ABSTRACT
Aim: The aim of this study is to compare canal transportation and centering ratio using of Protaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) and Revo-S (RS) (MicroMega, Besancon Cedex, France) compared to Protaper Universal (PTU) (Dentsply Maillefer, Ballaigues, Switzerland) nickel-titanium rotary file systems in curved root canals using cone-beam computed tomography.

Materials and Methods: Ninety maxillary mesiobuccal first molar uncalcified canals with mature apex, curvature of 20°–45° (the Estrela method) and minimum 20-mm length were selected. The samples were randomly divided into three groups of 30 teeth each, respectively, Group I PTU, Group II PTN, and Group III RS Rotary systems and Instrumented according to the manufacturers’ instructions. Pre- and post-instrumentation cone-beam tomographic scan was performed in same position to calculate canal transportation and centering ability at 2 mm, 5 mm, and 8 mm from the root apex. Statistical analysis was performed with ANOVA and Post-hoc Tukey test.

Results: PTU had maximum mean canal transportation and minimum mean centering ratio at all levels, whereas PTN showed minimum mean canal transportation and maximum mean centering ratio. The results were statistically significant.

Conclusions: In terms of canal transportation and centering ratio in the middle and coronal third of the root, PTN and RS performed better than PTU. However, in apical third, PTN performed best among all other groups.

Keywords: Canal transportation, centering ratio, Protaper next, Revo-S

INTRODUCTION

Instruments during the canal preparation should not deviate from the original pathway or else result in canal transportation. Maintaining the canal centering is difficult in curved canals compared to straight canals, as during instrumentation, procedural errors such as transportation of the apical foramen or the creation of zips, elbows, ledges can occur which may lead to loss of working length (WL), perforation, and separation of instruments.
present generation files causes less transportation in curved canal and maintains its shape.\textsuperscript{[4]}

New concept fifth-generation Ni-Ti files, Protaper next (PTN), and Revo-S (RS) have been introduced with asymmetric off-centered cross sections for the root canal shaping. The PTN (Dentsply Maillefer, Ballaigues, Switzerland) is a Ni-Ti rotary file system and the manufacturer claimed that it has significant design features, which causes file to remain centered within the canal.

The RS Ni-Ti file system is another fifth-generation file with asymmetrical triangular cross section introduced by MicroMega (Besançon, France). This smaller off-centered cross-section allows more flexibility by generating snake-like swaggering movement and offers a better ability to negotiate curves.

Hence, the purpose of this in-vitro study was to evaluate canal preparation using these, novel fifth-generation PTN and RS rotary file systems compared with Protaper universal (PTU) for canal transportation and centering ability using cone-beam computed tomography (CBCT).

MATERIALS AND METHODS

Sample selection and preparation

Ninety curved maxillary molars extracted for periodontal or prosthetic reasons were selected for this study after taking ethical clearance (IECGDCH/CONS.3/2014). Radiographs of teeth in both the buccolingual and mesiodistal directions were taken for sample selection. Only teeth with closed apices and no significant calcifications were included. Tissue fragments and calculus were removed using ultrasonic scaler. About 0.5% NaOCl was used in wide-mouthed plastic jars for initial collection and storage medium. After immersing in the NaOCl for at least half an hour to dissolve organic tissue, then liquids were discarded and the teeth were transferred into separate jars containing physiologic saline. Access opening was done with No 2-round carbide bur (SS White, Lakewood, New Jersey) and Endo-Z bur (Dentsply Maillefer, Ballaigues, Switzerland). Distobuccal and palatal roots of all the teeth were separated using a diamond disc and contra-angled micromotor handpiece at the furcation. To determine the WL, a size #10 K-file was inserted into the remaining mesiobuccal canal until it was visible at the apical foramen. The WL of each canal was calculated to be 1 mm less than the length obtained by the initial file. The selected teeth were embedded in 5cm × 5cm circular silicon putty block. The putty block was then placed on the acrylic template that was mounted on the CBCT machine and arrows were drawn on the block as well as on the template to guide the reposition of the block for the postoperative scan. Thus, pre- and post-operative positioning of the samples was standardized. The embedded teeth were scanned using CS 9300 Carestream CBCT scanner with tube voltage of 75 KV and tube current of 6.3 MA for 20 s. The sections were 90-µthickness from apex to the canal orifice. Canal curvature angle and radius were measured according to the method described by Estrela et al. using CBCT scan [Figure 1a].\textsuperscript{[5]}

Curvatures between 20° and 45° and radius between 3 mm and 8 mm were selected. According to radius, canal curvature was classified as Small radius ($r \leq 4$ mm): severe curvature; Intermediary radius ($r > 4$ and $r \leq 8$ mm): moderate curvature; Large radius ($r > 8$ mm): mild curvature.\textsuperscript{[6]} Teeth that did not meet the criteria of this angle and radius (mild curvature) were excluded from the study.

The specimens were randomly allocated to 1 of 3 groups ($n = 30$) based on the canal curvature angle and radius. Biomechanical preparation was done with torque controlled endomotor Endomate DT (NSK) using 5 ml of 3% sodium hypochlorite (Prime Dental, Maharashtra, India) as intermittent irrigation after each file. Group I was instrumented using PTU (Dentsply Maillefer, Ballaigues, Switzerland) with SX, S1, S2, F1, and F2 (Speed-300 rpm, Torque-2.5 Ncm). Group II was instrumented using PTN (Speed-350 rpm, Torque-2 Ncm) X1 and X2(Dentsply Maillefer, Ballaigues, Switzerland), and Group III was instrumented using RS system (MicroMega, Besancon Cedex, France) SC1, SC2 and SU (Speed-300 rpm, Torque-0.8 Ncm) according to the manufacturer’s instructions. In all three groups, final filing was up to 25 size at apex with 6% taper. All the files were used for single time only. There was no instrument separation in any of the samples in all the groups. All the samples in all the groups were prepared by the same operator after canal preparation; each canal was irrigated with 2 ml of 17% EDTA for 1 min. Final irrigation was done with 2 ml of 3% sodium hypochlorite. Postinstrumentation scan was done using the same parameters as preoperative scan.

Evaluation of canal transportation and centering ratio

The amount of canal transportation was determined by measuring the shortest distance from the edge of uninstrumented canal to the most peripheral part of the root at 2 mm, 5 mm, and 8 mm (mesial and distal) and then comparing this with the same measurements obtained from the instrumented images [Figure 1b].\textsuperscript{[6,7]}

The following formula was used for the calculation of transportation at each level for both the Groups:

$$([A1 - A2] - [B1 - B2])$$

where, $A1$ is the shortest distance from the mesial edge of the curved root to the mesial edge of the uninstrumented canal.
B1 is the shortest distance from distal edge of the curved root to the distal edge of the uninstrumented canal. A2 is the shortest distance from the mesial edge of the curved root to the mesial edge of the instrumented canal. B2 is the shortest distance from distal edge of the curved root to the distal edge of the instrumented canal. According to this formula, a result of ‘0’ indicates no canal transportation. A result other than ‘0’ means that transportation has occurred in the canal.

According to Gambill et al.,[8] “The mean centering ratio” indicates the ability of the instrument to stay centered in the canal. This ratio was calculated for both the groups at each level using the following ratio:

\[
\frac{(A1 - A2)}{(B1 - B2)}
\]

Or

\[
\frac{(B1 - B2)}{(A1 - A2)}
\]

If these numbers are not equal, the lower figure is considered as the numerator of the ratio. According to this formula, a result of ‘1’ indicates perfect centering. Intergroup comparison of all the specimens was made.

**Statistical analysis**

Statistical analysis was performed using ANOVA and Post-hoc Tukey test with the help of Statistical Packages for Social Sciences version 18.0 (SPSS Inc., Chicago, Illinois, USA) by considering \( P < 0.05 \) as statistically significant.

**RESULTS**

Table 1 shows mean, standard deviation, and standard error values of canal transportation and centering ratio at three different levels of all groups. Table 2 shows post-hoc tukey HSD test for transportation and centering ratio at three different level between all groups. Significant \( (P < 0.05) \) results are shown with red color. Hence, for both canal transportation and centering ratio, PTN performed significantly better than PTU in all 3 level (2, 5, 8 mm from apex). However, there were no significant differences between PTN and RS instruments in the apical, middle third of root.

**DISCUSSION**

Root canal shaping is one of the most important steps in canal treatment. It is essential in determining the efficacy of all subsequent procedures, including chemical disinfection and root canal obturation. Shaping is largely influenced by highly variable root canal anatomy. Opposed to most root canals that are curved, the endodontic instruments are made from straight blanks. They have a tendency of straightening the canal during preparation.[9] These aberrant results of root canal shaping make it difficult for clinicians to remove infected tissues and achieve a properly sealed root canal obturation and might consequently increase the risk for root canal treatment failure.[10] Many factors have been identified that exert an impact on the incidence of canal transportation and canal centering ability including file design and metallurgy.[11] Hence, here we have compared the canal transportation and centering ratio caused by different file generations, design, and metallurgy as PTU is the second-generation file system, whereas PTN and RS are the fifth-generation file systems having different metallurgy and cross-section designs.

In our study, we selected natural teeth as there were certain drawbacks of using rotary instruments in resin blocks. Hülsmann et al. reported that the use of simulated canals in resin blocks does not reflect the results of the instruments in root canals of natural teeth because of the hardness and abrasion behavior of acrylic resin and root dentine may not be identical.[12] Mesiobuccal root canals of extracted maxillary molars were used in the present study as they usually present an accentuated curvature and mesiodistal flattening.[13] These characteristics are additional shortcomings during
PTN showed the most promising result among the three groups. This result was similar to the result observed by Saberi et al. and Elnaghy. Various studies show similar results that PTN is better in terms of transportation and centering ratio when compared with PTU. This may be due to decreased flexibility of PTU. The flexibility of the instrument depends on complex interrelationships between different parameters such as instrument design, core diameter, pitch, metallurgical properties, and surface treatments of instruments. An increase in taper is related to the increase in core diameter, increase in the force applied against the walls and decrease in flexibility as in PTU. The results are obtained in conformity to Bonaccurso et al. and Javaheri and Javaheri who found PTU to produce more apical transportation than any other instrument.

PTN showed the least transportation and maximum centering ratio at 2 mm $\text{(}P<0.05\text{)}$ because they remove less amounts of dentin compared with other instruments, with an apical taper of 0.08. This may be because of the offset asymmetric cross-section design of this instrument, and progressive percentage tapers on a single file. The off-set design further minimizes the engagement between the file and dentin. Moreover, PTN instruments are manufactured from M-Wire alloy, which has been proposed to improve file flexibility and resistance to cyclic fatigue while retaining cutting efficiency.

**Table 2: Post-hoc tukey honestly significant difference test for transportation and centering ratio at three different level between all groups**

| DEPENDENT VARIABLE | FILE SYSTEM | FILE SYSTEM | Mean difference between groups | SE  | P  |
|--------------------|-------------|-------------|--------------------------------|-----|----|
| Transportation (A1-A2)−(B1-B2) 2 mm | PTU | PTN | 0.10 | 0.027 | 0.001 |
| | PTU | RS | 0.02 | 0.027 | 0.733 |
| | PTN | RS | −0.08 | 0.027 | 0.014 |
| Transportation (A1-A2)−(B1-B2) 5 mm | PTU | PTN | 0.20 | 0.041 | <0.001 |
| | PTU | RS | 0.20 | 0.041 | <0.001 |
| | PTN | RS | 0.00 | 0.041 | 1.000 |
| Transportation (A1-A2)−(B1-B2) 8 mm | PTU | PTN | 0.10 | 0.038 | 0.026 |
| | PTU | RS | 0.10 | 0.038 | 0.021 |
| | PTN | RS | 0.00 | 0.038 | 0.996 |
| Centering ratio (A1-A2)/(B1-B2) 2 mm | PTU | PTN | −0.23 | 0.097 | 0.049 |
| | PTU | RS | 0.01 | 0.097 | 0.998 |
| | PTN | RS | 0.24 | 0.097 | 0.043 |
| Centering ratio (A1-A2)/(B1-B2) 5 mm | PTU | PTN | −0.19 | 0.086 | 0.048 |
| | PTU | RS | −0.19 | 0.086 | 0.043 |
| | PTN | RS | 0.01 | 0.086 | 0.996 |
| Centering ratio (A1-A2)/(B1-B2) 8 mm | PTU | PTN | −0.13 | 0.083 | 0.275 |
| | PTU | RS | 0.02 | 0.083 | 0.967 |
| | PTN | RS | 0.15 | 0.083 | 0.178 |

$P<0.05=$Significant. Red mark values are significant. SE=Standard error; PTU: Protaper universal; PTN: Protaper next; RS: Revo-S
In our study at apical third PTN showed minimum transportation and maximum centering ratio, but in middle and cervical third, PTN and RS showed similar better results. This can be attributed to the beneficial effects of instrumentation techniques of both the files, which are fifth-generation off-set files having asymmetrical cross-section. This increases the available volume for upward debris elimination. Both have modified guiding tip, progressive pitch and variable taper of 6° along the length. The comparable apical transportation was less and mean centering ability was superior of RS than PTU which may be due to asymmetrical cutting profile of RS which facilitates penetration by a snake-like swaggering movement and offers a root canal shaping and apical finishing that is closely adapted to the anatomical and ecological criteria of the canal. Furthermore, RS has one cutting edge which makes it less aggressive as compared to others.[25]

Apical transportation of more than 300 µm can have a negative impact on the seal of the obturation and subsequent treatment failure.[26] In this study, we found that at any level the transportation did not exceed the critical limit. Thus, we can say that all three files are safe to use and will not cause transportation beyond the critical limit.

However, this study does not agree with the Bürklein et al.,[11] Saber et al.[27] and Capar et al.[22] who evaluated the transportation produced by different files systems including PTN, PTU and concluded that no significant differences were found between the file systems in terms of canal transportation. These studies might have demonstrated a significant difference if more sample size, angle, and uniform distribution of angle and radius had been done.

CONCLUSIONS

Within the limitation of this study, we found in terms of canal transportation and centering ratio, in the apical, middle, and coronal third of the root, PTN performed best among all three files. In middle and apical third, RS also showed comparable results with PTN. This is an in vitro study, therefore, it is possible that the inferences from the study might not correlate completely, with similar situations clinically. Further studies are needed to clarify the clinical performance of the new fifth-generation files.

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Conflicts of interest
There are no conflicts of interest.

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