

Cone Beam Computed Tomography Analysis of TruNatomy, One Curve, and ProTaper Gold in the Canal Preparation of Curved Maxillary First Premolars: An In Vitro Study

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Abstract

Introduction: Root canal preparation is a critical step in endodontic treatment, particularly in curved canals. The palatal groove of the maxillary first premolar is often considered a risk zone, and the amount of remaining dentin plays a significant role in the prognosis and fracture resistance of teeth after treatment. This study compared the canal shaping ability and preservation of the original canal anatomy using TruNatomy, ProTaper Gold, and One Curve in the curved root canals of maxillary first premolars.

Methods: Forty-two human maxillary first premolars with mature apices and canal curvatures between 25 and 35 degrees were selected. The teeth were randomly assigned to three groups (14 per group). The canal was prepared using the TruNatomy, ProTaper Gold, and One Curve file systems. Pre-preparation and post-preparation scans were obtained using cone beam computed tomography at 2, 3, 5, and 7 mm from the apex. Canal transportation, centering ability, and residual dentin were evaluated. Statistical analysis was performed using Kruskal-Wallis and one-way ANOVA tests.

Results: The TruNatomy system demonstrated less canal transportation in mesiodistal and buccolingual directions. The mean residual dentin thickness in the TruNatomy group was 0.2036 ± 0.1608 mm, which was lower than that in the ProTaper Gold group (0.2700 ± 0.1461 mm) and comparable to that in the One Curve group (0.2057 ± 0.1461 mm).

Conclusion: TruNatomy, ProTaper Gold, and One Curve were effective and safe for root canal preparation, with no significant differences in their ability to preserve canal anatomy and residual dentin.

Keywords: Cone beam computed tomography, Rotary file, Reciprocating endodontic files, Root canal preparation



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Introduction

Successful root canal treatment requires effective removal of pulp remnants and debris, preservation of the canal's anatomical integrity, and prevention of undesirable changes in tooth structure. An ideal canal preparation should maintain the original path of the canal while minimizing alterations, especially in the apical region (1). The amount of the remaining dentin in the canal walls is a critical factor in enhancing the strength of the root after endodontic therapy, as excessive removal increases the risk of root fracture and serious clinical complications (2,3).

Specific regions (e.g., the mesial surface of the maxillary first premolar and areas with deep furcal depressions) are more susceptible to strip perforations and vertical root fractures due to the thinning of canal walls (4, 5). Particular attention has been directed toward cervical dentin, located

approximately 4 mm above and below the alveolar bone crest, as its reduction can significantly compromise the structural integrity of the root under occlusal forces (6-8).

The maxillary first premolar is known for its complex anatomy, including a high incidence of canal bifurcation, deep mesial depressions, and significant variability in canal morphology (9). Consequently, it is regarded as one of the most challenging teeth to treat in root canal therapy (10). Studies have shown that between 15.8% and 21.5% of teeth undergoing endodontic treatment are maxillary first premolars, underscoring the clinical importance of understanding their anatomical variations (11). A high percentage of these teeth exhibit a buccal bifurcation depression. In one study, it was reported to be nearly 100%, which is an important consideration during canal preparation (12).



One of the primary challenges in canal preparation is canal transportation, which is characterized by the abnormal deviation of the canal path and excessive removal of tooth structure (13, 14). This issue is more common with stainless steel files due to their higher rigidity, often leading to significant deviations from the original canal path (15). For this reason, rotary nickel-titanium (NiTi) files with their greater flexibility and improved canal-centering ability were developed to reduce canal transportation and enable more successful treatments. However, conventional NiTi files, despite their advantages, may still cause unwanted dentin removal due to their superelastic properties (16,17). This issue has led to the development of advanced rotary systems to address these limitations (18).

Among these advanced systems, ProTaper Gold (Dentsply, PTG, Tulsa, OK, USA) stands out for its optimized metallurgy and progressive tapered design, providing greater flexibility while reducing the risk of cyclic fatigue (19). Another system, One Curve (Micro Mega, Paris, France), which utilizes reciprocating motion, demonstrates greater resistance to fracture compared to traditional rotary instruments (20,21). Additionally, the TruNatomy system (Dentsply Sirona, Maillefer, Ballaigues, Switzerland), with its narrower design and increased flexibility, effectively reduces canal transportation and facilitates more precise canal shaping (22).

Several methods have been proposed for assessing the remaining dentin thickness following canal preparation (23). Among them, cone beam computed tomography (CBCT) has become a widely used advanced technique, offering high-resolution three-dimensional (3D) imaging with greater accuracy compared to conventional periapical radiographs (24). This non-invasive tool enables a more precise evaluation of canal wall thickness (25,26).

Although multiple studies have evaluated the performance of various rotary systems, direct comparisons of ProTaper Gold, TruNatomy, and One Curve in preserving dentin thickness, canal transportation, and centering ability in maxillary first premolars remain limited. To address this gap, the present study aims to compare these three systems using CBCT analysis.

Materials and Methods

This study was conducted after obtaining ethical approval from the Ethics Committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1402.271). Human maxillary first premolars were obtained from patients who underwent therapeutic extractions (primarily for orthodontic reasons). In addition, written informed consent for tooth donation was obtained at the time of extraction. All teeth were anonymized prior to inclusion in the study, with no personal identifiers recorded, in accordance with institutional ethical standards. Patient age was not considered or investigated, as the focus of this study was solely on the anatomical characteristics of the teeth.

Inclusion Criteria

The following criteria were applied for selecting the teeth used in this study (27-29):

- Fully developed roots: Teeth had to have fully developed roots with patent and mature apical foramina.
- Presence of two separate canals: The teeth had to have two distinct and separate canals with separate apical foramina and orifices.
- Moderate root curvature: The root curvature angle had to be in the range of 25° and 35°.
- Teeth extracted for orthodontic treatment: All teeth were extracted as part of planned orthodontic treatment, ensuring atraumatic extraction.
- The teeth had to have no clinical symptoms indicating parafunctional habits or pathology.
- The teeth had to have undergone no prior endodontic treatment or restorations affecting root canal morphology.
- The teeth had to have the minimum length appropriate for the study parameters.

Exclusion Criteria

- Teeth with immature roots or incomplete apical development
- Teeth with any structural damage, such as cracks, fractures, or pathological changes
- Teeth with severe calcification or abnormally closed teeth
- Teeth with curvatures greater than 35° or less than 25° (30,31).

In this study, to assess the root curvature, initial periapical radiographs were used to ensure that the teeth met the inclusion criteria. Schneider's method, along with Scanora software (version 5.1), was employed to calculate the curvature angle. Moreover, for higher accuracy and more precise (3D) evaluation, CBCT images were taken before and after instrumentation using standardized imaging protocols to ensure consistency. The CBCT machine (Cranex 3D, Soredex, Tuusula, Finland) had a voxel size of approximately $0.2 \text{ mm}^3 \times 0.2 \text{ mm}^3 \times 0.2 \text{ mm}^3$. Moreover, the field of view was standardized for all samples, allowing the observation of canal curvature and centering in both buccolingual and mesiodistal directions. Thus, root curvature was evaluated in a 3D and precise manner rather than relying solely on 2D images (32).

Tooth Preparation

After extraction, all selected teeth were stored in 0.1% thymol solution at room temperature to prevent dehydration and bacterial growth until the preparation stage. Before the procedures, the teeth were rinsed with 5.25% sodium hypochlorite to reduce surface contamination and microbial load.

A #4 round bur (Dentsply Maillefer, Switzerland) was used to access the root canals. The initial canal negotiation was performed using a #10 K-file (Dentsply

Maillefer, Switzerland) to determine the working length. The working length was visually measured by observing the tip of the K-file at the apical foramen and subtracting 1 mm, and radiographic confirmation was performed when necessary.

All procedures were conducted by a single experienced endodontist to ensure consistency and eliminate inter-operator variability. Finally, all teeth were decoronated at the cemento-enamel junction and mounted in acrylic resin blocks using a custom positioning device. The orientation of each tooth during mounting was standardized using reference markers to ensure consistent positioning relative to the CBCT sensor and the rotary handpiece during instrumentation and imaging.

Pre-instrumentation Imaging

Prior to the start of the instrumentation process, the teeth were imaged using CBCT (NewTom, Verona, Italy). Imaging parameters were set at 110 kVp, 3.6 mA, and an exposure time of 5.4 seconds, with a voxel size of $0.15 \text{ mm}^3 \times 0.15 \text{ mm}^3 \times 0.15 \text{ mm}^3$ and a field of view of $8 \text{ cm} \times 8 \text{ cm}$. The images were used to accurately evaluate the curvature and centering of the canals. The same imaging parameters, voxel size, and field of view were applied for both pre-instrumentation and post-instrumentation scans in order to ensure consistency and comparability. In addition, the standardized positioning of the teeth was maintained using a custom holder with reference markers to align the samples relative to the imaging sensor.

Instrumentation Methods

In this study, 42 human maxillary first premolars with fully formed apices were randomly divided into three groups ($n=14$ per group) for instrumentation. All instrumentation procedures were performed by the same experienced endodontist in order to ensure consistency and minimize operator variability.

Group A: ProTaper Gold System (Dentsply Maillefer, Ballaigues, Switzerland): The ProTaper Gold system has been designed for the instrumentation of moderately curved canals. This system includes the Sx, S1, S2, F1, and F2 files, which are sequentially utilized for canal shaping and cleaning. All files were operated using a continuous rotary motion with an endodontic motor (X-Smart Plus, Dentsply Sirona) set at a speed of 300 rpm and a torque of 2.0 N·cm, according to the manufacturer's recommendations.

In this group, the Sx file was first employed for initial canal preparation, followed by the S1, S2, F1, and F2 files for final shaping and cleaning of the root canal.

Group B: TruNatomy System (Dentsply Sirona, Spring Lake, USA): The TruNatomy system has been developed for curved canals and utilizes several tools, such as the orifice modifier, glide path files, and prime files, for shaping and cleaning the canal. This system is particularly suitable for teeth with complex and curved canals. All files were operated in continuous rotary motion at 500

rpm and 1.5 N·cm torque. Following the manufacturer's instructions, the sequence of files for final shaping was orifice modifier → glide path files → prime files.

Group C: One Curve System (MicroMega, Paris, France): The One Curve system has been designed to facilitate the instrumentation of curved and complex canals. The system uses R25 files and orifice shapers for canal preparation. In this group, the orifice shaper was employed to prepare the canal orifice, and the R25 file was then used for the final canal shaping. Instrumentation was performed with rotary motion at 300 rpm and 2.5 N·cm torque (Sequence: orifice shaper → the R25 file for final shaping). After reaching working length, the file was moved in and out in a pecking motion five times to ensure adequate cleaning.

Irrigation and Final Rinsing

All teeth were irrigated during the instrumentation process using 5.25% sodium hypochlorite solution, which is commonly utilized in clinical practice for effective disinfection. This choice was justified due to its widespread use and antimicrobial properties. After each file, a #15 file was introduced for cleaning to remove any debris or bacterial remnants from inside the canal.

Post-instrumentation Imaging

After completing the instrumentation process, the teeth were subjected to CBCT imaging again. These images were employed to compare the canal deviation and centering before and after instrumentation.

Formulas and Data Analysis

Distances at various levels of the root canal were measured to evaluate the deviation and centering of the root canals. The following formulas were used to calculate the deviation and centering of the canals at different levels from the apical foramen (33):

Canal Deviation Calculation

Mesiodistal Direction: $(m1 - m2) - (d1 - d2)$

Buccolingual Direction: $(b1 - b2) - (l1 - l2)$

Canal Centering Calculation

Mesiodistal Direction: $(m1 - m2) / (d1 - d2)$ or $(d1 - d2) / (m1 - m2)$

Buccolingual Direction: $(l1 - l2) / (b1 - b2)$ or $(b1 - b2) / (l1 - l2)$

where $m1$ and $m2$ are the distances from the canal wall to the root surface in the mesiodistal direction before and after instrumentation. In addition, $d1$ and $d2$ denote the distances from the canal wall to the root surface at the apical level before and after instrumentation. Moreover, $b1$, $b2$, $l1$, and $l2$ represent the distances from the canal wall to the root surface in the buccolingual direction at various levels of the root canal before and after instrumentation.

The measurements were performed by two calibrated examiners, and inter-examiner reliability was assessed

using the intraclass correlation coefficient, demonstrating high agreement. Cross-sectional slices at 2 mm, 3 mm, 5 mm, and 7 mm from the apex were standardized using anatomical landmarks and software-assisted alignment.

Statistical Analysis

Both one-way analysis of variance (ANOVA) and Kruskal-Wallis tests were employed to compare the means between groups, depending on the distribution and homogeneity of the data. The specific test applied for each comparison is provided in Table 1. A P value less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS software (version 26).

Results

The canal transportation and centering ability were evaluated at four levels from the apex (2 mm, 3 mm, 5 mm, and 7 mm) and in two directions (buccolingual and mesiodistal).

Canal Transportation

In terms of canal transportation, the TruNatomy group showed slightly lower mean values at all levels. At 2 mm from the apex, the mean transportation values in the buccolingual direction were 0.110 mm, 0.097 mm, and 0.083 mm for the ProTaper Gold, One Curve, and TruNatomy systems, respectively. At 3 mm, the buccolingual transportation was the highest in the One Curve group (0.130 mm) compared to ProTaper Gold (0.120 mm) and TruNatomy (0.102 mm). At 5 mm, the mean values were 0.115 mm, 0.105 mm, and 0.091 mm for the ProTaper Gold, One Curve, and TruNatomy groups, respectively.

At 7 mm, canal transportation remained slightly lower in the TruNatomy group (0.080 mm) compared

to the ProTaper Gold (0.100 mm) and One Curve (0.097 mm) groups. However, none of these differences were statistically significant ($P > 0.05$), indicating that all systems represented comparable performance (Figure 2).

Centering Ability

Regarding centering ability, no statistically significant differences were observed among the three systems at any of the evaluated levels ($P > 0.05$). However, a consistent trend favored TruNatomy, particularly at the 5 mm and 7 mm levels. At 3 mm in the mesiodistal direction, the centering ratios were 0.73, 0.75, and 0.79 for the ProTaper Gold, One Curve, and TruNatomy groups, implying a slight advantage of the TruNatomy system.

At 5 mm in the buccolingual direction, the corresponding ratios were 0.68, 0.70, and 0.76 for ProTaper Gold, One Curve, and TruNatomy, respectively. These results confirmed that TruNatomy maintained better centering ability, especially in the mesiodistal direction. Overall, centering was generally superior in the mesiodistal compared to the buccolingual direction across all systems, though these differences did not reach statistical significance (Figure 3).

Residual Dentin Thickness

The evaluation of the residual dentin thickness in the palato-gingival groove area revealed mean values of 0.2700 ± 0.14608 mm, 0.2036 ± 0.16080 mm, and 0.2057 ± 0.14608 mm for ProTaper Gold, TruNatomy, and One Curve, respectively. Statistical analysis using one-way ANOVA ($P = 0.395$) and the Kruskal-Wallis test

Table 1. Residual Dentin Thickness in Three Systems at the Palato-Gingival Groove

	Mean	Standard Deviation	P Value*	P Value**
ProTaper Gold	0.2700	0.14608		
TruNatomy	0.2036	0.16080	0.395	0.360
One Curve	0.2057	0.14608		
Total	0.2264	0.14461		

Note. *P: One-way analysis of variance. **P: Kruskal-Wallis test.

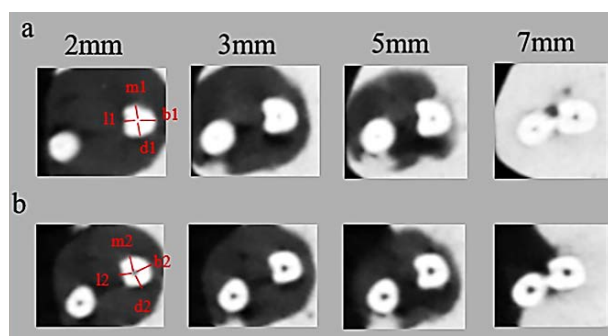


Figure 1. CBCT Scans Prior to (a) and following (b) Instrumentation. Note. CBCT: Cone beam computed tomography

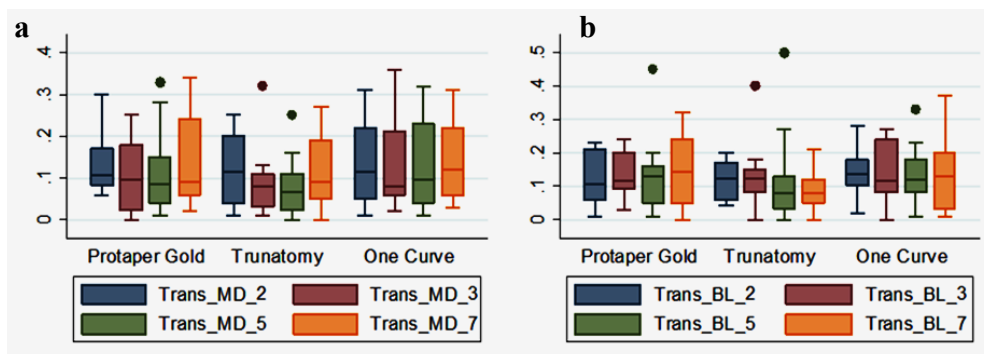


Figure 2. Canal Transportation at 2 mm, 3 mm, 5 mm, and 7 mm From the Apex in (a) Mesiodistal Dimension and (b) Buccolingual Dimension

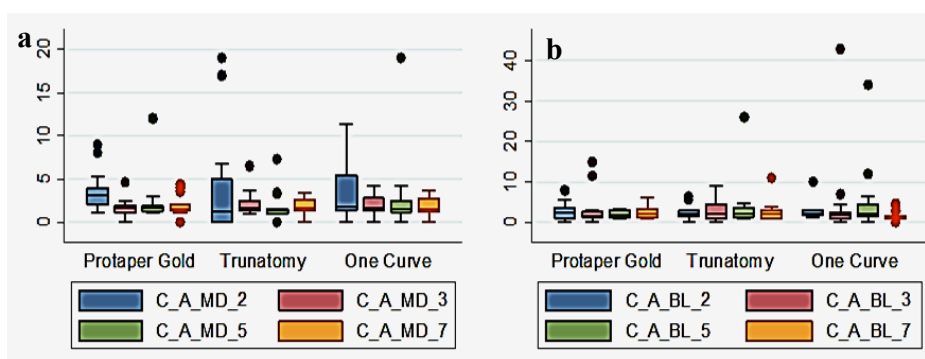


Figure 3. Centering Ability at 2 mm, 3 mm, 5 mm, and 7 mm From the Apex in (a) Mesiodistal Dimension and (b) Buccolingual Dimension

($P=0.360$) indicated no significant differences between the groups. These results suggest that all three systems effectively preserved sufficient dentin thickness during instrumentation and caused no excessive thinning in this anatomically sensitive region (Table 1).

Our findings demonstrated that all three file systems perform similarly across various assessments, including canal transportation, centering ability, and residual dentin thickness. There were no significant differences among the systems in any of the measured parameters, indicating that all file systems can effectively preserve dentin structure and perform similarly in root canal treatment procedures.

Discussion

One of the main goals of endodontic treatment is to preserve the natural root canal by creating a funnel-shaped form from the apex to the coronal area (34). In recent years, root canal preparation protocols have shifted toward minimally invasive techniques aimed at preserving the maximum amount of coronal and radicular dentin (35). To achieve this goal, advanced systems (e.g., TruNatomy, One Curve, and ProTaper Gold) have been developed, each with its own advantages and limitations (36,37).

The evaluation of root canal instruments is commonly based on measuring canal transportation and centering ability, which reflect the quality of canal preparation (28). Various factors (e.g., canal anatomy, instrument design, alloy composition, and instrumentation technique) can significantly influence the degree of displacement within the root canal during preparation (38). Apical displacement can threaten the final seal of the root canal filling and pose risks like inadequate disinfection of the root canal system, which could negatively impact the treatment outcome (39). Previous studies have shown that displacements greater than 0.3 mm can have a negative effect on treatment results (40,41). Therefore, the present study compared these instrumentation systems in terms of canal displacement, remaining dentin thickness, and the ability to maintain canal centering.

The root canal system can be evaluated using various methods, each of which has its limitations (42). Although micro-computed tomography (CT) is considered the gold standard (43), due to practical limitations, this study

employed CBCT imaging as a non-invasive technique with acceptable accuracy, which allows for a reliable 3D assessment of canal morphology and improves the reproducibility of measurements compared to conventional 2D radiography (44).

In this study, canal displacement was measured at distances of 2 mm, 3 mm, 5 mm, and 7 mm from the apex in the mesiodistal and buccolingual directions. These levels were selected based on prior micro-CT and CBCT investigations, demonstrating that measurements at 3 mm, 5 mm, and 7 mm from the apex capture critical zones of curvature and instrumentation effects (45,46). The results showed no significant differences among the three systems at any level. In addition, the overall displacement remained below 0.15 mm, which falls within clinically acceptable limits (47). The lack of a significant difference between systems may be due to the similar features and precise engineering designs of the instruments that effectively limit canal transportation. Furthermore, the standardized sample selection and consistent instrumentation protocol likely contributed to the same results.

Moreover, the results of this study revealed no significant difference in canal transportation between the three systems that would lead to significant clinical errors; however, the average transportation in the TruNatomy system was less than that in the other two systems. The relatively lower transportation observed in TruNatomy files may be attributed to their unique structural features (e.g., an off-centered cross-section, a regressive taper design, smaller tip size, and advanced heat-treated NiTi alloy), which enhance flexibility and cyclic fatigue resistance (48,49). This finding aligns with the results of the study by Kim et al (50), reporting lower displacement values for the TruNatomy system. These design features allow TruNatomy instruments to better conform to the canal curvature, reduce torsional stress, and minimize the risk of procedural errors, particularly in narrow or severely curved canals (51,52).

Based on the findings of our study, there was no significant difference in the ability of the files to center the canal, which is consistent with the findings of Kabil et al (48). They compared the displacement and centering ratios of the ProTaper Next, TruNatomy, and XP Endo Shaper systems, concluding that all three systems had

similar capabilities in displacement and centering curved canals. Canal centering refers to the ability of endodontic instruments to maintain the canal path in the center, which is a crucial parameter for the success of endodontic treatments (53). The similarity in centering performance may also be influenced by operator skill and the use of a single, calibrated clinician for all procedures, reducing inter-operator variability.

In comparison with the study by Karkehabadi et al (54), which demonstrated more displacement in the ProTaper system in the mesial roots of lower first molars, the present study found no significant differences in displacement and centering. This discrepancy may be due to anatomical differences, tooth type selection, and standardized instrumentation parameters used in this study.

Furthermore, the results of this study confirmed that the displacement in the buccolingual direction was greater than in the mesiodistal direction, which may be because of the use of specific filing techniques to prevent damage to critical areas. This finding is also in line with the results of Karkehabadi et al (54).

Several studies have compared the displacement of the canal in rotary systems with rotary and reciprocating movements. Among them, You et al (55) found no significant difference in apical displacement between the two types of file movements, which is in agreement with the findings of the present study. On the other hand, Gergi et al (56) compared the root canal geometry in preparations with the Reciproc and Wave One systems with reciprocating motion and the Twisted File system with rotary motion, finding that the Twisted File system caused less displacement than the other two systems. This contrast may reflect differences in instrument design, alloy properties, and the multi-file versus single-file approach, highlighting the importance of considering both canal anatomy and instrument characteristics when interpreting results.

Similarly, Kabil et al (48) concluded that reciprocating instruments caused greater canal transportation, while the ProTaper Next, TruNatomy, and XP Endo Shaper systems showed comparable performance in terms of displacement and canal centering. Overall, these findings suggest that clinical decisions should prioritize the canal anatomy and procedural goals over the specific choice of system, provided that modern rotary systems with similar metallurgical properties are used.

Additionally, our findings revealed no statistically significant difference in the remaining dentin thickness at the furcation area among the three systems. Although the ProTaper Gold system displayed slightly greater remaining dentin thickness, this difference was not significant and may be attributed to variations in file designs (e.g., cutting angle and blade thickness). Evaluating the remaining dentin thickness is of particular importance because excessive dentin removal can damage the teeth and increase the likelihood of fractures, thereby affecting the prognosis of endodontic treatment (2,57).

In particular, upper first premolars, with their unique morphological complexities (11) and furcation grooves in the buccal roots of two-rooted premolars (58,59), are more prone to cracking and perforation during root canal instrumentation (60).

The results of this study may be due to the precise designs and flexible features of endodontic instruments, which help reduce excessive dentin removal and create minimal changes in the remaining dentin thickness. Silva et al (61) evaluated canal displacement, remaining dentin thickness, and healthy canal areas and observed no significant differences between the systems regarding healthy canal wall areas and remaining dentin thickness. However, they reported slight differences in apical displacement in mesial canals and the percentage of dentin removal from the coronal section, although these differences did not lead to significant clinical errors. Moreover, Heyse et al (62) compared the remaining dentin thickness in the danger zone of the second mesiobuccal canal between the ProTaper Gold and Vortex Blue systems, reporting that both systems left minimal remaining dentin.

In this study, the coronal portion of the canal was evaluated because excessive dentin removal from this area can weaken the root structure and negatively affect the tooth prognosis, which may cause strip perforation and damage to the root (63,64). The observed differences in file performance may be due to variations in file tip size, file taper, design, and sharpness. Additionally, the One Curve system, being a single-file system (unlike ProTaper Gold and TruNatomy), may have different effects on the outcomes.

Nonetheless, this study had some limitations that should be acknowledged. The Schneider technique used for evaluating canal curvature may not have fully captured the 3D complexity of root canal anatomy compared to advanced imaging methods (e.g., micro-CT). Moreover, differences in the taper between the ProTaper Gold and One Curve systems might have influenced the results. These factors underscore the necessity for the cautious interpretation of findings. Accordingly, future research should consider employing standardized tapers, larger sample sizes, and more precise imaging modalities to validate and expand upon these findings. Additionally, investigating the clinical performance of these systems in vivo can provide more comprehensive insights.

Conclusion

Clinically, all three systems effectively minimize canal transportation, maintain canal centering, and preserve dentin thickness, underlining the importance of selecting appropriate preparation methods to protect tooth structure and improve prognosis. This study has provided valuable comparative data on TruNatomy, One Curve, and ProTaper Gold, displaying their potential in minimally invasive endodontics. However, further research is needed to address study limitations and enhance clinical guidelines.

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Competing Interests

There is no financial or non-financial conflict of interests related to this research.

Ethical Approval

This study was conducted after obtaining ethical approval from the Ethics Committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1402.271).

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