

EFFICACY OF RECIPROC R40 AND REVO-S IN PREPARATION OF OVAL ROOT CANALS- AN EX-VIVO CONE BEAM COMPUTED TOMOGRAPHY STUDY

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ABSTRACT

Aim: To evaluate the efficacy of Revo-S and Reciproc R40 NiTi files in preparation of oval root canals using Cone Beam Computed Tomography (CBCT).

Methodology: Forty extracted single rooted premolars were divided into 2 groups ($n=20$). Group 1 (R-S) were prepared with Revo-S up to size #40/.06. Group 2 (R40) were prepared to the same size with a single file R40. Pre- and post-instrumentation CBCT scanning was done. Calculated parameters were: increase (D) in canal volume and surface area. Transportation, centering ability, and untouched canal areas were tested at 3, 6, 9 mms axial sections. Statistical analyses were made using Mann-Whitney U and Friedman's test ($P \leq 0.05$).

Results: Significant increase in D volume ($P = .000$ and $P = .003$ for R-S and R40 respectively) and D surface area ($P = 0.048$ and $P = 0.038$ for R-S and R40 respectively) was found for both instrumentation kinematics with no significant differences between them. Canals' transportation and decreased centering ratio were detected in both groups at all tested levels with insignificant smaller values in the M-D direction. Exception was found at 9mm level where a significantly highest transportation was found in R-S group ($P = 0.022$). Both instruments left untouched canal areas which were insignificantly greater in R-S group ($26.5 \pm 8.93\%$ for R40 and $31.7 \pm 4.96\%$ for R-S).

Conclusions: The tested systems caused small canal transportation with a comparatively better centering for Reciproc R40. Irrespective of the instrumentation kinematic, circumferential preparation of oval canals remains an inherent incapability. CBCT is a valuable tool allowing calculation of the canals' volume.

KEY WORDS: Instrumentation kinematics, Oval root canals, Computed tomography, Root canal volume, Revo-S, Reciproc.

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INTRODUCTION

Three dimensional cleaning and shaping of root canals is an important step that should be effectively and efficiently done to guarantee three-dimensional obturation and hence successful outcome of root canal treatment (Peters et al. 2001, Hülsmann et al. 2005). This target will never be achieved except with a competently shaped canal along its entire perimeter and length that follow and respect its original geometry (Peters et al. 2001, Jungmann et al. 1975, Ding-ming et al. 2007). The introduction of rotary NiTi instruments along with the crown-down instrumentation techniques allowed canals' instrumentation with lower shaping errors or mishaps; like transportations, ledges, or perforations (Garip & Günday 2001, Weiger et al. 2002, Shahriari et al. 2009, Vaudt et al. 2009, Li et al. 2011). This is due to its inherent super-elasticity and the various design features, modifications, and heat treatments (Shen et al. 2013, Lopes et al. 2013). However, instruments specific design features resulted in different capabilities in performance (Peters et al. 2001, Peters et al. 2003, Hashem et al. 2012, Celik et al. 2013).

Reaching to all canal recesses remained an inherent inability with most of the instrumentation techniques (Li et al. 2011, Peters et al. 2003, Wu et al. 2000, Grecca et al. 2007, Paqué et al. 2009, Paqué et al. 2011). Oval and long oval canals represent a challenge for complete anatomic enlargement (Grecca et al. 2007, Zmener et al. 2005, Grande et al. 2008, Taha et al. 2010, Paqué et al. 2010). Jou et al. (2004) defined oval canals as having a maximum diameter twice that of the minimum diameter while long oval canals as having a maximum diameter of double this ratio. An un-instrumented canal area was reported in most previous studies to range from 4% to 83% (Li et al. 2011, Paqué et al. 2009, Paqué et al. 2010, Wu & Wesselink 2001, Grande et al. 2007, Elayouti et al. 2008, Peters & Paqué 2011). Unfortunately, this jeopardizes effective removal of

infected dentin and tissue remnants. Lateral brushing action was recently advocated as a complement of rotary instrumentation (Peters & Paqué 2010).

Revo-S system (RS; Micro-Mega, Besancon Cedex, France), is an example of a modified design NiTi instrument system that was presented with claims to revolutionize and maximize root canal instrumentation with its snake-like movement (Diemer & Mallet 2008). This is owed to its asymmetric cross section with a reported increased flexibility, centering ability, and minimum transportation as claimed by the manufacturer. Most importantly, its design allows brushing motion to be done on the lateral canal walls to complete circumferential instrumentation of oval canals geometries. However, literature survey revealed that few studies were conducted on the effectiveness of this instrument system during preparation of oval and long oval canal. Even the few reported researches which were done on curved canals; presented contradictory results (Peters et al. 2003, Aguiar et al. 2012).

The single file concept was raised lately to complete the root canal preparation with one file only (Yared 2008). The Reciproc instrument (VDW GmbH, Munich • Germany) was presented along with the modified balanced force reciprocation movement with claims of simplicity, efficiency, and drastic reduction in instruments' separation together with minimization of cross infection. It is made from M-Wire which was reported to impart greater resistance to cyclic fatigue and greater flexibility than traditional nickel-titanium (Burklein et al. 2012). The system is presented as a pre-sterilized, non autoclavable instrument suitable also for lateral brushing action (Yared 2008). Three sizes are available that suits various canal initial sizes, namely, R25, R40, and R50. Whether this revisited balanced force instrumentation technique (Roane et al. 1985) will be able to completely and efficiently shape the oval canals three dimensionally using one single file

is needed to be investigated. Various studies were conducted using R25 (Burklein et al. 2012, De-Deus et al. 2013). To our knowledge, the efficacy of reciprocation using Reciproc R40 as compared to continuous rotation in shaping of medium size oval canals was not yet investigated. Therefore, the aim of this study was to test the efficacy of Reciproc R40, reciprocating NiTi single file and the Revo-S NiTi full rotary system in shaping of oval canals using cone-beam computed tomography (CBCT).

MATERIALS AND METHODS

Teeth selection:

Freshly extracted human single rooted mandibular premolars were used in the study. Teeth were selected to possess a single canal of type I (Vertucci 1984); as verified radiographically and canal curvature from 5°-10° (Schneider 1971). Teeth were shortened to a standard length of 18mm and accessed using diamond burs. Canals were scouted with size #20 at the apex. Specimens that accommodated size 20 Stainless Steel K-files (Dentsply Maillefer) were used in the study. Teeth were arranged in an upright position in a specially constructed mold and pre-scanned using CBCT "i-CAT" imaging system (Imaging Science International, Hatfield, PA). The field of view size was 16 cm diameter and 4 cm height. The scanning time was specified as 26.9 seconds. The operating parameters were 120 kV, and 5 mA with slice thickness of 0.125 mm. From the acquired axial 2D images; maximum and minimum canal diameters at 6 mm from the root apices were measured using the measure length tool of the in-vivo5 soft ware (Anatomage, USA). Only teeth with a bucco-lingual to mesio-distal diameter \geq to 2 times were kept for the study.

Forty teeth that possessed all the inclusion criteria were divided randomly into two equal groups of twenty teeth each ($n = 20$) namely, group R-S and group R40 for Revo-S and Reciproc

R40 instrumentation respectively. Root canals of both groups were negotiated using size number 10 Stainless Steel K-files until it appeared flush with the apex as shown through a fixed distance magnifying lens. Working lengths were adjusted at one millimeter shorter than that length and recorded.

Teeth samples instrumentation:

Teeth samples were instrumented while in their place in the molds. One operator did the whole instrumentations without accessing the pre-instrumentation CBCT 3D images. Teeth of each group were instrumented with the respected system in a crown down manner with a strict following of the manufacturer's directions. The VDW motor (VDW.SILVER® RECIPROC® GmbH, Munich Germany) was used in both groups after adjusting the mode to the Revo-S using the DR's CHOICE for the R-S group (300 rpm/1.5 Ncm) and to RECIPROC ALL for the R40 group.

Revo-S instrumentation:

Canals of group R-S were prepared with the full sequence of Revo-S files. This started by the SC1 (#25/.06 taper) to the canals' coronal 2/3 in a gentle downward movement. The SC2 (#25/.04 taper) was then carried to the full canal length with a progressive 3 wave movements. This was followed by the SU shaper finishing file (#25/.06 taper) to the full working length also in a gentle downward movement. The three apical shapers: AS (#30, #35, and #40 with tapers .06) were used to complete apical preparation to a standard final apical size of #40/.06 taper.

Reciproc R40 instrumentation:

In group R40, canals were prepared using a single file size R40 (#40/.06 taper). The Reciproc instrument was introduced at the canal orifice then moved utilizing a light pressure in an in and out pecking motion taking care not to exceed amplitude of 2mm. Instrument was removed after 3 in-and

out movements (3pecks) to be cleaned with sterile gauze before re-introduction in the canal. This shaping movement was continued until full working length has been reached as recommended by the manufacturer.

During canals instrumentation in both groups; files were removed from the canals once the working length was reached. Apical preparation was completed to a final apical size of #40/.06 taper for group R-S and to #40/.06 taper for group R40. This was followed by four brushing strokes (2 to the buccal and 2 to the lingual) one mm shorter than the working length. Throughout the instrumentation canals were irrigated with 2.5% sodium hypochlorite using side vented 27-G needle (Patterson® Dental). This totaled 7ml of sodium hypochlorite volume irrigation for each canal. New set of instruments was used after preparation of three canals.

Pre- and Post-instrumentation CBCT image acquisition and analysis:

Pre- and post-instrumentation acquired data were measured and compared using the images analysis software as follows:

Increases in volume and surface area

Canals volume and surface area were calculated from the 3D reconstruction data using mimics software (Materialize, USA). The volume of interest was taken from the buccal cemento-enamel junction to the root apex. Using the segmentation module on the software, threshold was calculated for each tooth (-1000 – 100 HU) and cropping was performed at each tooth to create a mask for each root canal individually. After segmentation the volume and surface area of segmented canals were calculated pre- and post-instrumentation. The differences were calculated as the increase in canals' volume (D) and (D) surface area.

Untouched canal areas

This parameter was tested by calculation of untouched canal areas at three pre-determined

axial sections, namely, 3, 6, and 9mm from the root apex using the explorer tool. Resultant matched axial cross section images of the pre- and post-instrumented canals were given different colors and superimposed using Adobe photo-shop software. Un-instrumented areas were then automatically calculated and expressed as percentages.

Canal transportation calculation

Amount of canal transportation was calculated in the mesio-distal (M-D) and the bucco-lingual (B-L) directions following Gambill's et al. (1996) formula: (M1-M2) - (D1-D2) and (B1-B2)-(L1-L2) at the three predetermined root cross section levels namely; 3mm, 6mm, and 9mm from the apex. M1 represented the shortest thickness of the un-instrumented canal cross section at the mesial, while M2 represented the shortest thickness of the counterpart instrumented canal's same cross section at the mesial (figure 1). Similarly, D1 represented the shortest thickness of the un-instrumented canal at the distal; while D2 represented the shortest thickness of the instrumented canal at the same cross section to the distal. When the calculated transportation was positive it means that the transportation is towards the mesial side. A negative transportation means that the transportation is towards the distal side (Gambill et al. 1996). Same is true for the direction of transportation bucco-lingually.

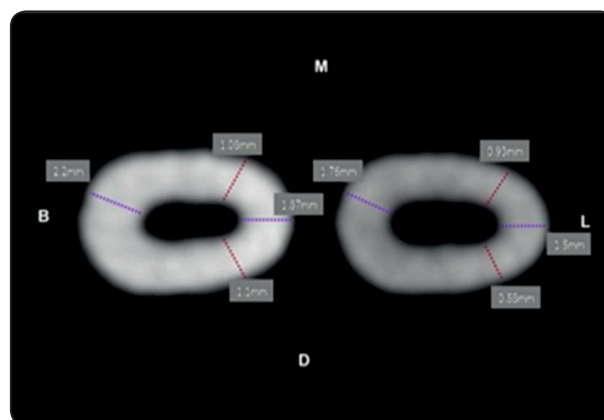


Fig. (1) CBCT dentin thickness measurements taken in a prepared canal calculating transportation and centering ratio values.

Centering ratio calculation

Centering ability was calculated for each pair of root canal sections (pre-and post-instrumented) at the three predetermined root cross section levels namely; 3mm, 6mm, and 9mm from the apex using the following ratio⁽³⁸⁾: (M1-M2) / (D1-D2) or (D1-D2) / (M1-M2) for the mesio-distal direction and (B1-B2) / (L1-L2) or (L1-L2) / (B1-B2) for the bucco-lingual direction. Accordingly, a “zero” value denoted absence of canal transportation, a positive value denoted transportation in the buccal or mesial directions. A negative value denoted transportation in the lingual or distal (Gambill et al. 1996).

Statistical Analysis

Results of each tested parameter were tabulated and subjected to statistical analysis using IBM (IBM Corporation, NY, USA) SPSS statistics Version 20 for Windows. Numerical data were presented as mean and standard deviation (SD) values. Mann-Whitney U test was used for comparisons between the two groups. Friedman’s test was used to compare between axial root sections. Wilcoxon signed-rank test was used for pair-wise comparisons between axial root sections when Friedman’s test was significant. The significance level was set at $P \leq 0.05$.

RESULTS

Increase in canal volume, surface area as well as the percentages of un-instrumented areas are presented as means and standard deviations (SD) in table 1.

Canal volume and surface area

Canal volume increased significantly after instrumentation with R-S and R40 groups ($P= 0.000$ & 0.003 respectively). The mean increase in canal volume for the studied groups was found to be comparable with no statistical significant difference between them ($P = 0.570$).

Both R-S and R40 instrumentation groups resulted in a significant increase in canal surface area ($P= 0.048$ & 0.038 respectively). On the other hand, there was no statistically significant difference between the two groups ($P = 0.261$).

Untouched canal areas

The two tested instrumentation kinematics left untouched canal areas which were slightly greater in R-S group as compared to the R40 one (31.6% and 26.5% respectively). However, the difference was statistically insignificant ($P=0.147$).

Canal transportation:

Results of canal transportation are presented in table 2. Various degrees of canal transportation were found in the two experimented groups at all studied levels. Transportation ranged from .021mm to .073mm in the R-S group, and from .002mm to .084mm in the R40 group. No statistically significant differences were detected between the studied groups in the amount of transportation at 3 and 6mm levels in both MD and BL directions. At 3mm level, transportation occurred to the mesial and lingual directions in RS as well as R40 groups.

TABLE (1) Mean \pm SD of volume increase, surface area increase, and un-instrumented canal areas.

Evaluation	R-S (n=20)	R40 (n=20)	P value
D Volume (mm ³)	4.016 \pm 1.63	4.386 \pm 1.44	.570
D Surface area (mm ²)	8.600 \pm 2.22	7.070 \pm 3.41	.261
Un-instrumented area %	31.625 \pm 2.96	26.500 \pm 1.93	.147

At 6mm level, in the MD direction, comparable transportation values were recorded for RS and R40 groups (0.020 ± 0.022 and 0.018 ± 0.011 respectively) in the same direction mesially. However, in the BL direction, transportation direction differed in the RS group where it occurred to the buccal. At 9mm level, greater transportation values were recorded for the RS group as compared to the R40 group ($-0.073 \pm .025$ and $- .002 \pm .08$ respectively) in the MD direction. This difference was statistically significant ($P= .022$). Transportation in both groups was to the distal direction. However, in the BL direction, no statistically significant differences were detected between RS and R40 groups ($P=.331$). Transportation direction was to the lingual in both tested groups.

Centering ratio:

Centering ratio values are presented in table 3. Centering ratio was lower than 1 in both groups at all tested levels with no significant differences between them at 6mm and 9mm from the apex in either the MD or BL directions. The lowest mean centering ratio was recorded for the R-S group in the BL direction at 3 mm level ($.31 \pm .22$). This value was found to be significantly different from that of R40 group at the same level and direction. Generally, centering ratio diminished towards the apical third of the root in both tested groups.

It worth mentioning that, in the present study, no instrument separation was found during either preparation with Revo-S or Reciproc instruments.

TABLE (2) Statistical analysis of canal transportation values (mm) in the MD and BL directions at the three tested canal levels.

Root level		R-S	R40	Mann-Whitney U test (P value)
MD	3mm	.021± .017	.010±.016	.616
BL		- .041±.019	- .084±.026	.174
BL	6mm	.020± .022	.018±.011	.117
MD		.021 ±.023	- .073±.021	.674
BL	9mm	- .044±.024	- .060±.027	.331
MD		- .073±.025	- .002±.080	.022*

**Denotes statistical significance*

TABLE (3) Statistical analysis of centering ratio values in the MD and BL directions at the three tested canal levels.

Root level		R-S	R40	U test (P value)
MD	3mm	.44 ± 0.30	.46 ± 0.30	.801
BL		.31 ± 0.22	.53 ± 0.27	.011*
MD	6mm	.71 ± 0.19	.64 ± 0.28	.563
BL		.47 ± 0.28	.58 ± 0.23	.193
MD	9mm	.64 ± 0.29	.62 ± 0.31	.819
BL		.56 ± 0.32	.63 ± 0.26	.557

**Denotes statistical significance*

DISCUSSION

The introduction of NiTi rotary systems has revolutionized root canals' instrumentation both in quality and time of preparation. Reported advantages are rapid efficient preparation, better shaping and centering ability, less transportation, and more standard preparation size. However, as revolving gyratory instruments, they have a tendency to remain centralized in the canals irrespective of the original canal shape. This might result in un-instrumented surfaces jeopardizing treatment outcome. Many studies have reported the inability of rotary instrumentation to reach all dentinal walls in oval-shaped root canals. Again, trials to intentionally increase the preparation size to include all the canals' perimeter might result in thinning and / or perforation. Circumferential filing was the classic method for hand instrumentation of oval canals coronal to the minor diameter region (Wu et al. 2003). Effectiveness of NiTi instrument during canal shaping and circumferential brushing was noted to be a function of its active part design (Diemer et al. 2013). Larger canal sizes needs to be prepared with larger NiTi instruments. Here differences between instruments' designs, cross section shape, and movement kinematics will materialize. Asymmetric cross section design was recently reported to positively affect files performance in shaping of long oval canals by reduction of axial stresses (Diemer et al. 2013). Revo-S and Reciproc are two recently introduced instruments with asymmetric triple helix and double helix respectively and different movement kinematics. The aim of this study was to compare between these two asymmetric instruments in their effectiveness during preparation of oval canals.

The current study was conducted on human extracted teeth. This allowed an ex-vivo simulation of the in-vivo dentin hardness and texture with maintenance of the normal minor variations in canals geometrical characteristics. In comparison, artificial canals in acrylic blocks, although provide standard

canal sizes and curvatures were criticized because they result in bigger chips and heat generation during instrumentation (Hülsmann and Stryga (1993), Franco et al. 2011, Berutti et al 2012). Selected teeth had long oval cross section as confirmed by CBCT axial sections shots and curvatures ranging from 5-10 degrees (Schneider (1971)). This curvature range was considered among the inclusion criteria to authenticate that zero degree curvatures are the exception among single canalled premolar teeth (Grande et al. 2007, Grande et al. 2008). The CBCT imaging system was used in the present study as non-destructive, evidence based, precise scanning tool for 3D quantitative/qualitative assessment of the tested shaping ability parameters (Peters et al. 2003, Jou et al. 2004, Grande et al. 2007, Peters & Paqué 2011, Peters et al. (2001), Neelakantan et al. (2010), Paqué F & Peters (2011), Aguiar et al. 2012). Until recently comparisons on shaping ability are sometimes made using pre and post-instrumentation radiographic pictures (Burklein et al. 2012, Celik et al. 2013). This method cannot produce accurate dimensional measurements. Again, as a two dimensional picture, canal volume and perimeter change wouldn't be assessed. In a comparative study, Aguiar et al. (2012) and Aguiar et al (2012) found that, the CBCT imaging system provided repeatable and more accurate results compared to the double radiographic superimposition methods. Also canal cross sections cannot be radiographed at various levels except if preceded by actual tooth cross sectioning and sample destruction^(7,8). Furthermore, Berutti & Fedon (1992) compared the thickness of dentin-cementum on cross sections and radiographs and found that the amount of hard tissue was in fact about one-fifth less than that appearing on the radiograph. Michetti et al. (2010) reported that, a strong to very strong correlation was found between the values obtained by CBCT and those from the histologic sections.

In the present study width and length of root canals' axial sections were measured at 6mm from the

apex using CBCT shots. A minimum of a larger to smaller diameter of 2 to 1 was selected and considered in the long oval category. Jou et al (2004) defined oval canals as having a maximum diameter of up to 2 times greater than the minimum diameter while long oval as having a maximum diameter of two to four times greater than the minimum diameter. In fact, a sharp demarcation between oval and long oval canal is not practical, as both features can be present in the same root canal at different levels from the apex. A single root canal might be long oval at the coronal third which turn gradually to oval near to the canal's middle or apical thirds. For this reason, it was specified that measurement of canal dimensions should be at six mm level from the apex (Wu et al. 2000, Jou et al. 2004).

To standardize teeth length, specimens were shortened from the occlusal surface to a standard length of 18mm in concert with previous studies (Gambill et al. 1996, Paranjpe et al. 2012, de Gregorio et al. (2012), Yoldas et al. (2012)). This also assured reproducible reference points for the CBCT scanning due to the flattened occlusal surfaces. To guarantee that all teeth are kept in their positions for the post-instrumentation CBCT scanning, teeth were inserted vertically in two specially constructed molds. Throughout the whole procedure of instrumentation and later CBCT scanning, teeth were not removed from their artificial sockets in the molds.

In our study, the canal specimens were all instrumented to a standard apical size of #40 and a taper of 6% using the same motor adjusted according to the instrument type and kinematic movement tested. Revo-S manufacturer specified a range of rotation speed from 250 to 400 rpm among which 300 rpm was selected to be compatible with Reciproc instrument speed (Plotino et al. 2012). Post-instrumentation CBCT scanning was acquired using the CBCT (i-CAT) imaging system in a preparation for geometrical change calculation. Using the segmentation module, the volume and

surface area of segmented canals were calculated with the mimics software. Differences between these two parameters pre and post-instrumentation were calculated as volume increase and surface area increase in each group (Paqué et al. 2010, Paqué et al. 2011, Paqué & Peters 2011).

Untouched canal areas after instrumentation as well as transportation and centering ratio were calculated from specimen's axial sections at 3mm, 6mm, and 9mm from the apex. These cross sections were chosen to represent the apical, middle, and coronal root levels respectively (Peters et al. 2001, Vaudt et al. 2009, Peters & Paqué 2011, Neelakantan et al. 2010). A total of 120 axial sections were examined. Transportation and centering ratio parameters were calculated from the pre-and post-instrumentation dentin thickness values both at the M-D and B-L directions following Grande et al. (2007). Gambill et al. (1996) method was used for calculation of both parameters. Same methodology was followed in previous studies (Aguiar et al. 2012, Stern et al. 2012, Stern et al. 2012). Other method for measuring the centering ratio is by the calculation of the centers of gravity which were calculated for each slice and then connected along the Z-axis with a fitted line. This method was adopted by Peters et al. (2001), Paqué et al. (2009) and Paqué et al. (2011).

Canal volume increased significantly after instrumentation with either Revo-S- continuous rotation or Reciproc- reciprocation movements. This result was in accordance with most previous similar studies (Peters et al. 2001, Peters et al. 2003, Paqué et al. 2010, Peters & Paqué 2011). On the other hand, Franco et al. (2011) found that, in the apical canals third, continuous rotation produced a statistically significant enlargement of the canal as compared to reciprocation. These differences in the results might be caused by the differences in study details where in our study size # R40 Reciproc was experimented for its shaping ability and reported for the first time. On the other hand, in all preceding

studies either smaller, size #R25 Reciproc or other file designs were tested in reciprocation movements (Paqué et al. 2011, Burklein et al. 2012, Stern et al. 2012, Stern et al. 2012). In a recent investigation, when size # R40 Reciproc was compared to BioRace in their cleaning effectiveness of oval canals, both instrumentation techniques resulted in the same percentages of clean canals (Alves et al. 2012).

A statistically insignificant increase in canals' volume was detected for Reciproc as compared to Revo-S denoting a probability of higher cutting efficiency in the former instrument which may be attributable to the different cross sectional shape of the studied instruments. The Reciproc has an S-shaped cross section with positive rake angle. Schäfer et al. (2006) reported a significantly faster canal preparation with S-shaped Mtwo file. They claimed that, this cross section shape harbor aggressive cutting edges.

Both NiTi instrumentation techniques left areas of the canals walls that were untouched. This was found to be slightly greater in Revo-S group as compared to the Reciproc one ($31.7 \pm 4.96\%$ versus $26.5 \pm 8.93\%$ respectively). However, the difference was statistically insignificant. This result was in accordance with Paqué et al. (2011) who found untouched areas of $29.9 \pm 25.8\%$ after continuous rotation and $25.1 \pm 19.2\%$ after reciprocation using Protaper instruments in both motions tested. On the other hand, using six instrumentation techniques, Paqué et al. (2009) found untreated canal areas ranged from 4% to 100%. Li et al. (2011) examined ProTaper instruments for hand use up to size F3 in type I canals of mandibular premolars using a modified balanced forces motion and found that 27.4-83.0% of the canal surface remained untouched. The differences in the results might be caused by the differences in the study methodologies. Actually, untouched canal walls were reported for most of the previous studies irrespective of the canal type, width, or curvatures. However, this problem is

more pronounced when oval or long oval canals are concerned (Paqué et al. 2010). Peters & Paqué (2010) recommended that, circumferential filing should be used in preparation of such canals.

No statistically significant differences were detected between the studied groups in the amount of transportation at 3 and 6mm levels in both MD and BL directions. This result parallel that of Rüttermann et al. (2007). Transportation ranged from .021mm to .073mm in the R-S group, and from .002mm to .084mm in the R40 group. Generally, the resulted transportation for both studied instruments can be considered minimum according to previous reports where transportations up to 0.15mm were considered of minor effect (Freire et al. 2011). Curvature range used in the present study might be a cause. At 3mm and 6mm levels, transportation occurred to the mesial direction in RS as well as R40 groups. However, in the BL direction, transportation differed in the RS group where it occurred to the buccal. At 9mm level, significantly greater transportation values were recorded for the RS group as compared to the R40 group ($-.073 \pm .025$ and $-.002 \pm .08$ respectively) in the MD direction. The marked lower transportation for R40 at this mid-canal level might be due to the specific design features of this instrument. The Reciproc instrument has a progressive taper apically which turns gradually into a regressive taper more coronally leading to more instrument centralization and less transportation. Transportation in both groups was to the distal and lingual directions. This result is in accordance with a previously reported study concerning rotary instrumentation (Versiani et al. 2011).

Centering ratio decreased gradually towards the apex in both tested groups. The decrease in centering ratio was not statistically significant. This result was in accordance with Hashim et al. (2012) and Aguiar et al. (2012) concerning Revo-S. In the M-D direction, the values for centering ability were

better than in the B-L direction in both tested groups with no statistical significant difference between them. Most of the previous studies reported also eccentric preparation concerning oval canals irrespective of the tested instrument (Hashem et al. 2012, Celik et al. 2013, Peters & Paqué 2011, Aguiar et al. 2012, Stern et al. 2012). Rüttermann et al. (2007) found that, rotary system "flex master" and oscillating instrument "Endo-Eze" resulted in eccentric instrumentation. In the present study, the highest centering ratio was found at the middle canal third in both Revo-S and Reciproc groups (a mean of 0.71 and 0.64 respectively) in accord with the transportation results, denoting a tendency for both instruments to remain centralized in this region. On the other hand, a statistically significant lower centering ratio was detected in the Revo-S group at 3mm from the apex. This result was in agreement with that of another CBCT study where a statistically significant lowest centering ratio was registered for Revo-S as compared to TF, GTX, and Protaper at 5.2mm level (Hashem et al. 2012). Whether this trend is inherited in Revo-S owing to its snake-like movement, need to be investigated.

CONCLUSION

Within the limitations of this study, it can be concluded that, both Revo-S rotary instruments and Reciproc R40 reciprocating single file resulted in an effective, similar and significant increase in canal volume and prepared surface areas. The two instrumentation kinematics caused small canal transportation with a comparatively better centering ability for Reciproc R40. Irrespective of the instrumentation kinematic movement, preparation of all canal walls of oval and long oval canals remains an inherent incapability.

Conflict of interest: The authors deny any conflict of interest relevant to this article

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