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Multidimensional Analysis of Canal Transportation and Centering Ability of WaveOne Gold and ProTaper Next File Systems in Curved Root Canals

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Abstract

Introduction: Advances in endodontic instrumentation are centered around innovation of variable metallurgy and designs of endodontic files to reduce procedural errors. However, there is a lack of consensus in the literature with regard to the shaping ability of WaveOne Gold (WOG) and ProTaper next (PTN) endodontic file systems in the curved root canals. This study aimed to measure and compare the amount of canal transportation (CT) and centering ability (CA) in the coronal, middle, and apical thirds of root canals prepared using the WOG file and PTN system using cone-beam computed tomography (CBCT). **Materials and Methods:** A total of sixty single-rooted teeth with Type I Vertucci canal and moderate 10-30° canal curvature according to AAE guidelines were collected and divided into two groups: Group 1: WOG system, Group 2: PTN. Baseline and post-operative CBCT scans were obtained for all the specimens using the same exposure parameters. The CT and CA of each root canal at 3, 6, and 9 mm, corresponding to the coronal, middle, and apical third, were calculated. The data was analyzed using SPSS. The level of significance was kept at 0.05. **Results:** At the 6 mm level, The WOG system exhibited statistically less canal transportation (CT) in mesio-distal dimension compared to PTN (P=0.005). The direction of transportation was predominantly towards the distal and lingual aspects for both systems. The centering ability (CA) of WOG was statistically higher than that of PTN at 9 mm level (P=0.023). However, all measured transportation values for both systems fell within the clinically acceptable threshold of <0.15 mm. **Conclusion:** Within the limitations of this *in vitro* study, both the WOG and PTN Next file systems prepared moderately curved root canals with clinically acceptable accuracy, maintaining canal transportation within a safe range. The observed statistical differences are of uncertain clinical significance given the measurement resolution of CBCT.

Keywords: Canal Transportation; Curved Root Canals; Cone-beam Computed Tomography; Root Canal Preparation; Shaping Ability

Introduction

In endodontics, optimal root canal preparation is critical for preservation of original canal morphology, the size, and the spatial position of the apical foramen, to establish a continuous tapering funnel from the access cavity to the apical foramen [1]. Adherence to a well-executed clinical protocol is considered a key factor in ensuring the long-term success of endodontic therapy [2]. However, endodontic instruments present inherent challenges, such as a tendency to deviate from the original axis in curved root canals, which can alter canal dimensions and result in procedural errors [3]. Therefore, advances in endodontics are centered around the innovative instruments incorporated with diverse metallurgy and designs that affect the root canal shaping ability [4].

Due to the inherent flexibility and ability to lower iatrogenic errors, NiTi rotary files have been a mainstay in endodontics by incorporating unique alloys, various cross-sectional designs, variable tapers, cutting angles, number of flutes, radial land, and heat treatment that are characteristic of manufacturing approaches to demonstrate significantly greater performance to cyclic fatigue and torsional stress [5, 6]. In the era of contemporary

Figure 1. Measurement of tooth length and degree of canal curvature (Schneider technique)

endodontics, new technology and innovation in the automation of mechanical root canal preparation has gained enough momentum [7]. The WaveOne Gold (WOG) (Dentsply Sirona, Ballaigues, Switzerland) consists of M-NiTi alloy, is an innovative reciprocating file system with balanced kinematics and cyclic fatigue resistance, with deeper flutes, and improved flexibility [8, 9]. It features left-hand threads instead of conventional right-hand threads and an inverted helix, so counter-clockwise rotations engages and clockwise rotations disengage the file, also tips adapted (non-cutting) precisely to match the canal curvature [10-12]. As the instrument begins to rotate in one direction, it cuts and becomes engaged with the canal wall, then it disengages in the reverse direction, and the stresses are eventually reduced [12, 13]. Similarly, the ProTaper Next (PTN) (Dentsply Sirona, Ballaigues, Switzerland) is an advanced M-Wire NiTi file system with positive cutting angles of approximately 60°, designed with a bilaterally symmetrical quadrilateral cross-section, variable taper, and an offset center of rotation that generates a "swaggering effect" to minimize the screw-in tendency and offers enhanced resistance to torsional stress and improved durability against wear [14, 15].

Research by Eliasz *et al.* and Shi *et al.* [15, 16] demonstrated that WOG showed better clinical outcomes than PTN in preserving the original canal anatomy and enhancing fracture resistance. Conversely, findings by Ismail *et al.* [17] indicated that PTN outperformed WOG in terms of flexibility and torsional resistance. While previous studies have compared these systems, often using micro-CT, there remains a value in validating their performance using cone-beam computed tomography (CBCT), a technology more readily available in clinical and research settings. Therefore, the present study aims to evaluate and compare the three-dimensional canal transportation and centering ability of the WOG and PTN systems in moderately curved root canals using CBCT, to provide a clinically oriented assessment of their shaping accuracy and safety. Thereby generating a null hypothesis that there will be no difference in the shaping ability of WOG and PTN file systems in radicular dentin than in curved root canals.

Materials and Methods

The present study was carried out in accordance with the CRIS guidelines (checklist for reporting *in vitro* study) and the World Medical Association Declaration of Helsinki [18]. Ethical approval was obtained from the ethical review committee.

Sample size

Open Epi software version 3.0 (Open Source Epidemiologic Statistics for Public Health, Rollins School of Public Health, Emory University, Atlanta, GA, USA) was used to compute sample size. Based on a recent research by Kaddoura *et al.*, the reference mean and standard deviation (SD) for shaping abilities of WOG and Fanta AF-F One files were taken to be 0.06±0.05 mm and 0.09±0.03 mm in the coronal third, respectively [19]. The sample is calculated to be 60 (n=30), with 80% power and a 95% confidence interval. While based on a comparison involving a different file system, this calculation provided a conservative estimate of the required sample size to detect a clinically relevant difference in shaping ability.

Sample selection and preparation

Through a non-probability consecutive sampling technique, single-rooted teeth with Type I (single canal) Vertucci canal and moderate 10-30° canal curvature according to AAE Endodontic Case Difficulty Assessment form & Guidelines (2010), that were calculated through the Schneider technique, were included (Fig. 1) [20, 21]. Endodontically treated teeth, immature teeth, teeth with cracks and fractures, calcifications, and pathological root resorption were excluded. The collected teeth were debrided by using an ultrasonic scaler (Hu-Friedy, Ultrasonic Piezon Scaler 250, Chicago, IL, USA) for attached periodontal ligaments and calculus. All the samples were autoclaved at 121 °C for 15 min. Preoperative periapical radiographs of each tooth were obtained and uploaded to Sidexis 4.3.1 software (Dentsply Sirona, York, PA, USA).

The teeth were numbered and randomly divided into two groups *via* the random number table method, and mounted in a wax platform to help facilitate the handling and obtaining reproducible images during the CBCT scan (Fig. 2). After acquiring baseline pre-operative CBCT (Galileos; Sirona Dental

Figure 2. *A*) Teeth mounted on a wax arch block to simulate jaw; *B and* C) The simulated jaws were then tapped in a machine prop for obtaining CBCT

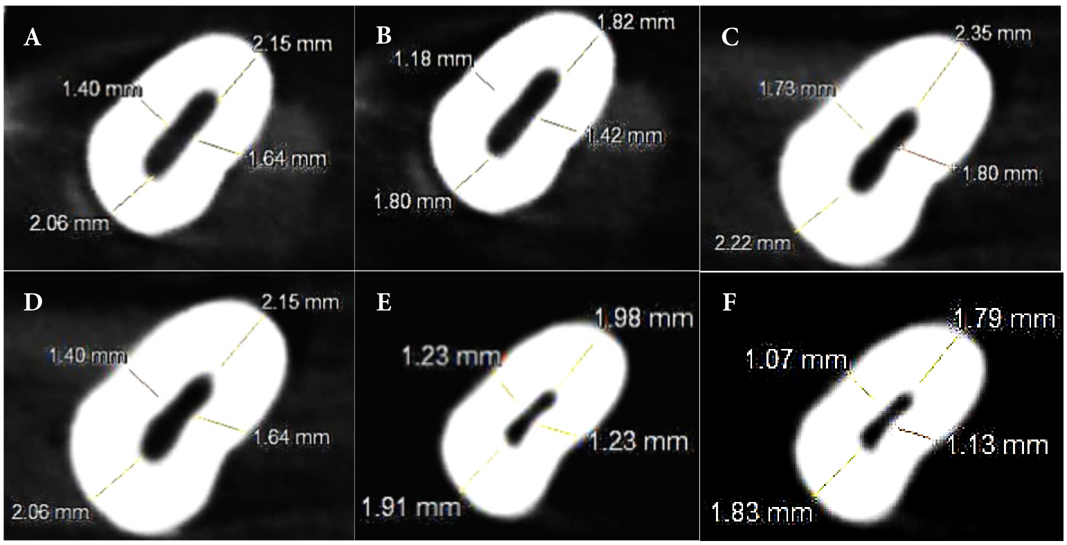

Figure 3. levels *A*) Pre-operative image at 9 mm; *B*) Post-operative image at 9 mm; *C*) Pre-operative image at 6 mm; *D*) Post-operative image at 6 mm; *E*) Pre-operative image at 3 mm; *F*) Post-operative image at 3 mm. *m1* and *m2* represent the minimum mesial dentin thickness before and after instrumentation, respectively; *d1* and *d2* the minimum distal dentin thickness; *b1* and *b2* the minimum buccal dentin thickness; and *l1* and *l2* the minimum lingual dentin thickness before and after instrumentation, respectively.

System, Bensheim, Germany) at 60-90 kV power output, 3-6 mA tube current, Img. Vol 8 × 8, voxel size of 0.1-0.2, Scanning (L) of 14 sec, and exposure time for 2-5 sec, the image synchronization tool was used for coronal, sagittal, and axial views. All the samples were subjected to preparation of straight-line access cavity using rounded diamond burs ISO 001/014 (Mani Dia BR-41, Mani, Japan) in a high-speed handpiece, negotiating the canal, and obtaining patency using K-file #10 (Dentsply Maillefer, OK, USA). The glide path was then prepared, followed by a ISO k-file #20 and/or #25 at a length of 0.5 mm short of radiographic working length. One group was treated using the WOG system (Dentsply Maillefer, USA) with the primary file (25/0.07) following manufacturer guidelines. The other group was prepared by the PTN file system (Dentsply Maillefer, USA), comprised of X1 (17/0.04) followed by X2 (25/0.06) at 300 rotations per min and 2.2 N/cm torque. The canal was subsequently irrigated with 10 mL 3% NaOCl using side vented needle irrigation syringe and 10 to 12 mg of 17% EDTA (RC-Prep; Premier Dental, Philadelphia, PA) at each successive instrumentation. After preparation, paper points (Dentsply Sirona, USA) were used for dehydrating the canals. Following instrumentation, post-operative CBCT scans were obtained using the same exposure parameters. Evaluation of CT and CA was carried out through measuring pre and post-instrumentation dimensions of remaining dentin thickness from the points of inner and outer highest circumference in cross-section of the prepared root canal (Fig. 3). Two qualified raters trained on 10 independent scans measured the pre-and post-instrumentation dimensions. Fleiss' kappa (0.825) showed that the operators' judgements were in good agreement (95% CI, 0.820 to 0.829, $P<0.005$). The examiners were blinded to the procedures and groups.

Analysis of canal transportation

The mesiodistal and buccolingual dimensions in cross-sections were measured at 3, 6, and 9 mm from the apex, corresponding to the coronal, middle, and apical third. The measurements of CT were taken as proposed by Singh *et al.* [22] using the following formulas;

Mesiodistally= $(m1 - m2) - (d1 - d2)$
Buccolingually= $(l1 - l2) - (b1 - b2)$
m1: Minimum pre-instrumentation linear dimension from the mesial contour of the root to the canal
m2: Minimum post-instrumentation linear dimension from the mesial contour of the root to the canal
d1: Minimum pre-instrumentation linear dimension from the distal contour of the root to the canal
d2: Minimum post-instrumentation linear dimension from the distal contour of the root to the canal
b1: Minimum pre-instrumentation linear dimension from the buccal contour of the root to the canal
b2: Minimum post-instrumentation linear dimension from the buccal contour of the root to the canal
l1: Minimum pre-instrumentation linear dimension from the lingual contour of the root to the canal
l2: Minimum post-instrumentation linear dimension from the lingual contour of the root to the canal
According to the aforementioned formulae, a value of zero indicated no canal transportation, whereas positive and negative values indicated distal and buccal transportation, as well as mesial or lingual transmission, respectively.

Analysis of centering ability

The CA was calculated similarly to the aforementioned criteria using the following formulae; [22]

Centering ability (CA)=$\frac{m1-m2}{(d1-d2)}$ or $\frac{d1-d2}{(m1-m2)}$

The fraction with the lower values was considered for statistical analysis in the aforementioned equation. The value one indicated complete centering, whereas the lower values pointed out alterations in the canal route.

Statistical analysis:

The data were analyzed using the Statistical Package for Social Sciences, version 23.0 (SPSS; IBM, Armonk, NY, USA). The Shapiro-Wilk test confirmed normal distribution. Descriptive statistics were expressed as mean and standard deviation. Inter-group comparisons were performed using the Independent *t*-test with Bonferroni adjustment, while intra-group comparisons at 3, 6, and 9 mm levels were assessed through repeated measures ANOVA. A significance threshold of $P<0.05$ was applied.

Results

The mean tooth length was 20.87±1.88 mm, and the mean root curvature angle was 25.29±4.72°, with no significant distribution bias between the groups ($P>0.05$) (Table 1). Inter-group comparison of canal transportation (CT) in mesio-distal and bucco-lingual directions revealed a statistically significant difference at 6 mm from the apex, where WOG demonstrated superior results compared to PTN ($P<0.05$) (Tables 2 & 3).

Intra-group comparison of CT at mesio-distal dimensions showed that PTN exhibited significant differences at all three levels ($P<0.05$). Mesial transportation was recorded as 0.01±0.18 mm and 0.01±0.04 mm at the apical and coronal thirds for PTN and WOG, respectively, while distal transportation was observed at other levels. Lingual transportation was noted across all levels in both groups, except at the middle third of PTN, which showed buccal transportation of 0.11±0.25 mm (Table 2). Furthermore, WOG demonstrated greater centering ability (0.62±0.18 mm) compared to PTN (0.42±0.43 mm) at 9 mm from the apex ($P<0.05$). It should be noted that the high standard deviation observed for PTN at the 9 mm level indicates considerable variability in its centering ability within the study sample (Table 4).

Discussion

The primary finding of this *in vitro* study is that both the reciprocating WOG and PTN systems produced canal preparations within clinically acceptable limits in moderately curved root canals, with all recorded transportation values remaining below the 0.15 mm threshold [23, 24]. While statistical analysis revealed differences in canal transportation (CT) at the 6 mm level and centering ability (CA) at the 9 mm level, the most clinically relevant outcome is the safe performance of both systems.

The findings of the current study showed that WOG observed better outcomes in the middle third of the root canal in terms of CT. Both file systems observed greater canal transportation toward the distal and lingual directions. One plausible explanation could be that root canal curvature was most frequently localized at the apical third (53.9%), followed by the coronal (33.3%) and the middle (12.8%) third, so revealed better localization of instruments at 6 mm of the root canal [25]. Additionally, previous studies have documented that single-rooted teeth often present greater curvature in the buccolingual and mesial directions, which may have influenced the observed pattern of canal transportation in this study [26].

Emphasizing the comparison using different kinematics in maintaining file orientation centrally, WOG reported a better value of centralization than PTN in the coronal third of prepared root canals. These findings are consistent with the study by Singh *et al.* [22] and Gajoum *et al.* [27] reported greater values of CA and more numbers of centralized circumferential points in reciprocating file systems as compared to rotary files. Furthermore, investigations have shown that WOG preserves the original foramen size when compared to PTN [28]. One hypothesis suggests that the advantage of reciprocating motion in WOG over continuous rotation is that it may reduce root canal irregularity [12]. Also, PTN has a susceptibility to remove more dentin from the outer wall of the curved canals [29]. This propensity to follow a straight path, along with lower flexibility of PTN than WOG account for further deviation from the canal curvature. Likewise, a study by Santa-Rosa *et al.* [30] reported that WOG produces lesser deviations in the canal curvatures. Although WOG demonstrated a statistically higher mean centering ratio at the coronal level, the substantial variability in PTN's performance, as evidenced by its large standard deviation, suggests that its clinical behavior may be less predictable in this region. The clinical significance of this difference in mean centering ratio remains uncertain.

The parameters to determine alterations in morphology in prepared canals after root canal treatment should be carefully analysed. Most of the previous studies utilized two-dimensional radiographic assessment or resin block simulators to determine these outcomes [16, 31]. However, the most significant disadvantages of this methodology are the two-dimensional assessment of three-dimensionally prepared canals, as well as the differences in the hardness level between resin blocks and dentin. The technique that was used to measure CT and CA in the present study was adapted and modified from the technique developed by Gambill *et al.* [32] and Singh *et al.* [22] which used four points circumferential measurements along a single plane in CBCT.

In the present study, CBCT allowed multiple imaging before and after root canal instrumentation, but the resolution of this tool is lower than that of micro-CT [33]. However, a final apical size equivalent to ISO 25 was prepared, and a 0.1-0.2 mm voxel size was considered appropriate to detect the canals and perform accurate measurements [34]. In addition, the micro-CT imaging technique, despite its higher resolution, is well known to be time-consuming, especially for a high number of dental samples like the one used in our study [35]. Although the recent versions of microCT scanners have overcome this problem, the overall cost of this technique remains higher than that of CBCT technology.

Table 1. Inter-group comparison of length and angle of study samples

Morphometry	Groups	Mean (SD)	*P*-Value
Tooth length (mm)	PTN	20.94 (1.98)	0.799
	WOG	20.81 (1.81)	
Root angle (degrees)	PTN	24.39 (4.58)	0.140
	WOG	*26.20 (4.77)*	

Independent t-test; P<0.05

Table 2. Inter and intra-group comparison of CT at mesio-distal dimensions at three levels from the apex

Mesio-distal [Mean (SD)] level of measurement from apex				
Groups	**3 mm**	**6 mm**	**9 mm**	***P*-value**
PTN	-0.01 (0.18)	0.13 (0.14)	0.04 (0.18)	0.005*
WOG	0.02 (0.12)	0.03 (0.11)	-0.01 (0.04)	0.033*
***P*-value**	0.419	0.005*	0.208	-

*Independent t-test; P<0.05; *Adjusted p-values*

Table 3. Inter and intra-group comparison of CT at bucco-lingual dimensions at three levels from the apex

Bucco-lingual [Mean (SD)] level of measurement from apex				
Groups	**3 mm**	**6 mm**	**9 mm**	***P*-value**
PTN	-0.03 (0.17)	0.11 (0.25)	-0.03 (0.15)	0.877
WOG	-0.01 (0.09)	-0.003 (0.08)	-0.02 (0.11)	0.771
***P*-value**	0.603	0.018	0.783	-

Independent t-test; P<0.05

Table 4. Inter and intra-group comparison of CA at three levels from the apex

Mean (SD) level of measurement from apex				
Groups	**3 mm**	**6 mm**	**9 mm**	***P*-value**
PTN	0.55 (0.27)	0.49 (0.26)	0.42 (0.43)	0.474
WOG	0.45 (0.32)	0.42 (0.28)	0.62 (0.18)	0.389
***P*-value**	0.211	0.318	0.023	-

Independent t-test; P<0.05

The average tooth length in this study was determined to be 20.8 mm, representing the most prevalent length observed [36]. Moreover, the study included moderate 10°-30° canal curvature according to AAE Guidelines, as the incidence of moderate curvature was reported to be more than severe curvature of root canals [37]. The random allocation of samples observed no distribution bias between the groups with respect to mean tooth length and angle of curvature in root canals. Studies suggested that WOG have a lower percentage of variable tapers at each level as compared to PTN. These micro-manufacturing features are imperative for improved clinical outcomes. Literature suggest that for preparation in the middle and cervical thirds of the root canal, it is recommended to use greater taper instruments for optimal dentin removal in the safety zone of root canals to avoid procedural errors [38].

It is imperative to interpret these quantitative findings in the context of the study's methodological limitations. The CBCT voxel size of 0.1-0.2 mm represents the fundamental unit of measurement, meaning that changes smaller than this range are at the limit of the tool's detection capability. Consequently, the precise numerical values for CT and CA reported here should be viewed with caution, as the measurement error may be of a similar magnitude to the effects being measured [33, 35]. Therefore, the claim of clinical '*superiority*' for one system over the other is not well-supported by our data. Instead, our results affirm that clinicians can expect both file systems to perform adequately in canals with moderate curvature.

Conclusion

Within the limitations of this CBCT study, both the WaveOne Gold and ProTaper Next systems demonstrated a clinically acceptable and comparable shaping ability in moderately curved root canals, with all deviations remaining within a safe range. The statistical differences observed are likely below the threshold of clinical relevance. Future research utilizing higher-resolution imaging modalities, such as micro-CT, is recommended to quantify subtle differences between these file systems with greater precision.

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Conflict of interest

None.

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Ethical approval

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Authors' contributions

Conceptualization: RG; Methodology: SAT/RG; Formal Analysis and Investigation: RG; Writing-Original Draft Preparation: SAT/RG; Writing-Review and Editing: SAT; Supervision: SAT. All authors read and approved the final manuscript.

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