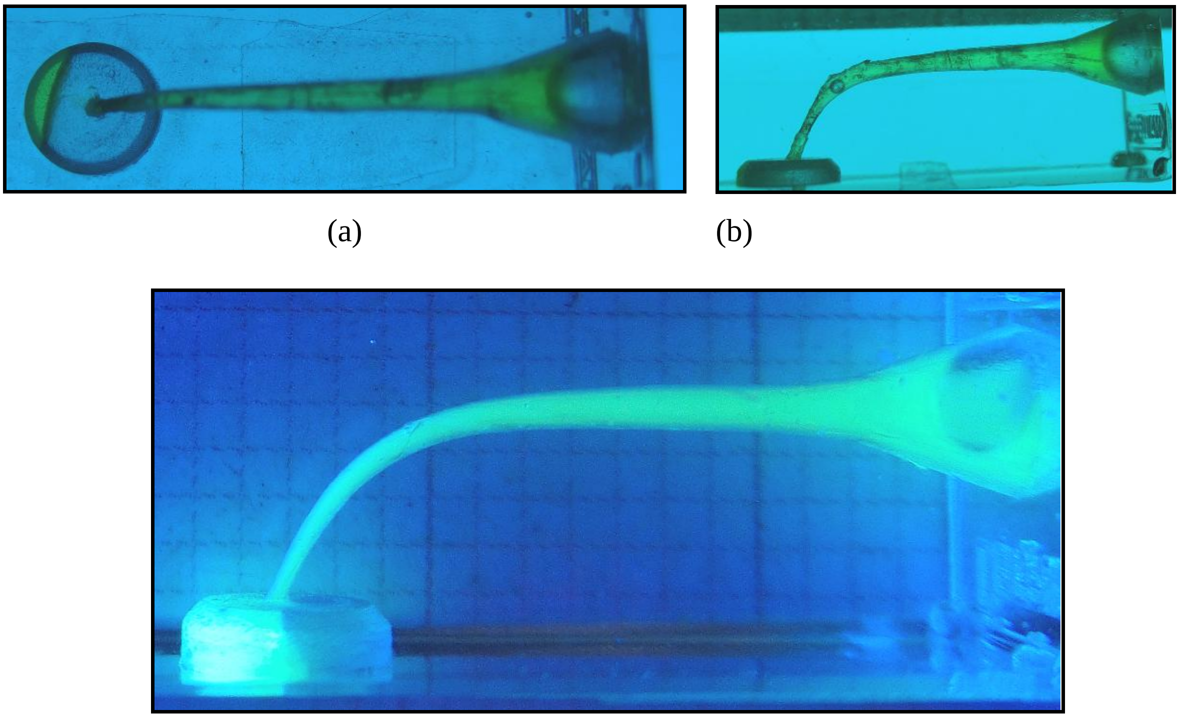
It would be possible to take advantage of the block transparency to obtain the transportation and final shape of the canal. Two projections of the canal should be enough to extract a quasi-3D geometry admitting that the file geometry doesn't originate irregular cross sections. To speed up the evaluation of the canal preparation, an experimental setup using double illumination and double image recording can be foreseen as is presented in (Figure 40).



(a) (b)

Figure 40: A diagram represents a CAD view of one solution for the system assembly, the position of the video cameras and illumination system. On top of the proposed device, shown on the left image the acrylic block is placed using a handle (a,b).

Finally, a new concept for the block illumination is also proposed (Figure 41) by substituting the normal light source by a color LCD. Using different light colors and filling canal with different fluids, it is possible to improve the contrast avoiding the need for image processing.



(a) (b) (c)

Figure 41: Three different high-resolution colors displays LCD within the canals (a-c).

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SIENTIFIC PRODUTION

POSTERS

Poster presented at the Annual Meeting of the Portuguese Society of Endodontologia July- 2014. In Porto "Shaping Ability of Endodontic Rotary Files (literature review)." Ranya Eleman, José A. Capelas.

Poster presented at the 4º Congresso Conjunto das Sociedades Espanhola e Portuguesa de Microscopia "MFS20 September-2015. in Porto "Studying the topographic changes in ProTaper Next endodontic rotary file by Scanning Electron Microscopy (SEM)". Ranya Eleman, José A. Capelas and Manuel F. Vieira

PAPER PUBLICHID

Elemam RF, Capelas JA, Vaz MAP, Viriato N, Pereira ML, Azevedo A, West J. Evaluating Root Canal Transportation After Several uses of PTN File. J Contemp Dent Pract 2015;16(12):1-6.

Elemam RF, Capelas JA, Vaz MAP, Viriato N, Pereira ML, Azevedo A, West J."In vitro evaluation of root canal transportation after use of BT-RaCe files. Rev Port Estom Med Den Cir Maxil.2016

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Elemam RF, Capelas JA,Vieira M. Effect Of Repeated Use On Topographical Features Of Protaper Next Endodontic Rotary File. At The Journal of International Oral Health (JIOH)

PAPERS UNDER REVIEW

Elemam RF, Capelas JA, Vaz MAP, Viriato N, Pereira ML, Azevedo A " In vitro evaluation of root canal transportation after several uses of BT-race and ProTaperNext files". At the Journal of Dentistry of Tehran University of Medical Sciences.

ANNEXES

ANNEX I: FORMULAS

FORMULAS USED TO CALCULATE ROOT CANAL TRANSPORTATION

Gambill's equation where (X1-X2) - (Yl-Y2); X1 represented the shortest distance from the outside of the curved root to the periphery of the un-instrumented canal, Y1 represented the shortest distance from the inside of the curved root to the periphery of the un instrumented canal, X2 represented the shortest distance from the outside of the curved root to the periphery of the instrumented canal, and Y2 represented the shortest distance from the inside of the curved root to the periphery of the instrumented canal.

Garip method where X1-X2/Y1-Y2; Xl=Preoperative distance between canal margin and tooth border on the inner wall of root curvature, X2=postoperative distance between canal margin and tooth border on the inner wall of root curvature, Yl=Preoperative distance between canal margin and tooth border on the outer wall of root curvature, Y2= postoperative distance between canal margin and tooth border on the outer wall of root curvature.

Cunningham’s method : A method to measure the curve that the endodontic instrument must negotiate to reach the apical foramen: Point ” a” was marked at the middle of the file at the level of the canal orifice. A line drawn with a straight edge aligned parallel to the file image from point a to a point where the instrument deviated from the straight edge which is “ point b”. A third point (c) was made at the apical foramen Angle is measured at the intersection of lines a and b and b and c. [(224)]

Schneider’ method: A method to measure the angel of curvature. First line drawing parallel to the long axis of the canal, followed by second line drawn from the apical foramen to intersect with the first at the point where the canal began to leave the long axis of the tooth and the formed acute angle measured by means of a protractor [(225)].

Zang formula: A method used for measuring the centering ratio [(89)]. Where (M1-M2)/(D1-D2). whereas M1, the measurement of the quantity of voxels from the external surface of the mesial portion of the root to the mesial wall of the non-instrumented canal, M2 was the measurement of the quantity of voxels from the external root surface of the mesial portion of the root to the wall of the canal after instrumentation. D1 was the measurement of the quantity of voxels of the external surface of the distal portion of the root to the distal wall of the no instrumented canal. D2 was the measurement of the quantity of voxels from the external surface of the distal portion of the root to the distal surface of the canal after instrumentation.

Calhoun and Montgomery formula where (X1-X2)/Y [90] was also assumed [24, 59] where X1 represents the maximum extent of canal movement in one direction, X2 is the movement in the opposite direction, Y is the diameter of the final canal preparation and lower centering ratio indicating better centering of the instrument in the canal.

ANNEX II: TABLES

TABLES OF THE RESULTS

The amount of resin removed during filing using PTN at all eleven locations in both outer and inner side of the canals in mm are listed in (Table)

Table 9: Amount of resin removed during filing using PTN files in both outer and inner side of the canals walls in mm.

Locations	0 mm		0.5 mm		1 mm		2 mm		3 mm		4 mm		5 mm		6 mm		7 mm		8 mm		9 mm	
B.N	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**
B1	0.02	0.15	0.06	0.08	0.07	0.11	0.08	0.1	0.16	0.11	0.2	0.13	0.29	0.08	0.37	0.07	0.32	0.14	0.3	0.19	0.31	0.31
B2	0.04	0.09	0.06	0.09	0.04	0.1	0.09	0.12	0.13	0.14	0.17	0.17	0.26	0.14	0.33	0.113	0.29	0.18	0.29	0.24	0.28	0.28
B3	0.1	0	0.06	0.07	0.06	0.1	0.09	0.09	0.12	0.13	0.18	0.14	0.28	0.11	0.3	0.14	0.26	0.19	0.3	0.23	0.29	0.25
B4	0.06	0.09	0.06	0.08	0.06	0.11	0.08	0.12	0.13	0.14	0.16	0.14	0.27	0.11	0.29	0.12	0.28	0.21	0.28	0.26	0.27	0.29
B5	0.14	0.07	0.08	0.08	0.08	0.11	0.13	0.13	0.13	0.16	0.18	0.17	0.24	0.12	0.29	0.12	0.25	0.18	0.24	0.21	0.29	0.24
B6	0	0.11	0.05	0.13	0.21	0.05	0.07	0.15	0.23	0.11	0.17	0.19	0.26	0.24	0.28	0.17	0.26	0.25	0.24	0.27	0.33	0.21
B7	0	0.12	0.03	0.12	0.03	0.13	0.07	0.14	0.11	0.16	0.15	0.17	0.25	0.14	0.29	0.14	0.28	0.22	0.26	0.25	0.26	0.27
B8	0.05	0.09	0.05	0.07	0.04	0.09	0.09	0.12	0.12	0.12	0.19	0.14	0.27	0.11	0.36	0.06	0.32	0.15	0.3	0.2	0.28	0.26
B9	0	0.11	0.04	0.09	0.03	0.12	0.04	0.15	0.1	0.19	0.14	0.19	0.2	0.12	0.25	0.15	0.2	0.22	0.2	0.28	0.18	0.31
B10	0.074	0.07	0.05	0.08	0.22	0.06	0.12	0.12	0.23	0.15	0.17	0.17	0.24	0.28	0.34	0.13	0.26	0.31	0.33	0.22	0.3	0.33
B11	0.06	0.09	0.06	0.08	0.06	0.11	0.11	0.12	0.14	0.14	0.18	0.15	0.25	0.13	0.33	0.13	0.3	0.17	0.3	0.22	0.3	0.25
B12	0.07	0.12	0.04	0.13	0.05	0.15	0.08	0.13	0.13	0.16	0.19	0.19	0.25	0.15	0.31	0.16	0.28	0.23	0.29	0.29	0.28	0.29
B13	0	0.16	0.05	0.12	0.04	0.14	0.05	0.14	0.08	0.19	0.13	0.23	0.22	0.17	0.26	0.17	0.23	0.24	0.21	0.3	0.19	0.34
B14	0	0.14	0.04	0.09	0.04	0.09	0.09	0.12	0.13	0.14	0.14	0.18	0.22	0.14	0.3	0.12	0.28	0.2	0.26	0.25	0.25	0.3
B15	0	0.13	0	0.14	0	0.14	0.03	0.16	0.07	0.21	0.1	0.22	0.2	0.19	0.24	0.17	0.21	0.22	0.18	0.27	0.16	0.3
B16	0.08	0.12	0.05	0.12	0.07	0.14	0.08	0.15	0.1	0.2	0.15	0.19	0.24	0.16	0.28	0.2	0.23	0.26	0.23	0.31	0.22	0.34
B17	0.1	0.05	0.05	0.09	0.06	0.11	0.1	0.11	0.12	0.17	0.15	0.16	0.26	0.13	0.33	0.12	0.29	0.18	0.28	0.21	0.26	0.24
B18	0.07	0.1	0.07	0.11	0.06	0.15	0.1	0.14	0.14	0.18	0.19	0.16	0.27	0.13	0.35	0.13	0.31	0.16	0.29	0.21	0.28	0.26

Locations	0 mm		0.5 mm		1 mm		2 mm		3 mm		4 mm		5 mm		6 mm		7 mm		8 mm		9 mm	
B.N	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**
B19	0	0.12	0.04	0.09	0.06	0.09	0.1	0.11	0.13	0.15	0.19	0.12	0.27	0.1	0.32	0.07	0.31	0.16	0.31	0.19	0.29	0.2
B20	0	0.11	0.01	0.09	0	0.1	0.03	0.11	0.08	0.14	0.1	0.14	0.16	0.14	0.22	0.13	0.2	0.2	0.21	0.36	0.19	0.31
B21	0.08	0.04	0.05	0.08	0.02	0.12	0.06	0.14	0.12	0.18	0.16	0.16	0.24	0.14	0.26	0.17	0.26	0.25	0.25	0.29	0.23	0.3
B22	0.09	0.04	0.05	0.08	0.05	0.1	0.08	0.11	0.14	0.16	0.15	0.16	0.24	0.14	0.28	0.13	0.26	0.21	0.26	0.24	0.24	0.27
B23	0.04	0.08	0.06	0.1	0.05	0.11	0.09	0.12	0.14	0.11	0.16	0.16	0.24	0.15	0.31	0.12	0.28	0.19	0.28	0.21	0.27	0.26
B24	0.03	0.1	0.03	0.07	0.05	0.09	0.06	0.11	0.1	0.13	0.17	0.12	0.24	0.07	0.3	0.07	0.26	0.13	0.22	0.21	0.22	0.25
B25	0	0.04	0.05	0.05	0.09	0.08	0.08	0.12	0.12	0.15	0.16	0.16	0.21	0.13	0.32	0.1	0.3	0.16	0.3	0.22	0.28	0.26
B26	0	0.06	0	0.08	0	0.09	0.03	0.12	0.07	0.13	0.06	0.16	0.12	0.16	0.19	0.14	0.21	0.19	0.19	0.24	0.16	0.27
B27	0.06	0.11	0.05	0.11	0.06	0.11	0.09	0.14	0.13	0.15	0.17	0.16	0.24	0.14	0.28	0.16	0.23	0.22	0.24	0.28	0.24	0.31
B28	0.08	0.05	0.08	0.08	0.07	0.11	0.11	0.11	0.13	0.19	0.14	0.17	0.22	0.18	0.28	0.18	0.24	0.25	0.23	0.3	0.23	0.32
B29	0.05	0.12	0.06	0.11	0.06	0.13	0.1	0.15	0.13	0.15	0.17	0.16	0.24	0.15	0.27	0.18	0.24	0.24	0.24	0.29	0.22	0.31
B30																						
B31	0.047	0.13	0.048	0.1	0.04	0.12	0.08	0.14	0.12	0.17	0.16	0.19	0.22	0.14	0.3	0.13	0.26	0.19	0.26	0.25	0.26	0.3
B32	0	0.06	0.03	0.05	0.04	0.06	0.04	0.11	0.06	0.12	0.1	0.14	0.16	0.14	0.22	0.12	0.22	0.18	0.2	0.23	0.2	0.25
B33	0.11	0.05	0.05	0.08	0.06	0.11	0.1	0.14	0.13	0.15	0.17	0.15	0.27	0.14	0.3	0.14	0.26	0.19	0.26	0.23	0.24	0.27
B34	0.07	0.11	0.05	0.1	0.07	0.11	0.11	0.12	0.13	0.14	0.15	0.15	0.25	0.13	0.3	0.15	0.28	0.19	0.27	0.25	0.25	0.27
B35	0.07	0.15	0.05	0.11	0.06	0.13	0.12	0.14	0.14	0.14	0.21	0.13	0.28	0.12	0.31	0.12	0.28	0.2	0.26	0.26	0.21	0.278
B36	0	0.08	0.03	0.08	0.05	0.05	0.05	0.1	0.1	0.1	0.13	0.07	0.2	0.07	0.24	0.08	0.22	0.13	0.21	0.19	0.17	0.216

B.N: Block Number
Inn: canal inner wall surface
Out: canal outer wall surface

Table 10: Transportation of the canal center after instrumentation using PTN file.

Block number	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
B1	-0.06	-0.012	-0.016	-0.0125	0.0275	0.036	0.105	0.1475	0.09	0.0525	0.0465
B2	-0.02	-0.017	-0.03	-0.015	-0.006	0.001	0.058	0.1125	0.055	0.026	0.0035
B3	0.05	-0.008	-0.0235	-0.001	-0.0045	0.0175	0.081	0.081	0.0355	0.035	0.019
B4	-0.01	-0.011	-0.026	-0.017	-0.0035	0.0095	0.078	0.0885	0.035	0.009	-0.0085
B5	0.03	0.0015	-0.015	-0.003	-0.012	0.0045	0.061	0.086	0.032	0.015	0.0245
B6	-0.05	-0.0385	-0.044	-0.0395	-0.024	-0.009	0.045	0.0565	0.0165	-0.013	-0.0465
B7	-0.06	-0.0445	-0.0525	-0.033	-0.0235	-0.0085	0.054	0.077	0.0295	0.005	-0.0085
B8	-0.02	-0.011	-0.023	-0.0145	0.0025	0.0275	0.0765	0.148	0.085	0.048	0.01
B9	-0.05	-0.0255	-0.046	-0.056	-0.0415	-0.0235	0.038	0.051	-0.009	-0.0405	-0.063
B10	-0.001	-0.0185	-0.0305	0.0005	0.0125	0.004	0.07	0.1055	0.076	0.0575	0.043
B11	-0.01	-0.006	-0.0245	-0.0085	-0.0005	0.013	0.0635	0.098	0.062	0.039	0.0245
B12	-0.02	-0.044	-0.052	-0.0285	-0.0145	0.001	0.0495	0.0725	0.0275	0.003	-0.0025
B13	-0.081	-0.037	-0.0505	-0.044	-0.055	-0.048	0.024	0.0455	-0.0065	-0.046	-0.0755
B14	-0.074	-0.0245	-0.026	-0.0175	-0.009	-0.019	0.038	0.0915	0.0395	0.0075	-0.0245
B15	-0.0665	-0.072	-0.074	-0.063	-0.0725	-0.0575	0.003	0.032	-0.0075	-0.0465	-0.074
B16	-0.02	-0.0375	-0.033	-0.039	-0.0515	-0.018	0.0435	0.0385	-0.015	-0.0385	-0.061
B17	0.027	-0.0165	-0.022	-0.005	-0.0245	-0.009	0.0645	0.1075	0.0545	0.0365	0.01
B18	-0.0155	-0.0205	-0.042	-0.0195	-0.0205	0.0125	0.07	0.114	0.0735	0.041	0.01

Block number	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
B19	-0.0635	-0.0255	-0.0125	-0.007	-0.0075	0.0355	0.0845	0.1245	0.0775	0.0625	0.043
B20	-0.057	-0.0515	-0.041	-0.031	-0.021	0.0115	0.045	-0.004	-0.004	-0.076	-0.0635
B21	0.018	-0.0145	-0.05	-0.0365	-0.0285	-0.0005	0.048	0.043	0.006	-0.0165	-0.035
B22	0.023	-0.016	-0.0235	-0.016	-0.0085	-0.004	0.0515	0.0765	0.026	0.0085	-0.014
B23	-0.019	-0.021	-0.0275	-0.017	0.0155	-0.0015	0.0475	0.095	0.0485	0.034	0.0015
B24	-0.036	-0.0185	-0.019	-0.0235	-0.015	0.025	0.082	0.1135	0.065	0.0065	-0.0155
B25	-0.024	-0.003	0.001	-0.02	-0.0145	0.001	0.0415	0.1105	0.0705	0.039	0.0065
B26	-0.033	-0.0495	-0.044	-0.032	-0.051	-0.0185	0.0245	0.0065	-0.024	-0.055	-0.055
B27	-0.0255	-0.0305	-0.029	-0.0235	-0.0125	0.006	0.049	0.06	0.0045	-0.017	-0.035
B28	0.015	-0.0015	-0.0195	-0.0005	-0.027	-0.0135	0.0205	0.048	-0.005	-0.0345	-0.0465
B29	-0.0315	-0.0255	-0.036	-0.028	-0.009	0.005	0.045	0.048	0	-0.0265	-0.044
B30											
B31	-0.0430	-0.0275	-0.0385	-0.0275	-0.024	-0.0125	0.086	0.033	0.0035	-0.0205	-0.0205
B32	-0.034	-0.012	-0.011	-0.035	-0.0285	-0.0205	0.01	0.051	0.0185	-0.013	-0.0245
B33	0.0325	-0.017	-0.025	-0.016	-0.009	0.0085	0.0625	0.0845	0.032	0.0125	-0.013
B34	-0.0195	-0.0205	-0.0225	-0.009	-0.004	0.001	0.0575	0.0755	0.0475	0.0095	-0.0075
B35	-0.0385	-0.03	-0.0335	-0.013	0.0045	0.0375	0.0805	0.0935	0.037	-0.0025	-0.0305
B36	-0.0415	-0.0255	0.0005	-0.026	0.0025	0.026	0.0675	0.08	0.044	0.009	-0.023

Table 11: Amount of resin removed during filing using BT-Race files in both outer and inner side of the canals walls .

BN	0mm		0.5mm		1mm		2mm		3mm		4mm		5mm		6mm		7mm		8mm		9mm	
	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out	Inn	out
B1	0.14	0.18	0.09	0.14	0.09	0.15	0.15	0.12	0.18	0.12	0.23	0.11	0.27	0.10	0.36	0.06	0.32	0.11	0.27	0.18	0.23	0.18
B2	0.12	0.12	0.12	0.13	0.14	0.12	0.18	0.10	0.19	0.13	0.22	0.13	0.28	0.10	0.34	0.08	0.31	0.11	0.24	0.19	0.24	0.21
B3	0.05	0.28	0.09	0.18	0.13	0.15	0.22	0.13	0.26	0.14	0.33	0.14	0.34	0.09	0.39	0.07	0.33	0.11	0.25	0.18	0.22	0.24
B4	0	0.33	0.11	0.20	0.13	0.15	0.19	0.09	0.30	0.10	0.38	0.09	0.36	0.07	0.40	0.06	0.28	0.14	0.20	0.20	0.15	0.30
B5	0	0.20	0.10	0.16	0.12	0.16	0.16	0.13	0.19	0.16	0.25	0.16	0.29	0.14	0.32	0.10	0.25	0.17	0.22	0.27	0.20	0.25
B6	0.06	0.27	0.05	0.18	0.06	0.18	0.12	0.13	0.15	0.15	0.17	0.16	0.21	0.18	0.21	0.17	0.16	0.24	0.11	0.30	0.09	0.33
B7	0.03	0.11	0.10	0.08	0.12	0.09	0.14	0.10	0.16	0.09	0.22	0.11	0.26	0.09	0.24	0.06	0.26	0.10	0.21	0.13	0.19	0.12
B8	0.07	0.23	0.09	0.18	0.09	0.17	0.14	0.15	0.15	0.16	0.20	0.17	0.27	0.14	0.31	0.10	0.27	0.15	0.18	0.24	0.17	0.28
B9	0.04	0.29	0.08	0.19	0.12	0.17	0.17	0.13	0.22	0.17	0.28	0.12	0.32	0.10	0.33	0.12	0.26	0.21	0.23	0.26	0.16	0.31
B10	0	0.22	0.07	0.17	0.08	0.15	0.18	0.07	0.17	0.12	0.20	0.14	0.23	0.15	0.22	0.15	0.19	0.24	0.13	0.30	0.09	0.31
B11	0.06	0.20	0.05	0.19	0.09	0.19	0.14	0.15	0.17	0.15	0.27	0.13	0.29	0.12	0.31	0.12	0.25	0.17	0.18	0.22	0.18	0.27
B12	0.12	0.15	0.10	0.11	0.13	0.10	0.19	0.03	0.22	0.09	0.26	0.10	0.30	0.07	0.30	0.08	0.27	0.13	0.23	0.14	0.26	0.15
B13	0.06	0.31	0.09	0.22	0.11	0.17	0.21	0.12	0.26	0.15	0.31	0.16	0.37	0.11	0.39	0.08	0.34	0.16	0.24	0.19	0.22	0.25
B14	0.06	0.25	0.07	0.22	0.09	0.22	0.15	0.15	0.16	0.18	0.19	0.18	0.24	0.15	0.28	0.12	0.22	0.21	0.17	0.27	0.15	0.30
B15	0.06	0.32	0.08	0.19	0.11	0.17	0.20	0.14	0.26	0.16	0.30	0.12	0.35	0.10	0.37	0.08	0.32	0.16	0.28	0.20	0.26	0.27
B16	0.17	0.14	0.13	0.09	0.10	0.12	0.19	0.08	0.20	0.07	0.25	0.07	0.31	0.06	0.32	0.07	0.28	0.12	0.24	0.16	0.24	0.17
B17	0.10	0.17	0.08	0.15	0.10	0.17	0.18	0.14	0.19	0.13	0.23	0.14	0.25	0.15	0.25	0.15	0.21	0.20	0.20	0.25	0.15	0.27

BN	0mm		0.5mm		1mm		2mm		3mm		4mm		5mm		6mm		7mm		8mm		9mm	
	Inn	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**	**Inn**	**out**
B18	0.06	0.13	0.09	0.12	0.12	0.12	0.19	0.08	0.25	0.09	0.27	0.08	0.30	0.08	0.34	0.08	0.29	0.13	0.28	0.17	0.25	0.18
B19	0.13	0.21	0.13	0.20	0.13	0.18	0.16	0.15	0.21	0.18	0.29	0.15	0.37	0.13	0.46	0.07	0.42	0.10	0.31	0.19	0.26	0.26
B20	0.07	0.23	0.09	0.18	0.10	0.14	0.17	0.11	0.20	0.14	0.27	0.15	0.30	0.12	0.33	0.10	0.26	0.16	0.2	0.22	0.15	0.32
B21	0.04	0.26	0.09	0.15	0.13	0.14	0.19	0.14	0.25	0.15	0.30	0.11	0.33	0.07	0.33	0.05	0.31	0.13	0.28	0.18	0.23	0.17
B22	0	0.5	0	0.33	0.06	0.24	0.19	0.18	0.30	0.18	0.38	0.16	0.35	0.15	0.32	0.15	0.24	0.22	0.18	0.24	0.18	0.31
B23	0	0.21	0.07	0.17	0.08	0.17	0.11	0.16	0.13	0.20	0.16	0.22	0.21	0.21	0.21	0.21	0.18	0.24	0.17	0.26	0.14	0.31
B24	0.12	0.30	0.09	0.20	0.10	0.18	0.20	0.10	0.21	0.15	0.27	0.17	0.30	0.15	0.33	0.14	0.28	0.18	0.25	0.22	0.21	0.27
B25	0.09	0.19	0.06	0.19	0.08	0.20	0.13	0.17	0.15	0.20	0.17	0.23	0.23	0.20	0.27	0.16	0.28	0.18	0.24	0.21	0.20	0.29
B26	0	0.23	0.04	0.14	0.08	0.14	0.13	0.15	0.17	0.16	0.22	0.16	0.24	0.13	0.28	0.12	0.23	0.18	0.17	0.23	0.16	0.26
B27	0	0.28	0.04	0.20	0.06	0.20	0.16	0.15	0.26	0.16	0.34	0.11	0.36	0.10	0.35	0.08	0.29	0.15	0.14	0.21	0.23	0.24
B28	0	0.22	0.07	0.14	0.12	0.16	0.19	0.09	0.25	0.11	0.32	0.12	0.31	0.10	0.35	0.08	0.29	0.17	0.27	0.20	0.26	0.24
B29	0.06	0.25	0.09	0.15	0.07	0.14	0.21	0.10	0.22	0.13	0.28	0.12	0.30	0.10	0.29	0.12	0.25	0.20	0.20	0.23	0.18	0.25
B30	0.04	0.24	0.12	0.18	0.15	0.12	0.17	0.12	0.24	0.15	0.37	0.10	0.34	0.09	0.29	0.12	0.22	0.18	0.19	0.21	0.16	0.26
B31	0.09	0.21	0.04	0.18	0.05	0.18	0.11	0.18	0.11	0.17	0.2	0.17	0.22	0.16	0.33	0.09	0.30	0.11	0.25	0.17	0.23	0.21
B32	0.12	0.13	0.09	0.16	0.08	0.13	0.12	0.11	0.20	0.12	0.23	0.17	0.25	0.15	0.28	0.13	0.25	0.18	0.24	0.20	0.18	0.24
B33	0.17	0.14	0.08	0.17	0.08	0.18	0.10	0.16	0.20	0.13	0.21	0.17	0.28	0.14	0.30	0.09	0.30	0.12	0.27	0.19	0.29	0.24
B34																						
B35	0.08	0.10	0.08	0.13	0.08	0.16	0.13	0.12	0.18	0.10	0.24	0.11	0.28	0.10	0.28	0.10	0.23	0.14	0.21	0.22	0.21	0.21
B36	0.06	0.10	0.08	0.14	0.09	0.16	0.12	0.12	0.18	0.11	0.23	0.13	0.26	0.11	0.27	0.12	0.23	0.15	0.18	0.22	0.17	0.23

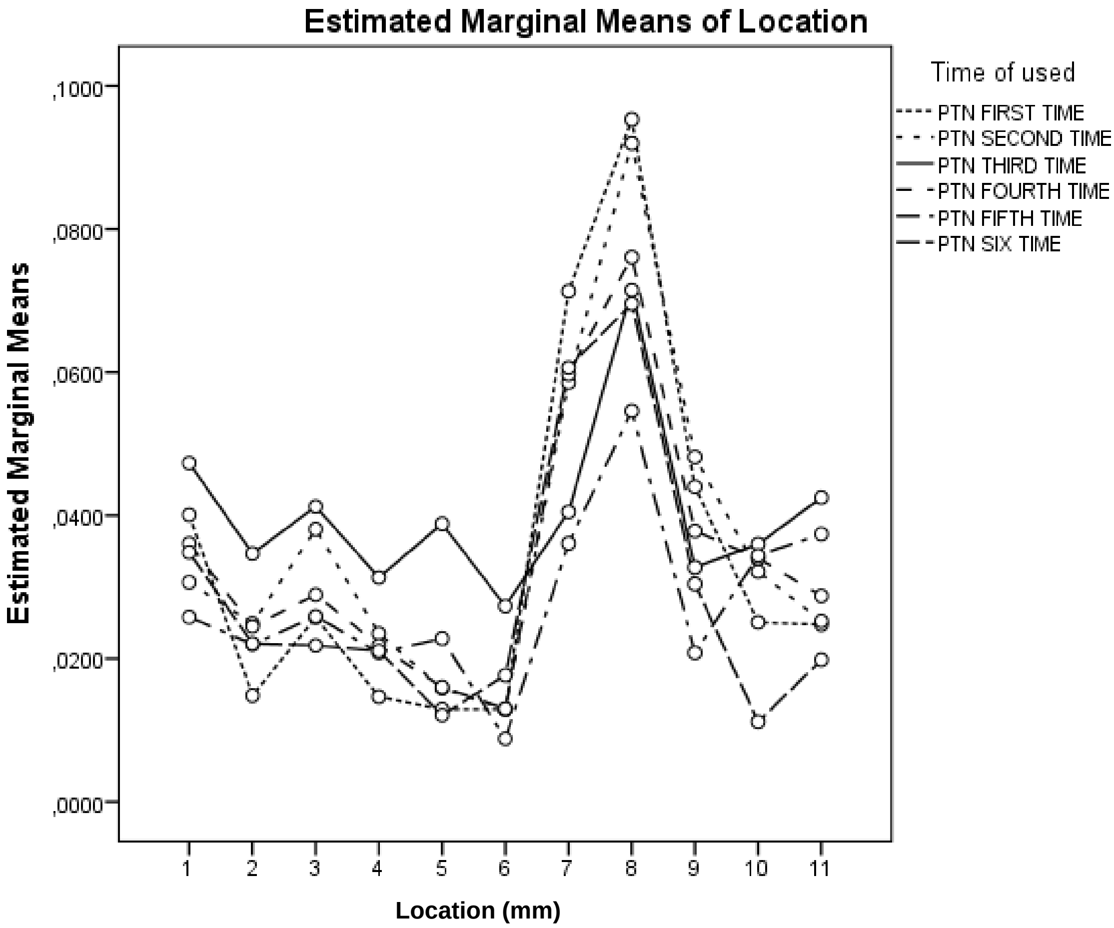
Table 12: Transportation of the canal center induced by BT-Race calculated using the formula.

Block number	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
B1	-0.023	-0.027	-0.028	0.017	0.032	0.058	0.087	0.146	0.106	0.043	0.025
B2	0	-0.0035	0.008	0.0365	0.027	0.0425	0.0885	0.1305	0.1025	0.028	0.011
B3	-0.116	-0.046	-0.01	0.045	0.061	0.092	0.123	0.162	0.109	0.034	-0.008
B4	-0.168	-0.045	-0.01	0.053	0.101	0.145	0.145	0.173	0.071	-0.0005	-0.074
B5	-0.104	-0.029	-0.019	0.019	0.016	0.042	0.073	0.11	0.039	-0.024	-0.022
B6	-0.105	-0.066	-0.059	-0.005	0.003	0.004	0.016	0.017	-0.039	-0.097	-0.12
B7	-0.039	0.011	0.014	0.02	0.034	0.054	0.086	0.0925	0.08	0.041	0.036
B8	-0.08	-0.049	-0.038	-0.004	-0.003	0.017	0.0635	0.104	0.058	-0.029	-0.056
B9	-0.125	-0.054	-0.022	0.019	0.029	0.08	0.1095	0.1055	0.027	-0.013	-0.079
B10	-0.11	-0.049	-0.036	0.052	0.0225	0.032	0.039	0.035	-0.022	-0.086	-0.11
B11	-0.069	-0.069	-0.053	-0.005	0.01	0.07	0.0855	0.094	0.038	-0.021	-0.043
B12	-0.014	-0.004	0.015	0.082	0.066	0.078	0.115	0.11	0.067	0.044	0.053
B13	-0.122	-0.066	-0.029	0.047	0.052	0.078	0.129	0.154	0.087	0.024	-0.015
B14	-0.096	-0.072	-0.066	-0.001	-0.013	0.006	0.044	0.078	0.005	-0.051	-0.075
B15	-0.13	-0.053	-0.0275	0.027	0.05	0.092	0.129	0.143	0.082	0.038	-0.003
B16	0.011	0.018	-0.008	0.0535	0.064	0.0905	0.123	0.125	0.08	0.04	0.035
B17	-0.034	-0.034	-0.033	0.02	0.029	0.0435	0.051	0.052	0.006	-0.028	-0.058
B18	-0.038	-0.016	-0.001	0.056	0.083	0.095	0.111	0.127	0.084	0.055	0.034

Block number	0mm	0.5mm	1mm	2mm	3mm	4mm	5mm	6mm	7mm	8mm	9mm
B19	-0.044	-0.035	-0.023	0.007	0.012	0.072	0.122	0.191	0.156	0.06	-0.0005
B20	-0.0835	-0.045	-0.018	0.029	0.03	0.06	0.092	0.115	0.05	-0.013	-0.085
B21	-0.112	-0.029	-0.006	0.025	0.051	0.099	0.1325	0.139	0.0875	0.0475	0.033
B22	-0.25	-0.167	-0.09	0.005	0.059	0.109	0.1015	0.0875	0.0135	-0.029	-0.066
B23	-0.109	-0.052	-0.042	-0.023	-0.033	-0.031	0.002	-0.0005	-0.029	-0.046	-0.084
B24	-0.09	-0.058	-0.043	0.053	0.0295	0.053	0.072	0.096	0.05	0.013	-0.026
B25	-0.048	-0.066	-0.061	-0.02	-0.027	-0.028	0.014	0.057	0.05	0.0125	-0.045
B26	-0.119	-0.0535	-0.0275	-0.009	0.001	0.0295	0.057	0.082	0.025	-0.031	-0.052
B27	-0.144	-0.077	-0.066	0.006	0.05	0.1145	0.132	0.136	0.069	-0.034	-0.005
B28	-0.113	-0.036	-0.016	0.049	0.071	0.097	0.105	0.134	0.06	0.035	0.009
B29	-0.099	-0.031	-0.037	0.051	0.046	0.079	0.098	0.087	0.024	-0.013	-0.035
B30	-0.1	-0.029	0.012	0.024	0.046	0.133	0.128	0.084	0.022	-0.008	-0.05
B31	-0.061	-0.07	-0.067	-0.036	-0.03	0.011	0.032	0.12	0.095	0.039	0.01
B32	-0.008	-0.038	-0.022	0.005	0.039	0.029	0.051	0.074	0.036	0.021	-0.027
B33	0.013	-0.045	-0.049	-0.027	0.033	0.021	0.069	0.104	0.091	0.039	0.022
B34											
B35	-0.012	-0.027	-0.038	0.004	0.039	0.063	0.087	0.091	0.043	-0.005	-0.002
B36	-0.023	-0.03	-0.037	-0.002	0.037	0.053	0.075	0.078	0.037	-0.02	-0.03

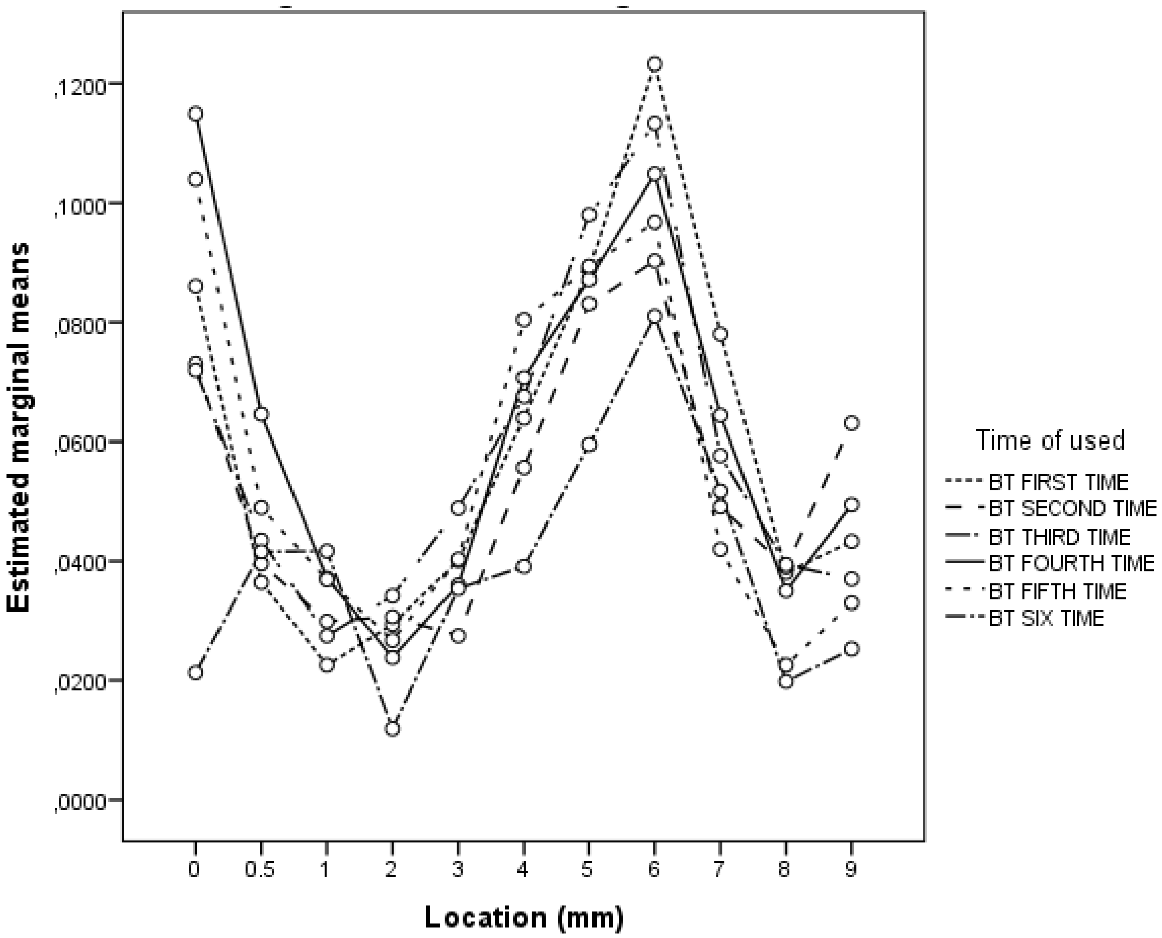
ANNEX III: GRAPHS

GRAPHS OF THE RESULT



Graph 4: Marginal means of transportation dependent on canal location and number of times of PTN files uses.

(**factor 1**: Locations **1**=0mm, **2**=0.05mm, **3**=1mm, **4**=2mm, **5**=3mm, **6**=4mm, **7**=5mm, **8**=6mm, **9**=7mm, **10**=8mm, **11**=9mm)



Graph 5: Marginal means of transportation dependent on canal location and number of times of BTRace files uses.

ANNEX IV: OUTPUT

OUTPUT 1

Descriptive Statistics of the comparison btween the BT-Race and PTN

	Type of file	Time	Mean	Std. Deviation	N
Measure of transportation at apex (0 - 3mm)	BT	Once	,042917	,0217722	6
		Twice	,040133	,0109899	6
		Third	,045200	,0139307	6
		Fourth	,055300	,0308349	6
		Fifth	,051367	,0105107	6
		sixth	,030380	,0091399	5
		Total	,044611	,0185476	35
	PTN	Once	,021650	,0103210	6
		Twice	,026600	,0159902	6
		Third	,038683	,0193311	6
		Fourth	,025467	,0083162	6
		Fifth	,023460	,0120720	5
		sixth	,022385	,0058173	6
		Total	,026457	,0132436	35
	Total	Once	,032283	,0196783	12
		Twice	,033367	,0148685	12
		Third	,041942	,0164211	12
		Fourth	,040383	,0265772	12
		Fifth	,038682	,0180534	11
		sixth	,026019	,0082321	11
		Total	,035534	,0184262	70
Measure of transportation in middle of canal (4 - 6mm)	BT	Once	,092028	,0483564	6
		Twice	,076333	,0246078	6
		Third	,092972	,0366657	6
		Fourth	,087583	,0426787	6
		Fifth	,088833	,0370991	6
		sixth	,059867	,0180629	5
		Total	,083595	,0355963	35

Descriptive Statistics of the comparison btween the BT-Race and PTN

	Type of file	Time	Mean	Std. Deviation	N
	PTN	Once	,059861	,0197215	6
		Twice	,054500	,0170140	6
		Third	,046444	,0143800	6
		Fourth	,049611	,0238909	6
		Fifth	,033167	,0128138	5
		sixth	,049306	,0146281	6
		Total	,049262	,0181407	35
	Total	Once	,075944	,0390110	12
		Twice	,065417	,0231697	12
		Third	,069708	,0359928	12
		Fourth	,068597	,0384789	12
		Fifth	,063530	,0399871	11
		sixth	,054106	,0163682	11
		Total	,066429	,0329468	70
Measure of transportation in coronal of canal (7 - 9mm)	BT	Once	,053139	,0186843	6
		Twice	,050389	,0134832	6
		Third	,044694	,0093068	6
		Fourth	,049611	,0150398	6
		Fifth	,032528	,0054062	6
		sixth	,032267	,0124909	5
		Total	,044100	,0147571	35
	PTN	Once	,031278	,0161161	6
		Twice	,035194	,0188907	6
		Third	,037083	,0073521	6
		Fourth	,033528	,0174246	6
		Fifth	,030867	,0106676	5
		sixth	,020472	,0037319	6
		Total	,031419	,0137429	35
	Total	Once	,042208	,0201763	12
		Twice	,042792	,0175445	12
		Third	,040889	,0089297	12
		Fourth	,041569	,0176457	12
		Fifth	,031773	,0078029	11
		sixth	,025833	,0103591	11
		Total	,037760	,0155292	70