Original Article

Assessment of Apical Transportation Caused by Nickel–Titanium Rotary Systems with Full Rotation and Reciprocating Movements using Extracted Teeth and Resin Blocks with Simulated Root Canals: A Comparative Study

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ABSTRACT

Objectives: We compared apical transportation in the WaveOne and ProTaper Next systems, which are rotary nickel–titanium systems with reciprocating and continuous rotation movements, respectively, using manual measurements obtained from resin blocks with simulated root canals and double digital radiographs of extracted teeth. **Materials and Methods:** We used 30 resin blocks with simulated root canals and 30 extracted teeth for this study. The same endodontist performed root canal shaping using the WaveOne or ProTaper Next system. We assessed apical transportation by measuring the amounts (in mm) of material lost 1 mm from the apical foramen in the resin blocks and by using double digital radiography for the extracted teeth. Significant differences between groups were assessed using *t*-tests. $P < 0.05$ was considered statistically significant. **Results:** The amount of apical transportation differed significantly between the two systems when resin blocks were used for assessment ($P < 0.05$), but there were no significant differences when extracted teeth were used ($P < 0.05$). **Conclusions:** In the current study, there was no significant difference in apical transportation between natural teeth prepared using WaveOne and those prepared using ProTaper Next. However, significant differences were observed between the two systems with resin blocks. These findings indicate that the use of resin blocks is not an accurate method for apical transportation evaluation.

KEYWORDS: *Apical canal transportation, digital radiograph, extracted teeth, nickel–titanium, rotary systems, simulated canal*

Date of Acceptance:
28-Oct-2017

INTRODUCTION

Cleaning and shaping of the root canal system are essential steps in root canal treatment.[1] Maintenance of the original shape of the canal and the position of the apical foramen are essential requirements in root canal shaping.[2] However, in curved canals, it is difficult to achieve this goal because shaping instruments and methods can displace the canal from its original axis,[3] which increases the probability of procedural errors such as canal transportation, apical zipping, canal ledges, strip perforations, and instrument separation.[4] Transportation of the root canal during cleaning and shaping may result in the incomplete removal of debris and jeopardize the outcome of treatment.[5] The aggressive removal of dentin from one point or the unbalanced removal of dentin from the main tooth axis leads to apical canal transportation.[6] The assessment of apical transportation is not straightforward. Although no specific criteria are available for evaluation, various methods have

Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/njcp.njcp_200_17

PMID: *******

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How to cite this article: Alrahabi M, Zafar MS. Assessment of apical transportation caused by nickel–titanium rotary systems with full rotation and reciprocating movements using extracted teeth and resin blocks with simulated root canals: A comparative study. Niger J Clin Pract 2017;XX:XX-XX.

been used, each with advantages and disadvantages.[7] Resin blocks with simulated canals offer a standardized basis, which is essential for assessment.[8] In addition to the simplicity of photographic acquisition and analysis, pre- and postinstrumentation evaluations of resin blocks are convenient.[9,10] However, differences between resin and the natural tooth structure should be considered before relying on the results obtained from resin blocks.[11] Double digital radiography, which involves the assessment of apical transportation using superimposed pre- and postinstrumentation radiographs, was first introduced by Iqbal *et al*.[12] The benefits of this technique include its low cost, ease of manipulation, and ability to accurately detect canal transportation.[13]

The introduction of nickel–titanium (NiTi) systems in the field of endodontics has led to remarkable developments in root canal shaping[14] and has minimized canal transportation.[15]

Recently, several types of NiTi systems have been used to simplify root canal instrumentation. Of these, WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) uses reciprocating movements and generally requires only one file for the entire canal preparation procedure,[16] while ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland), which exhibits an offset mass of rotation and a rectangular cross-section, uses unique asymmetrical movements (continuous rotation) similar to those of a snake.[17]

In the present study, we compared apical transportation in the WaveOne and ProTaper Next NiTi systems using manual measurements obtained from resin blocks with simulated root canals and double digital radiographs of extracted teeth. We also compared the results obtained from the resin blocks and those obtained from the extracted teeth.

Materials and Methods

Thirty resin blocks with simulated root canals (Dentsply Maillefer) were divided into two groups (Groups 1 and 2), as were 30 extracted human permanent mandibular first molars (Groups 3 and 4).

Resin block groups

We divided 30 resin blocks with simulated root canals into two equal groups. The blocks in Group 1 were prepared using the WaveOne system and those in Group 2 were prepared using the ProTaper Next system. The taper of the simulated canals was 2%, and their length was 17 mm. The canals were straight for 17 mm and curved for 5 mm in the apical section. The size of the canals was equivalent to that of the ISO file #15, and their total curvature was 40° as determined through Schneider's method.[18]

We used a special mold to facilitate the acquisition of standardized pre- and postinstrumentation photographs with a digital camera (Nikon D3200, Nikon, Inc.). To improve the color contrast of the photographs, we injected all canals with black ink before instrumentation and red ink after instrumentation. A series of photographs of each canal was captured before and after instrumentation and saved to a personal computer.

Extracted tooth groups

We randomized 30 extracted mandibular first molars into Groups 3 and 4. Those in Group 3 were prepared using the WaveOne system, and those in Group 4 were prepared using the ProTaper Next system. The curvature of the mesial roots ranged from 25° to 40° as determined through Schneider's method.[18] The teeth were decrowned and the mesiobuccal roots were determined. After irrigation with 1% sodium hypochlorite, the patency of the canals was scouted with a #10 K-file (Dentsply Maillefer). The working length (WL) was determined by subtracting 1 mm from the point where the file tip extruded from the apical foramen. We embedded the teeth in resin cubes (25 mm^3) to maintain a standard position for all radiographs. A special platform was manufactured to obtain standardized baseline radiographs with a #10 K-file inserted up to the continuous WL and postinstrumentation radiographs with a master apical file using the parallel technique with a RVG 6200 Sensor (Carestream Health, Inc., Atlanta, GA, USA).

Root canal shaping

The same endodontist with 10 years of experience performed all root canal shaping procedures in all four groups. A glide path for the extracted teeth was created using manual stainless steel hand files up to the #10 K-file. The specimens in Groups 1 and 3 were prepared using the primary WaveOne instrument (size 25 and 0.08 taper) in accordance with the manufacturer's instructions. The instrument was replaced after the preparation of four canals. The specimens in Groups 2 and 4 were prepared using the ProTaper Next system in accordance with the manufacturer's instructions. The master apical file was the X2 file (size 25, taper 6%). The instruments were replaced after the preparation of three canals.

Assessment of apical transportation

We used Photoshop (Adobe Systems, San Jose, CA, USA) to superimpose the pre- and postinstrumentation images of the resin blocks [Figure 1] and the pre- and

postinstrumentation digital radiographs of the extracted teeth [Figure 2]. ImageJ software (National Institute of Mental Health, Bethesda, MD, USA) was used to evaluate apical transportation as described below.

- In the resin blocks, we measured the amount (in mm) of material lost 1 mm from the apical foramen of the root canal through the following equation [Figure 3]:
  D (difference) = Do (outer resin removed) − Di (inner resin removed)
- In the extracted teeth, we measured the difference (in mm) between the tip of the #15 Kfile, which was inserted up to the continuous WL on the preinstrumentation radiograph and the tip of the master apical file (X2 or primary file). The measurement was performed on two superimposed X-rays [Figure 4].

A positive value indicated outward transportation, and a negative value indicated inward transportation. The closer the value was to zero, the more balanced the preparation was.

Statistical analysis

All statistical analyses were performed using SPSS software (ver. 20; SPSS, Inc., Chicago, IL, USA). Means and standard deviations were calculated for each group, and *t*-tests were used to assess differences between groups stratified according to the NiTi system and the assessment method used. $P < 0.05$ was considered statistically significant.

Results

The amount of apical transportation was significantly less ($P < 0.05$) with the ProTaper Next system than with the WaveOne system when the resin blocks were used for assessment. However, there was no significant difference ($P > 0.05$) when extracted teeth were used for the assessment. Furthermore, the two assessment methods showed a similar amount of apical transportation ($P > 0.05$) when the ProTaper Next system was used for preparation, whereas assessment using resin blocks showed significantly greater apical transportation compared with assessment using extracted teeth when the WaveOne system was used ($P < 0.05$). Figure 5 shows the values of apical transportation derived from each NiTi system and assessment method. Table 1 shows the mean apical transportation values obtained using extracted teeth and resin blocks for the ProTaper Next and WaveOne systems.

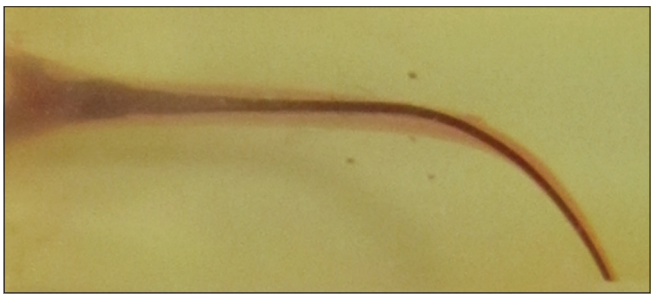

Figure 1: Superimposed pre- and postinstrumentation images of resin blocks

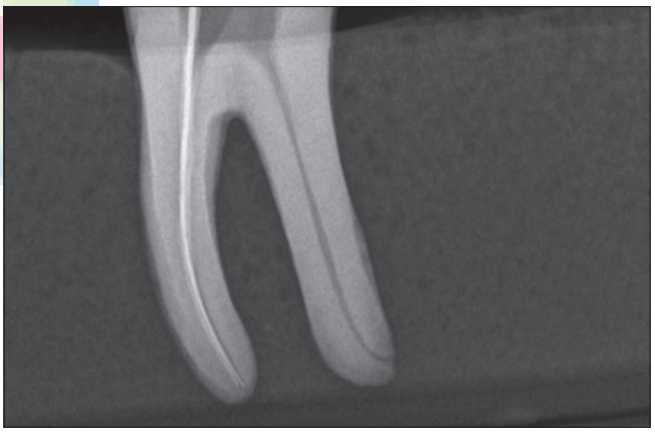

Figure 2: Superimposed pre- and postinstrumentation radiograph with #15 Kfile and master nickel–titanium file

Table 1: Mean apical transportation values (mm) associated with each method of assessment and nickel-titanium system used

Resin blocks with simulated root canals (subtraction of the amount of removed)		Extracted teeth (double digital radiographs)		ProTaper Next		WaveOne	
ProTaper Next	WaveOne	ProTaper Next	WaveOne	Resin blocks with simulated root canals (subtraction of the amount of removed resin)	Extracted teeth (double digital radiographs)	Resin blocks with simulated root canals (subtraction of the amount of removed resin)	Extracted teeth (double digital radiographs)
0.06±0.02	0.11±0.03	0.05±0.03	0.06±0.01	0.06±0.02	0.05±0.03	0.11±0.03	0.06±0.01
$P<0.001$		$P=0.24$		$P=0.29$		$P<0.001$	

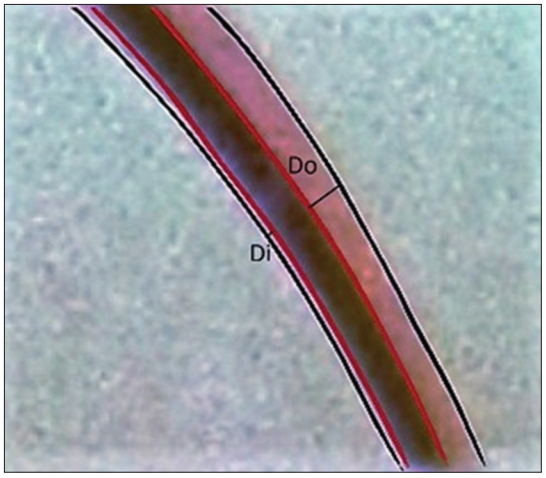

Figure 3: The measurement of the amount (in mm) of material lost 1 mm from the apical foramen of the root canal through the following equation: D (difference) = Do (outer resin removed) − Di (inner resin removed)

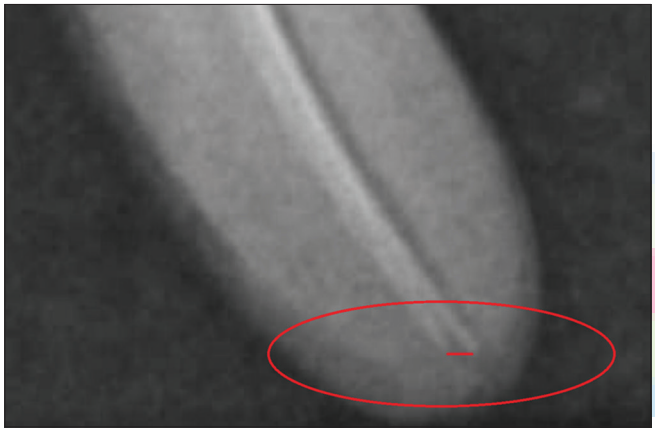

Figure 4: The measurement of the difference (in mm) between the tip of the #15 Kfile and the tip of the master apical file (X2 or primary file) which they inserted up to the continuous working length. The measurement was performed on two superimposed pre- and postinstrumentation X-rays

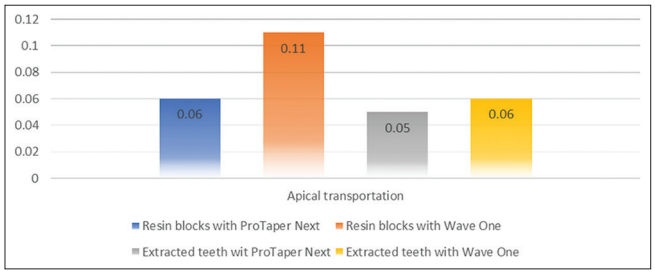

Figure 5: Apical transportation values associated with the nickel–titanium system and assessment method

Discussion

In the present study, we compared apical transportation in the WaveOne system which uses reciprocating movements and the ProTaper Next system which uses continuous rotation movements. For the assessment of apical transportation, we used both resin blocks with simulated root canals and extracted teeth and compared the results obtained in both.

During canal shaping, transportation or deviation may occur due to a tendency of the file to revert to its original linear shape and the reaction torque with regard to the root canal wall particularly in a curved canal.[19] When canals are curved, an apical transportation of >0.3 mm may cause significant leakage along the apical section after obturation.[20] In the present study, the mean amount of apical transportation with both the WaveOne and ProTaper Next systems was <0.3 mm with both methods of assessment (resin blocks and extracted teeth).

When we used double digital radiographs of extracted teeth for assessment, there was no significant difference in the amount of apical transportation between the WaveOne and ProTaper Next systems. This finding is consistent with those of a previous study[21] in which cone beam computed tomography (CT) was used to evaluate canal transportation caused by the WaveOne and ProTaper Next systems during instrumentation of the mesial canals of mandibular molars. There are several previous reports indicating that the instrumentation of root canals in extracted teeth using reciprocating movements does not increase the amount of apical transportation as compared with continuous rotation movements.[22-24] One study that used micro-CT showed that the ProTaper Next system caused less transportation than the WaveOne system.[25] However, other studies comparing the WaveOne system with other rotary NiTi systems using extracted teeth have reported that significantly less apical transportation was associated with the WaveOne system.[26,27]

In contrast to our results in extracted teeth, we found that apical transportation was significantly greater with the WaveOne system than with the ProTaper Next system when resin blocks with simulated root canals were used for assessment. This finding is consistent with those of previous studies.[28-30]

Several studies have used resin blocks to evaluate canal preparations.[8,31] The use of simulated canals in endodontic studies allows for standardization of the evaluation procedures for canal shaping[32] and provides consistent root canal morphology.[33] Simulated canals also provide the same hardness and abrasion characteristics every time.[9] Although simulated canals in resin blocks provide reproducibility, standardization, and high accuracy, their use does not meet clinical standards due to differences in hardness between resin and dentin. The microhardness of resin blocks is 20–24 kg/mm^2 and that of dentin is 35–40 kg/mm^2. This difference may affect the assessment of transportation.[9] In fact, several reports have mentioned the influence of hardness

differences between resin and dentin on the results of clinical studies.[33-35]

Studies that have used resin blocks to evaluate the shaping abilities of NiTi systems and the amounts of transportation caused by them have revealed that reciprocating movements produce more centered canals than continuous rotation movements.[23,36] In the present study, when the ProTaper Next system which uses continuous rotation movements was used for preparation, there were no significant differences in apical transportation between extracted teeth and resin blocks. However, we noted a significant difference between the two assessment methods when the WaveOne system which uses reciprocating movements was used for preparation. This may be a result of taper and cross-section differences between the WaveOne and ProTaper Next systems. The primary instrument in the WaveOne system exhibits a continuous decrease of 8% in taper from the tip to the shaft (0.8, 0.65, 0.6, 0.55).[37] The taper of the X2 file in the ProTaper Next system is 0.06. Moreover, all files have a variable taper along their WLs.[38] The cross-section of the primary instrument in the WaveOne system presents radial lands in the tip region. In the middle part and near the shaft, the morphology changes from a modified triangular/convex cross-section with radial lands to a triangular/convex cross-section with a neutral rake angle.[37] The instruments in the ProTaper Next system present a rectangular cross-section with an offset mass of rotation.[38] This is considered to contribute to the snake-like, swaggering movements of the files during advancement into the root canal.

Conclusions

Within the limitations of the present study, we demonstrated that the WaveOne system which uses reciprocating movements resulted in significant differences in apical transportation between simulated canals in resin blocks and natural extracted teeth prepared by the same operator. Conversely, when the ProTaper Next system which uses continuous rotation movements was used for preparation, no significant differences were observed. Furthermore, double digital radiographs of the extracted teeth showed that a similar amount of apical transportation was caused by the two rotary NiTi systems. These findings indicate that the use of resin blocks with simulated root canals for the assessment of canal transportation may lack accuracy. Moreover, further studies using three-dimensional tools such as micro-CT are necessary for the evaluation of NiTi systems with regard to their shaping abilities and associated amounts of apical canal transportation.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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