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A Cone-Beam Computed Tomography Imaging-Based Comparative Study on Root Canal Preparation Using Three Different Nickel-Titanium Instruments

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ABSTRACT. *Objective: The goal of this study is to use cone-beam computed tomography (CBCT)-based three-dimensional (3D) imaging to compare the performance of three nickel-titanium instruments, namely, Mtwo, ProTaper Universal, and ProTaper. Next, in the preparation of the curved mesiobuccal root canal of the maxillary first molar. Conclusion: In root canal preparation, the ProTaper Next nickel instrument generates a moderate degree of dentin removal and is associated with the least transportation in the apical segment, which is the most crucial region.*

KEYWORDS: *Cone-beam computed tomography (cbct); Root canal therapy, Root canal preparation; Nickel-titanium instrument; Apical transportation*

1. Introduction

The main purpose of root canal preparation is to eliminate or reduce microorganisms in the root canal system while maintaining its original shape and path. The anatomy and morphology of the root canal system is complex and includes the canal isthmus, intercanal communicating branches and lateral canals, thus complicating effective preparation of the root canal system [1]. However, modern root canal therapy requires that after preparation, the root canal path is naturally formed: the region from the crown to the apex must form a conical shape, apical foramina must retain their original contour, and no significant changes should be applied to the natural orientation of the root canal [2, 3]. Although most root canals have curvatures, root canal preparation devices are usually manufactured in a straight line and cannot be bent or curved. Thus, root canal preparation often leads to apical transportation to curved root canals, such as the mesiobuccal root canal of the maxillary first molar. Consequently, therapy often contributes to ledge formation in the root canal or deviation of the root canal, which severely affects the preparation process and root canal quality and compromises the therapeutic outcome [4, 5]. The three nickel-titanium instruments for root canal preparation examined in this study, namely, Mtwo, ProTaper Universal, and ProTaper Next, are common in dental practice. However, no study has explored whether the three instruments may cause apical transportation in the preparation of curved root canals (such as the mesiobuccal root canal of the maxillary first molar). Cone-beam computed tomography (CBCT) is one imaging technique used to evaluate the quality and efficacy of root canal preparation. CBCT has the advantages of a low radiation dose and a small visual field, which improve the resolution and diagnostic performance. Moreover, CBCT scans are more accurate than traditional radiographs and can facilitate three-dimensional (3D) measurements of the root canal, allowing comprehensive analysis of apical transportation of the curved mesiobuccal root canal of the maxillary first molar after root canal preparation using the three nickel-titanium instruments. This study provides clinical data from root canal preparation that can help clinicians to better understand the nickel-titanium instruments designed for root canal preparation, reflecting the clinical significance of this study.

2. Methods

2.1 Study Subjects

From September 2016 to December 2018, 36 isolated maxillary first molars were selected from the

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Department of Stomatology, the First Affiliated Hospital of Jinan University, Guangzhou, China. These specimens were extracted from patients who were diagnosed with severe periodontitis with grade 3 tooth mobility (the teeth should be extracted). The selection criteria for the isolated teeth were maxillary first molars with no endodontic treatment, intact mesiobuccal root canals, complete apical development, and no obvious dental tissue caries or root canal resorption. In addition, this study excluded teeth with double mesiobuccal canals and selected only those with a single mesiobuccal canal to simplify root canal imaging measurements, improve the accuracy, and avoid errors in graphic measurements.

According to the method of root canal curvature measurement proposed by Shneider and the curvature of the mesiobuccal root canal, 22 of the 36 extracted teeth were slightly curved specimens (< 15°), and 14 were severely curved specimens (> 15°). The specimens were then randomly divided into three experimental groups, with 8 slightly curved teeth and 4 severely curved teeth in the Mtwo group and 7 slightly curved teeth and 5 severely curved teeth in both the ProTaper Universal group and the ProTaper Next group.

Table 1 Grouping of the Isolated Teeth

Curvature	Slight (< 15°)	Severe (> 15°)
Mtwo group	8	4
ProTaper Universal group	7	5
ProTaper Next group	7	5
Sum	22	14

2.2 Procedure and Methods of Root Canal Preparation

The central fossa of an extracted tooth was drilled to open the pulp cavity and remove its top. The mesiobuccal root canal was explored with a 10# or 15# stainless steel K file, which was applied with ethylenediaminetetraacetic acid (EDTA) root canal lubricant to dredge the mesiobuccal root canal to reach the apical foramen and thus determine the working length. Then, the three nickel-titanium instruments were used for root canal preparation. The crown-down method was employed for Mtwo-based preparation, where files were successively used (i.e., from the smallest 10# purple file to the largest 25# red file) to prepare the working length to reach the apical foramen. The crown-down method was also used with the ProTaper Universal instrument. Preparation was started with a red Sx file, and an F1 file, F2 file and F3 file were used successively. Except for the Sx file, each nickel-titanium file was used to prepare the working length to reach the apical foramen. The crown-down method was also used with the ProTaper Next instrument. The procedure started with a yellow X1 file and ended with a red X2 file. Most of the curved root canals could be prepared with only two nickel-titanium files. During preparation, each file was required to prepare the working length and reach the apical foramen.

2.3 Cbct Scanning

All the selected maxillary first molars were scanned and reconstructed by CBCT before and after root canal preparation. The CBCT machine used in this study was the Kodak 9000C model purchased from Renew Digital (Norcross, GA, United States). The scanning parameters were set (current 8 mA, voltage 70 kV, and scanning time 10 s) to perform CBCT 3D scanning. After scanning was completed, image reconstruction was performed using the corresponding software on the machine, and then the graphics were measured and the corresponding data were acquired. (Shown in Figure 1, Figure2 and Figure3)

2.4 Acquisition, Measurement, and Calculation of the Imaging Data

After obtaining 3D images, the cross-sections were measured at 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, and 8 mm from the apical foramen (Fig.4), as described by Gambill et al. [6]. During measurement, the mesioproximal-mesiodistal direction at each cross-section was designated as the X-axis, and the buccal palatine direction was designated as the Y-axis. Subsequently, the following thicknesses of the root canal wall were measured: the pre-preparation thickness of the mesial root canal wall X_1; the pre-preparation thickness of the mesiodistal root canal wall X_3; the post-preparation thickness of the mesial root canal wall X_2; the post-preparation thickness of the mesiodistal root canal wall X_4; the pre-preparation thickness of the buccal root canal wall Y_1; the pre-preparation thickness of the palatine root canal wall Y_3; the post-preparation thickness of the buccal root canal wall Y_2; and the post-preparation thickness of the palatine root canal wall Y_4. According to the formulas introduced by Gambill et al. [6], the following values were calculated at each cross-section: the

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increase in the root canal diameter, $(X_1\text{-}X_2) + (X_3\text{-}X_4)$ for the mesiodistal direction and $(Y_1\text{-}Y_2) + (Y_3\text{-}Y_4)$ for the buccal palatal direction; root canal transportation, the absolute value of $[(X_1\text{-}X_2) - (X_3\text{-}X_4)]$ for the mesiodistal direction and the absolute value of $[(Y_1\text{-}Y_2) - (Y_3\text{-}Y_4)]$ for the buccal palatal direction; and the centering ratio, $(X_1\text{-}X_2)/(X_3\text{-}X_4)$ for the mesiodistal direction and $(Y_1\text{-}Y_2)/(Y_3\text{-}Y_4)$ for the buccal palatal direction. The results were statistically analyzed.

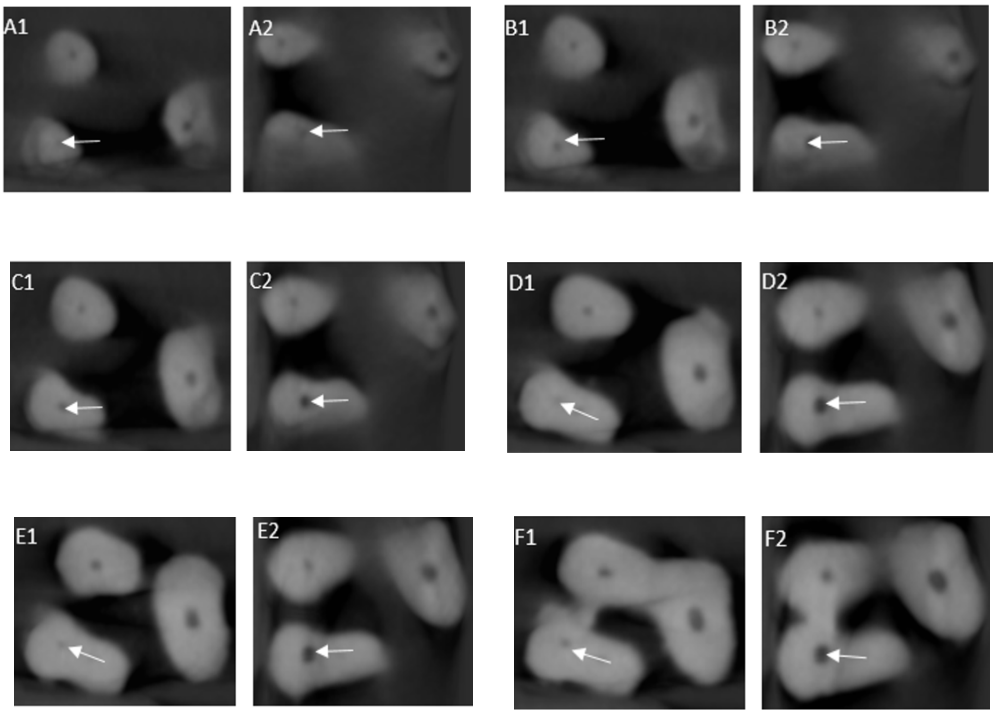

Figure.1 The Cross-Sections of Cbct Image Were Measured At 3 Mm(a), 4 Mm(B), 5 Mm(C), 6 Mm(d), 7 Mm(e), and 8 Mm(f) from the Apical Foramen Before(1) and after(2) Preparation Using the Mtwo Instruments.

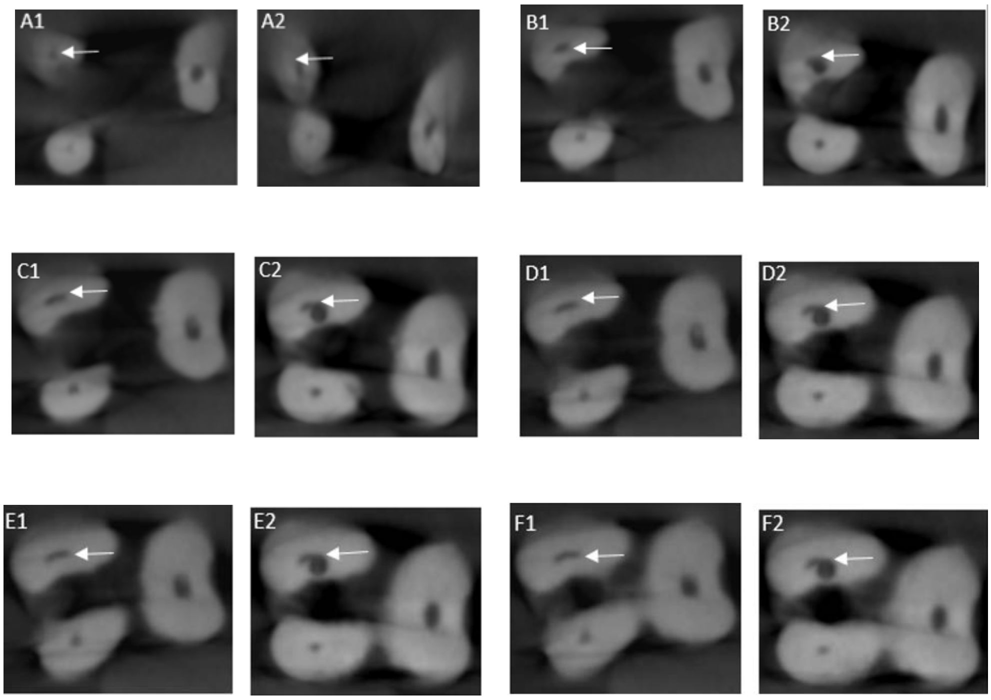

Figure. 2 The cross-sections of CBCT image were measured at 3 mm(A), 4 mm(B), 5 mm(C), 6 mm(D), 7 mm(E),

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and 8 mm(F) from the apical foramen before(1) and after(2) preparation using the ProTaper Universal instruments.

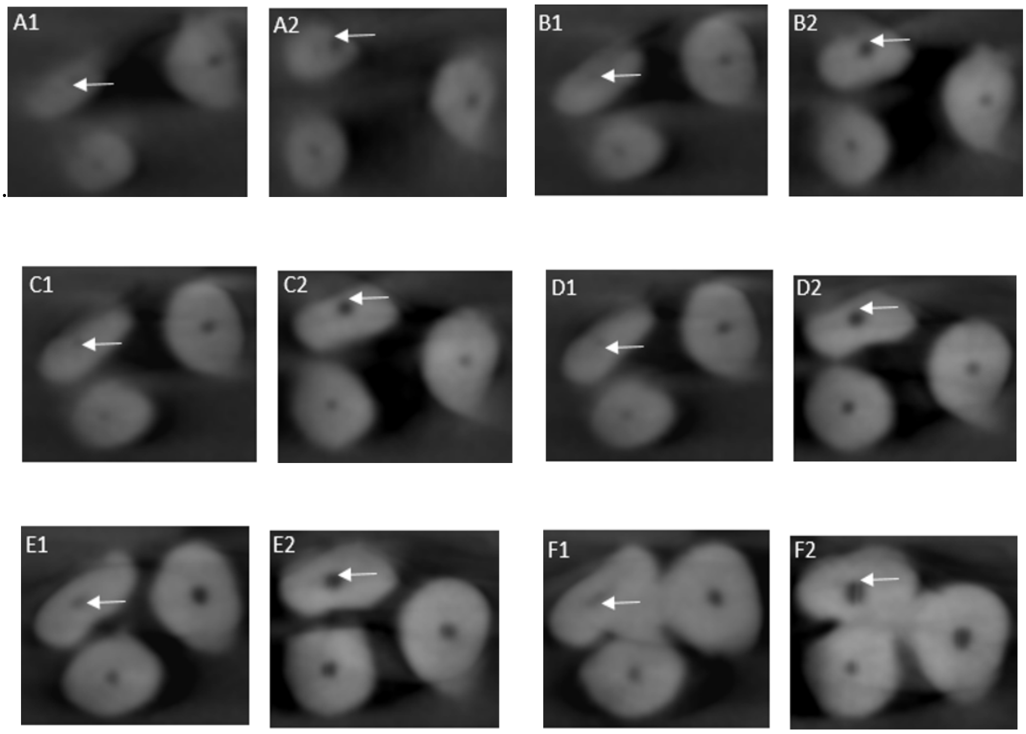
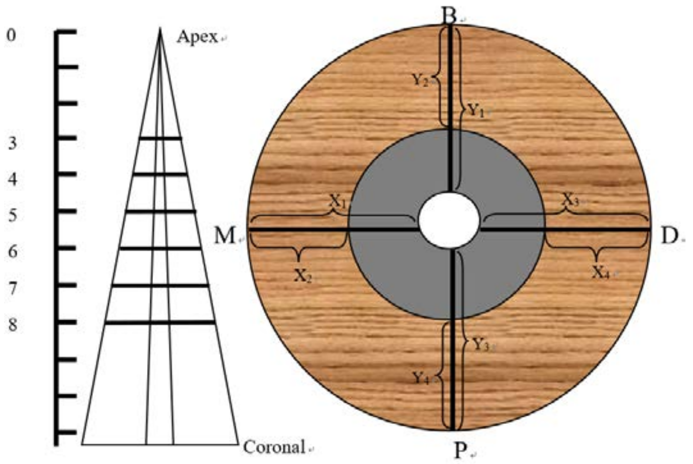


Figure.3 The cross-sections of CBCT image were measured at 3 mm(A), 4 mm(B), 5 mm(C), 6 mm(D), 7 mm(E), and 8 mm(F) from the apical foramen before(1) and after(2) preparation using the ProTaper Next instruments.

2.5 Statistical Methods

The data in this study are all expressed as x ± s. SPSS16.0 software was used for the statistical analysis. Depending on the data distribution, a two-sample *t*-test or one-way analysis of variance (ANOVA) was employed to analyze the increase in the root canal diameter, canal transportation, and the centering ratio, and then the Student-Newman-Keuls (SNK) test for pairwise comparisons or the Friedman rank sum test was used to examine statistical differences between the groups. $P < 0.05$ was considered statistically significant.



Fiureg.4 Schematic Diagram of Cbct Image Measurement.

3. Results

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3.1 Increase in the Root Canal Diameter

According to the measurement method illustrated in Fig. 1, increases in the root canal diameter before and after preparation using the Mtwo, ProTaper Universal, and ProTaper Next instruments in both slightly curved root canals and severely curved root canals were compared. As shown in Table 2, the comparisons using both one-way ANOVA and the SNK test at each cross-section in either category of root canals consistently revealed significant differences among the three instruments ($P < 0.05$). In other words, regardless of the curvature of the root canals (slight or severe) or the distance from the apex, the resulting increases in the root canal diameter with the three instruments were in the order of ProTaper Universal > ProTaper Next > Mtwo, revealing that among the three instruments, ProTaper Universal was the best nickel-titanium instrument for cutting the internal wall of the root canal, followed by ProTaper Next and then Mtwo.

Table 2 Comparison Of the 3d Averages of Root Canal Diameter Increases Before and after Preparation Using the Three Nickel-Titanium Instruments (X ±s) (Mm)

Distance from the apical foreman		Root canals with slight curvatures (n=22)			Root canals with severe curvatures (n=14)		
		Mtwo group	PTU group	PTN group	Mtwo group	PTU group	PTN group
Apex	3 mm	0.24±0.02	0.33±0.04	0.26±0.04*	0.23±0.02	0.32±0.04	0.25±0.04*
	4 mm	0.26±0.02	0.36±0.04	0.29±0.05*	0.26±0.02	0.38±0.04	0.29±0.05*
Middle root	5 mm	0.29±0.03	0.39±0.04	0.34±0.05*	0.31±0.03	0.40±0.04	0.36±0.05*
	6 mm	0.33±0.03	0.44±0.05	0.41±0.04*	0.33±0.03	0.47±0.04	0.43±0.05*
Crown	7 mm	0.36±0.03	0.56±0.05	0.51±0.06*	0.37±0.04	0.58±0.04	0.52±0.06*
	8 mm	0.39±0.04	0.63±0.05	0.59±0.06*	0.41±0.04	0.64±0.05	0.58±0.06*

*: Both one-way ANOVA and the SNK test revealed that the three instruments exhibited significant differences ($P < 0.05$) at each cross-section in either category of root canals.

3.2 Transportation of Root Canals

The canal transportation results before and after preparation using the Mtwo, ProTaper Universal, and ProTaper Next instruments in both slightly curved root canals and severely curved root canals were compared. Subsequent statistical analyses using both one-way ANOVA and the SNK test showed that except for the middle segment (i.e., 5 mm and 6 mm from the apex) of severely curved root canals, significant differences ($P < 0.05$) existed among the instruments. As shown in Table 3, for apical cross-sections at 3 mm and 4 mm, the canal transportation generated by the three instruments was in the order of ProTaper Universal > Mtwo > ProTaper Next regardless of whether the curvatures were slight or severe. The results revealed that ProTaper Next led to the lowest canal deviation. For the root segments at 5 mm and 6 mm of slightly curved root canals, the transportation results were in the order of ProTaper Universal > ProTaper Next > Mtwo. Thus, Mtwo exhibited the best performance for these segments. However, the three instruments exhibited no significant differences for segments at 5 mm and 6 mm of severely curved root canals ($P > 0.05$). For the root segments at 7 mm and 8 mm, the resulting transportation in both slightly curved root canals and severely curved root canals was in the order of ProTaper Universal > ProTaper Next > Mtwo, indicating that Mtwo generated the best results for the crown region.

Table 3 Comparison Of the 3d Averages of Root Canal Transportation Before and after Preparation Using the Three Nickel-Titanium Instruments (X ±s) (Mm)

Distance from the apical foreman	Root canals with slight curvatures (n=22)			Root canals with severe curvatures (n=14)		
	Mtwo group	PTU group	PTN group	Mtwo group	PTU group	PTN group
3 mm	0.08±0.031	0.12±0.042	0.06±0.026*	0.11±0.043	0.17±0.049	0.06±0.023*
4 mm	0.07±0.029	0.13±0.046	0.05±0.024*	0.11±0.044	0.18±0.053	0.07±0.023*
5 mm	0.04±0.022	0.07±0.036	0.08±0.033*	0.07±0.037	0.09±0.035	0.09±0.039
6 mm	0.04±0.026	0.06±0.035	0.09±0.031*	0.06±0.033	0.08±0.033	0.09±0.041
7 mm	0.06±0.039	0.16±0.053	0.12±0.046*	0.06±0.041	0.22±0.084	0.14±0.044*
8 mm	0.07±0.034	0.16±0.051	0.12±0.041*	0.07±0.044	0.24±0.085	0.15±0.043*

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*: Both one-way ANOVA and the SNK test revealed that the three instruments exhibited significant differences (P < 0.05) at each cross-section in either category of root canals.

3.3 The Centering Ratio of Root Canals

The centering ratios before and after the preparation using the Mtwo, ProTaper Universal, and ProTaper Next instruments in both slightly curved root canals and severely curved root canals were compared. Subsequent analyses using both one-way ANOVA and the SNK test revealed that for both categories of root canals, no statistical differences existed among the three instruments ($P > 0.05$). As shown in Table 4, regardless of the segment or curvature, the resulting centering ratios were in the order of ProTaper Universal > Mtwo > ProTaper Next. The results suggested that ProTaper Next led to the lowest canal deviation. However, these differences were not statistically significant ($P > 0.05$).

Table 4 Comparison Of the 3d Averages of the Centering Ratios Before and after Preparation Using the Three Nickel-Titanium Instruments (X ±s) (%)

Distance from the apical foreman		Root canals with slight curvatures (n=22)			Root canals with severe curvatures (n=14)		
		Mtwo group	PTU group	PTN group	Mtwo group	PTU group	PTN group
Apex	3 mm	0.52±0.36	0.62±0.42	0.34±0.25	0.59±0.41	0.67±0.49	0.36±0.26
	4 mm	0.53±0.34	0.63±0.46	0.35±0.24	0.57±0.39	0.68±0.48	0.36±0.26
Middle root	5 mm	0.44±0.32	0.58±0.37	0.41±0.33	0.46±0.37	0.59±0.35	0.42±0.34
	6 mm	0.43±0.33	0.56±0.35	0.43±0.37	0.46±0.36	0.58±0.33	0.42±0.35
Crown	7 mm	0.46±0.35	0.66±0.43	0.42±0.35	0.46±0.35	0.69±0.44	0.44±0.38
	8 mm	0.47±0.34	0.66±0.41	0.42±0.34	0.47±0.35	0.69±0.45	0.45±0.37

*: Both one-way ANOVA and the Newman-Keuls test revealed that the three instruments exhibited significant differences (P < 0.05) at each cross-section in either category of root canals.

4. Discussion

In 2010, the American Association of Endodontists defined apical transportation as excessive cutting of the external lateral walls and inadequate cutting of the internal dentin of a curved root canal in 1/3 of its apical region, which results in deviation in the direction of the root canal from the original central axis, leading to alteration of the root canal path and failure to maintain its original linear shape. Such transportation may lead to ledge formation in the root canal or perforation of the lateral wall of the root canal [7]. Later, the term "canal centering ability" was proposed as a measure to evaluate the centering ability of nickel-titanium instruments during the preparation process [8]. This concept has been widely used to evaluate the biomechanical preparation process for various root canals and to assess the quality and effectiveness of different methods, instruments and techniques. Reportedly, 63.33% (n = 38) of studies on root canal preparation examined the centering ability of nickel-titanium instruments [9].

The Mtwo instrument used in this study is one of the most widely used nickel-titanium instruments in dental practice. This nickel-titanium instrument is used with a conventional method to prepare root canals; that is, all the nickel-titanium files must reach the working length of the whole root canal during root canal preparation, where the method of synchronous cutting and molding is adopted. Each file must be used to cut the entire root canal to the apical foramen, thereby effectively eliminating bacteria and toxins on the inner wall and ensuring effective preparation of the inner wall of the root canal. Due to the design concept of synchronization during preparation, each file reaches the working length of the root canal. Because of the tip-to-rod tapered design of each file, excessive cutting of the lateral wall of a curved root canal is inevitable when striving to achieve full-length preparation of the root canal, consequently resulting in different degrees of canal transportation or canal diversion at bending points and thus changing the direction of the central axis of the root canal. Therefore, the Mtwo instrument has certain application limitations for the preparation of curved root canals [10].

The design concept of the ProTaper Universal instrument has the following unique features: ① The cross-section is engineered as a slightly convex triangular surface, which substantially improves the cutting efficiency, and is fracture-resistant; ② The multigroove design and different helical angles minimize the likelihood of thread trapping in the root canal wall and maximize the discharge of debris through the root canal orifices, thereby reducing the risk of instrument separation in the root canal due to stress concentration; ③ The

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tip is relatively flat and has no sharp turn, and the instrument can therefore gradually enter the root canal and reach the apex during operation, thus avoiding damage to the lateral wall; ④ The continuous multitaper cutting edge design can effectively change the elasticity of the instrument and improve the cutting efficiency; and ⑤ The instrument employs the crown-down approach, which is beneficial for effective preparation of root canals [11-13].

The ProTaper Next instrument is the third nickel-titanium instrument used for root canal preparation in our study, which is an improved version of the ProTaper Universal instrument. The design concept of the ProTaper Next instrument is an extension of the ProTaper Universal instrument and likewise features a single-use sequence of files, which can be applied to all clinical cases. The most prominent trait of the ProTaper Next instrument is the use of M-WIRE NiTi material. On the basis of retaining the cutting efficiency of the original ProTaper Universal, this material confers high flexibility to the files. Consequently, the files have an improved anti-cyclic fatigue ability when preparing curved root canals. Because cyclic fatigue is the most important cause of the separation of instruments in root canals, the design of the ProTaper Next instrument can substantially reduce this risk. In addition, its flexibility also renders it suitable for maintaining the original anatomical structure and natural direction of curved root canals, which greatly minimizes the occurrence of apical transportation. The design of the cutting edge with a variable taper further optimizes the crown-down approach. Moreover, the most unique design feature of the ProTaper Next instrument is related to the design of its cross-section, which adopts a unique eccentric rectangular contour and allows the file move in a serpentine motion. Although the continuous movement is similar to that of other instruments, the serpentine motion can provide more space for the discharge of debris in the root canal and maintain the centering ability of the instrument. Because of the internal elasticity of the root canal, the ProTaper Next instrument exhibits an excellent ability to clean the inner walls of root canals [14, 15]. Combined with the flexibility of its M-WIRE NiTi material, this instrument has unique advantages in preparing curved root canals.

In general, in addition to the metallurgical characteristics and the design of nickel-titanium instruments, other factors, including the selection of preparation methods and the complex anatomical structure of the root canal system, also affect canal transportation and the centering ability during root canal preparation [16]. A literature review showed that 86.84% (n = 33) of studies on root canal preparation used the mesial canals of mandibular molars with medium curvatures to analyze apical transportation and the centering ability. The results revealed that canal transportation in the apical area tended to occur on the external walls of curved root canals as well as the internal walls at the coronal 1/3 and middle 1/3 of curved root canals [17]. Nearly one-third of studies in the literature have reported that when nickel-titanium instruments were used for preparation of curved root canals, canal transportation mainly occurs at the apical 1/3 of the root canal[18, 19], which is similar to the results of our study.

Canal transportation of 0.3 mm within the apical 1/3 region is reportedly not conducive to subsequent root canal filling and sealing of the apical foramen, which ultimately affects the therapeutic effect of root canal therapy [20, 21]. Our results showed that after preparation with the three instruments, the minimum root canal transportation was 0.04 mm, and the maximum transportation was 0.24 mm, which were both within the limit of 0.3 mm. Thus, the three nickel-titanium instruments can meet the requirements of tight sealing of the apical foramen. Among the instruments, ProTaper Next and Mtwo produced relatively small apical transportation and exhibited a satisfactory centering ability for root canals.

Taken together, we concluded that ProTaper Next removes a moderate amount of dentin during root canal preparation and generates the smallest amount of canal transportation in the most critical apical segment. In addition, this instrument requires only two nickel-titanium files to complete the procedure for most root canals, which saves substantial operative time, and is the primary choice among the three nickel-titanium instruments.

Declaration of Conflict of Interest

All contributing authors declare no conflicts of interest.

Acknowledgments

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