

Research Article



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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Author Contributions

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Root canal volume change and transportation by Vortex Blue, ProTaper Next, and ProTaper Universal in curved root canals

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ABSTRACT

Objectives: The aim of this study was to compare root canal volume change and canal transportation by Vortex Blue (VB; Dentsply Tulsa Dental Specialties), ProTaper Next (PTN; Dentsply Maillefer), and ProTaper Universal (PTU; Dentsply Maillefer) nickel-titanium rotary files in curved root canals.

Materials and Methods: Thirty canals with 20°–45° of curvature from extracted human molars were used. Root canal instrumentation was performed with VB, PTN, and PTU files up to #30.06, X3, and F3, respectively. Changes in root canal volume before and after the instrumentation, and the amount and direction of canal transportation at 1, 3, and 5 mm from the root apex were measured by using micro-computed tomography. Data of canal volume change were statistically analyzed using one-way analysis of variance and Tukey test, while data of amount and direction of transportation were analyzed using Kruskal-Wallis and Mann-Whitney *U* test.

Results: There were no significant differences among 3 groups in terms of canal volume change ($p > 0.05$). For the amount of transportation, PTN showed significantly less transportation than PTU at 3 mm level ($p = 0.005$). VB files showed no significant difference in canal transportation at all 3 levels with either PTN or PTU files. Also, VB files showed unique inward transportation tendency in the apical area.




Conclusions: Other than PTN produced less amount of transportation than PTU at 3 mm level, all 3 file systems showed similar level of canal volume change and transportation, and VB file system could prepare the curved canals without significant shaping errors.

Keywords: Canal volume; ProTaper Next; ProTaper Universal; Transportation; Vortex Blue; X-ray micro-computed tomography

INTRODUCTION

Cleaning and shaping of root canal system while maintaining the original canal curvature have always been a challenge because shaping errors such as ledges, zipping, strip perforation, and apical transportation can occur, particularly in curved canals [1]. Thus, various approaches were made to improve the mechanical properties of nickel-titanium (NiTi) rotary file, such as different instrumental designs and thermomechanical processing techniques [2-5].

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In 2011, ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) and Vortex Blue (VB; Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) systems were introduced in the market. Those instruments were manufactured using M-wire alloy through thermomechanical process. Many researchers have reported improved cyclic fatigue resistance of those file systems [2,6-9].

PTN system is characterized by its unique rotary motion and design, as well as M-wire alloy. In the study of shaping ability, PTN showed greater centering ability than ProTaper Universal (PTU; Dentsply Maillefer) [10-12]. VB files are also made from M-wire alloy and have a unique blue color. VB files have been reported to have improved cyclic fatigue resistance and flexibility compared to ProFile Vortex (Dentsply Tulsa Dental Specialties) files [8,13].

However, to our knowledge, research results on the shaping parameters of VB system were not yet available when this study was undertaken. Therefore, this study was aimed to evaluate and compare the effect of different NiTi instruments (VB, PTN, and PTU) on root canal volume change and canal transportation in curved root canals by using micro-computed tomography (micro-CT).

MATERIALS AND METHODS

This study was approved by Institutional Review Board of Wonkwang University Daejeon Dental Hospital (W1502/003-001). Thirty-two extracted human maxillary and mandibular molars were collected. They were examined under a microscope (OPMI pico, Carl Zeiss, Oberkochen, Germany) at $\times 8$ magnification. The teeth without caries, crack, or previous dental treatments were selected. Preoperative periapical radiographs were taken to select the teeth that met with the conditions. Canals with severe calcification, resorption, or abnormal anatomy were excluded. Canal curvatures of mesiobuccal and distobuccal canals of maxillary molars, and mesiobuccal and mesiolingual canals of mandibular molars were assessed with the method of Schneider [14], and root canals with 20° – 45° curvatures were chosen. After this process, 8 teeth were excluded, and 30 canals from 24 teeth were finally selected.

Specimen preparation

The teeth were stored in 0.01% sodium hypochlorite (NaOCl; sodium hypochlorite solution, Duksan pure chemicals, Ansan, Korea) at room temperature before use. After access cavity preparation, size 10 K-files were inserted beyond the 1 mm of apex to check the apical patency. Working length was determined as 1 mm shorter than the length to the apical foramen. The glide path was established with size 15 K-files.

The teeth were divided into 3 groups, according to the NiTi files used: VB, PTN, and PTU ($n = 10$). The distribution of the teeth was determined with Kruskal-Wallis test, concerning the parameters such as canal curvature and the initial canal volume.

VB group: VB files were used in the sequence of sizes 15/0.06, 20/0.06, 25/0.06, and 30/0.06 at a rotational speed of 500 rpm and 3 Ncm torque.

PTN group: PTN files were used in the sequence of X1, X2, and X3 at a rotational speed of 300 rpm and 2 Ncm torque.

PTU group: PTU files were used in the sequence of S1, S2, F1, F2, and F3 at the rotational speed of 300 rpm and 2 Ncm torque.

Each canal was prepared with in-and-out motion using the Smart X plus engine (Dentsply Maillefer). Intentional brushing motion against the canal wall was avoided to exclude its possible influence on dentin removal. Files were discarded after single-usage. After the use of each file, canal irrigation was performed with 2 mL of 2%, 40°C NaOCl solution. Thirty-gauge irrigation needle (Steri Irrigation Tips, Diadent, Cheongju, Korea) was used. After canal preparation, each canal was irrigated with 5 mL of 17% ethylenediaminetetraacetic acid (EDTA) solution for final rinse and then was dried with sterile paper points.

Micro-CT analysis

A custom-made mold for each tooth was made with a putty impression material to facilitate mounting of the tooth. All the teeth were scanned using a micro-CT system (SkyScan 1174, SkyScan bvba, Aartselaar, Belgium) with an isotropic resolution of 9.9 μm at 59 kV and 167 mA. The number of slices varied according to the length of each root, ranging from 700 to 900. The scanned images were reconstructed with the software NRecon (NRecon reconstruction 64bit, Bruker micro CT, Kontich, Belgium) and the reconstructed images were loaded on the software Dataviewer (Bruker micro CT), to take sectional images of axial view for assessment.

1. Measurement of canal volume change

Using image analysis software CTAn v 1.12 (Bruker micro CT), the canal volume was measured before and after the instrumentation. The region of interest was established from the canal orifice to the apical foramen. The changes in canal volume were calculated.

2. Evaluation of canal transportation

Cross-sectional images at the position of 1, 3, and 5 mm from the root apex were used to evaluate the amount and the direction of transportation. Preoperative and postoperative images were superimposed, and transportation value was calculated according to the following equation suggested by Gambill *et al.* [15] (**Figure 1**).

$$\text{Transportation value} = (X1 - X2) - (Y1 - Y2)$$

X1 and Y1 showed the distance from uninstrumented canal to the root. X1 was the shortest distance from canal edge to the outside (lateral) edge of the root, and Y1 was the shortest distance from canal edge to the inside edge of the root.

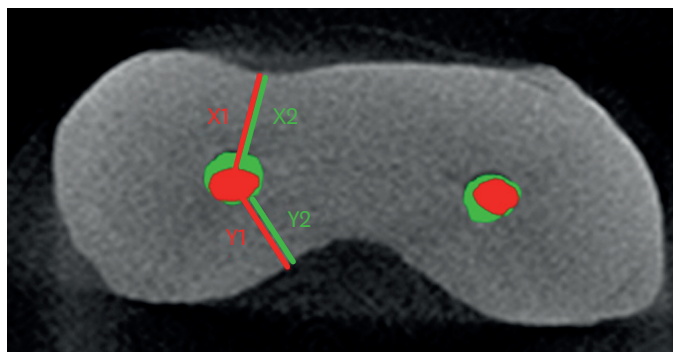


Figure 1. Superimposition of cross-sectional micro-computed tomography (micro-CT) scans before (red) and after (green) the instrumentation for calculating root canal transportation. X is the shortest distance from canal edge to the outside edge of the root, and Y is the shortest distance from canal edge to the inside edge of the root.

distance from canal edge to the inside (medial) edge of the root. X2 and Y2 showed the distance from instrumented canal to the root. X2 was the shortest distance from canal edge to the outside edge of the root, and Y2 was the shortest distance from canal edge to the inside edge of the root. The amount of transportation was assessed using the absolute value of the results from the formula, and the direction of transportation was assessed using the total value obtained [16]. A value of 0 from the formula represents there is no canal transportation. In terms of the direction of transportation, a positive value means outward transportation, and a negative value means inward transportation.

Statistical analysis

Data were first verified with the Kolmogorov-Smirnov test for the normality of the distribution and the Levene test for homogeneity of variances. The data of the canal volume change were normally distributed and homogenous, so they were analyzed using one-way analysis of variance and Tukey test. The transportation data were analyzed using Kruskal-Wallis test and Mann-Whitney *U* test for *post hoc* comparison (SPSS Statistics version 18.0, IBM Corporation, Chicago, IL, USA). The significance level was set at $p < 0.05$.

RESULTS

In preoperative analysis, there was no significant difference in root canal curvature and canal volume among the 3 groups.

Change in root canal volume

In micro-CT images, all the canals showed smooth and continuously tapered form after the instrumentation (**Figure 2**). No significant differences were found in volume changes among the 3 groups (**Table 1**).

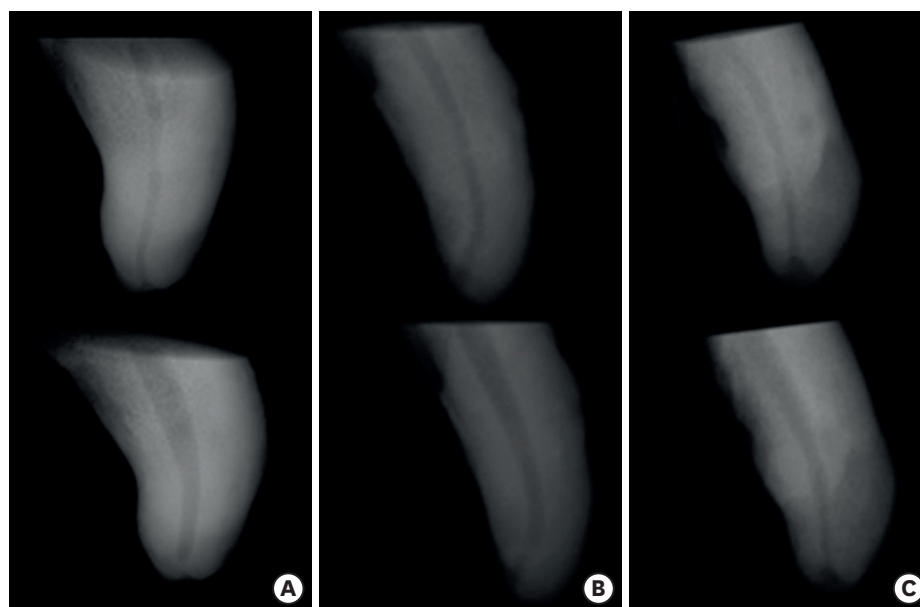


Figure 2. Representative 3-dimensional reconstructed micro-computed tomography (micro-CT) images of each group. Before (upper side) and after (lower side) the instrumentation. (A) Vortex Blue, (B) ProTaper Next, and (C) ProTaper Universal.

Table 1. Changes in root canal volume (mm³) by 3 file systems

Stage	VB group	PTN group	PTU group
Preoperative	2.69 ± 1.03	2.85 ± 1.22	3.18 ± 0.79
Postoperative	4.30 ± 1.05	4.64 ± 1.64	5.61 ± 1.48
Changes*	1.60 ± 0.44	1.80 ± 0.84	2.43 ± 1.10

Data shown are mean ± standard deviation.

VB, Vortex Blue; PTN, ProTaper Next; PTU, ProTaper Universal.

*There was no statistically significant differences among 3 groups ($p > 0.05$).

Amount of canal transportation

The mean absolute values of canal transportation at 1, 3, and 5 mm levels from the apex of each group are presented in **Table 2**. Representative micro-CT images are shown in **Figure 3**.

At 1 mm and 5 mm levels: no statistically significant differences were found among the 3 groups.

Table 2. Average amount and direction of transportation (mm) of 3 file systems

Finding	Group	Level		
		1 mm	3 mm	5 mm
Amount of transportation (absolute value)	VB	0.12 ± 0.10	0.09 ± 0.10 ^{ab}	0.26 ± 0.19
	PTN	0.11 ± 0.07	0.08 ± 0.10 ^a	0.13 ± 0.09
	PTU	0.24 ± 0.18	0.28 ± 0.21 ^b	0.23 ± 0.14
Direction of transportation (original value)	VB	-0.07 ± 0.15	-0.04 ± 0.13	-0.12 ± 0.31
	PTN	-0.03 ± 0.13	0.04 ± 0.12	-0.11 ± 0.11
	PTU	0.02 ± 0.30	0.17 ± 0.31	-0.13 ± 0.25

Data shown are mean ± standard deviation.

VB, Vortex Blue; PTN, ProTaper Next; PTU, ProTaper Universal.

In the amount of transportation at 3 mm level, different superscript letters indicate statistically significant differences between groups ($p < 0.05$).

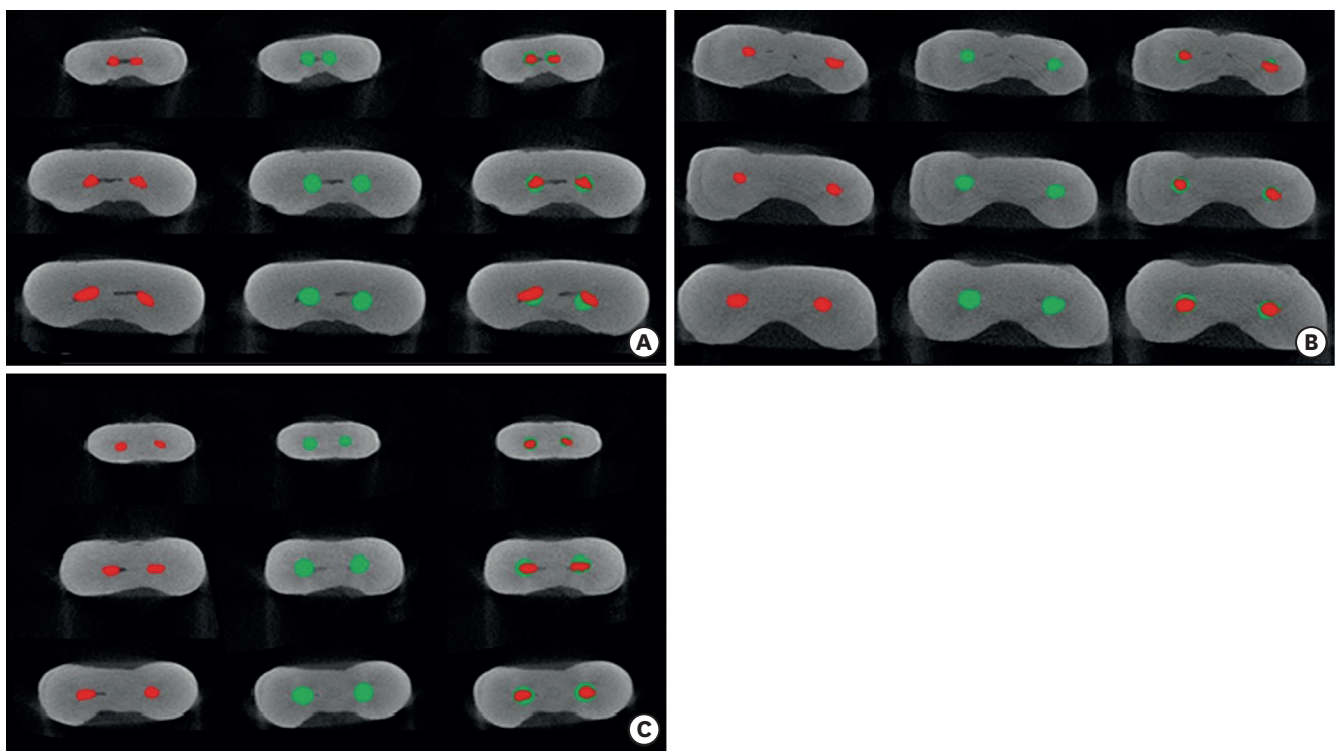


Figure 3. Representative sectional images at the level of 1, 3, and 5 mm from the apex (from top to bottom) of each group. Before (red: left side), after (green: middle side) the instrumentation, and superimposition of the 2 images (right side). (A) Vortex Blue, (B) ProTaper Next, and (C) ProTaper Universal.

At 3 mm level: PTN group showed significantly less transportation than PTU group ($p = 0.005$). However, there were no statistically significant differences between VB and PTN group, and between VB and PTU group.

Direction of canal transportation

The mean original values of canal transportation at 1, 3, and 5 mm levels from the apex showed no significant differences (**Table 2**).

At 1 mm level: inward transportation tendency was observed in VB and PTN group, and outward tendency was observed in PTU group.

At 3 mm level: VB group showed inward transportation tendency, whereas PTN and PTU group showed outward tendency.

At 5 mm level: all 3 groups showed inward transportation tendency.

DISCUSSION

In the present study, shaping ability of 3 different NiTi rotary file systems was evaluated using micro-CT technology. Micro-CT allows 3-dimensional approach and noninvasive evaluation of surface area, volume, and cross-sectional images quantitatively [6]. In the researches on endodontics, various resolutions from 8.9 to 41 μm have been used [17,18]. In the study of Huang *et al.* [19], micro-CT with high resolution allowed more effective inspection and provided more detailed information. In this study, relatively small voxels were obtained with 9.9 μm resolution, which allowed more accurate investigation.

In infected canals, infected dentin as well as bacteria, their byproducts, and necrotic tissue should be removed to the compatible levels for the optimal outcome [20]. However, excessive dentin removal could lead to weakening of teeth or even root fractures [21]. Therefore, appropriate removal of dentin is critical. In the current study, there was no significant difference in root canal volume change among 3 groups. This is in accordance with other studies that reported similar shaping abilities among different NiTi rotary systems [10,22]. The mean volume changes by VB, PTN, and PTU systems were 1.60 ± 0.14 , 1.80 ± 0.27 , and $2.43 \pm 0.35 \text{ mm}^3$, respectively, similar to previous studies [18,23].

Another important parameter of shaping ability is the root canal transportation. Transportation may lead to high risk of straightening the original canal curvature, excessive dentin removal and ledge formation and it could significantly affect long-term prognosis [22]. A previous study revealed that canal transportation was more pronounced in the narrow curved canals [24]. Therefore, teeth with root canal curvature more than 20° were included in the current study.

The transportation value was investigated by 2 ways; the amount of transportation as the absolute value, and the direction of transportation as the original value. In terms of the absolute value, statistically significant difference existed only between PTN and PTU at 3 mm level from the apex. PTN group exhibited significantly less transportation than PTU group. Majority of studies regarding these files revealed that PTN showed less transportation than PTU [11,12,25]. Possible explanation for this is that PTN files have smaller taper in the

apical region than PTU files [26]. Comparing the apical taper of final files used, PTU F3 was 0.09 and PTN X3 was 0.07 [22]. Therefore, as the larger core mass of the F3 instrument has increased stiffness at the tip, more transportation could occur in PTU group [27]. Moreover, the improved flexibility of PTN file can be explained by its unique design features and movement (rectangular cross-section and off-centered mass of rotation) which reduced contact with the root canal wall [6]. In addition, the different composition of PTN with PTU could contribute this result. PTN files are manufactured using M-wire with a proprietary thermomechanical process [7]. Many researchers reported that the systems with M-wire showed improved cyclic fatigue resistance and flexibility [7,10,12,13,25]. This flexibility of M-wire might influence the reduced amount of canal transportation of PTN.

Regarding the file composition, VB files are also manufactured using M-wire, and they have unique blue color because of the titanium oxide layer [8]. Though the specific manufacturing process of this blue alloy has not been disclosed, recent researches suggested the possible explanation for the higher flexibility and the greater fatigue resistance compared to another M-wire alloy, ProFile Vortex. M-wire could have different proportions of austenite, martensite, and R-phase, depending on the processing conditions [28-30]. Because R-phase shows lower shear modulus than martensite or austenite, and the transformation strain for R-phase transformation is less than one tenth that of martensitic transformation, VB instruments are more flexible than ProFile Vortex instruments [29]. Blue treatment might make some differences on the proportion of R-phase in M-wire. However, in the present study, VB files did not show significantly less transportation than either PTN or PTU files. Unlike PTN, VB instrument has a triangular cross-section and shows uniform contact with having 3 contact points to the canal wall during rotation. These features of VB files are presumed to share more similarities with PTU than PTN files. It seems the advantage of VB files in having an enhanced metallurgical property does not fully outweigh its potential limitations of geometric and rotary features. In addition, one of the limitations of this study is the possible lack of anatomy standardization of extracted human teeth. Although efforts were made on even distribution to 3 groups, which is confirmed by Kruskal-Wallis test, human teeth have more variations in canal anatomy than simulated artificial canals of resin block [31]. This factor might have affected the result of the study. However, human teeth were chosen because of similar microhardness with natural dentin [32]. Also for resin block, heat generation might soften the resin, leading to binding of cutting blades [32,33]. Therefore, more researches are required to verify the effectiveness of this blue alloy.

In the evaluation of the direction of transportation, PTU showed the tendency of outward transportation at the apical level (at 1 and 3 mm levels from the apex) and inward transportation at mid-coronal level (at 5 mm level from the apex). Thicker and more rigid characteristics of PTU than PTN might have caused this straightening effect [34]. Also, VB showed unique inward transportation tendency at apical level (at 1 and 3 mm levels from the apex). All 3 files have different movements and morphological characteristics, such as cross-sectional shape, cutting angle, helix angle, taper, etc. Even a slight change of these factors might have affected the cutting efficacy or the tendency of forwarding in the canal. Further studies are required to specify the influencing factors.

At 5 mm level from the apex, all 3 file systems showed inward transportation tendency. It is worth pointing out that, with prescribed manufacturer's directions, coronal flaring is a prerequisite with proper endodontic instruments. Glide path and coronal enlargement are crucial to achieve more direct path to the apical third with removing coronal interferences

and these also allow safe usage [22,35]. A previous study reported that the creation of a glide path and preliminary enlargement enhances the performance of PTN instrument, whereas PTN without a glide path results in a higher mean volume of removed dentin especially on the middle and coronal portion of the root [36]. In the current study, the procedure of coronal flaring was omitted to precisely evaluate the preparation systems only. Therefore, it might have influenced the result and thus the analyzed parameters should be interpreted with caution.

Previous reports already clarified that the canal transportation can be considered as a procedural error that results in inadequate root canal cleaning and the persistency of periapical lesions [37,38]. In this regard, Wu *et al.* [39] reported that apical transportation over 0.3 mm could negatively affect the sealing ability of filling material. In this study, the mean amount of transportation was within the range of 0.08–0.28 mm. This value is lower than the critical canal transportation value proposed by Wu *et al.* [39] Therefore, although there was a statistically significant difference in the amount of canal transportation at 3 mm level, all 3 files could be used in the clinical situations with acceptable performance.

CONCLUSIONS

Within the limitation of this study, VB system showed similar amount of canal volume change with both PTN and PTU files. For the amount of canal transportation, PTN files exhibited less transportation than PTU files at 3 mm level. VB files showed similar transportation with PTU or PTN files. Also, VB files showed unique inward transportation tendency in the apical area. Overall, VB file system could prepare the curved canals without significant shaping errors.

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