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ORIGINAL RESEARCH

Shaping Ability of WaveOne and ProTaper NEXT Rotary Nickel–titanium File Systems in Simulated Curved Root Canals

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ABSTRACT

Objective: The goals of a root canal therapy cannot be met without good access to the canal, which may in turn lead to procedural errors. This *in vitro* study was done to evaluate and compare the shaping ability of WaveOne® (DENTSPLY Maillefer, Ballaigues, Switzerland) and ProTaper NEXT® (DENTSPLY Maillefer, Ballaigues, Switzerland) rotary nickel–titanium (NiTi) files systems in simulated S-shaped and L-shaped root canals respectively.

Materials and methods: Twenty simulated S-shaped and L-shaped root canals in resin blocks were randomly assigned into four groups according to the rotary system used (n = 40). The canals were prepared to a 25 tip size using WaveOne® or ProTaper NEXT®. Pre- and postoperative photos of each simulated canal were captured using a professional camera at standardized distance and position. The images were superimposed with the aid of Adobe Photoshop Elements 7.0 software. Ten lines at a distance of 1 mm each were selected from the superimposed canal images to measure central axis transportation and curvature straightening using a software program. The data recorded were analyzed using Statistical Package for the Social Sciences version 18.0 data analysis software.

Results: The data analyzed showed that, in simulated S-shaped root canals, ProTaper NEXT® preserved the best coronal curvature significantly ($p<0.05$) compared with WaveOne®, but both the file systems were able to straighten the curvature significantly. In simulated L-shaped root canals, ProTaper NEXT® caused less central axis transportation than WaveOne® at both curved and apical sections ($p<0.05$) but produced more transportation at straight section. The canal curvature was well maintained with ProTaper NEXT® rotary system.

Conclusion: Among the two rotary file systems evaluated, ProTaper NEXT® demonstrated superior shaping ability compared with WaveOne® at curved sections in both S-shaped and L-shaped canals.

Keywords: Canal axis transportation, Curvature straightening, Rotary NiTi systems.

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INTRODUCTION

The cleaning and shaping of root canal space is one of the most significant and fundamental aspects of endodontic therapy.[1] The main goals of root canal therapy is to flush out the infected and necrotic tissue out of root canals, to create smooth walls facilitating irrigation and gutta-percha filling, to preserve the anatomy of apical foramen, and to conserve the sound root dentin for good prognosis of the tooth.[2,3] The ideal shaping procedures described by Schilder have shown to be clinically unattainable in many cases because much of the canal wall surfaces remain untouched following mechanical instrumentation due to canal curvatures.[4,5]

In recent years, many kinds of nickel–titanium (NiTi) rotary files have been introduced to facilitate root canal preparation. These instruments have greatly improved cutting efficiency and helped to reduce procedural errors during canal shaping.[6] However, one of the biggest concerns is the fracture of instrument during treatment.

Yared[7] proposed endodontic instrumentation technique which utilizes a reciprocating movement *vs* rotating movement of NiTi files. It has been claimed that reciprocating motion provides more resistance to cyclic fatigue of rotary NiTi endodontic files and also aims to reduce the risk of instrument fracture by engaging the file in a clockwise motion, and then immediately disengaging it in a anticlockwise motion. Reciprocating NiTi file system presents as a new standard in root canal instrumentation with the possibility of reducing procedural abberations.[8]

One of the popular single-file systems is the WaveOne® (DENTSPLY Maillefer, Ballaigues, Switzerland) which is designed to be used with a dedicated reciprocating motion. These files are manufactured with M-wire technology which involves a special thermal processing of the metal that improves flexibility and resistance to cyclic fatigue.[9] Additional development in file system is the ProTaper NEXT® (DENTSPLY Maillefer, Ballaigues, Switzerland) with rectangular cross-section design for greater strength and incorporates the convergence of three significant design features: Progressive percentage tapers on a single-file, M-wire technology, and offset design which is used in continuous motion.[10]

The aim of the present study was to evaluate and compare the shaping ability of ProTaper NEXT® and WaveOne® NiTi rotary systems in simulated severely curved S-shaped and L-shaped root canals.

MATERIALS AND METHODS

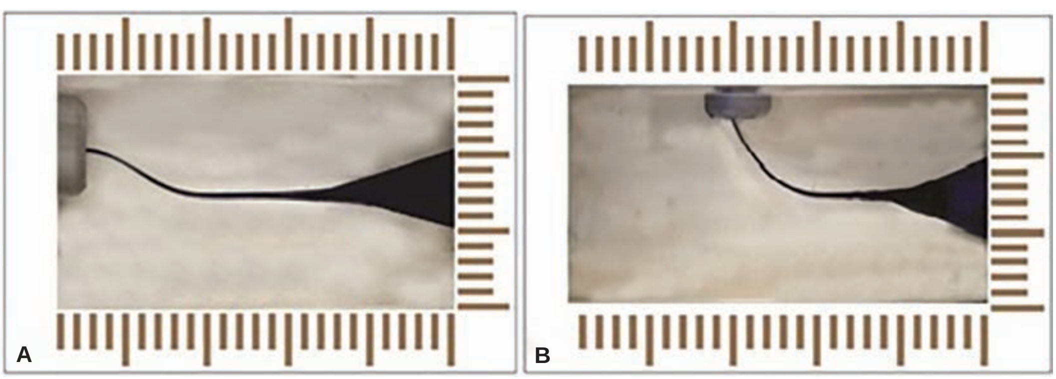
The present study was done using 20 S-shaped simulated root canals (Endo-Training–Bloc-S, DENTSPLY Maillefer, Ballaigues, Switzerland) and 20 L-shaped simulated root canals (Endo-Training–Bloc-L, DENTSPLY Maillefer, Ballaigues, Switzerland), which were randomly divided into four study groups respectively (n = 10), according to the rotary NiTi file system used for canal preparation. The S-shaped simulated canal had a taper of 0.02, an apical diameter of 0.15 mm, and a length of 16 mm. The angles and radii of the coronal curvature and apical curvature were 30° and 5 mm; and 20° and 4.5 mm respectively. The L-shaped simulated canal had a taper of 0.02, an apical diameter of 0.15 mm, length of 16 mm, and curvature of 30° and 5 mm. So the study had four experimental groups as shown below.

- *Group I*: Root canal preparation in S-shaped canal prepared with WaveOne® rotary system
- *Group II*: Root canal preparation in S-shaped canal prepared with ProTaper NEXT® rotary system
- *Group III*: Root canal preparation in L-shaped canal prepared with WaveOne® rotary system
- *Group IV*: Root canal preparation in L-shaped canal prepared with ProTaper NEXT® rotary system.

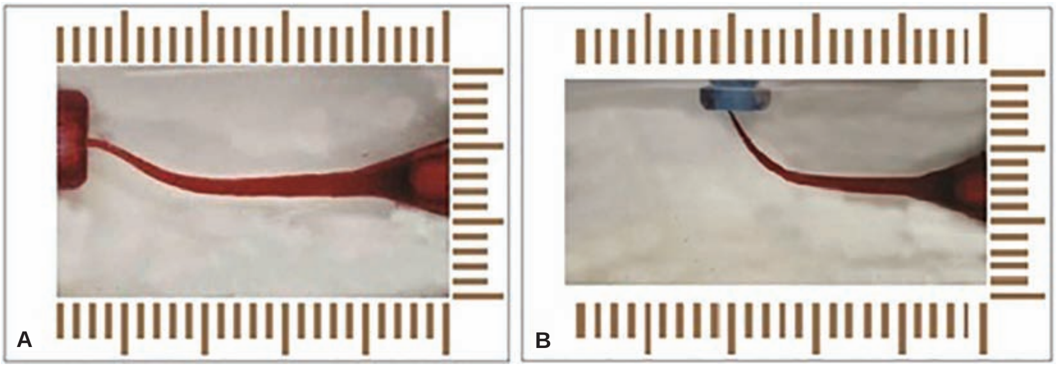
The preinstrumented resin blocks were coded individually by carving the assigned number on the blocks, away from the simulated canal on the block, using a metal pin to ensure identification during subsequent image analysis. The blocks were then injected with Blue India ink (Dr Ph. Martin's, Golden, Colorado, USA) (Fig. 1) to allow the canal to be clearly visible during image capture and to recognize it from the canal after preparation. The image capture was accomplished using a digital camera (Canon; Canon 550D, Tokyo, Japan) mounted on a modified microscope stage. The camera was kept at a fixed distance and at 90° to resin blocks so that pre- and postcanal preparation images could be superimposed. The fixed camera also eliminated any distortion or magnification of the subsequent images.

All the canals were prepared by the same operator and not more than six canals were prepared in a single day to prevent operator fatigue. The root canal was prepared by single-length technique according to the manufacturer's guidelines. All files are operated by a 1:16 reduction gear hand-piece powered by the X-Smart^{Plus} motor (DENTSPLY Maillefer, Ballaigues, Switzerland), ProTaper NEXT® file were used in a constant rotation at a speed of 300 rpm with light apical pressure, while the primary WaveOne® file was used in a reciprocating working motion generated by the motor ("WaveOne all" mode). Each canal was prepared to the standard working length (16 mm) in a crown-down sequence, and the final apical preparation was set to size 25 (X2 ProTaper NEXT®, primary WaveOne® files) in each group.

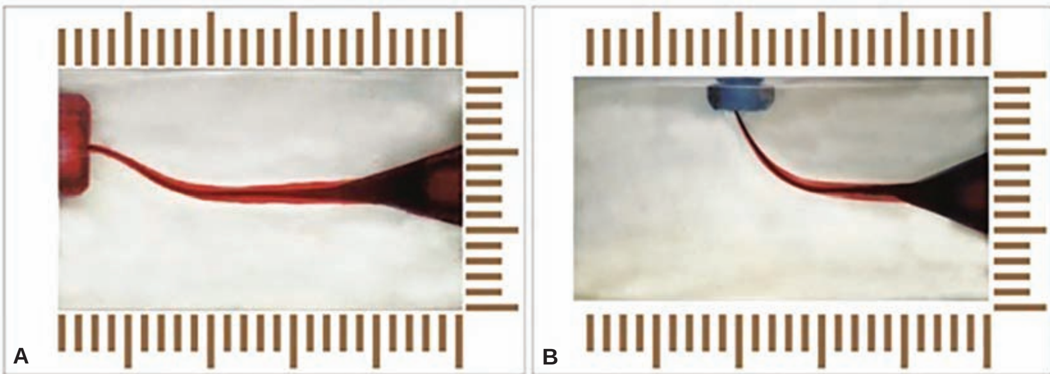
The canals were instrumented with #10 K-file (DENTSPLY Maillefer Ballaigues, Switzerland) followed by #13, #16 PathFile (DENTSPLY Maillefer Ballaigues, Switzerland) to ensure canal patency and provide glide pathway to the working length (16 mm). Then, #19 PathFile, WaveOne® Primary file (tip size 25 and apical taper of 0.08), in groups I and III, was used in a programmed reciprocating motion, whereas in groups II and IV, the preparation for the full length of the canal was carried out with ProTaper NEXT® files X-1, X-2. The #19 PathFile was not used in groups II and IV because the ProTaper NEXT® X1 was size #17 with 0.04 taper. The files were used in a continuous/progressive up-and-down motion



Figs 1A and B: Canals injected with blue ink prior to root canal instrumentation: (A) S-shaped canal, (B) L-shaped canal



Figs 2A and B: Canals injected with red ink after root canal instrumentation: (A) S-shaped canal; and (B) L-shaped canal



Figs 3A and B: Superimposed image of the pre- and postinstrumented canals: (A) S-shaped canal; and (B) L-shaped canal

for three times and taken out according to the manufacturer's instructions. The flutes of the instrument were cleaned after three in-and-out movements (pecks) using gauze wetted with Glyde agent. The canals were copiously irrigated with distilled water until all debris was flushed out from the canal.

The root canal was irrigated with 2 mL of distilled water between each file size, using a 27-gauge needle. The patency of the canal was maintained using a size #10 K-file. The instrument was replaced with a new instrument after use in three canals. After the completion of root canal instrumentation, all the prepared canals were filled with Red India ink (Dr Ph. Martin's, Golden, Colorado, USA) to record the shapes of the prepared canals (Fig. 2). The images of the prepared canals were made using the same technique and instruments used for image capture before instrumentation of resin blocks as described earlier. The images were uploaded into Adobe Photoshop Elements 7.0 software program (Adobe System Inc, San Jose, CA, USA) for processing. The pre- and postinstrumentation images were superimposed into one picture with the aid of software program to ensure accurate superimposition (Fig. 3). A grid image was placed in the block surface which helped in precise matching of pre- and postinstrumented canal blocks.

The measurement lines were arranged in 1-mm radius centering on the apical line. The next line centered on the crossover line of the previous line and the central axis of original canals, and continued till the 10th line was obtained. In S-shaped canals, lines 0 to 4 conformed to the apical curve, lines 3 to 7 conformed to the coronal curve, and lines 8 to 9 to the straight portion (Fig. 4). In L-shaped canals, the lines 0 to 2 confined to the apical portion, lines 3 to 7 to the curved portion, and lines 8 to 9 to the straight portion of the canals (Fig. 5). The transportation of the canal's center was calculated by subtracting the amount of resin removed at the outer wall from that removed at the inner wall divided by two. A positive result means that transportation occurs mainly on the inner surface of the canal curvature and negative value means that transportation occurs mainly on the outer surface of the canal curvature.[11] The measurement of the degree of straightening from original canals was determined by Cunningham's method for S-shaped canals and Schneider's method for L-shaped canals.[12,13]

The data obtained were analyzed using Statistical Package for the Social Sciences version 18.0 (SPSS, Chicago, Illinois, USA). The results were statistically analyzed by using one-way analysis of variance and the *post hoc* Tukey's test considering the normal distribution

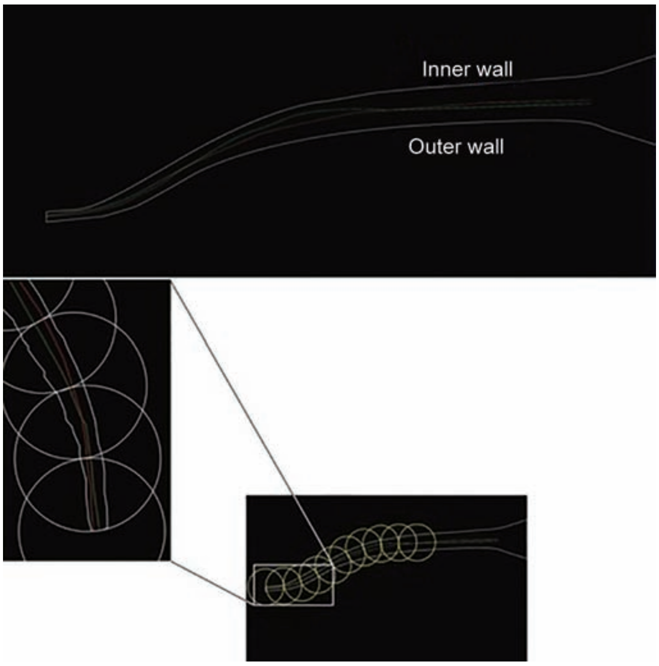


Fig. 4: Measurement lines arranged in 1 mm radius centering on apical point starting from 0 mm in S-shaped canal

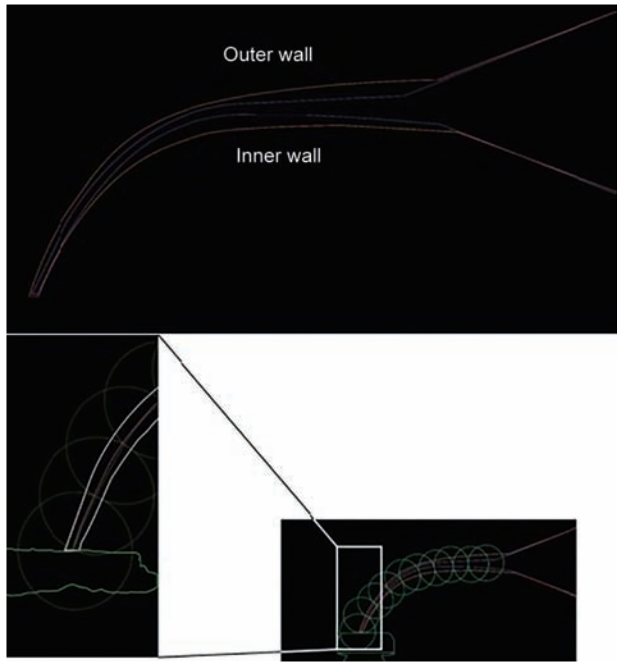


Fig. 5: Measurement lines arranged in 1 mm radius centering on apical point starting from 0 mm in L-shaped canal

and homogeneity of variance. The data for each set of measurements were analyzed by using the Kolmogorov–Smirnov test. The significance level was set at $p < 0.05$.

RESULTS

The outcome of the measurement is as follows:

- *Central axis transportation in S-shaped canal*: Both of the file systems were able to demonstrate straightened canal curvatures from the mean axis. The group in which WaveOne® files were used demonstrated straight canals more compared with the ProTaper NEXT® file group, although the difference was not statistically significant ($p > 0.05$) (Table 1). The coronal curvature at lines 6 and 7 presented more straightening with WaveOne® files as compared with ProTaper NEXT files, which was statistically significant ($p < 0.05$). The apical constriction was well maintained with ProTaper NEXT®.
- *Central axis transportation in L-shaped canal*: The WaveOne® file system caused more central axis transportation as compared with ProTaper NEXT® and the difference was statistically significant at many lines. Significant differences in the mean values were observed at 0 and 1 mm of apical portion; 5 and 6 mm of curved portion; 8 and 9 mm of coronal portion ($p < 0.05$) (Table 2). WaveOne® caused more transportation at lines 6 and 7 mm compared with other lines. ProTaper NEXT® maintained good apical constriction compared with WaveOne®.
- *Degree of straightening*: The mean degree of straightening from the original curvature in S- and L-shaped canals is presented in Table 3. As claimed by the manufacturer of simulated canals, in S-shaped root canals, the original angle of coronal curvature was 20° and the apical one was 30°. There was a significant difference in the coronal curvature straightening between the two rotary systems ($p < 0.05$). WaveOne straightened the curvature more compared with ProTaper NEXT® ($p < 0.05$). There was no significant difference in apical curvature straightening between

Table 1: Mean and SD of central axis transportation after instrumentation measured at 10 lines from the apex in S-shaped canal

	Central axis transportation (in mm)									
Groups	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
WaveOne®										
Mean	0.05^a	0.06^a	0.12^a	0.13^a	0.05^a	0.19^a	0.22^a	0.14^a	0.05^a	0.03^a
SD	0.04	0.03	0.04	0.02	0.04	0.03	0.04	0.05	0.03	0.04
ProTaper NEXT®										
Mean	0.06^a	0.05^a	0.12^a	0.12^a	0.05^a	0.16^a	0.18^b	0.10^b	0.07^a	0.04^a
SD	0.04	0.02	0.04	0.05	0.03	0.04	0.03	0.02	0.04	0.02

Same superscript letter within a column indicates mean with nonsignificant values ($p > 0.05$); SD: Standard deviation

Table 2: Mean and SD of central axis transportation after instrumentation measured at 10 lines from the apex in L-shaped canal

	Central axis transportation (in mm)									
Groups	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
WaveOne®										
Mean	0.09[a]	0.10[a]	0.06[a]	0.06[a]	0.15[a]	0.22[a]	0.15[a]	0.06[a]	0.03[a]	0.02[a]
SD	0.03	0.02	0.03	0.03	0.02	0.03	0.04	0.02	0.02	0.01
ProTaper NEXT®										
Mean	0.05[b]	0.06[b]	0.05[a]	0.06[a]	0.12[a]	0.15[b]	0.09[b]	0.06[a]	0.06[b]	0.07[b]
SD	0.01	0.03	0.02	0.04	0.02	0.02	0.03	0.03	0.02	0.03

Same superscript letter within a column indicates mean with nonsignificant values ($p > 0.05$); SD: Standard deviation

Table 3: Mean values and SD of straightened angles from original angles in S- and L-shaped canals

	S-shaped canals		*L-shaped canals*
Groups	*Coronal curvature straightening*	*Apical curvature straightening*	*Curvature straightening*
WaveOne®	6.59 ± 0.76[a]	18.78 ± 1.83[a]	5.36 ± 0.48[a]
ProTaper NEXT®	4.32 ± 0.97[b]	20.46 ± 2.13[a]	1.21 ± 0.93[b]

Same superscript letters in the column indicate mean with no significant values ($p < 0.05$); SD: Standard deviation; The values are expressed in degrees

the two systems ($p > 0.05$). There was a noticeable straightening of the apical curvature with both the rotary systems. As claimed by the manufacturer of simulated canals, the original angle is 30° for both L and S-shaped canals, which was straightened more with the WaveOne® system. The difference between both systems was statistically significant ($p < 0.05$).

DISCUSSION

Root canal shaping is considered to be one of the most important procedures in endodontic therapy as it provides a suitable pathway for root canal irrigation and subsequent root canal filling.[14] The introduction of NiTi instruments with excellent elastic property to the endodontic field has made the root canal shaping procedures easy and simple.[15] A variety of root canal instruments have been introduced in the market, thereby providing clinicians with more options for precise root canal shaping and filling. These systems are distinct in their cross section, instrumentation sequence, microstructure, and motion dynamics.

A successfully cleaned and shaped root canal should provide excellent access to the root and minimize preparation errors. The root canals when being instrumented can have considerable curvature which may make the access to the apex very difficult. According to Schilder,[2] an ideal preparation is one with a continuous taper wider at the coronal portion and narrowing to the apex. There may be chances that a number of procedural errors, such as blockages, ledges, zips, perforations, and fractured instruments, can occur when shaping root canals.[3] The NiTi rotary files have become the standard for preparation of the root canal system because of their super elasticity; due to their very low values of elastic modulus, they cause less canal transportation and their ability to stay more centered in the canal.[16-18] However, shaping ability and resistance to cyclic fatigue fracture are of special significance when evaluating the performance of NiTi files.[19]

The shaping ability of NiTi files depends on several factors, such as taper, geometrical cross section, movements, file system composition, and alloy microstructure. Bergmans et al[20] reported that the progressive tapered shaft design of the ProTaper NEXT® instrument increases the flexibility of files, while decreasing taper makes files much stiffer. The WaveOne® primary has a decreasing taper, whereas in ProTaper NEXT®, X1 and X2 files have a progressive taper at the apical section and a decreasing taper at the coronal section.[21] Hence, ProTaper NEXT® makes it more flexible than WaveOne® at the apical section, thus causing less transportation at apical section in severely curved canals.

The present study evaluated the shaping ability of two NiTi file systems, namely the WaveOne® and ProTaper NEXT® in simulated S-shaped (multicurved) and L-shaped (curved) root canals. The results of this study demonstrated that there was a significant difference in canal shaping ability of these NiTi files.

ProTaper NEXT® caused less transportation at apical section and maintained well the canal curvature in L-shaped canals; however, they produced more transportation at straight section compared with WaveOne®, whereas in S-shaped canals, both the files straightened the apical curvature but ProTaper NEXT® produced the least coronal straightening. The apical constriction was well maintained in both S and L canals with ProTaper NEXT®. Wu et al[19] and Bürklein et al[22] have also demonstrated similar findings in their study comparing different rotary NiTi systems. Another important similarity was found with the results of the study by Dhingra et al[23] where they concluded that ProTaper NEXT® had better centric ability than WaveOne® and ProTaper®.[11] On the contrary, this study is not in agreement with the outcomes of the study done by Jain et al,[24] where it was concluded that the ProTaper NEXT® caused more transportation compared with other rotary NiTi systems.

The geometrical cross sections of NiTi files do have a crucial role in the canal preparation. The geometrical cross section varies from triangle, rectangle, and slender-rectangle to square. Previous studies have reported that files with square geometrical cross section have the highest screw-in force and flexural stiffness. The square ones are followed by rectangular, triangular, and slender-rectangle ones in terms of screw-in force and flexural stiffness.[25] WaveOne® changes cross sections over the working length from a modified convex triangle in the tip region to a convex triangle near the shaft, whereas ProTaper Next® has an off-centered rectangular cross section, thus making the files rotate in a unique asymmetrical fashion.[26,27] Accordingly, the ProTaper Next®, with rectangular cross section and decreasing taper at the coronal section, had higher screw-in force and flexural stiffness than WaveOne®, resulting in more transportation at the straight section in severely curved canals.

It has been demonstrated that single-file reciprocating systems (Reciproc® and WaveOne®) result in a decreased time of shaping and a similar maintenance of the original curvature of the canal when compared with conventional or multifile rotary systems.[28,29] Some authors are of the opinion that single-file techniques are suggested for root canal preparation mostly based on ease of handling and its simplicity rather than proven effectiveness of the instruments.[24] The present study demonstrated that ProTaper NEXT®, a multifile rotary system with continuous motions, caused least transportation compared with the single-file WaveOne® rotary system. This could be better explained by the fact that single-file system has sharp cutting edges and provides with high cutting efficiency leading to more canal transportation.[19] Therefore, the results of the present study were in disagreement with the findings of other previous studies which concluded that a multifile rotary system with continuous motions caused more transportation compared with the single-file system.[28,29]

In the current study, the microstructure of the file system did not influence the findings of the study as both WaveOne® and ProTaper NEXT® were mainly made up of martensite wires produced by M-wire technology.[30] The M-wire technology instruments have nanocrystalline microstructure which provides a higher strength and wear resistance for the instruments.[31] The martensite phased alloys are reported to be flexible and ductile.[32]

CONCLUSION

Within the limitations of the study, the following conclusion were drawn:

- ProTaper NEXT® demonstrated superior shaping ability compared with WaveOne® at curved area in both the canals.
- ProTaper NEXT® preserved the coronal curvature better than WaveOne®.
- Both the rotary systems straightened the apical curvature remarkably.

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