MICRO COMPUTED TOMOGRAPHIC EVALUATION OF CANAL TRANSPORTATION AND CENTERING ABILITY OF PROTAPER UNIVERSAL, HYFLEX EDM AND WAVEONE GOLD - AN INVITRO STUDY

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"MICRO COMPUTED TOMOGRAPHIC EVALUATION OF CANAL TRANSPORTATION AND CENTERING ABILITY OF PROTAPER UNIVERSAL, HYFLEX EDM AND WAVEONE GOLD - AN INVITRO STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. B. VENI ASHOK, M.D.S.,** Professor, Department of Conservative Dentistry and Endodontics, Ragas Dental College and Hospital, Chennai.

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This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY** in partial fulfillment for the degree of **MASTER OF DENTAL SURGERY – CONSERVATIVE DENTISTRY AND ENDODONTICS, BRANCH IV**. It has not been submitted (partial or full) for the award of any other degree or diploma.

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On verification with the urkund.com website for the purpose of plagiarism check, the uploaded thesis file from introduction to conclusion contains **3 percentage** of plagiarism, as per the report generated and it is enclosed in Annexure – II.

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ABBREVIATIONS USED

S.NO	ABBREVIATIONS	
1	NiTi	Nickel Titanium
2	HEDM	Hyflex EDM
3	WOG	WaveOne GOLD
4	PTU	ProTaper Universal
5	NaOCL	Sodium hypochlorite
6	EDTA	Ethylenediamine tetraacetic acid
7	CM	Control memory
8	>	Greater than
9	<	Less than
10	mm	Millimeter
11	Micro-CT	Micro-Computed Tomography
12	#	Size
13	**%**	Percentage
14	EDM	Electric discharge machining
15	CT	Canal transportation
16	CR	Centering ratio

Introduction

INTRODUCTION

Success of endodontics is mainly attributed by the following three basic steps- mechanical preparation, disinfection and a three dimensional obturation of root canal system. Chemomechanical preparation is a critical step in endodontic procedure. The main purpose of root canal instrumentation is to clean and shape the root canal system and to allow the placement of a fluid tight seal, hence influencing the outcome of the treatment.[91]

Schilder emphasized that the root canal should have a continuously tapering conical form, from access cavity till the apex, with the narrowest cross sectional diameter at the apex and the largest at the orifice preserving the apical foramen and not altering the original canal curvature as this is the most appropriate canal shape for irrigation and obturation.[92]

However, these objectives are difficult to achieve because of the highly variable root canal anatomy. Achieving a proper taper in a curved canal becomes difficult as there are chances of canal transportation and loss of centering ability. Excessive dentin removal in single direction within the canal rather than in all directions equidistantly from the main tooth axis causes what is known as canal transportation which is an undesirable deviation from natural canal path and centering ability is the ability of the instrument to stay centered in the canal.[4]

Deviation from the original canal curvature can lead to: [31]

1. Excessive and inappropriate dentin removal.
2. Straightening of the canal and creation of a ledge in the dentinal wall.
3. A defect known as an elbow which forms coronal to the elliptical – shaped apical seal.
4. Canal with hourglass appearance.
5. Over – preparation that weakens the tooth, resulting in fracture of the root.

Traditionally, inflexible stainless steel instruments have been used for root canal instrumentation. But, such instruments have a tendency to cause number of procedural errors like apical transportation, zip and ledge formation can occur along with loss of working length.[3]

To overcome these, significant amount of research have taken place which resulted in the introduction of NiTi instruments by Walia et al. (1988) who employed a nickel–titanium arch wire to fabricate a root canal file. NiTi is well known for its superior characteristics of super elasticity and shape memory.The mechanical properties of NiTi endodontic instruments including flexibility, torsional resistance, and flexural fatigue are fundamental requirements of endodontic instruments for successful outcome. NiTi instruments have progressively undergone several changes over the decades viz geometry designs to enhance the fracture resistance and flexibility. These

NiTi systems differ from one another in the design of cutting blades, taper, tip configuration.[70]

Despite these improvements, file separation during root canal preparation in continuous rotation motion (Barbakow & Lutz1997) is one of main drawback. Although many factors play a role in NiTi file failures, two of the most important reasons are cyclic and torsional fatigue.[82]

Cyclic fatigue failure occurs because of the alternating tension/compression cycles that instruments are subjected to when flexed in the region of maximum curvature of the canal and torsional fatigue occurs in narrow straight canal when file tip binds to the canal and shaft continues to rotate.[88]

To avoid or decrease the incidence of instrument separation newer kinds of NiTi endodontic files fabricated by proprietary thermomechanical processes such as M-wire files, Controlled memory (CM) files , and R-phase wire have been introduced and have shown improved flexibility and cyclic fatigue resistance compared to traditional NITI files like ProTaper Universal.[86]

Several researchers advocated reciprocating motion instead of the continuous rotation motion to increase cyclic fatigue resistance.[52] Reciprocating motion has an advantage for the preparation of curved canal and maintaining the original form of the canal while shaping the root canal.[52] Two of these single-file systems, Reciproc (VDW, Munich, Germany) and WaveOne (WO) (Dentsply Tulsa Dental Specialties, Tulsa, OK), are used in a reciprocating motion and are made of a special NiTi alloy (M-Wire) to increase flexibility and improve cyclic fatigue resistance of the instrument.[48]

Furthermore to increase the durability and strength of the instrument has led to the introduction of novel technologies like Electric discharge machining (EDM) and Gold treatment in endodontic field for the first time.

HyFlex EDM (HEDM; Coltene/Whaledent AG, Altstaetten, Switzerland) is the recently introduced file system in the market which is manufactured by EDM process. The spark erosion caused by this EDM process hardens the surface of NiTi file, which results in superior fracture resistance and improved cutting efficiency. HEDM NiTi files are manufactured from Controlled Memory alloy technology like the HyFlex CM (Coltene/Whaledent AG) NiTi files. HEDM has file shaft with 3 different cross sections: triangular in the coronal third, trapezoidal in the middle third, and almost quadratic in the apical third.[48]

WaveOne GOLD is the first file system to manufacture by GOLD treatment process. WaveOne GOLD (WOG, Dentsply Maillefer) is modified from WaveOne and as same movement kinematics like Wave One, but the cross section of the file has been modified to the parallelogram structure with two cutting edges in order to make the file more flexible. The most importantly WaveOne GOLD is made from GOLD alloy technology, which is based on heating the file and then slowly cooling it whereas WaveOne is made from M-Wire technology involving heat treatment before the production. The manufacturer claims that the flexibility of files is improved through this new heat treatment method.[48]

Shaping ability of endodontic files can be evaluated by various methods such as reassembly technique (Bramante et al. 1987, hulsmann et al 1999, kuttler et al 2001), radiographic comparisons (southward et al. 1987, jardine and gulabivala 2000) and silicone impressions of canals (goldman et al 1989). These methods are limited as they are two dimensional, not accurate and invasive. Newer mode of investigation like Computed tomography, spiral CT AND Cone Beam Computed tomography allow a noninvasive and reproducible three dimensional evaluation of the external and internal morphology of the tooth[67].

Emergence of Micro-computed Tomography (Micro-Ct) has opened up new possibility in the field of endodontics. The micro-CT is a non-destructive and noninvasive method to obtain two- and three-dimensional images. This technology has been widely applied to evaluate root canal anatomy, techniques and materials related to the endodontic treatment. Classic feature of micro-CT is that it allow the use of the same sample for different tests without destruction of the sample which is very important particularly when is required to evaluate volume pre and post instrumentation, quality of root canal obturation or removal of the material from root canal (retreatment) in high resolution than clinical scanners. Other advantages of micro-CT are the possibility of repeated scanning and the manipulation of image using specific software.[40]

The purpose of this invitro study was to evaluate the canal transportation and centering ability of three rotary systems namely ProTaper Universal (full sequence rotary system), Hyflex EDM (continuous rotation motion, control memory wire and EDM technology), and WaveOne GOLD (single file system, reciprocating motion, Gold heat treatment procedure) in the preparation of curved mesial root canals of mandibular molars using micro-CT imaging.

Aim and Objectives

AIM AND OBJECTIVES

AIM:

The aim of the present invitro study was to determine and compare the canal transportation and centering ability of ProTaper Universal, Hyflex EDM and WaveOne GOLD using Micro-CT.

OBJECTIVES:

1. To determine and compare the canal transportation in curved mesiobuccal canal of mandibular first molars of ProTaper Universal, Hyflex EDM and WaveOne GOLD using micro-CT.

2. To determine and compare the centering ability in curved mesiobuccal canal of mandibular first molars of ProTaper Universal, Hyflex EDM and WaveOne GOLD using micro-CT.

Review of Literature

REVIEW OF LITERATURE

Schilder(1974)[92] discussed the cleaning and shaping of root canals in the symposium on endodontics. He suggested that the apical portion of curved canals is best manipulated with in and out strokes of the files that have been precurved to simulate the curve of the root canals. Reaming action in the apical third of curved canals should be avoided as it can cause undesirable reverse flow to that portion, in the canals and tend to cause instrument breakage. He pointed out that a tapering funnel preparation is required for cleaning the root canal system effectively and to permit the compaction of gutta percha with either vertical or lateral forces.

Weine et al (1975)[76] studied the effect of preparation procedures on original canal shape and on apical foramen. Simulated canals in acrylic blocks were used for first time in his study. The study showed that following routine preparation in a curved canal, S shape which was not a tapering funnel from orifice to the apex was produced. Instead the prepared canal funnelled down to a site short of the apex, which they called the elbow, and then widened towards the apex, which was called the zip.

Weine et al (1976)[77] studied the effect of the preparation with hand instrumentation and endodontic hand pieces on original canal shape simulated resin blocks. The more that any instrument was rotated within a canal with a sharp curve near the apex, the greater was the widening of the preparation between the curve and the tip of the preparation. According to them, the canals in resin blocks were exactly the same, though the preparation was not identical to in vivo preparation. Further the study showed that canals with sharp curvatures, mechanical hand pieces and reaming action with hand instruments created wider zips, than hand instrumentation with flaring and removal of flutes.

Gambill JM et al (1996)[20] compared the nickel titanium and stainless steel instrumentation using computed tomography in thirty six single rooted teeth. They found that Ni-Ti instruments used in a reaming technique caused significantly less canal transportation($p< 0.05$), removed significantly less volume of dentin ($p<0.05$), required less instrumentation time ($p<0.05$), and produced more centered and rounder canal preparations than k-flex stainless steel files used in a quarter turn/pull technique.

Wu et al (2000)[78] studied the occurrence of apical transportation (AT) complicating the root filling procedure and resulting in a compromised seal. In part I of their study, human mandibular premolars with single, curved or straight canals were prepared by Lightspeed or a step-back hand filing technique. An AT index was determined using a double exposure radiographic technique. The prepared canals were obturated using lateral condensation of gutta percha. Leakage along the apical 3 mm of root filling was measured with a fluid transport model. After hand filing, AT and perforation occurred in 87% of the curved canals. The AT indices were > or = 0.4 mm. After

Lightspeed preparation, AT occurred in only 19% of the curved canals. The hand filing/curved group leaked statistically significant more than the hand filing/straight and Lightspeed/curved groups ($p = 0.002$). It was concluded that the occurrence of AT was a factor that negatively influences the apical seal when curved canals were obturated by lateral condensation of gutta-percha

Peters OA et al (2001)[53] assessed effects of four Ni–Ti preparation techniques on root canal geometry by using micro computed tomography. It was found that all instrumentation techniques left 35% or more of the canals surface area unchanged.

Peters OA et al (2003)[52] evaluated the performance of ProTaper instruments in shaping root canals of extracted human maxillary molars using micro-CT. Teeth samples were scanned, before and after shaping with ProTaper. Canals were three-dimensionally reconstructed and evaluated for volume, surface area, canal transportation and prepared surface. Authors found that volume and surface area increased significantly and gross preparation errors were found infrequently. Apical canal transportation ranged from 0.02 to 0.40 mm and was independent of canal type and 'wide' canals had a significantly higher ($P < 0.05$) proportion of unprepared surfaces than 'constricted' canals. It was concluded that canals in maxillary molars were prepared invitro using ProTaper instruments without major procedural errors.

Paque et al (2005)[49] evaluated the performance of Endo-Eze Anatomic Endodontic Technology (AET) stainless steel instruments in shaping maxillary molar root canals employing micro-CT. They found that Endo-Eze AET instruments shaped root canals in maxillary molars with substantial canal transportation, particularly in mesiobuccal root canals. Preparation with this instrument removed high volumes of dentine, even though apical preparation was size 30. Based on the results, it was concluded that Endo-Eze AET cannot be recommended for the preparation of teeth with curved root canals.

Javerhi et al (2007)[29] compared the apical transportation and changes in canal curvature of Hero 642, RaCe, and ProTaper in mesiobuccal canals of 60 maxillary first molars using a radiographic platform. Statistically significant difference was found in ProTaper group. They suggested that ProTaper file system should be implemented in combination with other less tapered more flexible systems, like RaCe, in preparing curved canals.

Bonaccorso et al (2008)[7] compared the shaping ability of ProTaper, Mtwo, BioRaCe, and BioRaCe + S-Apex instruments in simulated canals with an S-shaped curvature. It was found that ProTaper instruments caused more pronounced canal transportation in the apical curvature ($P < .01$) than all other instruments. They concluded by saying that NiTi systems including less tapered and more flexible instruments like S-Apex seem to be useful when shaping the curved canals.

Versiani MA et al (2008)[74] evaluated the influence of shaft design on the shaping ability of ProTaper, ProFile, and ProSystem GT rotary instruments in sixty curved mesial canals of mandibular molars. It was concluded that all instruments were able to shape curved mesial canals in mandibular molars to size 30 without significant errors. The differences in shaft designs seemed not to affect their shaping capabilities.

Lopez et al (2008)[38] studied the level of apical transportation in mesiobuccal roots of upper molars after manual instrumentation with stainless steel files, preparation with the K3 system, and with a reciprocating NSK handpiece. They found that the stainless steel file sizes #35 and #40 caused significant apical transportation, and K3 system proved safe for apical preparation, with little deviation.

Vaudt J et al (2009)[72] investigated instrumentation time, working safety and the shaping ability of two rotary nickel– titanium (NiTi) systems (Alpha System and ProTaper Universal) in comparison to stainless steel hand instruments in mesial root canals of mandibular molars. They found that instrumentation time of the Alpha System was significantly reduced compared with ProTaper Universal and hand instrumentation. The Alpha System showed significantly less apical straightening compared with the other instruments. In the apical cross-sections, Alpha System resulted in significantly less uninstrumented canal walls compared with stainless steel files. It was concluded that despite the demonstrated differences between the systems, an apical straightening effect could not be prevented; areas of uninstrumented root canal wall were left in all regions using the various systems.

Yin X et al (2010)[81] assessed the efficacy of ProTaper rotary system and traditional instruments by using micro–computed tomography (micro-CT) in mandibular molars with C-shaped canals. They observed that ProTaper rotary system maintained the canal curvature with few procedural errors, whereas traditional instrumentation can clean more canal surface.

Gergi R et al (2010)[21] compared canal transportation and centering ability of 2 rotary nickel-titanium (NiTi) systems (Twisted Files [TF] and Pathfile-ProTaper [PP]) with conventional stainless steel K-files in ninety root canals with severe curvature and short radius. Amount of transportation and centering ability were assessed. They found that less transportation and better centering ability occurred with TF rotary instruments ($P < .0001$). K-files showed the highest transportation followed by PP system. PP system showed significant transportation when compared with TF ($P < .0001$).

Yang G et al (2011)[79] studied the effects of Mtwo and ProTaper Universal (PTU) on root canal geometry three-dimensionally by using micro–CT in 20 canals. The parameters evaluated were canal surface area, volume, structure model index, thickness, straightening, canal transportation, and uninstrumented surface area. They found that the preparation significantly changed canal surface area, volume, structure model index, thickness, and canal curvature. There was no significant differences between instrument types concerning these parameters and uninstrumented surface area. The canals prepared with PTU showed larger values of transportation compared with those in Mtwo group at the apical third. It was concluded that both of the instrumentation systems produced canal preparations with adequate geometry. PTU produced larger transportation at apical third.

Ounsi HF et al (2011)[46] studied the shaping capacity of NiTi rotary instruments by photographic or micro–computed tomography (micro-CT) measurements. Ten new sets of ProTaper Universal instruments were used in 60 resin blocks simulating curved root canals. Groups 1 to 6 (n = 10) represented the first to sixth use of the instrument, respectively. Digitized images of the prepared blocks were taken in both mesiodistal (MD) and buccolingual (BL) directions and area measurements were calculated using AutoCAD (Autodesk Inc, San Rafael, CA). They found significant differences between groups ($P < .001$). Regarding measurement type, there were no significant differences between BL and MD measurements, but there were significant differences between micro-CT and BL measurements ($P < .001$) and micro-CT and MD measurements($P = .001$). Significant differences were also noted between uses sand concluded that canal preparations are significantly smaller after the third use of the same instrument.

You SY et al (2011)[83] studied the shaping ability of reciprocating motion and continuous rotation motion in curved root canals. The mesiobuccal and distobuccal canals of maxillary molars were instrumented with ProTaper rotary files. The canals in the continuous rotation motion (CM) group were prepared by using continuous rotation with pecking motion, whereas the canals in the reciprocating motion (RM) group were prepared with reciprocating motion (clockwise 140 degrees and counter clockwise 45 degrees).They found that the application of reciprocating motion during instrumentation did not result in increased apical transportation when compared with continuous rotation motion, even in the apical part of curved canals. It was concluded that reciprocating motion might be an attractive alternative method to prevent procedural errors during root canal shaping.

Stern et al (2012)[67] compared the centering ability and the shaping ability of ProTaper (PT) files used in reciprocating motion and PT and Twisted Files (TF) used in continuous rotary motion using micro-computed tomography in sixty mesial canals of thirty mandibular molars. They found no difference in the transportation and centering ratio between the techniques and no significant difference between the times of instrumentation and concluded ProTaper files used in reciprocating motion and PT and TF used in continuous rotary motion were capable of producing centered preparations with no substantial procedural errors.

Pasqualini D et al (2012)[50] compared the ability of manual and mechanical glide path to maintain the original root canal anatomy in first permanent molars using Micro CT. It was confirmed that NiTi rotary PathFile instruments preserve the original canal anatomy and caused less canal aberrations.

Alves Vde et al (2012)[2] evaluated the occurrences of apical transportation and canal aberrations produced with different instruments used to create a glide path in the preparation of curved root canals, namely manual K-files and PathFile and Mtwo nickel-titanium rotary files and concluded that neither the manual instruments nor the PathFile or Mtwo rotary instruments used to create a glide path had any influence on the occurrence of apical transportation or produced any canal aberration.

Zhao D et al (2013)[85] studied the canal shaping properties of Hyflex CM, Twisted Files (TF), and K3 rotary nickel-titanium files by using micro–computed tomography in maxillary first molars. They found that Hyflex CM and TF instruments shaped curved root canals in maxillary first molar without significant shaping errors.

Elsherief et al (2013)[19] compared the effects of ProTaper, Revo-S and Hero Shaper in preparing the curved root canals using cone-beam computed tomography in human mandibular molars. They found that all instruments maintained the original canal curvature well with no significant differences between the different files. It was concluded that all instruments maintained the original canal curvature well and were safe to use. Areas of uninstrumented root canal wall were left in all regions using the various systems.

Talati A et al (2013)[69] compared the shaping ability of Mtwo, RaCe and Medin rotary instruments during the preparation of curved root canals in Sixty mesiobuccal root canals of mandibular molars using pre- and post-instrumentation radiographs, the straightening of the canal and the apical transportation were determined with AutoCAD software. It was found that Mtwo instruments to be superior to the other rotary instruments.

Kumar B S et al (2013)[33] compared canal transportation and centering ability of Twisted and Hyflex Rotary Files with stainless steel hand k-flexofiles by using Spiral Computed Tomography in 90 extracted human mandibular single rooted Premolar teeth. All the teeth were scanned before and after instrumentation by using Spiral Computed Tomography. K-files showed highest transportation and less centered when compared to the Twisted and Hyflex rotary files. No significant difference was found between TF and Hyflex CM instruments.

Maitin et al (2013)[41] analysed the shaping ability of protaper, k3, RaCe and Mtwo using spiral computed tomography (CT) in eighty freshly extracted human mandibular first molars. They found that canals prepared with ProTaper had more canal transportation at all the three levels of root canal (coronal, middle and apical third). Canals prepared with Mtwo were well centered at coronal and middle third whereas, with RaCe canals were centered only at the apical third.

Capar et al (2014)[10] compared the effects of OneShape, ProTaper Universal F2, ProTaper Next X2, Reciproc (R), Twisted File Adaptive (TFA), and WaveOne primary rotary systems on transportation, canal curvature, centering ratio, surface area, and volumetric changes of curved mesial root canals of mandibular molar via cone-beam computed tomographic (CBCT) imaging. They found that the 6 different file systems straightened root canal curvature similarly and produced similar canal transportation in the preparation of mesial canals of mandibular molars. Reciproc instrumentation exhibited superior performance compared with the OS, TFA, and PU systems with respect to volumetric change.

Nazari Moghadam et al (2014)[43] studied the canal transportation and centering ability of Twisted File (TF) to that of Reciproc system using CBCT and found that both file systems were able to keep the original curvature of the canal and thus can be considered safe for clinical application.

Elnaghy AM et al (2014)[18] evaluated and compared the volume of removed dentin, transportation, and centering ability of ProTaper Next (PTN) system with and without glide path preparation by using cone beam computed tomography (CBCT) imaging. They found that there was no significant difference among the tested groups regarding the volume of removed dentin and centering ratio. It was concluded that PG/PTN instrumentation method revealed better performance with fewer canal aberrations when compared with instrumentation performed with PF/PTN or PTN only.

Zhao D et al (2014)[84] studied the canal shaping properties of ProTaper Next, ProTaper Universal, and WaveOne in mandibular first molars by using micro–computed tomographic (micro-CT) scanning. Canals were prepared with PTU, PTN, and WaveOne systems under hypochlorite irrigation. The volume of the untreated canal; the volume of dentin removed after preparation; the amount of the uninstrumented area; and the transportation to the coronal, middle, and apical thirds of canals were measured. They found that PTN, PTU, and WaveOne instruments shaped root canals in mandibular first molars without significant shaping errors. The curved canals prepared using PTN had less apical transportation than the canals prepared using WaveOne and PTU.

Hwang YH et al (2014)[26] compared the shaping ability of Mtwo, a conventional nickel-titanium file system, and Reciproc, a reciprocating file system. Root canal shaping was performed on the mesiobuccal and distobuccal canals of extracted maxillary molars. In the RR group (n = 15), Reciproc was used in a reciprocating motion; in the MR group, Mtwo was used in a reciprocating motion; and in the MC group, Mtwo was used in a continuous rotating motion. Micro–computed tomographic images taken before and after canal shaping were used to analyse canal volume change and the degree of transportation at the cervical, middle, and apical levels. The time required for canal shaping was recorded. It was concluded that in terms of shaping ability, Mtwo used in a reciprocating motion was not significantly different from the Reciproc system.

Reddy PJ et al (2014)[55] compared the shaping ability of two different rotary Nickel –Titanium (Ni-Ti) files, One shape file and Twisted files in a simulated artificial canals. It was found that the twisted files shaped the canals better than one shape file.

Saber et al (2015)[57] compared the shaping ability of ProTaper Next, iRaCe and Hyflex CM rotary NiTi files during the preparation of severely curved root canals in extracted human molar teeth. They found that use of PTN resulted in significantly greater canal straightening than IR and HF($P < 0.05$), with no significant differences between IR and HF ($P > 0.05$). There were no significant differences between the three groups with respect to apical transportation ($P > 0.05$). IR and HF were significantly faster than PTN ($P < 0.05$), with no significant differences between IR and HF ($P > 0.05$). It was concluded that all three files were safe to use in curved canals.

Burklein et al (2015)[8] compared the shaping ability of Mtwo, ProTaper Universal, ProTaper NEXT and BT-RaCe instruments during the preparation of curved root canals in extracted teeth. Using pre- and post-instrumentation radiographs, straightening of the canal curvatures and canal transportation were determined with a computer image analysis programme. Preparation time and instrument failures were also recorded. It was found that all instruments maintained root canal curvature well and were safe. However, care should be taken when using the BT-RaCe instrument due to its unique cylindrical design.

Marceliano-Alves et al (2015)[42] investigated the changes in three-dimensional geometry and the centering ability of root canals prepared with Reciproc, WaveOne, Twisted File and HyFlex CM systems using Micro-computed tomographic imaging technology in mesial canals of mandibular molars. They found that Twisted File and HyFlex CM systems were able to maintain the original canal anatomy with less canal transportation than Reciproc and WaveOne; however, these differences were unlikely to be of clinical significance.

Deepak J et al (2015)[16] compared the effects of fifth generation rotary systems [OneShape (OS), ProTaper Next (PTN), Revo S (RS)] on canal curvature, transportation and centering ratio of curved mesial root canals of mandibular molar via cone-beam computed tomographic (CBCT) imaging. They found that all file systems that were used, straightened the root canal curvature similarly. RS instrumentation exhibited superior performance compared with the OS and PTN systems with respect to transportation and centering ratio.

Hiran-us et al (2015)[22] studied the shaping ability of ProTaper Universal, ProTaper NEXT and iRace endodontic file systems by comparing three parameters: canal deviation, apical foramen position and instrumentation time. Pre- and post-operative images were superimposed to determine any canal deviation or change in apical foramen position. The instrumentation times were recorded. They found that iRace system resulted in the least mean canal deviation and the iRace system also required the least instrumentation time. The iRace system demonstrated the most favourable shaping ability in all three parameters.

Agarwal RS et al (2015)[1] compared the canal transportation, centering ability, and the time taken for preparation of curved root canals after instrumentation with One Shape and Wave One using cone-beam computed tomography (CBCT) in sixty mesiobuccal canals of mandibular molars. They found that there was minor difference between the tested groups. Single file systems demonstrated average canal transportation and centering ability comparable to full sequence Protaper system in curved root canals.

Uzunoglu E et al (2015)[71] studied apical transportation and centering ratios in curved root canals, which were instrumented with ProTaper Next up to size X3 and with OS up to OSA 1 in forty-eight mesial canals of mandibular molars. Apical transportation was assessed pre- and post-instrumentation using cone-beam computed tomographic (CBCT) scans of 1, 2, 3, 4, and 5 mm sections. No significant difference was found between the file systems regarding apical transportation and centering ratio values ($p > 0.05$). Transportation in the mesial direction was greater than the distal transportation for both file systems.

Stavileci M et al (2015)[66] evaluated and compared the root canal shaping efficacy of ProTaper rotary files and standard stainless steel K-files using micro-computed tomography in sixty extracted upper second premolars. They found that neither the manual nor the rotary techniques completely prepared the root canal and both the techniques caused slight straightening of the root canal.

Silva L et al (2016)[64] evaluated canal transportation and centering ability of ProTaper Next (PTN) and Twisted File Adaptive (TFA) systems using micro-computed tomographic (micro-CT) imaging. They found that the root canals prepared with either PTN or TFA systems had similar canal transportation and centering ratios at all levels ($P > 0.05$) and concluded that PTN and TFA had similar results regarding canal transportation and centering ability.

Coelho MS et al (2016)[13] evaluated the effects of establishing glide path on the centering ability and the preparation time of WaveOne and Reciproc in mesial root canals of mandibular molars. It was found that the preparation in groups without glide paths was swifter than the other groups (P=0.001). However, no difference was observed regarding centering ability. They concluded that establishing a glide path increased the total instrumentation time for preparing curved canals with WaveOne and Reciproc instruments. Glide path had no influence on the centering ability of these systems.

Shivashankar MB et al (2016)[62] compared the canal transportation and volumetric changes in the root canal dentin among Mtwo, ProTaper (PT) and ProTaper Next(PTN) file system using Computed Tomography (CT) in 45 mesiobuccal root canals of extracted first molar teeth. They found that all the three file systems tested in the study presented similar behavior with respect to the root canal transportation. Lesser canal transportation was recorded in Mtwo. But no statistically significant difference was seen in terms of canal transportation and volume of dentin removed between all three rotary systems ($p>0.05$).

Silva EJ et al (2016)[64] compared canal transportation in simulated curved canals prepared with ProTaper Universal and ProTaper Gold systems.

They found that PTG system produced overall less canal transportation in the curved portion when compared to PTU system.

Da Silva et al (2016)[15] compared the shaping ability of Bio- Race and ProTaper Next during the preparation of curved root canals in mandibular molars using micro–computed tomographic imaging. The percentage of dentin removed after preparation, root canal volume increase, untreated canal walls, structure model index, degree of canal transportation, and centering ability were measured. It was observed that instrumentation of moderately curved mesial roots with 2 independent root canals and foramina using the BR and PTN rotary file systems were equally effective. Both instrumentation systems caused negligible procedural errors with minimal apical transportation.

Santa-Rosa et al (2016)[59] evaluated the preparation of mesiobuccal (MB) root canals of maxillary molars with severe curvatures using WaveOne with reciprocating motion and OneShape with rotary movement, using micro-computed tomography (micro-CT). The shaping ability and amount of canal transportation were assessed by a comparison of the pre- and post-instrumentation micro-CT scans. He concluded that WaveOne and One Shape single-file systems were able to shape curved root canals, producing minor changes in the canal curvature.

Jardine AP et al (2016)[28] compared apical transportation, centering ratio during root canal preparation with Wizard Navigator (WN), WaveOne (WO), ProTaper Universal (PT) in mesiobuccal roots of maxillary molars using micro-computed tomography. They observed That WN, WO, and PT groups had a similar centering ratio without procedural errors or significant structural changes. At 5 mm from the apex, the WO group showed the largest canal transportation towards the furcation and the root canal preparation was faster than in the WN and PT groups.

Saberi et al (2017)[58] compared the centring ability and transportation of ProTaper Next (PTN), ProTaper Universal (PTU), Race 123 and RevoS using micro-computed tomography in mesial root canals of mandibular molars. They observed that ProTaper Next prepared more centred root canal shapes when compared with Race, PTU and RevoS. In the coronal and middle third of the root canals, the differences in centring between PTN and PTU/RevoS were significant. PTN root canal preparations were more centred than those achieved with all other instruments in the apical third.

Venino PM et al (2017)[73] studied the shaping ability of ProTaper Next (PTN) and the novel HyFlex EDM (HEDM) instruments by means of micro–computed tomography imaging in forty teeth. Root canal transportation and centering ratio were evaluated in mesiodistal and buccolingual directions at 5 levels. They found that HEDM and PTN files were similarly effective, and both safely prepared the root canals, respecting their original anatomies. HEDM files performed better in terms of buccolingual canal transportation and centering ratio at the section between the middle and coronal thirds.

Ozyurek T et al (2017)[48] compared the shaping ability of Reciproc, HyFlex EDM and WaveOne GOLD nickel-titanium (NiTi) files made of different NiTi alloys in S-shaped simulated canal and found that all of the tested NiTi files caused various levels of resin removal. WOG and HEDM NiTi files were found to cause a lower level of resin removal than RPC NiTi files.

Shreya gill et al (2017)[63] compared canal transportation and centering ability of Rotary Hyflex CM, WaveOne, Twisted files using Cone Beam Computed Tomography (CBCT) in curved mesiobuccal roots of maxillary molars. They found that Hyflex CM files maintaining the canal curvature with minimal deviation when compared to WaveOne and twisted files.

Materials and Methods

MATERIALS AND METHOD

ARMAMENTARIUM

- Sixty extracted mandibular molar teeth
- Diamond disc
- Straight hand piece (NSK, Japan)
- K –files no 10, 15 and 20 (MANI,INC)
- ProTaper Universal (DentsplyMaillefer, Ballaigues, Switzerland)
- Hyflex EDM (Coltene/Whaledent, Switzerland)
- WaveOne Gold (DentsplyMaillefer, Ballaigues, Switzerland)
- Endo Bloc (DentsplyMaillefer, Switzerland)
- 2.5% sodium hypochloride irrigating solution (Prime Dental Products P Ltd)
- 17% EDTA (RC HELP, Prime Dental Products P Ltd)
- Normal Saline (Eurolife healthcare Pvt. Ltd)
- Polyether impression material (Aquasil, DentsplyMaillefer)
- Custom made epoxy resin holder
- Endodontic motor (X-smart^{TM}plus, Dentsply Tulsa Dental,Tulsa,OK)
- Micro-CT (Bruker micro-CT skyscan 1176 DST- Nano Mission SR/ NM/ NS -1095/ 2012)

SAMPLE COLLECTION

Human mandibular molars extracted for various reasons unrelated to the study were collected for the study. All the teeth were cleaned, disinfected and stored in saline at 4ºC until use.

INCLUSION CRITERIA

Mandibular molars with fully formed apex having two separate mesial canals and apical foramen were included.

EXCLUSION CRITERIA

Teeth with root caries, open/immature apices, previous endodontic manipulation, calcifications, external resorption, dilacerations, anastomosis between canals and C-shaped canals were excluded.

SAMPLE SIZE

Sixty human mandibular molar roots were selected from the pool of collected samples which met the inclusion and exclusion criteria.

PREPARATION OF THE SPECIMENS

To standardize canal instrumentation, diamond disc with water coolant was used to decoronate all the teeth at cemento-enamel junction. Then the distal roots were separated leaving the mesial roots of mandibular molars with approximately 12±1mm in length preventing the introduction of confounding variables. Only the mesiobuccal canals were taken for instrumentation. Glide path was created with size #10 K files using 2.5% sodium hypochlorite and 17% EDTA as an irrigants. Working length was established by advancing file into canal until just visible at the apical foramen and then subtracting 1 mm from it.

Preoperative operative scanning of samples were done using Micro-CT. Then, sixty extracted teeth were divided into three instrumentation group as Group1 (Protaper Universal), Group 2 (Hyflex EDM) and group 3 (WaveOne GOLD) with twenty teeth each (n= 20). Thin layer of polyether impression material was used to coat the roots to simulate the periodontal ligament and were placed in acrylic resin holder which steamlines the core registration process.

All groups, were first enlarged to a size 20 K- file following which, they were subjected to instrumentation: Rotary files in Group 1 and 2, reciprocating files in group 3. Each instrument was used to prepare only four canals. Rotary and reciprocating instruments were used in rotation with a 6:1 reduction hand piece powered by a torque- limited endo motor (X-smart^{TM}plus, Dentsply Tulsa Dental). For each file, the individual torque limit and rotational speed recommended by the manufacturer were used. Reciprocating files were used in a reciprocating working motion generated by the motor. Canals were prepared according to the following protocol.

GROUP 1 (N=20): PROTAPER UNIVERSAL (PTU)

ProTaper rotary files were used at 300 rpm speed, 1.8 – 2.2 Ncm torque to prepare the canals. Sx used to enlarge the coronal portion of the canal, S1and S2 were used to shape middle third and F1, F2 were used to shape till working length.

In each group, 2.5% sodium hypochlorite and 17% EDTA was used as irrigant. After preparation, final irrigation was done with normal saline.

GROUP 2 (N=20): HYFLEX EDM

The instrumentation of root canal was done with the pecking motion. Files were used at 500 rpm and 2.5Ncm, with slightly apical pressure and brushing motion. The operative sequence was size 25, .12 taper (orifice opener) at two-third of the WL; size 10, .05 taper (glide path file); and size 25, .08 taper (one-file) till WL.

GROUP 3 (N=20): WAVEONE GOLD (WOG)

The primary reciprocating WaveOne gold file with size #25 and taper of .07 was used in the " WaveOne ALL" mode by the endomotor. The files are used with brushing action and a gentle inward 'stroking' motion of short 2–3mm amplitude with minimum apical pressure at 350 rpm.

MICRO- COMPUTERTOMOGRAPHY SCANNING

Samples were individually embedded in high-precision impression material with orifice facing down for precise repositioning during the acquisition of pre- and post-operative scans. Group of five mesial roots were positioned in a sample holder and were brought to carbon fiber bed of the micro-CT scanner (SkyScan 1174v2: Bruker micro-CT, Kontich, Belgium). Samples were scanned at 50 kV and 800 mA and an isotropic resolution of 19.6 micrometer. The long axes of the mesial roots were adjusted to be perpendicular to the beam to provide scans in the same sagittal positions. Then, these roots were scanned at 360 degree rotation around the vertical axis, camera exposure time of 7000 milliseconds. X-rays were filtered with a 1-mm-thick aluminum filter. the Acquired Images were reconstructed into cross sectional slices with NRecon v.1.6.9 software (Bruker micro-CT) using 15% beam hardening and ring artefact correction 5 % and similar contrast limit, resulting in the acquisition of 700 to 900 (pixel size 18 micron) transverse cross-sections per tooth.

EVALUATION METHODOLOGY

The recorded images were processed using CTAn v.1.14.4 software (Bruker micro-CT) to calculate quantitative parameters and construct visual 3D models. The volume of interest for each specimen, extending from the furcation region to the apex of the mesial root, was set by integrating regions of interest in all of the cross sections. The gray scale range was required to recognize the dentin before and after instrumentation was determined by using a density histogram with the global threshold method. Comparisons between the original segmented scan were performed to ensure the accuracy of the segmentation. Task lists were applied to generate separated binary images of the root canal space and dentin using a custom-processing tool.

ROOT CANAL TRANSPORTATION ANALYSIS

For root canal transportation analysis, axial sections corresponding to distances of 3, 6, and 9mm from the anatomic apex were selected. Canal transportation was calculated in millimetres using the formula

([X1-X2]-[Y1-Y2]) as described by **Gambill et al**

Where, X1 is the shortest distance between the mesial portions of the root and uninstrumented canal,

X2 is the shortest distance between the mesial portions of the root and instrumented canal, Y1 is the shortest distance between the distal portions of the root and uninstrumented canal,

And Y2 is the shortest distance between the distal portions of the root and instrumented canal.

According to this formula,

A result of 0 indicated no canal transportation.

A positive result indicated transportation away from the furcation.

And a negative result indicated transportation toward the furcation.

CENTERING ABILITY

It was calculated for each cross section using the values obtained in the assessment of root canal transportation with the ratio of (X1-X2) to (Y1-Y2). If these numbers were not equal, then the lower figure was considered to be the numerator of the ratio. According to this formula, a result of 1 indicated the optimal centering ability and closer the result to zero the worse the ability of the instrument to keep itself in canal central axis. The data obtained was subjected to statistical analysis.

METHODOLOGY - FLOWCHART

60 mandibular molar teeth with mature apices and separate roots were selected

▼

Teeth decoronated at the level of CEJ and distal roots were separated leaving mesial roots approximately 12±1mm in length

▼

WL was established with a size 15 k-file by withdrawing 1mm when the tip of the instrument was seen through the major foramen

▼

Pre-operative scanning of samples was done using micro-CT and images were reconstructed using NRecon sotware

▼

60 Samples were divided into three groups (n=20)

▼

GROUP 1	GROUP 2	GROUP 3
PTU	HEDM	WOG

▼

Instrumentation of mesiobuccal canal was done with each system (2.5%NaOCl and 17% EDTA was used as irrigant during instrumentation)

▼

Post-operative scanning of samples was done using Micro-CT and images were reconstructed using NRecon software

▼

Reconstructed images were processed using CTAn v.1.14.4 software

▼

The shortest distance from the canal wall to the external root surface was measured in the mesio-distal direction at 3mm, 6mm and 9mm from the apex was obtained from axial section of images.

▼

Canal transportation and Centering ratio was calculated based on the formula given by Gambill et al

Figures

FIGURE 1: EXTRACTED MANDIBULAR MOLAR TEETH

FIGURE 2: DECORONATED MANDIBULAR MESIAL ROOTS

FIGURE 3: MESIAL ROOTS EMBEDDED IN FABRICATED ACRYLIC BLOCKS

FIGURE 4: FILES AND ENDOBLOCS

FIGURE 5: IRRIGANTS USED

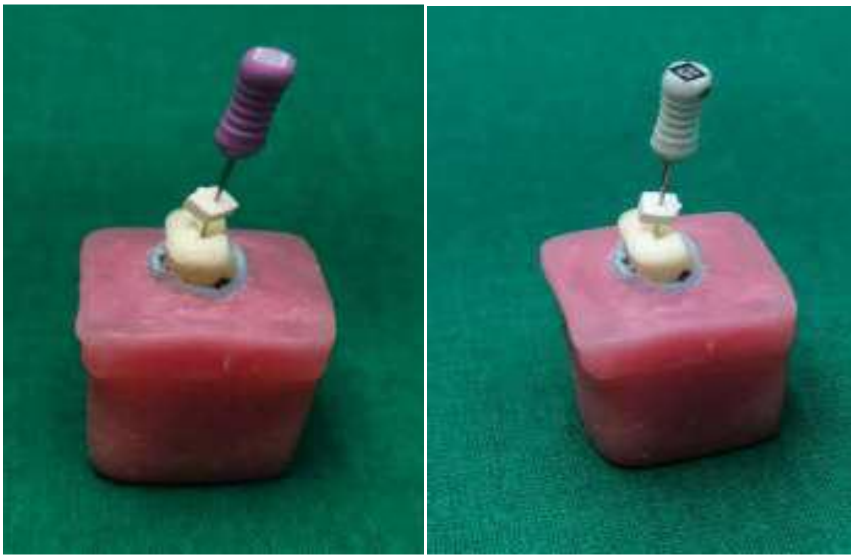


FIGURE 6: PATENCY WITH 10# K FILE, CANAL ENLARGEMENT WITH 15# K FILE

FIGURE 7: X SMART PLUS ENDOMOTOR

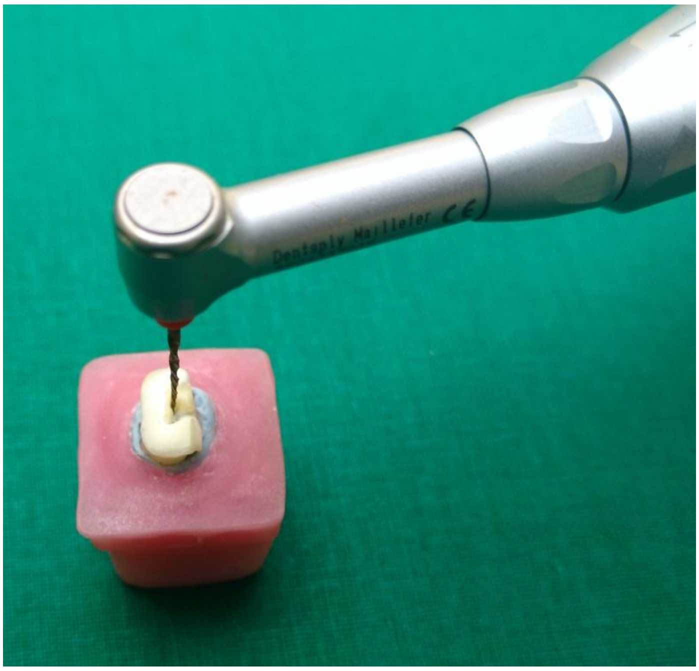


FIGURE 8: INSTRUMENTATION WITH FILES

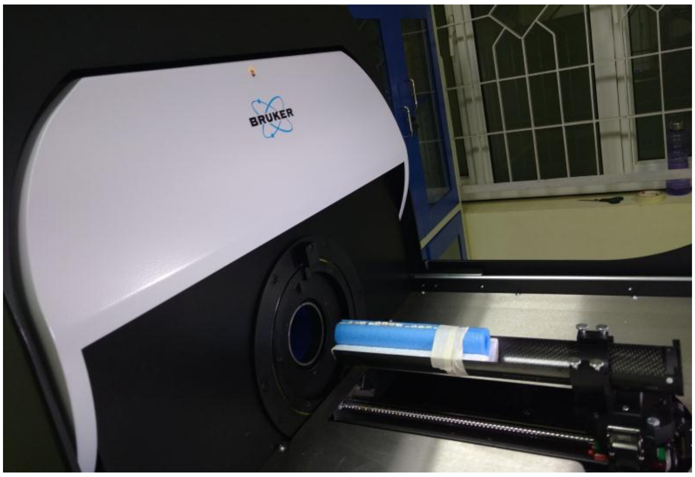
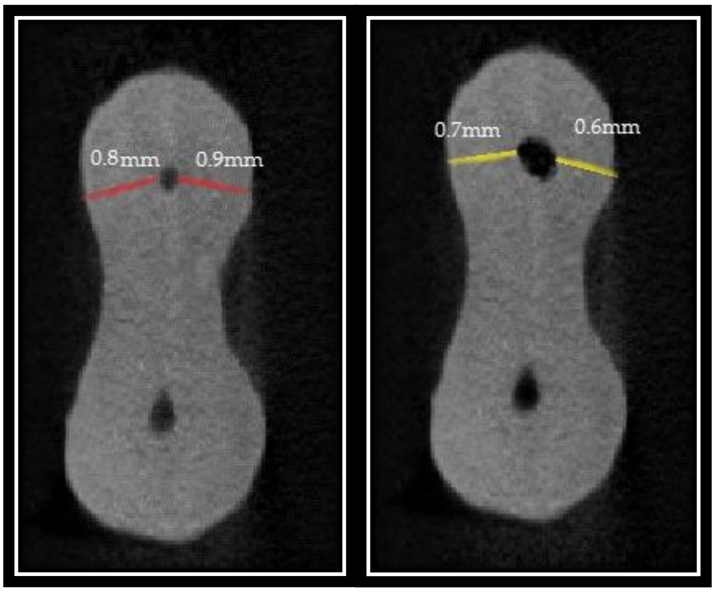
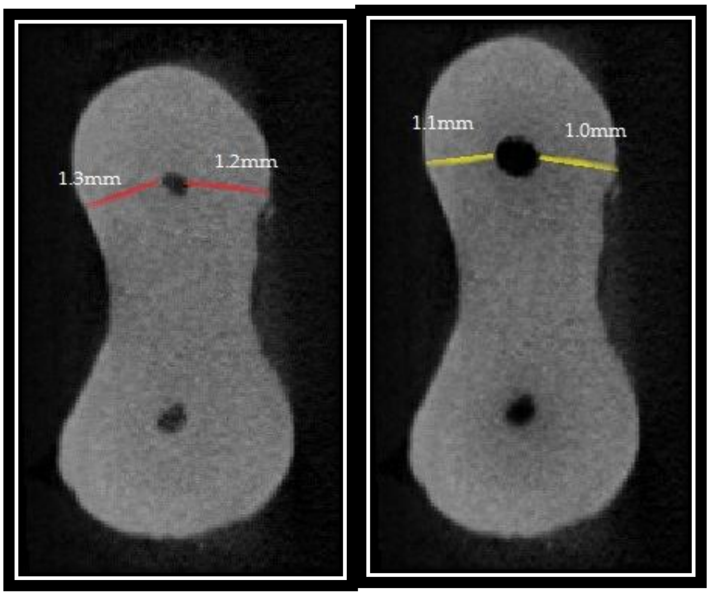


FIGURE 9: BRUKER MICRO-CT



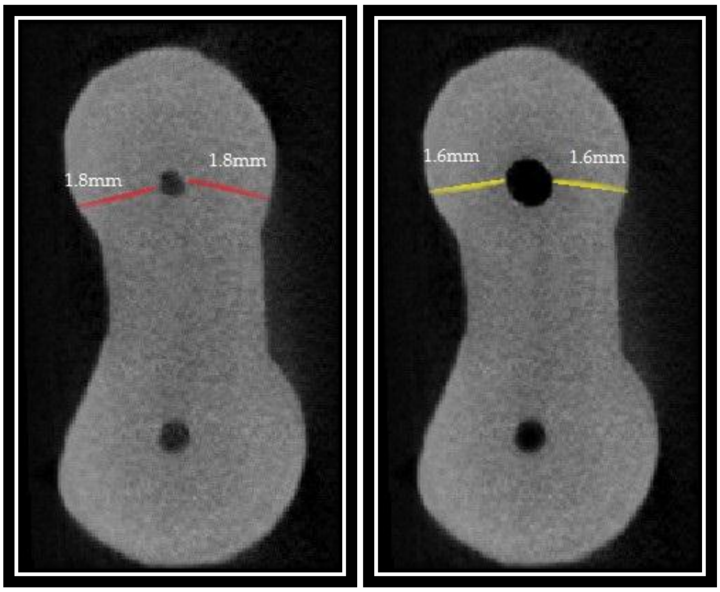
Pre-instrumentation Post-instrumentation

FIGURE 10: MICRO-CT IMAGE AT 3MM FROM APEX PTU GROUP



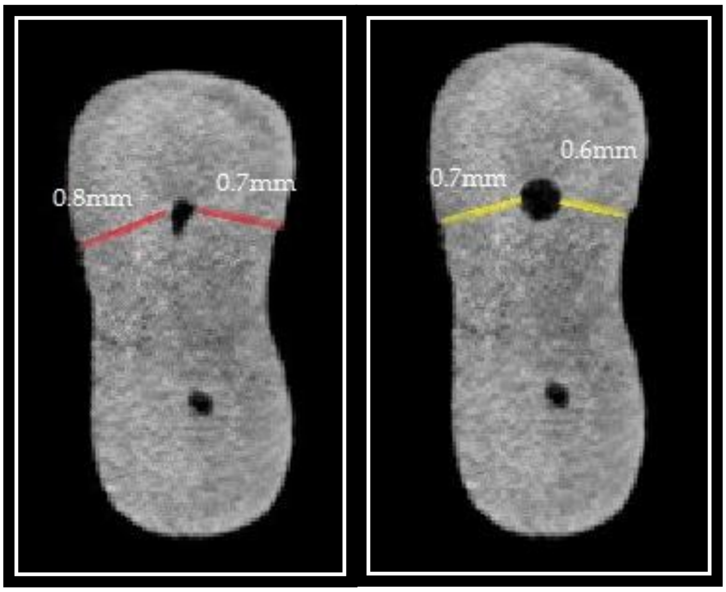
Pre-instrumentation Post-instrumentation

FIGURE 11: MICRO-CT IMAGE AT 6MM FROM APEX PTU GROUP



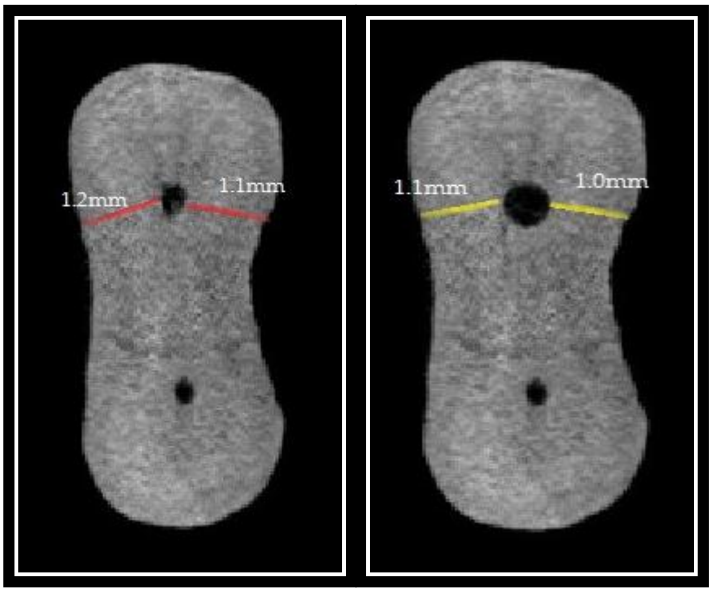
Pre-instrumentation   Post-instrumentation

FIGURE 12: MICRO-CT IMAGE AT 9MM FROM APEX PTU GROUP



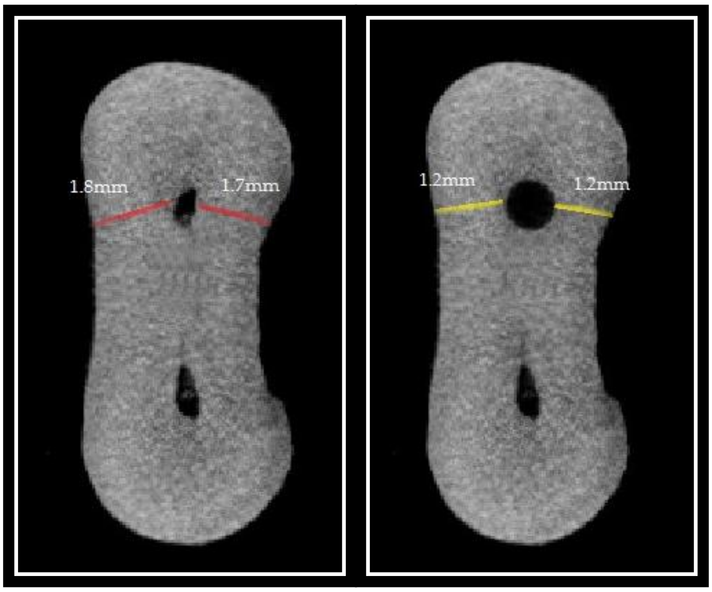
Pre-instrumentation   Post-instrumentation

FIGURE 13: MICRO-CT IMAGE AT 3MM FROM APEX HEDM GROUP



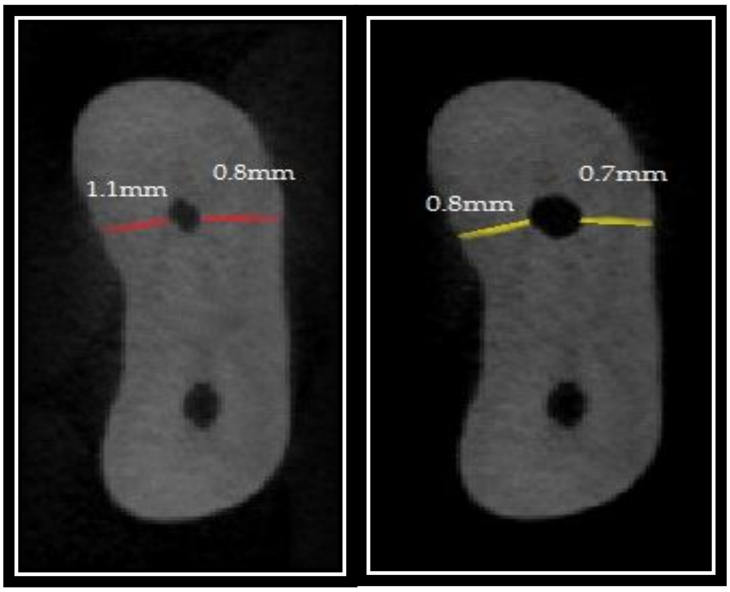
Pre-instrumentation Post-instrumentation

FIGURE 14: MICRO-CT IMAGE AT 6MM FROM APEX HEDM GROUP



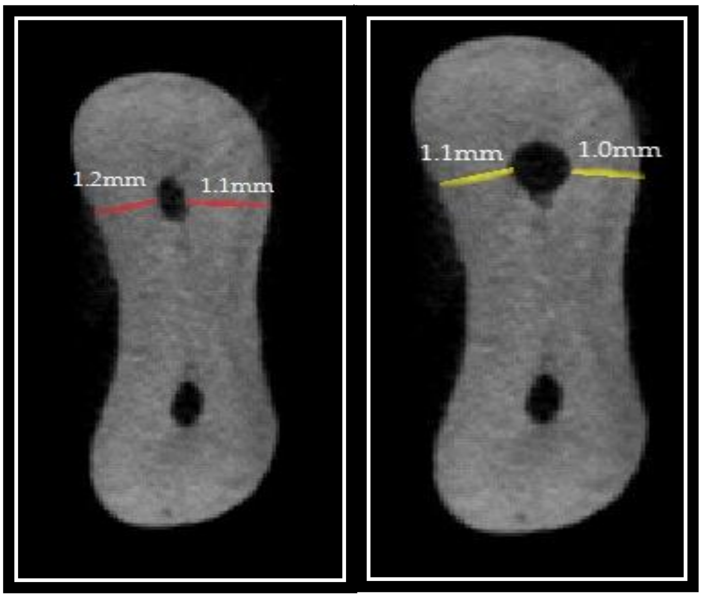
Pre-instrumentation Post-instrumentation

FIGURE 15: MICRO-CT IMAGE AT 9MM FROM APEX HEDM GROUP



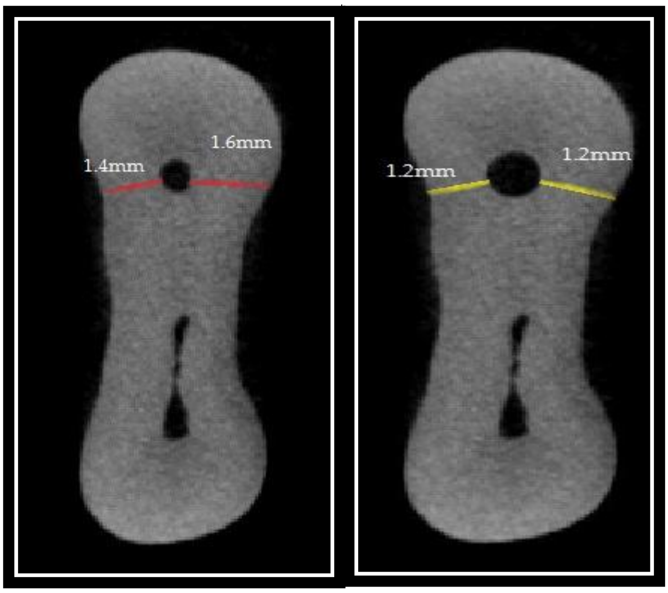
Pre-instrumentation Post-instrumentation

FIGURE 16: MICRO-CT IMAGE AT 3MM FROM APEX WOG GROUP



Pre-instrumentation Post-instrumentation

FIGURE 17: MICRO-CT IMAGE AT 6MM FROM APEX WOG GROUP



Pre-instrumentation   Post-instrumentation

FIGURE 18: MICRO-CT IMAGE AT 9MM FROM APEX WOG GROUP

Results

RESULTS

The data obtained were entered in an excel spread sheet and analyzed using SPSS (Statistical Package for Social Sciences) V.20 software. The confidence interval was set at 95% and p value was set for 0.05 and any value equal to or less than was considered to be significant.

Canal transportation was analyzed using kruskal walis test followed by tukeys post hoc test. Centering ability was analyzed using one way anova followed by tukeys post hoc test.

Table 1, 2 and 3 shows reading at 3mm, 6mm and 9mm pre- and post-instrumentation of three groups.

Table 4 shows canal transportation and centering ratio values of ProTaper Universal group at 3mm, 6mm and 9mm.

Table 5 shows canal transportation and centering ratio values of Hyflex EDM group at 3mm, 6mm and 9mm.

Table 6 shows canals transportation and centering ratio values of WaveOne GOLD group at 3mm, 6mm and 9mm.

Table 7, Graph 1 shows comparison of canal transportation at 3mm among PTU group, HEDM group and WOG group. The mean and SD values of canal transportation at 3mm of PTU group, HEDM group and WOG group were 0.195(±.1538), 0.030(±.0571) and 0.060(±.0940) respectively. There was a statistical significant difference between all three groups at 3mm. (p value <0.05)

Table 8, Graph 2 shows comparison of canal transportation at 6mm among PTU group, HEDM group and WOG group. The mean and SD values of canal transportation at 6 mm of PTU group, HEDM group and WOG group were 0.175(±.1682), 0.055(±.0887) and 0.080(±.1005) respectively. There was a statistical significant difference between all three groups at 6 mm. (p value <0.05)

Table 9, Graph 3 shows comparison of canal transportation at 9 mm among PTU group, HEDM group and WOG group. The mean and SD values of canal transportation at 9mm of PTU group, HEDM group and WOG group were -0.20(±.1654), 0.060(±.1095) and 0.085(±.1040) respectively. There was a statistical significant difference between all three groups at 9 mm. (p value <0.05)

Table 10 shows pair wise comparison of canal transportation at 3 mm 6 mm and 9mm. There was a significant difference between PTU group and HEDM group, PTU group and WOG group (p value<0.05). There was no significant difference between HEDM group and WOG group at 3mm, 6mm and 9 mm (p value>0.05).

Table 11, Graph 4 shows comparison of canal centering ability at 3 mm among PTU group, HEDM group and WOG group. The mean and SD values of centering ratio at 3mm of PTU group, HEDM group and WOG group were 0.4230(±.20329), 0.8000(±.25131) and 0.7325(±.30893) respectively. There was a statistical significant difference between all three groups at 3mm. (p value <0.05).

Table 12, Graph 5 shows comparison of canal centering ability at 6mm among PTU group, HEDM group and WOG group. The mean and SD values of centering ratio at 6mm of PTU group, HEDM group and group 3 were 0.4405(±.22700), 0.6745(±.27888) and 0.6655(±.31660) respectively. There was a statistical significant difference between all three groups at 6 mm. (p value <0.05).

Table 13, Graph 6 shows comparison of canal centering ability at 9 mm among PTU Group, HEDM Group and WOG Group. The mean and SD values of centering ratio at 9mm of PTU group, HEDM group and WOG group were 0.4940(±.24446), 0.7070(±.25931) and 0.7250(±.25521) respectively. There was a statistical significant difference between all three groups at 9 mm. (p value <0.05).

Table 14 shows pair wise comparison of canal centering ability at 3 mm 6 mm and 9mm. There was significant difference between PTU group and HEDM group, PTU group and WOG group (p value <0.05). There was no significant difference between HEDM group and WOG group at 3mm, 6mm and 9mm (p value> 0.05).

Tables and Graphs

TABLE 1: PROTAPER GROUP: READING AT 3MM, 6MM AND 9MM- PRE-INSTRUMENTATION AND POST- INSTRUMENTATION

Samples No:	3mm (Apical third)				6mm (Middle third)				9mm (Coronal third)			
	X1	X2	Y1	Y2	X1	X2	Y1	Y2	X1	X2	Y1	Y2
1	0.8	0.3	0.9	0.8	1.3	0.8	1.2	1.1	1.8	1.6	1.8	1.2
2	0.9	0.5	0.8	0.7	1.2	0.8	1.3	1.2	1.7	1.5	1.8	1.6
3	1.1	0.8	1.0	0.9	1.1	0.7	1.2	1.1	1.5	1.3	1.7	1.1
4	1.2	1.1	1.1	1.0	1.3	0.8	1.1	1.0	1.6	1.4	1.5	1.0
5	0.9	0.6	1.0	0.9	1.1	0.7	0.9	0.8	1.7	1.6	1.7	1.4
6	0.7	0.6	0.8	0.7	0.9	0.7	1.1	1.1	1.5	1.4	1.6	1.2
7	0.8	0.5	0.9	0.8	1.3	0.9	0.9	0.8	1.9	1.7	1.8	1.6
8	1.0	0.6	1.1	1.0	1.2	1.1	1.1	1.0	2.1	1.9	2.2	1.9
9	1.2	1.1	0.9	0.8	1.1	1.0	1.2	0.9	2.2	2.0	2.3	1.9
10	1.1	0.8	1.0	0.9	1.3	1.2	1.1	1.0	2.3	2.1	2.0	1.5
11	0.8	0.4	0.9	0.8	1.3	1.2	1.2	1.0	1.8	1.6	1.8	1.2
12	0.9	0.6	0.8	0.7	1.2	0.9	1.1	1.0	1.7	1.5	1.8	1.4
13	1.1	0.6	1.0	0.9	1.1	0.9	1.1	1.0	1.5	1.3	1.7	1.3
14	1.2	0.9	1.1	1.0	1.3	1.2	1.2	1.1	1.6	1.4	1.5	1.0
15	0.9	0.5	1.0	0.9	1.1	0.9	0.9	0.8	1.7	1.3	1.7	1.4
16	0.7	0.6	0.8	0.6	0.9	0.5	1.1	0.9	1.5	1.4	1.6	1.2
17	0.8	0.4	0.9	0.8	1.3	0.9	1.2	1.0	1.9	1.8	1.8	1.3
18	1.0	0.6	1.1	1.0	1.2	0.8	1.2	1.0	2.1	1.9	2.2	2.0
19	1.2	1.1	0.9	0.8	1.1	0.7	0.9	1.0	2.2	2.0	2.3	1.9
20	1.1	0.7	1.0	0.9	1.3	0.9	1.2	1.1	2.3	1.9	2.0	1.8

TABLE 2: HYFLEX EDM GROUP: READING AT 3MM, 6MM AND 9MM- PRE-INSTRUMENTATION AND POST-INSTRUMENTATION

Samples No:	3mm (Apical third)				6mm (Middle third)				9mm (Coronal third)			
	X1	X2	Y1	Y2	X1	X2	Y1	Y2	X1	X2	Y1	Y2
1	0.8	0.7	0.7	0.6	1.2	1.1	1.1	1.0	1.8	1.6	1.7	1.6
2	0.7	0.5	0.9	0.8	1.1	1.0	1.2	1.1	1.6	1.4	1.7	1.5
3	1.0	0.9	0.9	0.8	1.3	1.1	1.1	1.0	1.5	1.1	1.6	1.4
4	0.8	0.6	0.8	0.7	0.9	0.7	1.1	1.0	1.3	1.1	1.5	1.4
5	0.7	0.6	0.8	0.7	1.1	1.0	1.2	1.1	1.9	1.6	1.8	1.6
6	1.1	0.9	1.0	0.9	1.0	0.8	1.1	1.0	2.0	1.7	1.8	1.6
7	1.2	1.1	0.9	0.8	1.2	1.0	1.0	0.9	1.4	1.0	1.6	1.4
8	0.7	0.5	0.9	0.8	1.3	1.0	1.2	1.1	1.8	1.6	1.7	1.5
9	1.0	0.9	1.0	0.9	1.0	0.9	0.9	0.7	1.6	1.4	1.7	1.6
10	1.1	0.9	0.7	0.6	0.9	0.8	1.0	0.9	1.5	1.4	1.6	1.5
11	0.8	0.6	0.7	0.6	1.2	1.1	1.1	0.9	1.8	1.6	1.8	1.6
12	0.7	0.6	0.9	0.8	1.1	1.0	1.2	1.1	1.6	1.4	1.6	1.2
13	1.0	0.8	0.9	0.8	1.3	1.1	1.1	1.0	1.5	1.3	1.5	1.3
14	0.8	0.6	0.8	0.7	0.9	0.6	1.1	1.0	1.3	1.0	1.3	1.2
15	0.7	0.6	0.8	0.6	1.1	0.9	1.2	1.1	1.9	1.7	1.9	1.7
16	1.1	0.9	1.0	0.8	1.0	0.7	1.1	1.0	2.0	1.9	2.0	1.9
17	1.1	0.9	0.9	0.7	1.2	1.1	1.0	0.9	1.4	1.1	1.3	1.3
18	0.7	0.6	0.9	0.8	1.3	1.1	1.0	1.1	1.8	1.5	1.8	1.6
19	1.0	0.8	1.0	0.9	1.0	0.9	0.9	0.8	1.6	1.2	1.6	1.4
20	1.0	0.9	0.7	0.6	1.2	1.1	1.0	0.9	1.5	1.4	1.5	1.4

TABLE 3: WAVEONE GOLD GROUP: READING AT 3MM, 6MM AND 9MM- PRE-INSTRUMENTATION AND POST-INSTRUMENTATION

Samples No:	3mm (Apical third)				6mm (Middle third)				9mm (Coronal third)			
	X1	X2	Y1	Y2	X1	X2	Y1	Y2	X1	X2	Y1	Y2
1	1.1	0.8	0.8	0.7	1.2	1.1	1.1	1.0	1.4	1.2	1.6	1.2
2	0.8	0.7	0.9	0.8	0.9	0.6	1.2	1.1	1.8	1.6	1.7	1.5
3	1.1	0.8	1.0	0.9	1.1	1.0	1.2	1.0	1.7	1.6	1.7	1.3
4	1.2	1.1	1.1	1.0	1.0	0.7	0.9	0.8	1.5	1.3	1.6	1.4
5	0.9	0.7	1.1	1.0	1.1	0.5	1.2	1.1	1.6	1.5	1.7	1.3
6	1.0	0.7	0.9	0.8	1.2	1.1	1.1	1.0	1.5	1.3	1.7	1.3
7	0.8	0.7	0.9	0.7	1.0	0.7	0.9	0.8	1.4	1.2	1.6	1.2
8	0.9	0.8	1.1	1.0	0.9	0.8	0.9	0.8	1.8	1.6	1.8	1.4
9	1.0	0.9	1.2	1.1	1.2	1.0	1.1	1.0	1.9	1.7	2.0	1.6
10	0.9	0.7	1.1	1.0	1.3	1.2	1.2	1.1	1.6	1.4	1.7	1.3
11	1.1	1.0	0.9	0.8	1.2	1.0	1.2	1.1	1.4	1.2	1.5	1.1
12	0.8	0.7	0.9	0.8	0.9	0.6	0.9	0.8	1.8	1.6	1.7	1.3
13	1.1	1.0	1.0	0.9	1.1	0.8	1.0	0.9	1.7	1.5	1.6	1.4
14	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	1.5	1.3	1.7	1.5
15	0.9	0.6	0.8	0.7	1.1	1.0	1.0	0.9	1.6	1.4	1.8	1.6
16	1.0	0.9	0.9	0.8	1.2	1.1	1.0	0.9	1.5	1.3	1.7	1.5
17	0.8	0.7	0.9	0.8	1.0	0.9	0.8	0.7	1.4	1.2	1.6	1.4
18	0.9	0.6	1.0	0.9	0.9	0.6	0.9	0.8	1.8	1.6	1.8	1.6
19	1.0	0.9	1.1	1.0	1.2	1.1	1.0	0.9	1.9	1.7	1.7	1.5
20	1.1	0.8	0.8	0.7	1.2	1.1	1.1	1.0	1.4	1.2	1.6	1.2

TABLE 4: CANAL TRANSPORTATION AND CENTERING RATIO VALUES OF PROTAPER GROUP AT 3MM, 6MM AND 9MM

3MM		6MM		9MM	
CT	CR	CT	CR	CT	CR
0.4	0.2	0.4	0.2	-0.4	0.33
0.3	0.25	0.3	0.25	0	1
0.2	0.33	0.3	0.25	-0.4	0.33
0	1.0	0.4	0.2	-0.3	0.4
0.2	0.33	0.3	0.25	-0.2	0.33
-0.1	0.5	0.1	0.5	-0.3	0.25
0.2	0.33	0.3	0.25	0	1
0.3	0.25	0	1	-0.1	0.66
0	1	-0.2	0.33	-0.2	0.5
0.2	0.66	0	1	-0.3	0.4
0.3	0.25	-0.1	0.5	-0.4	0.33
0.2	0.33	0.2	0.33	-0.2	0.5
0.4	0.2	0.1	0.5	-0.2	0.5
0.2	0.33	0	1	-0.3	0.4
0.3	0.25	0.1	0.5	0.1	0.5
-0.3	0.5	0.2	0.5	-0.3	0.25
0.3	0.25	0.2	0.5	-0.4	0.2
0.3	0.25	0.3	0.25	0	1
0	1	0.3	0.25	-0.2	0.5
03	0.25	0.3	0.25	0.1	0.5

TABLE 5: CANAL TRANSPORTATION AND CENTERING RATIO VALUES OF HYFLEX EDM GROUP AT 3MM, 6MM AND 9MM

3MM		6MM		9MM	
CT	CR	CT	CR	CT	CR
0	1	0	1	0	1
0.1	0.5	0	1	0	1
0	1	0.1	0.5	0.2	0.5
0.1	0.5	0.1	0.5	0.1	0.5
0	1	0	1	0.1	0.66
0.1	0.5	0.1	0.5	0.1	0.66
0	1	0.1	0.5	0.2	0.5
0.1	0.5	0.2	0.33	0	1
0	1	-0.1	0.5	0.1	0.5
0	1	0	1	0	1
0.1	0.5	-0.1	0.5	0	1
0	1	0	1	-0.2	0.5
0.1	0.5	0.1	0.5	0	1
0	1	0.2	0.33	0.2	0.33
-0.1	0.5	0.1	0.5	0	1
0	1	0.2	0.33	-0.1	0.5
0	1	0	1	0.2	0.33
0	1	0.1	0.5	0.1	0.66
0.1	0.5	0	1	0.2	0.5
0	1	0	1	0	1

TABLE 6: CANAL TRANSPORTATION AND CENTERING RATIO VALUES OF WAVEONE GOLD GROUP AT 3MM, 6MM AND 9MM

3MM		6MM		9MM	
CT	CR	CT	CR	CT	CR
0	1	0.2	0.33	0.2	0.5
0.2	0.33	0	1	0.2	0.5
0	1	0.2	0.33	0	1
0.2	0.33	-0.1	0.5	0.1	0.5
0	1	0.2	0.33	0	1
0.1	0.5	0.1	0.5	-0.1	0.5
0.2	0.33	0	1	0.1	0.5
-0.1	0.5	0.2	0.33	0.2	0.5
0	1	0	1	0.2	0.5
0	1	0.1	0.5	0.2	0.5
0.1	0.5	0	1	0.2	0.5
0	1	0.1	0.5	0.2	0.5
0.1	0.5	0.2	0.33	0.2	0.5
0	1	0.2	0.33	0	1
0	1	0	1	0	1
0.2	0.33	0	1	0	1
0	1	0	1	0	1
0	1	0	1	0	1
0.2	0.33	0.2	0.33	0	1
0	1	0	1	0	1

TABLE 7: COMPARISON OF CANAL TRANSPORTATION AT 3MM AMONG PROTAPER GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P value
PROTAPER UNIVERSAL	0.195	.1538	.014*
HYFLEX EDM	0.030	.0571	
WaveOne GOLD	0.060	.0940	

*Kruskal walis test P value <0.05= statistically significant

TABLE 8: COMPARISON OF CANAL TRANSPORTATION AT 6MM AMONG PROTAPER GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P value
PROTAPER UNIVERSAL	0.175	.1682	.048*
HYFLEX EDM	0.055	.0887	
WaveOne GOLD	0.080	.1005	

*Kruskal walis test P value <0.05= statistically significant

TABLE 9: COMPARISON OF CANAL TRANSPORTATION AT 9MM AMONG PROTAPER GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P value
PROTAPER UNIVERSAL	-0.20	.1654	.01*
HYFLEX EDM	0.060	.1095	
WaveOne GOLD	0.085	.1040	

*Kruskal walis test P value <0.05= statistically significant

TABLE 10: PAIRWISE COMPARISON OF CANAL TRANSPORTATION WITH ALL GROUPS AT 3MM, 6MM AND 9 MM USING POST HOC TESTS – TUKEY HSD

Variables	Groups	Mean Difference	Std. Error	P Value
3 MM	Group 1 and Group 2	-.1650*	.0345	.000*
	Group 2 and Group 3	-.0300	.0345	**.662**
	Group 1 and Group 3	-.1350*	.0345	.001*
6 MM	Group 1 and Group 2	-.1200*	.0393	.009*
	Group 2 and Group 3	-.0250	.0393	**.801**
	Group 1 and Group 3	-.0950*	.0393	.049*
9 MM	Group 1 and Group 2	.2600*	.0409	.000*
	Group 2 and Group 3	.1450*	.0409	**.815**
	Group 1 and Group 3	.1150*	.0409	.018*

*Tukeys Post hoc test <0.05=statistically significant

Group 1-PTU Group 2- HEDM Group 3-WOG

TABLE 11: COMPARISON OF CANAL CENTERING ABILITY AT 3MM AMONG PROTAPER GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P VALUE
PROTAPER UNIVERSAL	.4230	.20329	.000*
HYFLEX EDM	.8000	.25131	
WaveOne GOLD	.7325	.30893	

*Oneway anova test P value <0.05= statistically significant

TABLE 12: COMPARISON OF CANAL CENTERING ABILITY AT 6MM AMONG PROTAPER GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P value
PROTAPER UNIVERSAL	.4405	.22700	.019*
HYFLEX EDM	.6745	.27888	
WaveOne GOLD	.6655	.31660	

*Oneway anova test P value <0.05= statistically significant

TABLE 13: COMPARISON OF CANAL CENTERING ABILITY AT 9MM AMONG PTU GROUP, HYFLEX EDM GROUP AND WAVEONE GOLD GROUP

GROUPS	Mean	SD	P value
PROTAPER UNIVERSAL	.4940	.24446	.009*
HYFLEX EDM	.7070	.25931	
WaveOne GOLD	.7250	.25521	

*Oneway anova test P value <0.05= statistically significant

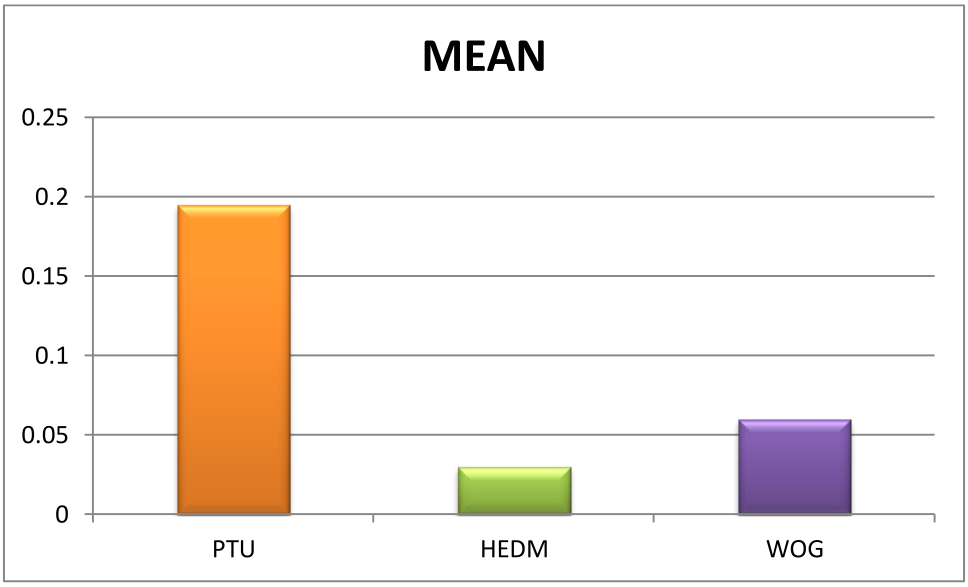
TABLE 14: PAIRWISE COMPARISON OF CANAL CENTERING ABILITY WITH ALL GROUPS AT 3MM, 6MM AND 9 MM USING POST HOC TESTS – TUKEY HSD

Variables	Groups	Mean Difference	Std. Error	P Value
3 MM	Group 1 and Group 2	-.1650*	.0345	.000*
	Group 2 and Group 3	-.0300	.0345	**.726**
	Group 1 and Group 3	-.1350*	.0345	.003*
6 MM	Group 1 and Group 2	-.1200*	.0393	.034*
	Group 2 and Group 3	-.0250	.0393	**.995**
	Group 1 and Group 3	-.0950*	.0393	.043*
9 MM	Group 1 and Group 2	.2600*	.0409	.027*
	Group 2 and Group 3	.1450*	.0409	**.973**
	Group 1 and Group 3	.1150*	.0409	.015*

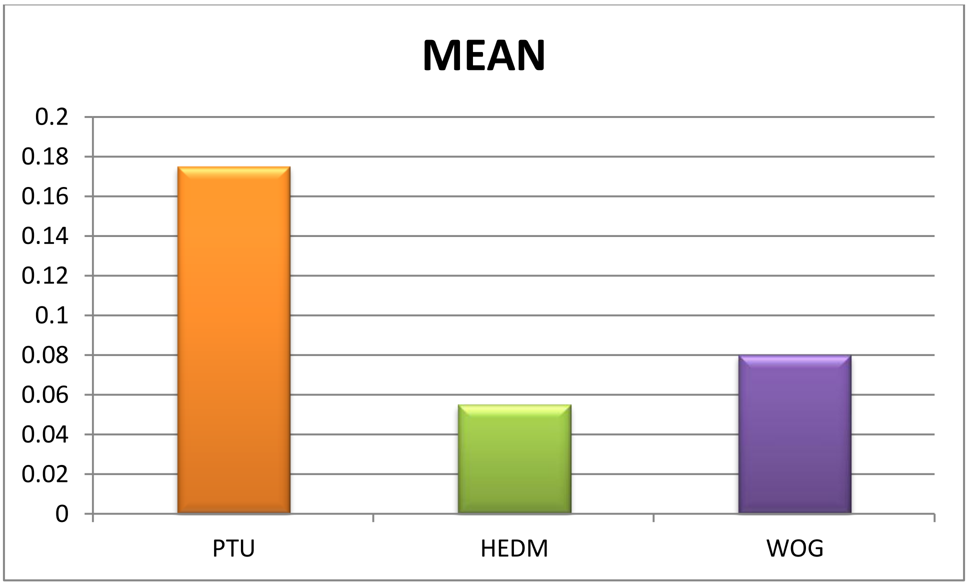
*Tukeys Post hoc test <0.05=statistically significant

Group 1-PTU Group 2- HEDM Group 3-WOG

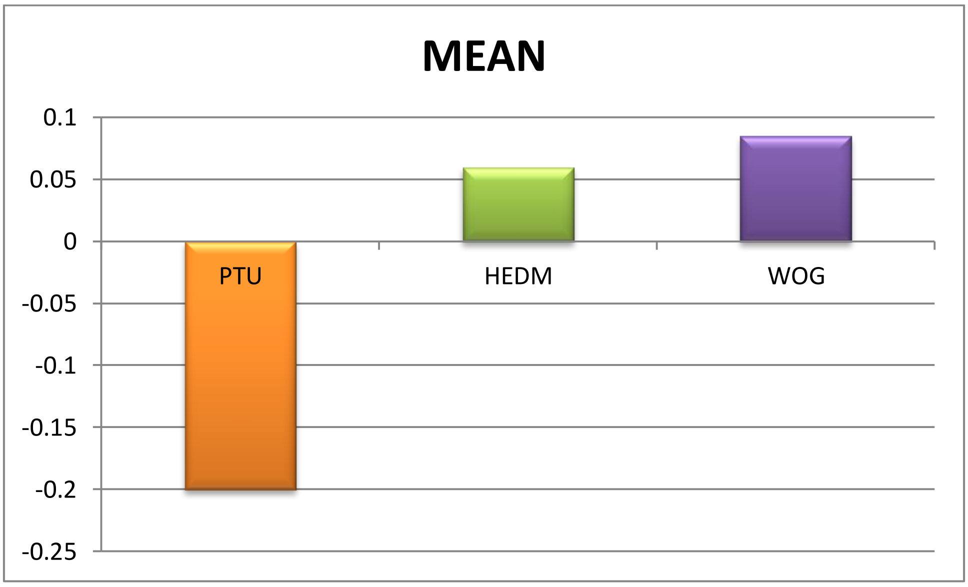
GRAPH 1: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL TRANSPORTATION AT 3MM



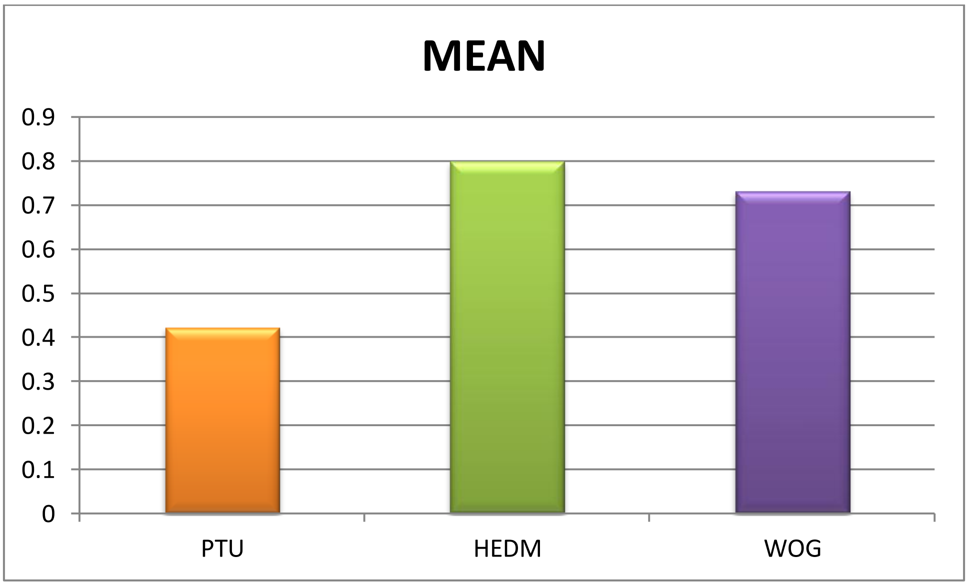
GRAPH 2: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL TRANSPORTATION AT 6MM



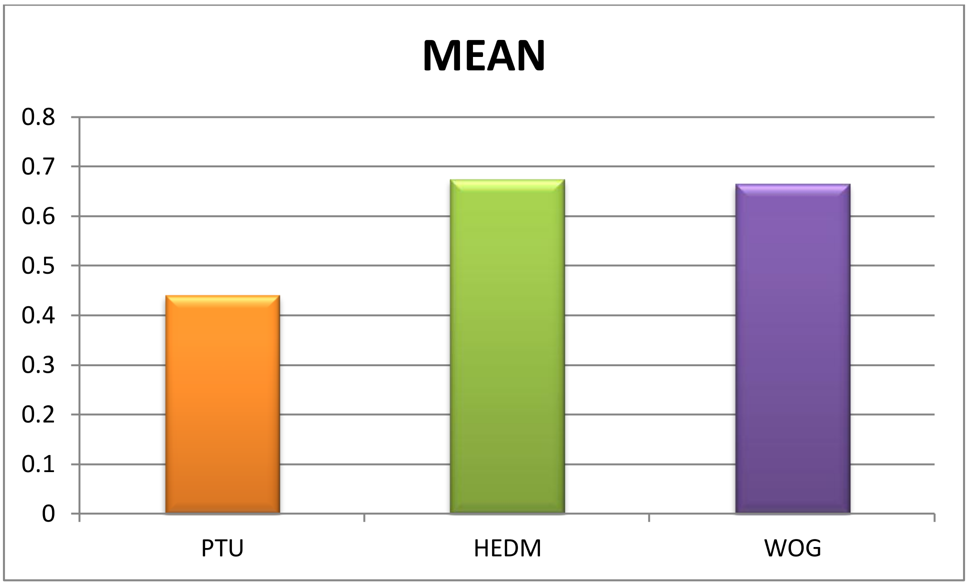
GRAPH 3: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL TRANSPORTATION AT 9MM



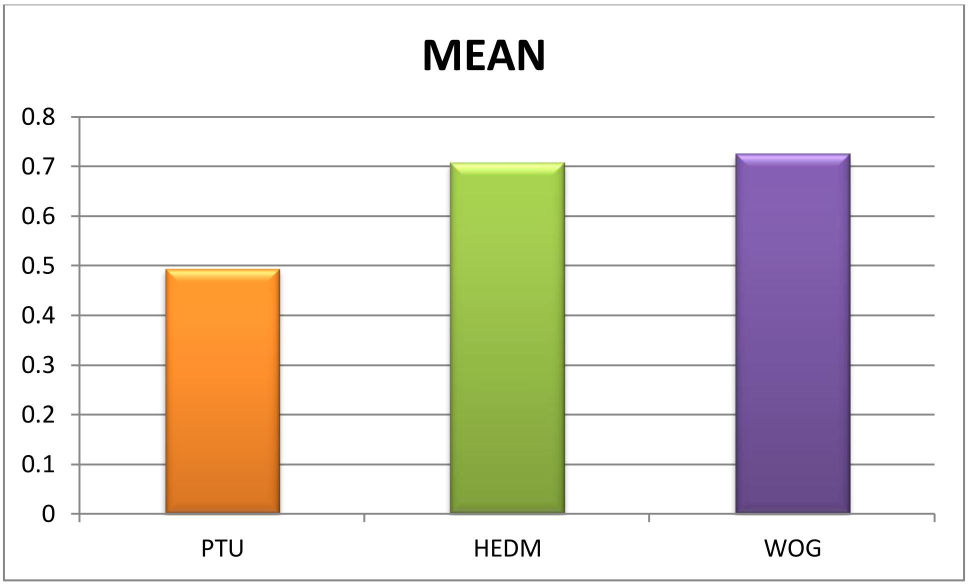
GRAPH 4: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL CENTERING RATIO AT 3MM



GRAPH 5: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL CENTERING RATIO AT 6MM



GRAPH 6: COMPARISON OF THREE GROUPS WITH RESPECT TO CANAL CENTERING RATIO AT 9MM



Discussion

DISCUSSION

The goal of root canal therapy is the removal of bacteria and their by-products from the root canal system and prevention of such an infection becoming re-established[39]. To achieve this, the root canal must be accessed, shaped and cleaned and eventually obturated. According to Ingle 60% of endodontic failures are due to incomplete obturation of the root canals while incomplete disinfection and biomechanical preparation contribute to the rest. Instrumentation along with disinfection is a key in augmenting the process and optimizing the obturation.[89]

Shaping and cleaning is performed by mechanically removing the infected and non-infected root canal tissue, along with some dentine from the root canal walls and chemical disinfecting by removing the bacteria and their products from within the root canal space.[39] Grossman[90] and Schilder[92] described mechanical instrumentation as the most important part of root canal therapy and considered as the foundation for successful outcome of endodontic treatment.

A successful treatment requires the creation of a smooth and progressively tapered preparation with the original anatomy maintained with the canal becoming narrower as it goes from coronal to apical with end of the preparation in its original position and not over enlarged. This will facilitate chemical debridement and subsequent filling to prevent re infection.[92]

Root canals are rarely straight and have a varying degree of curvature along their length, hence the instruments used when shaping and cleaning them can become stressed as the degree of curvature increases therefore, achieving a proper taper in a curved canal is very difficult.[36] Cleaning and shaping procedures in curved canal invariably lead to dentin removal from the canal walls rather than all direction from the main tooth axis causing canal transportation.[92 60]

According to the Glossary of Endodontic Terms of the American Association of Endodontists, Canal transportation is defined as follows: **'Removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation; may lead to ledge formation and possible perforation.'**[60] and centering ability is the ability of the instrument to stay centered in the canal.[31]

This canal transportation can lead to undesirable outcomes like:[17]

1. Loss of apical resistance and fluid tight seal due to straightening of the curved canals. There is also loss of original curvature and deviation or change in long axis of canal. These all changes may lead to apical extrusion of debris and microbes, irrigation solutions like NaOCl and EDTA, overextension of canal filling material.

2. Elbow formation or reverse apical shape formation.

3. After transportation at the apex, there is formation of elliptical shape. It also gives an hour glass appearance, tear drop or foraminal rip. This greatly affects the apical seal when obturated using lateral condensation invitro.

4. A perforation of the apical part of root canal while using rotary instruments with sharp cutting tips. Therefore canal transportation is serious threat during instrumentation.

Historically, root canal instrumentation has involved the use of stainless steel hand files. Numerous investigations have shown that procedural errors like elbows, zips, and danger zones and canal transportation (Cheung & Liu 2009) occurred with stainless steel instruments during preparation of curved root canals.[86]

To overcome this drawback, Nickel-titanium (Ni-Ti) alloy was proposed to be used in endodontics (Civijan,1975)[10]. Walia et al(1988) suggested a greater modification in endodontic instruments replacing stainless steel with a Ni-Ti alloy. Instrumentation of curved canals is made easier with introduction of Ni-Ti instruments. These instruments are super elastic and more flexible than stainless steel instruments before exceeding their elastic limits and hence does not require the precurving compared to stainless steel instruments to negotiate the curved canal.[17]

As Ni-Ti instruments require less stress to bend, they exert less force and being nonaggressive by nature, do not lead to excess cutting on either side and been found to be 2–3 times more elastic than stainless steel files (Carvalho LA et al 1999). Stainless steel, however, has tendency to cut more in one wall than the other. After the introduction of NiTi endodontic hand instruments by Walia et al., many rotary NiTi instruments have been marketed.[17]

However, the undesirable and unexpected separation of NiTi endodontic rotary files during root canal instrumentation caused by cyclic fatigue and/or torsional overload still remains a serious concern and drawback in clinical use.[88] To overcome this NiTi instruments have undergone a continuous evolution in terms of thermomechanical processing such as M-wire files (e.g. ProFile GT Series X, ProFile Vortex, and ProFile Vortex Blue: Dentsply Tulsa Dental Specialties, Tulsa, OK, USA), R-phase wire [e.g. Twisted files (TF) and K3XF files: SybronEndo, Orange, CA]and controlled memory (CM) files (e.g. HyFlex CM: Coltene Whaledent, Cuya hoga Falls, OH and TYPHOON Infinite Flex NiTi: Clinician's Choice dental Products, Milford, CT, USA).[86]

Additionally, in parallel with these developments, endodontic motors have undergone enhancement regarding torque control and kinematics that are adjustable in several directions to increase Cyclic and / or Torsional resistance especially in curved canal.[11]Interestingly, axial and rotational reciprocation combination was introduced in 1928(Cursor filing contra-Angle; W & H, Burmoos Austria) followed by axial reciprocation in 1958(Racer W &H) and rotational reciprocation (the Giromatic system, MicroMega). These systems were used in equal clockwise and counter clockwise rotation. Over time, these systems lost popularity because it produced greater procedural errors than hand filing (Weine et al. 1976).[80]

More recently, reciprocating motion regained popularity with the introduction of NiTi alloys and endodontic torque control motors. Yared et al (2008) introduced engine driven single file reciprocation for the preparation of curved canals. They used F2protaper instrument in reciprocation with unequal clockwise and anticlockwise movements which showed promising clinical results. This led to the introduction of reciprocation technology. This concept of reciprocation is evolved from balanced force technique (Roane et al. 1985) that allows shaping of even severely curved canals with hand instruments to larger apical diameter.[80]

The stress on the instrument is relieved by reciprocating movement and this could reduce the risk of cyclic fatigue caused by tension and compression. The reciprocation working motion consists of a counter clockwise (cutting direction) and a clockwise motion (release of the instrument), while the angle of the counter clockwise cutting direction is greater than the angle of the reverse direction. Due to the fact that the counter clockwise angle is greater than the clockwise one, it is claimed that the instrument continuously progresses towards the apex of the root canal. The angles of reciprocation are specific to the design of the particular instruments and are programmed in an electronic motor. Reciprocating system shows better smear and debris removal when compared to continuous rotary NiTi files.[82 6]

Further there was advancement in technology by the introduction of single file system. Benefits of single file system are shorter working time, reduction in number of instruments required to obtain desired shape, reduces cross contamination and instrument fatigue, unlike the commonly used full sequence rotary system.[9] Recently, Reciproc (VDW, Munich, Germany) and WaveOne (DentsplyMaillefer, Ballaigues, Switzerland) were introduced as reciprocating single file system in the market. It is reported that these file system prepare and clean root canals with only one instrument.[48]

In addition, constant hunt to improve the flexibility and strength of the instrument has led to the introduction of newer innovative technologies like Electric discharge machining (EDM) and Gold treatment in endodontic field for the first time.

Electrical discharge machining (EDM) is a non-orthodox machining concept which has been widely used to produce dies and molds. It is also used in aerospace, automotive industry for making finishing parts and in medical field in production of surgical equipments. This approach has been developed in the late 1940s.[45] The EDM is a noncontact material erosion mechanism recently introduced in endodontic field to manufacture rotary instruments from CM wire to improve the flexibility and cyclic fatigue resistance of the file. HyFlex EDM files (Coltene/Whaledent) is first file manufactured via an electro discharge machining (EDM) process.

Electro discharge machining (EDM) process converts electrical energy into thermal energy through a series of distinct electrical discharges occurring between the electrode and workpiece immersed in a dielectric fluid at a temperature in the range of 8000 to 12,000 °C or as high as 20,000 °C, this removes the material from a part.[23]

This process of melting and evaporating material from the workpiece surface is in complete inverse to the conventional machining processes, as chips are not mechanically produced. The material is removed with the erosive effect of the electrical discharges from electrode and workpiece. EDM does not make direct contact between the electrode and the work piece where it can eliminate mechanical stresses chatter and vibration problems during machining. Materials of any hardness can be cut as long as the material can conduct electricity. Since EDM does not induce mechanical stresses during machining, it provides an additional advantage in the manufacture of intricate products.[23,45]

Gold heat treatment is a new heat treatment process introduced in the endodontics. The gold process is a post manufacturing procedure in which the ground NiTi files are heat-treated and slowly cooled. From a technical context, the heat treatment modifies the transformation temperatures (austenitic start and austenitic finish), and this has a positive effect on the instrument properties. This process gives the file its peculiar gold finish, more importantly it considerably improves its strength and flexibility far in excess of its predecessor. WaveOne Gold is the first endodontic instrument to be manufactured by using this Gold treatment process.[75]

Various methods were available to investigate the efficiency of instrument and techniques for root canal preparation, a number of methods have been used to compare canal shape before and after instrumentation. The methods used for comparative analysis were radiography[68], scanning electron microscope[25], photographic assessment[5] and computer manipulation.[12] Radiography only provides a two dimensional image and a cross section of the root canal is impossible to observe.[21] The serial sectioning technique[21] is another method where it requires a complicated set up and physical sectioning of the teeth before preparation and this result in unknown tissue changes and loss of material.

The above mentioned methods are invasive in nature, exact repositioning of pre and post instrumented samples is difficult, they are technique sensitive and there is a disadvantage leading to loss of specimen.[20] As a result information acquired by using these methods could be misleading. With fast growing technology advances, what is demanded are non-invasive methods that would give precise information about canal preparation.

Non-destructive technology has been advocated for pre and post instrumentation evaluation of root canals. They are computed tomography, cone beam computed tomography reproducible three dimensional evaluation of the external and internal morphology of the tooth.

Emergence of Micro-computed Tomography (Micro-Ct) has substantially improved the perspectives of endodontic researches. This technology has been widely applied to evaluate anatomy, techniques and materials related to the endodontic treatment. Its operation is based on converging multiple X-ray beam on the sample and captured by a sensor. The projected X-ray is converted into digital images. The volumetric voxel (pixel) provided by micro-CT range in 5-50 μm. Smaller voxel size generates image with higher resolution than conventional clinical scanners.[40] The ability of the micro-CT technique to reveal the detailed three-dimensional anatomy of the root canal space and to allow a reliable quantitative evaluation of various outcome variables involved in the study of canal preparation techniques has been demonstrated (Peters et al. 2000, Bergmans et al. 2001, Yang et al. 2011, De-Deus et al. 2014). In fact, using micro-CT in conjunction with image processing and 3D visualization, it is possible to assess several canal preparation outcomes, such as: [44]

(i) Area of mechanically untreated (non-instrumented) canal wall (Paque et al.2010),

(ii) Volume of removed dentine and accumulation of hard-tissue debris resulting from canal preparation (De-Deus et al. 2014),

(iii) Risk areas for perforation, and

(iv) Root canal transportation (Yamamura et al. 2012).

The purpose of the study was to evaluate and compare the canal transportation and centering ability of Hyflex EDM files (continuous rotary motion, control memory wire and EDM technology), WaveOne Gold (single file system, reciprocating motion, Gold heat treatment procedure) and ProTaper Universal files (full sequence) using micro CT on mesiobuccal canals of mandibular molars

In the present study natural human teeth were used. Even though pre-fabricated resin blocks allow for standardization of degree, location and radius of root canal curvature in three dimensions as well as the root canal length (Peters 2004, Hulsmann et al. 2005), Human teeth simulate clinical conditions better than acrylic blocks as they reproduce the microhardness of dentine and the anatomic variation that frequently encountered in the clinical scenario.[34 14] The simulated root canal has a hardness commonly in the 20-22kg/mm^2 whereas dentine varies from 35-40 kg/mm^2.[21]

One of the drawbacks of using rotary instruments in resin blocks is the frictional heat generated by rotary instruments which may be sufficient to melt some resins and lead to binding of cutting blades, and separation of instrument. Resin debris formed during preparation of simulated root canals is not as fine as dentine debris and tends to tangle which may result in frequent blockages of the apical portion and difficulties in clearing it in resin canals.[37]

The mesial root canals of molars are usually curved, with the greatest curvature in the mesiobuccal canal[62]. Therefore, curved mesiobuccal canals often have greater canal transportation by instrumentation than most other canals. In this study sixty mesiobuccal root canal of mandibular molars were used after decoronating at the level of CEJ using diamond disc. These sixty samples were subjected to pre-instrumentation scanning using Micro-CT (SkyScan 1174v2: Bruker microCT, Kontich, Belgium) then samples were divided into three groups (n=20) ie ProTaper Universal (group one), Hyflex EDM (group two) and WaveOne GOLD (group three) and were subjected to instrumentation. The instrumentation was carried out in all the groups as per manufacture's instruction. In this study apical preparation was standardized to size 25, according to Buchanan, the amount of canal transportation increases with apical preparation greater than size 25. Hence, the apical preparation was limited to size 25 in the present study.

ProTaper universal files (group one) were chosen for comparison as they are amongst the most commonly used Ni-Ti instruments globally. (Dentsply Maillefer, Ballaigues, Switzerland). The ProTaper Universal instruments were designed by Dr. Cliff Ruddle, Dr. John West and Dr. Pierre Machtou and comprised of six instruments: three shaping files and three finishing files.[56]

This set is now available with two larger finishing files. It has a convex, triangular cross section and no radial lands; this creates a stable core and sufficient flexibility for the smaller files. The cross section of finishing files F3, F4 and F5 is slightly relieved for increased flexibility. A unique design element is varying tapers along the instruments long axes. The three shaping files have tapers that increase coronally, and the reverse pattern is seen in the five finishing files.[56]

Shaping files #1 and #2 have tip diameters of 0.185 mm and 0.2 mm, respectively, 14 mm long cutting blades, and partially active tips. The diameter of these files at D14 are 1.2 mm and 1.1 mm, respectively. The finishing files, F1-F5 have tip diameters of 0.2 mm, 0.25 mm, 0.3 mm, 0.4 mm and 0.5mm, respectively, between D0 and D3, and the apical tapers are 0.07, 0.08, 0.09, 0.06, and 0.05, respectively. The finishing files have rounded noncutting tips26 and are used in crown down manner.[88]

Hyflex EDM (Coltene/Whaledent, Switzerland) (group two) was used in sequence, .12 taper (orifice opener) of 17mm in length; size 10, .05 taper (glide path file) of 25mm in length; and size 25 (one-file, shaping file) of 25mm in length , and optional finishing files (40/.04 ,50/.03, 60/.02) with speed 500rpm and torque 2.5 Ncm. The cross section of file is variable along the entire length. The cross section close to the shaft is nearly triangular at the middle of the file it changes to trapezium and at the tip its quadratic cross section. [27]

This system has a variable taper, with apical 5mm as .08 taper and the remaining file at .04 taper. When compared to conventional Hyflex CM, HEDM is mainly composed of Martensite and R-phase revealing a peculiar structural property that increases phase transformation temperature and higher hardness. This hardened surface has a substantial impact on fatigue lifetime of HEDM.[35 36]

The rough spark machined surface produced by EDM process is unaffected after multiple uses, confirming high wear resistance. This uniquely rough and hard surface in the file improves cutting efficiency and increases the cyclic fatigue resistance to 700 % than conventional CM wires.[35 36]

WaveOne GOLD (group three) single-file reciprocating system available in four tip sizes: Small (20.07, yellow), Primary (25.07, red), Medium (35.06, green) and Large (45.05, white) available in 21 mm, 25 mm and 31 mm lengths. WaveOne GOLD has active cutting lengths of 16 mm, shortened 11 mm handles for improved posterior access. The cross-section of WaveOne GOLD is a Parallelogram with two 85-degree cutting edges in contact with the canal wall. It also features the off-center design of ProTaper Next, where only one cutting edge is in contact with the canal wall. Decreasing the contact area between the file and the canal wall reduces binding (taper lock) and, in conjunction with a constant helical angle of 24 degrees along the active length of the instrument, ensures little or no screwing effect.[75]

The tip of WOG is roundly tapered and semi-active, modified to reduce the mass of the center of the tip and improve its penetration into any secured canal with a confirmed, smooth and reproducible glide path. They engage and cut dentine in a 150 degree counterclockwise (CCW) direction and then, before the instrument has a chance to taper lock, disengage 30 degrees in a clockwise (CW) direction. The net file movement is a cutting cycle of 120 degrees and therefore after three cycles the file will have made a reverse rotation of 360 degrees.[75]

The cyclic fatigue resistance of WOG Primary is 50% greater than that of WaveOne Primary (which itself was twice as great as most standard rotary file systems), and the flexibility of WaveOne GOLD Primary is 80% greater than that of WaveOne Primary.[75]

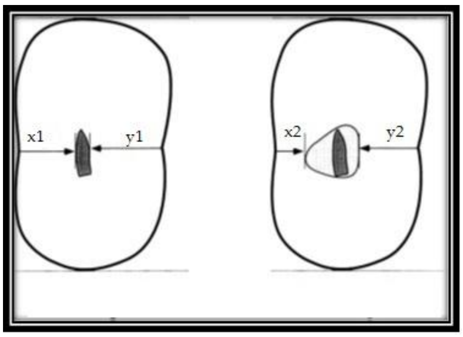
2.5% sodium hypochlorite was used for irrigation in the present study because higher concentrations of sodium hypochlorite (NaOCl) can significantly decrease the elastic modulus, and flexural strength of dentine when used as an endodontic irrigant. Sim et al. (2001) reported decreased microhardness of radicular dentine after exposure to NaOCl in concentrations 5.25%, but not when NaOCl was used in lower concentrations. [65]

17% EDTA, was used in this study, in gel form, to facilitate instrumentation of the root canal and make the negotiation of canals easier as they help of the file within the root.[90] It was used in the early stages of canal negotiation and shaping and in adjunct with the Nickel Titanium file systems. Sterile saline was used to neutralize the various chemical of the irrigants by its flushing action.

After instrumentation, Groups were subjected for post-operative scanning using Micro-CT. Scanned images were reconstructed using NRecon software (Bruker Micro- CT). Then images were subjected for quantitative analysis using CT analyzer (Bruker Micro-CT). Reading were taken at axial sections – 3mm, 6mm, 9mm from the apex to represent the apical, middle and coronal third respectively.

Canal transportation was calculated in millimeters using the formula ([X1-X2]-[Y1-Y2]) as described by **Gambill et al**[20] where X1 is the shortest distance between the mesial portions of the root and uninstrumented canal, X2 is the shortest distance between the mesial portions of the root and instrumented canal, Y1 is the shortest distance between the distal portions of the root and uninstrumented canal, and Y2 is the shortest distance between the distal portions of the root and instrumented canal. Pre- and post-operative measurements were compared to reveal the presence or absence of deviations in canal anatomy and to identify the most affected region.

The centering ratio was calculated for each cross section using the values obtained in the assessment of root canal transportation with the ratio of (X1-X2) to (Y1-Y2). If these numbers were not equal, then the lower figure was considered to be the numerator of the ratio. According to this formula, a result of 1 indicated the optimal centering ability.



DIAGRAMMATIC REPRESENTATION SHOWING MEASURESENTS FOR IMAGE CROSS SECTIONS

Canal transportation and centering ratio values were subjected to statistical analysis using Statistical Package for Social Sciences software (SPSS version 22, USA).

There was a statistically significant difference between three groups for canal transportation and centering ratio. On pair wise comparison between the groups, statistical significant difference was seen between ProTaper universal (group one) and Hyflex EDM (group two), ProTaper Universal (group one) and WaveOne GOLD (group three) and there was no statistical difference between Hyflex EDM (group two) and WaveOne GOLD (group three) for both canal transportation and centering ratio.

In the present study, ProTaper Universal system (group one) has shown more canal transportation and less centered at all the levels 3mm, 6mm and 9mm. At 3mm and 6mm ProTaper Universal system showed positive transportation ie transportation away from the furcation with the mean values of 0.195mm and 0.175mm respectively. At 9mm it showed negative transportation ie transportation towards the furcation with mean value of -0.20mm. The mean centering ratio values were .4230, .4405 and .4940 at 3mm, 6mm and 9mm respectively and as the values were closer to zero worse was the ability of PTU instrument to keep itself in the canal central axis.

The positive transportation of ProTaper Universal may be attributed to the greater taper (8%) and less flexibility of the instruments as explained by Schafer et al[61], that the percentage of taper is one of the main factors involved in canal transportation.

At 9mm ProTaper group removed more dentin towards the furcation, this may be due to the thin distal (furcal) root wall of the mesio-buccal canal of a mandibular molar especially in long roots (24 mm) than in short-rooted teeth (19 mm) Sauaia et al. (2006)[67]; it can therefore be assumed that strip perforations might occur more frequently in mandibular teeth with long roots than short-rooted mandibular teeth when using greater taper instruments..

Guelzow et al[60] found ProTaper to show the highest degree of straightening. At the middle (6mm) and coronal third (9mm), transportation was seen which can be mainly due to progressive taper along the cutting surface in combination with the sharp cutting edges which is in accordance with our study. The partially active cutting tip with ProTaper Universal rotary files may be reason for increased canal transportation at apical third (3mm).

The results obtained were in conformity to Bonaccorso et al[7], Maitin et al[41] and Javaheri et al[29] who found ProTaper to produce more apical transportation than any other instrument. In a study done by Elsherief et al[19] PTU removed significant amount of dentin at all the 3 levels of root canal with a canal transportation of 0.15, 0.12 and 0.11.respectively from apical to cervical third.

Wu et al[78] has stated that the critical canal transportation value is 0.3mm, as it was found that leakage occurs more frequently when apical transportation index is > 0.3mm. In a similar study Peters et al[53] reported that apical transportation ≤ 0.1mm is clinically acceptable. In this present study

ProTaper Universal showed mean transportation value of 0.195mm, 0.175mm and -0.20mm at 3mm, 6mm and 9mm which is greater than the value of study done by peters et al.

On comparing ProTaper Universal (Group one) and Hyflex EDM (group two), there was a statistical difference between them. Hyflex EDM showed perfect shaping ability with no canal transportation in more samples and better centered in the canal than ProTaper Universal.

Mean canal transportation values of Hyflex EDM were 0.030 mm, 0.055 mm and 0.060 mm at 3mm 6mm and 9mm respectively. This canal transportation mean values were comparatively less than the mean values of ProTaper group. Mean centering ratio values were .8000, .6745 and .7070 at 3mm, 6mm and 9mm respectively and this mean centering ratio values were greater than ProTaper group and HEDM maintained canal central axis.

In a study, Zhao et al[85 48] compared the shaping abilities of Twisted File, HyFlex CM, and K3 (Sybron Endo) NiTi files and reported that HyFlex CM caused less apical transportation. In another study, Saber et al[48] concluded that HyFlex CM files caused less transportation than PTN files made of M-Wire alloy and iRaCe (FKG, La Chaux-de- Fonds, Switzerland) files made of a conventional alloy.

Similarly, Burklein et al[48] also reported that HyFlex CM files led to less transportation than Revo-S files (Micro Mega, Besancon, France) made of a conventional alloy. Authors have related the less transportation of HyFlex

CM files to their flexibility and elastic structure (testarelli et al, 2011 peters 2012). Superior performance of Hyflex EDM in this study might be attributed to:[27]

- The Electro discharge machining procedure performed during the production.
- Variable cross sections design of the file shaft: quadratic in the apical third, trapezoidal in the middle third, and almost triangular in the coronal third.
- Extremely flexible as it uses controlled memory wires allows superior canal tracking.

Venino et al[73] found HFEDM showing less transportation at all three levels and more centered when compared with ProTaper next system. Since the Hyflex EDM is made by CM treatment, it was proven that CM wire files were flexible than conventional NiTi and M-Wire instruments.

There was statistical difference between ProTaper Universal (group one) and WaveOne GOLD (group two). WaveOne GOLD showed less transportation and more centered at all three levels. Mean canal transportation values of WaveOne GOLD were 0.060 mm, 0.080 mm and 0.085 mm at 3mm, 6mm and 9mm respectively which is less than ProTaper group. Mean centering ratio values were .7325, .6655 and .7250 at 3mm, 6mm and 9mm respectively which is greater than ProTaper group and WOG maintained the centrality in the canal.

This performance of Wave One GOLD in context to transportation and centering ability may be due to:[75]

- Reciprocation motion
- It is manufactured using advanced proprietary thermal process called gold process yielding super-elastic NiTi file.
- The cross-section is a parallelogram with two 85-degree cutting edges in contact with the canal wall, alternating with a patented DENTSPLY off-centered cross section where only one cutting edge is in contact with the canal wall.

It is known that transformation behavior of NiTi alloys is due to thermomechanical process. This transformation occurs as 1-stage A-to-M transformation in nickel-rich NiTi alloys and 2-stage A-R-M transformation after additional heat treatment, which creates finely dispersed Ti3Ni4 precipitates in the austenitic matrix. This Ti3Ni4 particles favors the formation of R-phase, but the alloy requires further cooling for martensite transformation to occur. Therefore, martensitic transformation occurs in 2 steps: A-R-M. Superelasticity or pseudoelasticity is associated with the occurrence of phase transformation of the NiTi alloy upon application of stress above a critical level, which takes place when the ambient temperature is above the so-called Austenite finish temperature of the material. The gold heat treatment process modifies the transformation temperatures (austenitic start and austenitic finish), and this may have a positive effect of instrument properties on shaping curved root canals.[47]

In a study, Hieawy et al[47] compared ProTaper Gold (Dentsply Maillefer) and ProTaper Universal files and reported that ProTaper Gold had a high austenite finish temperature value and that it exhibited 2-stage transformation behavior. Gagliardi et al[48] compared the ProTaper Universal (Dentsply Maillefer), PTN, and ProTaper GOLD (PTG, Dentsply Maillefer) NiTi files shaping ability and reported that PTN and PTG files performed less canal transportation and argued that this was because of the flexible alloy of PTG files.

In the present study, the WaveOne Gold showed good shaping ability without procedural errors which might be due to WaveOne Gold file's high Austenite finish temperature value and 2-stage transformation behavior. Therefore, this GOLD heat treatment process may be the reason for WaveOne GOLD effective performance in curved canal.

There was no statistical difference between Hyflex EDM(group two) and wave one GOLD(group three) in canal transportation and centering ratio at all three intervals. But Hyflex EDM showed less transportation and more centered when compared to WaveOne GOLD. Ozyurek et al[48] found that WaveOne GOLD and Hyflex EDM caused a lower level resin removal than Reciproc in simulated s-shaped canals but there was no statistical difference between Hyflex EDM and WaveOne GOLD.

The limitations in the present study were:

1. Instruments used in present study were of different taper. Since taper of instruments differs among the manufacturers so it cannot be standardized. Only instrument tip was standardized to size 25 in the present study.
2. Curvatures of the root canals were not standardized in the present study. This can be incorporated in the future studies where canal curvature for each specimen could be recorded and correlation done with the amount of canal transportation.

Within the limitation of present study, further research should be done in testing metallurgy of these novel file systems to be used in complex root canal anatomy for long term successful outcome.

Summary

SUMMARY

The present in-vitro study was undertaken to evaluate and compare the canal transportation and canal centering ability of three NiTi files (ProTaper Universal, Hyflex EDM, and WaveOne GOLD) at three different levels (3mm, 6mm and 9mm) from apex.

Sixty mesiobuccal canals of mandibular molars were included in the study, which were mounded on acrylic resin blocks. The specimens were divided into three groups (n=20).

Group 1 – ProTaper Universal

Group 2 – Hyflex EDM

Group 3 – WaveOne GOLD

Pre-operative Micro Computed Tomographic images were taken at three levels, (3mm, 6mm, and 9mm) from the apex. Instrumentation was done according to manufacturer’s instructions. Post-operative Micro-CT images were obtained and measurements were done.

The shortest distance from the canal wall to the external root surface was measured in the mesio-distal direction at 3mm, 6mm and 9mm from the apex. The calculation for canal transportation and canal centering ability was done according to formula given by **Gambill et al** and values were subjected to statistical analysis.

Conclusion

CONCLUSION

According to results of the present study:

1. Hyflex EDM and WaveOne GOLD performed best at all three levels in the root canals with less transportation and maximum canal centering ability.
2. There was no significant difference between Hyflex EDM and WaveOne GOLD
3. ProTaper Universal showed more transportation and less centered when compared to Hyflex EDM and WaveOne GOLD at all three levels.
4. ProTaper Universal showed positive transportation at 3 mm and 6 mm due to rigidity which may lead to canal straightening. Negative transportation at 9 mm due to greater taper which may lead to strip perforation.

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Annexures

ANNEXURE –I

RAGAS DENTAL COLLEGE & HOSPITAL

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TO WHOMSOEVER IT MAY CONCERN

Date: 6.1.2018

Place: Chennai

From
The Institutional Review Board,
Ragas Dental College & Hospital,
Uthandi,
Chennai – 600119.

The dissertation topic titled **"MICRO COMPUTED TOMOGRAPHIC EVALUATION OF CANAL TRANSPORTATION AND CENTERING ABILITY OF PROTAPER UNIVERSAL, HYFLEX EDM AND WAVEONE GOLD - AN INVITRO STUDY"** submitted by **Dr. ASHWIN .R** has been approved by the Institutional Review Board of Ragas Dental College & Hospital.

Dr. N.S. AZHAGARASAN, M.D.S.,
Member Secretary,
Institutional Review Board,
Ragas Dental College & Hospital,
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ANNEXURE –II

URKUND

Urkund Analysis Result

Analysed Document: thesis.pdf (D34879615)
Submitted: 1/21/2018 5:12:00 AM
Submitted By: ashwinr430@gmail.com
Significance: 3 %

Sources included in the report:

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