A Comparative Study to Evaluate Canal Transportation and Centering Ratio at Different Levels of Simulated Curved Canals Prepared by iRaCe, ProTaper NEXT and ProTaper Universal Files.

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Abstract: Background: Root canal preparation includes both shaping and enlargement of the endodontic space in conjunction with its disinfection, without any procedural error is of the utmost preference. Recently, in endodontic practice, the nickel-titanium instruments are used commonly for preparation of the root canal space. Nickel-titanium instruments are much more flexible than stainless steel files and have superior cutting efficiency. **Aim** of this study was to measure and compare the canal transportation and centering ability of iRaCe and ProTaper NEXT nickel titanium instruments with ProTaper Universal instruments in simulated curved canals at different levels and compare canal transportation and centering ability among different levels for each tested instrument. **Material and Methods:** Sixty simulated curved canals of 40°curvature were randomly divided into three groups of twenty canals each; the first group (group A) was prepared with iRaCe instruments, the second group (group B) was prepared with ProTaper NEXT instruments and the third group (group C) was prepared with ProTaper Universal instruments. The canals were prepared to an apical size 30 by crown-down instrumentation technique. Removal of material was measured at five different levels: at the canal orifice (O), half way to the orifice in the straight sections (HO); the beginning of the curve (BC); the crest of the curve (AC); the end point (EP). Pre- and post-operative photos of the simulated canals were taken in a standardized technique at magnification of 40X. An assessment of canal shape has been determined using Photoshop CC 2014 and AutoCAD 2014 software program. The data of canal transportation as well as centering ratio were analyzed statistically using Shapiro-Wilk, ANOVA and LSD tests. **Results:** the results of this study demonstrated that the iRaCe instruments showed a significantly less canal transportation and a significantly better centering ability than both ProTaper NEXT and ProTaper Universal instruments at all levels of measurements, followed by ProTaper NEXT instruments that showed a significantly less canal transportation and significantly better centering ability at all levels when compared with ProTaper Universal, while the ProTaper Universal instruments showed the highest values of canal transportation and the worst ability to stay centered in the canals at all levels. Considering the direction of canal transportation, the iRaCe instruments showed minimal transportation towards inner aspect of canal at coronal and at the apex of curve and towards outer aspect of canal at middle, beginning of curve and at the end point of the preparation, while ProTaper NEXT instruments were showed transportation usually towards the inner aspect of the canal at middle part of the canal and towards the outer aspect at coronal, beginning of curve, apex of curve and at the endpoint of the preparation, while ProTaper Universal files were usually towards the inner aspect at middle part of the canal and towards the outer aspect at coronal, beginning of curve, apex of curve and at the endpoint of the preparation. **Conclusion:** The study demonstrated that canal preparation with the three files of Ni-Ti instruments produced canal transportation. The iRaCe file showed less canal transportation and better centering ability than ProTaper Next and ProTaper Universal groups at all the five measuring levels, followed by ProTaper NEXT, while the ProTaper Universal files showed the least centering ability and increased straightening and canal transportation at all the five measuring levels especially at the apical portion of the canal.
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Key words: Canal transportation, centering ratio, iRaCe, ProTaper NEXT, ProTaper Universal.

1. Introduction

Root canal therapy is based on cleaning, shaping and sealing the root canal system (Torabinejad & Walton, 2009). The main objectives of root canal preparation are the removal of microorganisms from root canal system (Abou-Rass & Piccinino, 1982), as well as to produce a contentiously tapered funnel shaped canal with the smallest diameter at the apex and the widest diameter at the orifice without any procedural error (Mickel et al., 2003).

One of the common procedural errors that may occur during the preparation of the root canal space is transportation of the canal especially at the apical part; this condition is particularly true in canals that have evident curvature (Schafer & Vlassis, 2004; Hartmann et al., 2011). This procedural error can be defined as “unwanted shifting of canal's native shape to a new iatrogenic position’’ (American Association of Endodontists, 2003).

Development of nickel-titanium rotary instruments makes the root canal instrumentation easier and faster as well as has minimized the procedural errors such as ledge formation, zipping or canal transportation (Parashos & Messer, 2006, Ali et al., 2013).

Many manufacturers have incorporated different designs into their NiTi systems in order to minimize apical transportation and to achieve faster and more predictable canal preparation (Franco et al., 2011).

The iRaCe (FKG, La Chaux-de-Fonds, Switzerland) NiTi rotary files have been recently introduced as a simplified sequence of the RaCe system (FKG) (Sashidhar et al., 2014). The iRaCe instruments have a similar design features as RaCe instruments and have undergone the same surface treatment (Pramod et al., 2014). It is claimed by the manufacturer that this new sequence provides a quick, safe and effective protocol for preparation of curved root canals (Kamel et al., 2013).

ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) is a relatively new system. PTN instruments are made of M-wire, a unique NiTi alloy manufactured by a thermal treatment process that reportedly increases flexibility and resistance to cyclic fatigue (Ye & Gao, 2012). These instruments incorporate a variable regressive taper design, unique offset mass of rotation, and rectangular cross section, which according to the manufacturer are designed to reduce points of contact with the canal walls generating less fatigue in the instrument during use (Arias et al., 2014).

The ProTaper Universal (Dentsply, Maillefer, Switzerland) is made from the conventional nickel-titanium wire and has been used widely for root canal preparation as well as it is considered as the standard with which other new NiTi rotaty file are compared (Aguiar et al., 2009, Anil et al., 2014). The manufacturers of this system claimed that these files are particularly designed to prepare difficult curved root canals (Wu et al., 2011). The ProTaper Universal system is composed of three shaping and three finishing files. The ProTaper files possess a triangular cross-sectional design feature that reduces the area of contact between the file and the canal walls, also these instruments have what so called “minimally aggressive cutting tip” (Schirrmeister et al., 2006).

The purpose of this study is to compare canal transportation and centering ability of iRaCe and ProTaper NEXT nickel-titanium instruments with ProTaper Universal nickel-titanium instruments during shaping of simulated curved root canals in resin blocks.

2. Materials and Methods

Sixty readymade simulated curved canals made from clear polyester resin of.02 taper (Endo bloc., Dentsply, Maillefer, Switzerland); were used in this study to evaluate the instrumentation. The taper and diameter of all simulated curved canals were equivalent to a standard ISO size 10 root canal instrument.

The sixty simulated canals were 16 mm long (from the beginning of the funnel), the straight part being 11 mm long while the curved part was 5 mm long.

By using AutoCAD 2014 software program, the curvature of the simulated canals were mathematically defined with a radius of 5.5 mm, this results in an angle of 40°as stated by Pruett et al., in 1997, which is a modification of Schneider’s method, in which two parameters were used to calibrate canal curvature more accurately than the Schneider’s method (Pruett et al., 1997).

Sample grouping

The sixty resin blocks were divided into three groups of 20 canals each. The first group (group A) was prepared with iRaCe, the second group (group B) was prepared with ProTaper NEXT and the third group (group C) was prepared with ProTaper Universal instruments (Figure 1). Before starting the work, the samples were numbered and named as pre- and postoperative samples; this was facilitated the producing of the pre- and postoperative images.

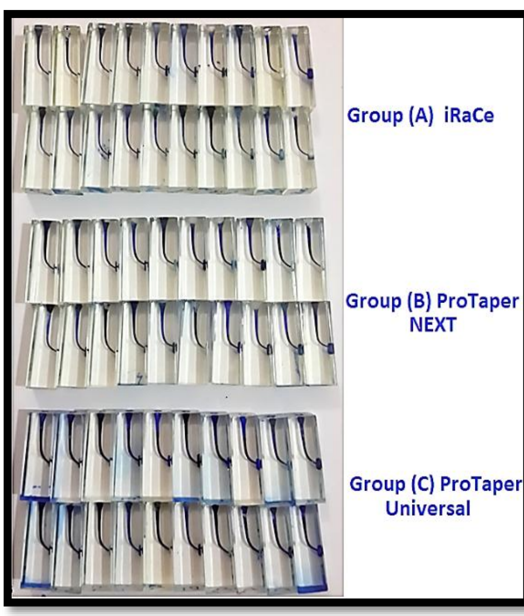


Figure (1): Sample grouping

Pre-operative preparation of the artificial canals:

Prior to preparation of the simulated canals, the first penetration was carried out with #10 K-file to the entire working length (i.e. 15 mm, to simulate natural teeth 1mm of the 16 mm of simulated canals length was shortened). Patency of simulated canals was examined by the same size before the preparation and assured after each sequence.

Before instrumentation of the simulated canals, each canal has been injected with a drawing ink using an irrigation syringe of 27 gauge needle, for enhancing the color contrast of the images of the simulated canals (Figure 2).

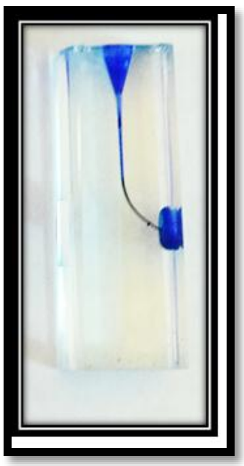


Figure 2: Simulated canal filled with a drawing ink before preparation

After injecting the canals with drawing ink and before instrumentation of the canals, each simulated canal were magnified 40X using stereomicroscope, then preoperative images of the canals were taken in a standardized technique using a digital camera that was fixed above the eye's lens of the microscope. After the images have been captured, they stored in computer (Pentium 4) and named as “pre-operative images”.

For the purpose of obtaining a consolidated position for the resin blocks under the objective lens of the stereomicroscope, a holder has been made from hard teflon materials, with a hole made in its central area that exactly matches the dimensions of the resin blocks in order to allow the resin blocks to be repeatedly placed and repositioned in the same exact location every time (Mariush & Mahdi, 2013). The central hole has been wrapped with a transparent paper where the chosen five reference levels have been drawn on it, so the simulated canals can be easily measured, also to act as a guide for superimposition of the pre- and post-operative images (Figure 3). After the imaging procedure, canals were cleaned with distilled water, using disposable syringe of 27 gauge (Mariush & Mahdi, 2013).

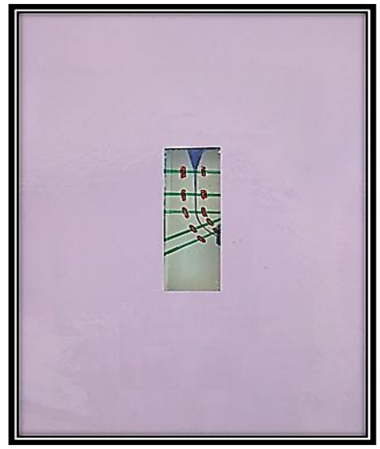


Figure 3: Artificial canal inside the teflon holder.

Instrumentation of the artificial canals:

The X-Smart Plus motor (Dentsply, Maillefer, Switzerland) was used with the all three NiTi systems for instrumentation of the artificial canals.

Before instrumentation, each file was dipped in a glycerin to act as a lubricant, and about 5 ml of distilled water has been used per canal for plentiful irrigation which performed over and over before as well as after the use of each instrument using disposable syringes with 27 gauge needles (Schäfer et al., 2006; Kassim & Al-Azzawi, 2012; Mariush & Mahdi, 2013).

The files were cleaned, after each application using a clean sponge stand in order to remove the resin debris. After preparation, the canal was irrigated with 5ml of distilled water to remove resin debris and dried with paper points.

All canals were enlarged to size 30. The sequences used in this study were following the manufacturer's instructions for each system as following:

Group A: **iRaCe endodontic instruments**

The iRaCe rotary instruments R1 (15/06), R2 (25/04) and R3 (30/04) were used to prepare the canals in a crown-down technique using 3 to 4 strokes according to the instructions of the manufacturers using gentle back and forth movements without using force to the full working length. The X-Smart Plus motor has been set into permanent rotation of 600 rpm and torque at 1.5 Ncm. This was within the range suggested by the manufacturers.

Each instrument was replaced after enlarging two canals or after a single use if deformation occurs to the instrument, this was within the range suggested by the manufacturers.

Group B: **ProTaper NEXT endodontic instruments**

The ProTaper NEXT X1 (17/04), X2 (25/06) file and X3 (30/07) rotary files were used in a crown-down technique using the X-Smart Plus motor that has been set into a permanent rotation at speed of 300 rpm, torque control of 2.0 Ncm (these settings are originally set in the X-Smart Plus motor for the ProTaper NEXT system as suggested by the manufacturers). The instrumentation procedure are accomplished using a light apical pressure in a brushing motion to the full working length according to the instructions of the manufacturers.

Each instrument was replaced after enlarging two canals or after a single use if deformation occurs to the instrument, this was within the range suggested by the manufacturers.

Group C: ProTaper Universal Endodontic Files

The ProTaper Universal instruments were used in a crown-down technique using 3 to 4 strokes according to the instructions of the manufacturers using a light in-and-out brushing movement. The X-Smart motor has been set into a permanent rotation at the speed 250 rpm and torque 3 Ncm for the shaping file SX (19/04) & S1(17/04), and speed 250 rpm and torque 2.0 Ncm for shaping files S2(20/04). While for finishing file F1 (20/07) the speed was 250 rpm and torque 1.5 Ncm and for finishing files F2 (25/08) & F3 (30/09) the speed was 250 rpm and torque 2.0 N.cm. These settings are originally set in the X-Smart Plus motor for ProTaper Universal system and were within the range suggested by the manufacturers. The SX file was used for 11 mm of the working length and the other files were used to the full working length.

Each instrument was replaced after enlarging two canals or after a single use if deformation occurs to the instrument, this was within the range suggested by the manufacturers.

Post-operative measurements

After completion the instrumentation, each simulated canal was injected again with a drawing ink then examined under 40X and the imaging process was repeated. At this experimental magnification, it was impossible to visualize the entire length of the simulated canal. One image on screen corresponded to 2 mm of the real canal length, so 8 images were needed to assemble the entire canal. Both X and Y coordinates on the microscope's nonius scale were recorded for each image, allowing repositioning and reproduction of the pictures at any given moment (i.e. pre- and postoperative) (Calberson et al., 2002, Kassim & Al-Azzawi, 2012; Mariush & Mahdi, 2013).

Adobe Photoshop CC 2014 program was used to gather all the 8 images of each canal (pre and pot-operative images) so the total length of canal was reproduced. The Pre- and postoperative digital images were stored in a Pentium 4 computer and by using Adobe Photoshop CC 2014 program, a composite image for each simulated canal was produced by superimposition of the pre- and post- instrumentation canal images (change in the opacity of the postoperative images) (Figure 4).

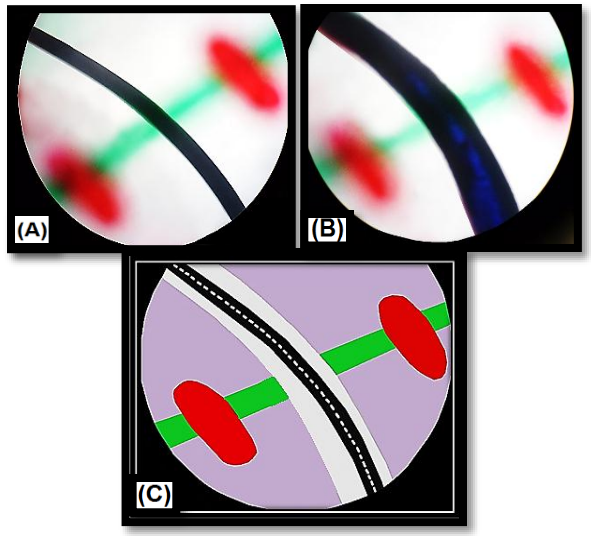


Figure4: An example of microscopic images of unprepared canal (A), prepared canal (B), and superimposed and treated images of unprepared and prepared canal using Adobe Photoshop software program (C).

By the help of Adobe Photoshop CC 2014 software program, the central line of the pre-operative canal was drawn. After that, measurements were obtained from the composite images of each block using AutoCAD 2014 software program. With aid of this program, the distance between the central line and the edge of pre-operative canal was measured on the inner curve (concave side) X1, and on the outer curve (convex side) Y1. Also the distance between the central line and the edge of the postoperative canal was measured on the inner curve (concave side) X2, and on the outer curve (convex side) Y2. Total width of the canal after preparation are also measured at tested levels.

The measurements were accomplished at five levels using a manner described by **Calberson et al.**, in **2002**, **Akhlaghi et al.**, in 2008 and **Mariush & Mahdi,** in 2013. All of the images have been captured from above the sample, thus all measurements had been taken at right angles to the surface of canal (Figure 5):

- **Point one (O):** the orifice of the canal.
- **Point two (HO):** the point half-way from the beginning of the curve to the orifice.
- **Point three (BC):** the point where the canal deviates from the long axis of its coronal portion and is called the beginning of the curvature.

- **Point four (AC):** the point where the long axes of the coronal and the apical portions of the canal intersect and called the crest of the curve.
- **Point five (EP):** the end point of preparation (at 15 mm of working length).

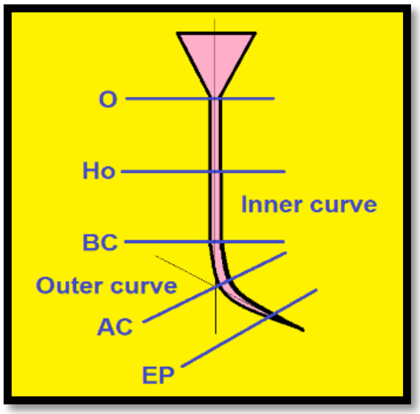


Figure 5: The five levels of measurement

After obtaining the measurements, the following formula was used to obtain a parameter:

β= D1- D2

Where; parameter **β** represent transportation of the filed canal.

D1(X2-X1): being the distance between the edge of the original (pre-operative) canal and the edge of the filed canal (post-operative) on concave side.

D2 (Y2-Y1): being the distance between the edge of the original (pre-operative) canal and the edge of the filed (post-operative) canal on the convex side.

A value thus obtained for the parameter (**β**), could be negative or positive, the negative value indicates a deviation of the long axis of the original canal toward the convex side of the filed canal (i.e. there is a transportation towards convex side), while the positive value indicates a deviation of the long axis of the original canal toward the concave side of the filed canal (i.e. there is a transportation towards concave side). The ideal result should be (0) presenting no shift of the long axis of filed canal.

The ratio of difference of the measurements of the concave and the convex parts of the post-operative canal was compared with the width of the filed canal (X2+Y2). The following formula was used to obtain a parameter of centering ratio **(Mariush & Mahdi, 2013)**:

Centering ratio= **[(D1- D2)/ D] × 100**

D (**X2** + **Y2**): being the width of the filed canal.

The smaller the ratio, the better the instrument remained centered in the canal. The data were analyzed statistically using ANOVA and LSD test.

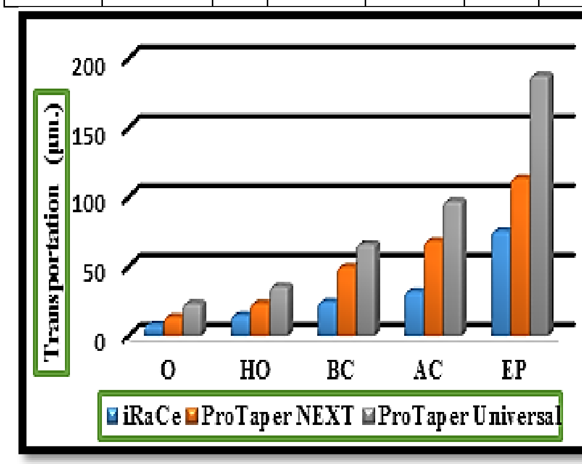
3. Results

Transportation

The results of the descriptive statistics which include the minimum, maximum, mean value, and standard deviation of transportation after instrumentation at five measuring levels in (µm) for the three groups are given in (Table 1) and (graph 1).

Table 1: Descriptive statistical results of transportation (µm.) after instrumentation for three groups at five levels.

Levels	Groups	N	Mean	S.D.	Min	Max
O	**A**	20	8.150	1.167	3	14
	B	20	13.650	1.720	9	19
	C	20	23.400	2.978	12	33
HO	**A**	20	14.950	1.170	10	20
	B	20	23.450	2.839	17	33
	C	20	35.750	3.941	23	57
BC	**A**	20	24.550	3.453	13	36
	B	20	49.750	3.385	37	65
	C	20	66.300	6.482	48	81
AC	**A**	20	31.950	4.370	22	45
	B	20	68.350	10.890	43	98
	C	20	96.950	9.473	81	118
EP	**A**	20	75.650	11.527	49	102
	B	20	113.60	11.843	93	141
	C	20	187.60	20.369	138	221



Graph 1: This graph showing the mean of transportation (µm.) for three groups at five measuring levels after instrumentation.

Table (1) showed that at all the five measuring levels, iRaCe (group A) showed the lowest mean values of transportation followed by ProTaper NEXT (group B), while the ProTaper Universal (group C) showed the highest mean values of transportation. The lowest mean value of transportation was showed by iRaCe at level (O) (8.150), while the highest value showed by ProTaper Universal at level (EP) (187.600).

The results of the inferential statistics using the Shapiro-Wilk test for testing the normality of data distribution of transportation after instrumentation for all groups at all levels showed that the data of transportation at each group in all levels are normally distributed, giving an indication that the data of transportation are parametric data, so the ANOVA test and LSD test could be used for comparison of the transportation among groups in each level as well as for comparison of the transportation among levels in each group. Analysis of variance (ANOVA) test was performed to identify the presence of any statistically significant difference among the means of canal transportation of all groups' at all five levels as shown in (Table 2). This table showed a highly significant difference among the three groups at all five measuring levels.

Table 2: Analysis of variance (ANOVA) test results of the transportation (µm.) after instrumentation for three groups at five levels.

Levels	ANOVA	Sum of Squares	d.f.	Mean Square	F-test	p-value
O	**Between Groups**	2385.83	2	1192.9	84.79	0.00 (HS)
	Within Groups	801.900	57	14.068		
	Total	3187.73	59			
HO	**Between Groups**	4374.53	2	2187.2	49.5	0.00 (HS)
	Within Groups	2513.65	57	44.09		
	Total	6888.18	59			
BC	**Between Groups**	17680.0	2	8840.0	139.6	0.00 (HS)
	Within Groups	3608.90	57	63.314		
	Total	21288.93	59			
AC	**Between Groups**	42452.8	2	21226.4	180.89	0.00 (HS)
	Within Groups	6688.45	57	117.341		
	Total	49141.2	59			
EP	**Between Groups**	129660.	2	64830.0	212.08	0.00 (HS)
	Within Groups	17424.1	57	305.68		
	Total	147084.183	59			

*HS P< 0.01

To evaluate the significant difference between each pair of groups at each level, the LSD test was performed and showed in (Table 3). This table showed a highly significant difference between group (A) and group (B) as well as between group (A) and group (C) and between group (B) and group (C) at all levels.

Table 3: LSD test results of canal transportation (µm.) after instrumentation at five measuring levels comparing the tested groups

Levels	Groups		Mean Difference	p-value
O	**A**	**B**	-5.500	0.000 (HS)
		C	-15.250	0.000 (HS)
	B	**C**	-9.750	0.000 (HS)
HO	**A**	**B**	-8.500	0.000 (HS)
		C	-20.800	0.000 (HS)
	B	**C**	-12.300	0.000 (HS)
BC	**A**	**B**	-25.200	0.000 (HS)
		C	-41.750	0.000 (HS)
	B	**C**	-16.550	0.000 (HS)
AC	**A**	**B**	-36.400	0.000 (HS)
		C	-65.000	0.000 (HS)
	B	**C**	-28.600	0.000 (HS)
EP	**A**	**B**	-37.950	0.000 (HS)
		C	-111.950	0.000 (HS)
	B	**C**	-74.000	0.000 (HS)

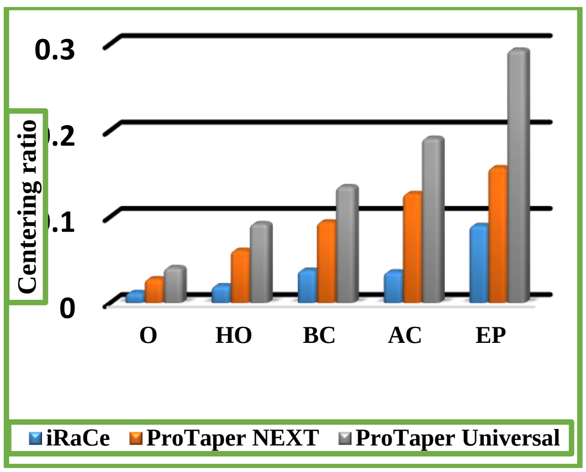
*HS P< 0.01

Centering Ratio

The results of the descriptive statistics that included the minimum, maximum, mean, and standard deviation values of the canal centering ratio at five measuring levels for the three groups in (%) shown in (Table 4) and (Graph 2).

Table 4: Descriptive statistical results of the canal centering ratio (%) after instrumentation for three groups at five levels.

Levels	Groups	N	Mean	S.D.	Min.	Max.
O	**A**	20	0.012	0.002	0.004	0.019
	B	20	0.028	0.006	0.011	0.039
	C	20	0.041	0.010	0.044	0.083
HO	**A**	20	0.020	0.006	0.009	0.031
	B	20	0.061	0.013	0.032	0.075
	C	20	0.092	0.011	0.072	0.119
BC	**A**	20	0.036	0.014	0.016	0.065
	B	20	0.094	0.023	0.069	0.106
	C	20	0.135	0.021	0.142	0.192
AC	**A**	20	0.038	0.008	0.033	0.079
	B	20	0.127	0.019	0.119	0.164
	C	20	0.191	0.039	0.189	0.292
EP	**A**	20	0.090	0.011	0.077	0.126
	B	20	0.157	0.030	0.162	0.195
	C	20	0.293	0.043	0.209	0.382



Graph 2: This graph showing the mean of centering ratio (%) for the three groups at five measuring levels after instrumentation.

Table (4) showed that at all the five measuring levels, iRaCe (group A) showed the lowest mean value of centering ratio followed by ProTaper NEXT (group B), while the ProTaper Universal (group C) showed the highest mean value of centering ratio. The lowest mean value of centering ratio was showed by iRaCe at level (O) (0.012), while the highest value showed by ProTaper Universal at level (EP) (0.043).

The results of the inferential statistics using Shapiro-Wilk test for testing the normality of distribution of the data of the centering ratio for all groups at all measuring levels showed that the data of centering ratio at all levels in the three groups are normally distributed, giving an indication that the data of centering ratio are parametric data, so that the ANOVA test and LSD test could be used for comparison of the centering ratio among groups in each level, as well as for comparison of the centering ratio among levels in each group.

Analysis of variance (ANOVA) test was performed to identify the presence of any statistically significant difference among the means of centering ratio of all groups' at all five levels as shown in (Table 5). This table showed a highly significant difference among the three groups at all five measuring levels.

Table 5: Analysis of variance (ANOVA) test results of centering ratio (%) after instrumentation for three groups at five levels.

Levels	ANOVA	Sum of Squares	d.f.	Mean Square	F-test	p-value
O	**Between Groups**	0.008	2	0.004	58.63	**0.00 (HS)**
	Within Groups	0.004	57	0.000		
	Total	0.013	59			
HO	**Between Groups**	0.052	2	0.026	111.5	**0.00 (HS)**
	Within Groups	0.013	57	0.000		
	Total	0.065	59			
BC	**Between Groups**	0.095	2	0.047	61.6	**0.00 (HS)**
	Within Groups	0.044	57	0.001		
	Total	0.138	59			
AC	**Between Groups**	0.242	2	0.121	186.0	**0.00 (HS)**
	Within Groups	0.037	57	0.001		
	Total	0.279	59			
EP	**Between Groups**	0.430	2	0.215	226.2	**0.00 (HS)**
	Within Groups	0.054	57	0.001		
	Total	0.484	59			

***HS P<0.01**

To evaluate the significant difference between each pair of groups at each level, the LSD test was performed and showed in (Table 6). This table showed a highly significant difference between group (A) and group (B) as well as between group (A) and group (C) and between group (B) and group (C) at all levels.

Table 6: LSD test results of centering ratio (%) after instrumentation at five levels comparing the tested groups

Levels	Groups		Mean Difference	p-value
O	**A**	**B**	-0.016	0.000 (HS)
		C	-0.029	0.000 (HS)
	B	**C**	-0.013	0.000 (HS)
HO	**A**	**B**	-0.041	0.000 (HS)
		C	-0.072	0.000 (HS)
	B	**C**	-0.030	0.000 (HS)
BC	**A**	**B**	-0.055	0.000 (HS)
		C	-0.097	0.000 (HS)
	B	**C**	-0.042	0.000 (HS)
AC	**A**	**B**	-0.091	0.000 (HS)
		C	-0.155	0.000 (HS)
	B	**C**	-0.064	0.000 (HS)
EP	**A**	**B**	-0.067	0.000 (HS)
		C	-0.203	0.000 (HS)
	B	**C**	-0.136	0.000 (HS)

***HS P<0.01**

4. Discussion

It is well known that when curvatures are present, root canal preparation becomes more difficult, and there is a tendency for all preparation techniques to divert the prepared canal away from the original axis (Javaberi & Javaberi, 2007). Transportation of root canal can be defined as "the undesirable deviation of canal's original shape to a new iatrogenic location" (Gluskin, 2006).

Difficulty in getting back the true shape of the root canal usually will lead to incomplete cleaning and shaping and over-cutting of the radicular dentine in one or two of the canal walls (Paqué et al., 2005). Transportation of the apical part of the canal that is more than 0.3 mm could endanger the results of the treatment due to the considerable reduction in the sealing efficiency of the root canal filling material (Wu et al., 2000).

The goals of this study were to determine and compare the canal transportation and centering ability using two rotary NiTi systems, iRaCe and ProTaper NEXT with the rotary ProTaper Universal system in simulated curved canals of 40° curvature at different levels. The ProTaper Universal was included in this study because it is the standard that is usually used to evaluate the new rotary NiTi files in comparative studies.

When comparing the shaping abilities of different instruments, it is important to have a similar apical preparation diameter (Bergmans et al., 2003). In this study the final apical preparation was set to size 30 in each group and no glide path was created prior to instrumentation to ensure comparability between the groups, also to simulate the clinical status when larger preparations could increase the risk of canal transportation and unwanted undermining of the tooth structure, while smaller preparations could neglect remnants of infected pulpal tissue and infected debris behind (Schäfer & Dammaschke 2009; Metzger et al., 2013).

Simulated curved canals in resin blocks were used in this study because it is advocated for reproducibility and standardization of the experimental design (Ahmad, 1989; Zohreh et al., 2008; Sebastian et al., 2014).

Together simulated canals in resin blocks and human extracted teeth were used for the analysis of canal transportation. The major advantage of extracted human teeth is to reproduce the clinical situation. However, it is difficult to standardize some variables such as root canal length and width, dentine hardness, calcification and pulp stones, location and nature of canal curvatures (Hülsmann et al., 2005). On the other hand, simulated resin root canals allow standardization of degree, location and radius of root canal curvature in three dimensions as well as the tissue hardness and the width of the root canals (Sebastian et al., 2014).

Nevertheless, some concern has been expressed regarding the differences in hardness between dentine and resin. Micro-hardness of dentine has been measured as 35-40 kg/mm^2 near the pulp space, while the hardness of resin materials used for simulated root canals is estimated to range from 20 to 22 kg/mm^2 depending on the material used (Schäfer & Vlassis, 2004; Burroughs et al., 2012).

Superimposition techniques of pre- and post-operative root canal outlines can be easily applied to simulated canals, thus facilitating measurement of deviations at any point of the canals using PC-based measurement. So, this model guarantees a high degree of reproducibility and standardization of the experimental design (Bonaccorso et al., 2009; Etevaldo et al., 2015).

In this study torque limited electric motor (X-smart plus motor) was used for instrumentation of the canals that can be set for various types of rotary instruments and is able to rotate the instrument in an inverted direction when the instruments is locked in the canal to prevent the fracture of the instrument (Zarei et al., 2013).

The findings of this study displayed that all of the three systems showed a trend to straighten the canals; yet it was the iRaCe system who preserved the best rate of shaping among the inner/outer walls over the total length of the simulated curved canals (i.e. values closest to 0) than that of the ProTaper NEXT and ProTaper Universal instruments.

The above findings are in agreement with other recent studies such as Kamel et al. in 2013 and Saber et al. in 2014. These observations could be related to the following reasons: first reason could be attributed to the difference in taper of the last instrument used for the preparation (4% for iRaCe vs. 7% for ProTaper NEXT, 9% for ProTaper Universal), when the taper increases, the instrument flexibility will be reduced increasing the risk of canal straightening (Saber et al., 2014). Second reason that the iRaCe instruments demonstrated a better shaping ability can be explained by their small cross-sectional area, which increases their flexibility and gives more space for debris removal (Sashidhar et al., 2014). Third reason is probably due to iRaCe design with altering straight and twisted areas along the instrument shank together with simple triangular cross section may eliminate screwing effect that might have a beneficial impact on the shaping ability of iRaCe. This design feature is claimed to prevent the screwing in effect thus reducing intra-operative torque values **(**Kamel et al., 2013; Adrija et al., 2015).

In this study the ProTaper Next instruments came in the second order when scored the second best results after iRaCe instruments regarding canal transportation and centering ratio. The PTN showed a significantly less canal transportation and a significantly better centering ability when compared with PTU at all the five measuring levels, these findings are in agreement with other recent studies Anil et al., 2014; Dhingra et al., 2014; Capar et al., 2014 and Hui et al., 2015. These findings could be related to the following reasons:

First reason is the off-centered cross-section of PTN which is rectangular in shape resulting in asymmetric motion. The asymmetric motion, results in only two edges of PTN instrument are in contact with canal wall at time, leads to an efficient canal preparation. Also the rotation of the off-centered cross-section creates an enlarged space for debris removal, optimizes the canal tracking and reduces binding (Pereira et al., 2013; Ismail et al., 2014; Elnaghy et al., 2014).

Second reason could be related to the increased flexibility of PTN file because of PTN system is made up of the M-wire Ni-Ti technology that is formed by a characteristic thermo-mechanical processing (it consists of the three crystalline phases, which are the deformed and micro twinned martensite, R-phase, and austenite phase) (Ye & Gao, 2012; Pereira et al., 2013). So this make the PTN instrument more flexible than PTU files as well as there is an increased resistance to cyclic fatigue. These findings are supported by previous studies Pongione et al., 2012;

Pereira et al., 2013 and Hui et al., 2015 that compared transportation by M-wire systems with those made of conventional NiTi.

In this study the ProTaper Universal sequence came in the last order regarding canal transportation and centering ratio at the five measuring levels which produced the highest resin removal at all the five measuring levels when compared with IR and PTN systems especially from the outer part of the curvature. The results obtained for PTU in the present investigation were comparable in terms of canal straightening with other studies that compare PTU with other NiTi systems, like Sonntag et al. 2007, Silva et al., 2009; González et al., 2012; Mariush & Mahdi 2013; Anil et al., 2014 and Hui et al., 2015. These findings could be related to the following reasons:

First reason is probably related to the large instruments that are passed through the major foramen. This might be explained by the tapers of the PTU instruments, the amount of the taper is one of the primary factors concerned in root canal transportation, because when the taper increases, the instrument flexibility will be reduced (Yang et al., 2007), this finding is supported by previous studies Kunert et al., 2010; Madureira et al., 2010; and Grazziotin et al., 2011. The shaping file F3 produced higher deviation in the apical area as a result of this instrument's increased taper (9%), because when the taper increases by (9%), the diameter of an F3 shaping instrument changed from 0.30 to 0.57 mm at the tip to 3 mm at the end, diminishing the flexibility of this instrument, this is supported by a recent study made by Manoel et al., in 2014.

Second reason for these unwanted effects could be related to the greater number of PTU files used for canals preparation together with the rotary movement that had been tested to be less effective in preserving the radicular curvature of canals (Giuliani et al., 2014; Etevaldo et al., 2015).

Third reason could be related to the cross sectional design of the PTU finishing file F3 (the cross section of F3 blades changes from U-shaped flutes in ProTaper to a triangular concave shape with a shallow U-shaped groove in ProTaper Universal), that results in the concentration of the pressure of the cutting edges on the canal wall, which probably result in increased risk of straightening of canal curvature during canal preparation (Aguiar et al., 2009; Câmara, 2009; Wu et al., 2011).

Fourth reason could be related to the sharp cutting flutes of PTU instruments (the system had no radial land). Radial lands are especially effective in supporting the edge of the cutting angle and reducing canal transportation because they help to distribute the pressure of the blades more uniformly around the circumference of a curved canal (Koch & Brave, 2002; Young et al., 2007). This is in contrast to files that lack radial lands, which concentrate all the pressure of the cutting edges on the canal wall and tend to straighten the curvature (Martins et al., 2012; Zanette et al., 2014).

Fifth reason, could be related to the flexibility of the files, shaping files S1 and S2 of the PTU showed greater flexibility when compared with the finishing instruments, this is reported by study made by Grazziotin et al., in 2011, this can be explained by the fact that the shaping instruments have increased flexibility at the tip because of their increasing conicity along the shaft (Bergmans et al., 2003; Grazziotin et al., 2011). Câmara et al., in 2009 recorded that one of the primary changes occurred in the ProTaper Universal system compared to ProTaper system was an increased in the flexibility of F1 and S1 files. However, the authors observed a decrease in this property in instruments F2 and F3 (Câmara et al., 2009;), this is further supported by other recent studies Kunert et al., 2010 & Pongione et al., 2012. This reality may help explain the results of this study.

Regarding the direction of canals transportation, this study demonstrated that at the apical part of the canals all the NiTi systems demonstrated an outer transportation. The main cause of this could be related to the shape memory of NiTi wire, when it is flexed at the curved part of the canal it will always try to straighten itself inside the canal. This will cause unbalanced lateral forces along walls of the canal resulting in an increased risk of ledge formation or unnecessary excessive removal of tooth structure and poor cleaning at inner apical part canal (Gluskin et al., 2006). While at the straight part of canals the PTN and PTU demonstrated an inner transportation, this could be related to the brushing movement in outward brushing strokes in lateral direction (Anil et al., 2014).

5. Conclusion:

1. The study demonstrated that canal preparation with the three files of Ni-Ti instruments produced canal transportation.
2. The iRaCe file showed less canal transportation and better centering ability than ProTaper Next and ProTaper Universal groups at all the five measuring levels.
3. The ProTaper Next file showed less canal transportation and better centering ability than ProTaper Universal files at all the five measuring levels.
4. The ProTaper Universal file showed the least centering ability and increased straightening and canal transportation at all the five measuring levels especially at the apical portion of the canal. Therefore, the ProTaper Universal files should be used with care

to avoid excessive removal of resin and consequently dentine in curved canals.

5. In all rotary file system sued in this study, the greatest canal transportation and least centering ability was at the apical portion of the canal, and the least canal transportation and the best ability to stay centered was recorded in the coronal third (orifice).

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