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# An In-Vitro Evaluation of Nano-Scaled Changing Surfaces Topographies of the Three Commercially Available Rotary File Systems in Biomechanical Preparation of Maxillary Premolars: An Atomic Force Microscopy-Based Original Research Study

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**KEYWORDS**
Nano-Scaled, Surfaces Topographies, Rotary File, Biomechanical Preparation, Atomic Force Microscopy (AFM), ProTaper Gold, WaveOne Gold, Edge One Fire

**ABSTRACT:**

Aim: This study aims to evaluate the nano-scaled changing surface topographies of the three commercially available rotary file systems in the biomechanical preparation of maxillary premolars by atomic force microscopy

Materials and Methods: This investigation studied 90 maxillary first premolars, selected for being free from caries and cracks, and stored in saline. After extracting the teeth for periodontal reasons, root surfaces were encapsulated in acrylic resin, and access cavities were standardized. The working length was confirmed with a No. 15 K-file. For the biomechanical preparation Three rotary file systems divided into three groups, group 1 ProTaper Gold, group 2 Wave One Gold (WOG)and group 3 Edge One Fire (EOF) were used for biomechanical preparation. These three Rotary files were analysed with Atomic Force Microscopy (AFM) to evaluate surface topographies and roughness by three parameters: Average Roughness (Ra), Root Mean Square Roughness (Rq) and Maximum Peak Height (Rp).

Statistical Analysis and Results: This study examined 90 maxillary first premolars, categorizing them into three groups based on the rotary file systems used for biomechanical preparation. Each tooth had an access cavity created and was instrumented accordingly. Group 1, with 30 teeth shaped using ProTaper Gold files, showed surface roughness measurements of Ra 160 ± 10, Rq 170 ± 13, and Rp 310 ± 20. Group 2, using Wave One Gold files, had Ra 220 ± 10, Rq 240 ± 15, and Rp 350 ± 20. Group 3, prepared with Edge One Fire files, recorded Ra 150 ± 10, Rq 140 ± 12, and Rp 300 ± 14. The Pearson Chi-Square test assessed statistical significance, with a summary table comparing the effectiveness of the rotary file systems on surface roughness through one-way ANOVA, offering insights for endodontic practices.

Conclusion: This study concluded that WaveOne Gold files have greater surface roughness compared to ProTaper Gold and Edge One Fire (EOF) Endo files, which could impact cleaning and shaping effectiveness. Additionally, the surface characteristics of these files deteriorate with clinical use, leading to increased roughness due to wear and tear. These results highlight the need for further research to better understand the performance of rotary files, which is essential for improving patient outcomes in endodontics.

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## Introduction

Dental caries, known colloquially as tooth decay, is a prevalent chronic infectious disease primarily instigated by cariogenic bacteria. These microorganisms metabolise sugars and carbohydrates, producing organic acids that lead to the demineralisation of the hard dental tissues, subsequently resulting in cavity formation. If left unaddressed, dental caries can escalate into more severe infections, often warranting interventions such as root canal therapy.[1,2] Root canal therapy is a fundamental endodontic procedure designed to salvage teeth that have undergone significant decay or infection. The protocol entails the systematic removal of infected pulp tissue, followed by disinfection and sealing of the root canal system. The principal aim of this treatment is to comprehensively clean the root canal, eradicating microbial contamination and mitigating the risk of future infections.[3,4] The cleaning and shaping of the root canal is a nuanced process that utilises both mechanical and chemical methodologies, collectively termed biomechanical debridement. This involves employing various endodontic instruments, including hand files and rotary file systems. In recent years, rotary file systems have gained traction due to their perceived advantages over manual techniques, including enhanced speed and consistency in canal shaping, which contributes to an improved patient experience characterised by reduced chair time.[5,6] However, the implementation of these systems is not without challenges, such as the complexities associated with selecting the appropriate system for specific cases and the potential for postoperative discomfort. For instance, the WaveOne Gold (WOG) system, a contemporary Gold-treated single-file endodontic system, features a distinctive parallelogram cross-section that optimises cutting efficiency. Conversely, the EdgeOne Fire system incorporates a comparable geometric configuration and is tailored for reciprocating motion, leveraging a proprietary heating process to enhance file flexibility.[7,8] Additionally, the ProTaper Gold (PTG) system is recognised as a multi-file approach, offering a diversified range of shaping and finishing files. It retains the geometric innovations of its predecessor, ProTaper Universal, while introducing enhanced performance capabilities for more effective root canal procedures. In the field of dental research, atomic force microscopy (AFM) stands out as a highly advanced imaging technique renowned for its exceptional resolution capabilities. This method allows researchers to conduct detailed assessments of surface roughness at the nanoscale level, making it particularly valuable in the study of dental materials and tissues.[9] AFM operates by scanning a sharp tip over the surface of a sample, enabling the acquisition of topographical data with incredible precision. This technique facilitates a comprehensive examination of the nano-structural and biomechanical properties of various biological samples, which is essential for understanding their performance in clinical settings.[10,11] A significant advantage of Atomic Force Microscopy (AFM) lies in its capability to precisely quantify essential surface metrics that play a crucial role in determining the behaviour of dental materials in real-world applications. Among these metrics, average roughness (Ra) serves as a fundamental indicator that provides a broad understanding of surface texture characteristics. In contrast, root mean square roughness (Rq) delivers a more nuanced and sensitive assessment of surface variations, capturing subtle changes that may influence material performance. Additionally, maximum peak height (Rp) is a critical measure that reveals the tallest point on the surface profile, offering insights into the peaks and valleys that can affect adhesion, wear, and overall functionality of dental materials.[12,13] By analysing these surface characteristics, researchers can draw valuable correlations between the physical properties of dental materials and their clinical efficacy. This information is crucial for developing new materials and improving existing ones, ultimately enhancing patient outcomes in dental treatments. In summary, AFM is an indispensable tool in dental research, providing deep insights into the interplay between surface attributes and clinical performance, paving the way for advancements in dental technology and material science.[14] This study aims to evaluate the nano-scaled changing surface topographies of the three commercially available rotary file systems in the biomechanical preparation of maxillary premolars by atomic force microscopy.

## Materials and Methods

This study was planned, abstracted and conducted in the Department of Conservative Dentistry and Endodontics

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of the institution. This study centers on an extensive analysis of a cohort of 90 maxillary first premolars, chosen through a meticulous selection process grounded in specific, rigorous criteria. Each specimen was ensured to be free from carious lesions, apical resorption, alterations to the root surface, and any pre-existing structural cracks that might compromise the study's integrity. To preserve the hydration within the dentinal tubules, all selected teeth were stored in a saline solution, maintaining optimal conditions for the tissues. Prior to conducting the experiment, all residual soft tissues and calculus were meticulously excised using a dental scaler, ensuring that the teeth were exclusively extracted for periodontal reasons. This careful selection enabled the research team to focus on healthy specimens that adhered to stringent inclusion criteria. These criteria notably excluded any teeth exhibiting multiple foramina, signs of root canal dilatation, signs of infection, or those that had undergone prior endodontic treatments. To facilitate safe handling and minimize contamination throughout the study, the root surfaces of the selected teeth were then encapsulated in acrylic resin. During the preparation phase, the occlusal surfaces of the teeth were leveled using precision diamond rotary instruments to create a uniform and smooth surface. Following this procedure, standardized access cavities were formed using a careful and methodical approach to ensure consistent access to the root canals. The working length of the canals was determined using a No. 15 K-file, carefully confirming that the working length was consistently maintained at 1mm shorter than the actual length at the major diameter of the apical foramen, thus ensuring appropriate instrumentation without risking damage to the apical region. The biomechanical preparation phase, which involved the cleaning, shaping, enlarging, and curving of the root canals, was conducted utilizing three distinct rotary file systems: ProTaper Gold, Edge One Fire (EOF), and WaveOne Gold (WOG). For thorough irrigation during this process, canals received a robust treatment of 3 mL of 2.5% sodium hypochlorite (NaOCl) between every file application, which effectively aids in the disinfection of the canals while facilitating the removal of debris. Upon completion of the instrumentation, a 1 mL solution of 17% ethylenediaminetetraacetic acid (EDTA) was applied for one minute to eliminate the smear layer generated during instrumentation, followed by a thorough rinse with 3 mL of 5.25% NaOCl, further enhancing the cleaning process. The final cleansing step was a 5 mL rinse with distilled water, after which the canals were dried meticulously with paper points to ensure they were adequately prepared for obturation. Root obturation was performed using gutta-percha along with the lateral condensation technique, a standard method that ensures dense packing of the filling material in the canals. In this study, we carefully categorized extracted maxillary first premolars into three distinct groups, each corresponding to a specific rotary file system used during the biomechanical preparation phase. Group 1 was treated with ProTaper Gold, known for its innovative design; Group 2 utilized Wave One Gold (WOG), recognized for its unique features; and Group 3 employed Edge One Fire (EOF), celebrated for its effectiveness in endodontic procedures. Once the root canal preparation was meticulously completed, the rotary files underwent a rigorous cleaning and drying process to ensure they were free from any contaminants before analysis. To explore the characteristics of the rotary file surfaces in detail, we employed Atomic Force Microscopy (AFM), a powerful technique that allowed us to perform a comprehensive examination of their surface topographies at the nanoscale. The study specifically focused on quantifying three key surface roughness parameters: Average Roughness (Ra), which measures the mean surface roughness; Root Mean Square Roughness (Rq), providing a statistical depiction of surface variations; and Maximum Peak Height (Rp), indicating the tallest peak on the surface profile. This thorough investigation aims to reveal subtle nanoscale changes in the surface characteristics of the three widely used rotary file systems, offering valuable insights into their performance in the biomechanical preparation of maxillary premolars as illuminated by detailed AFM analysis.

**Statistical Analysis and Results**

In this study, we conducted all statistical analyses using SPSS version 29.0, a robust tool for social science data analysis. We employed the chi-square test to assess the significance of differences in proportions among groups, allowing for a rigorous comparison of

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categorical data and ensuring our results accurately reflect the underlying patterns in the dataset.

**Results**

This study meticulously investigated the characteristics of 90 extracted maxillary first premolars, systematically categorizing them into three distinct experimental groups based on the specific rotary file systems utilized during the critical biomechanical preparation phase. This preparation involved several key steps, beginning with the careful creation of an access cavity for each tooth, followed by the determination of the working length, and concluding with the instrumentation of each root using the designated rotary file systems associated with each experimental group. Table 1 show the total number of teeth has been categorised into three distinct groups. In Group 1, a cohort of 30 extracted maxillary first premolars was shaped employing ProTaper Gold files, a widely recognized rotary file system known for its efficiency in endodontic procedures. To evaluate the surface roughness of the prepared roots in this group, advanced atomic force microscopy techniques were employed. This sophisticated approach allowed for the precise measurement of three critical surface roughness parameters: Average Roughness (Ra), which provides insight into the overall surface texture; Root Mean Square Roughness (Rq), offering a more nuanced view of surface irregularities; and Maximum Peak Height (Rp), indicating the tallest peaks present on the surface. Table 1 show the total number of teeth has been categorised into three distinct groups. Moving on to Group 2, which similarly comprised 30 extracted maxillary first premolars, the teeth were prepared utilizing Wave One Gold (WOG) files, another modern rotary file system designed for single-file endodontics. As with Group 1, the assessment methodology for evaluating surface roughness was consistently applied, ensuring a rigorous and standardized evaluation process across groups. Group 3 featured another set of 30 teeth, shaped using Edge One Fire (EOF) files, which are engineered to enhance cutting efficiency and reduce the stress experienced by the root structure during instrumentation. The evaluation of surface roughness in this group followed the exact protocols established for Groups 1 and 2, employing atomic force microscopy to measure the same parameters, thereby ensuring consistency in the comparative analysis of results.Picture 1-3 shows microscopic images captured using atomic force microscopy showcase three different types of reciprocating files before they undergo instrumentation, with the image representing a scale of 10 micrometers by 10 micrometers. The images feature: ProTaper Gold, recognized for its innovative design, WaveOne Gold (WOG), known for its efficiency and EdgeOne Fire (EOF), which is engineered for optimal performance in endodontic procedures. These file's intricate details are highlighted at the microscopic level (μm=micrometers).The findings for Group 1, depicted in Table 2, revealed notable surface roughness parameters: the Average Roughness (Ra) was recorded at 160 ± 10, indicating a relatively smooth surface, while the Root Mean Square Roughness (Rq) and Maximum Peak Height (Rp) were recorded at 170 ± 13 and 310 ± 20, respectively. Statistical significance among these findings was determined using the Pearson Chi-Square test, providing a robust framework for assessing the data's reliability. Table 3 details the results for Group 2, where the Wave One Gold (WOG) instruments were utilized. The recorded surface roughness measurements demonstrated an Average Roughness (Ra) of 220 ± 10, suggesting a rougher surface compared to Group 1. The Root Mean Square Roughness (Rq) was measured at 240 ± 15, and the Maximum Peak Height (Rp) at 350 ± 20, with statistical analysis again conducted through the Pearson Chi-Square test to ascertain significance. In Table 4, the outcomes for Group 3, which utilized Edge One Fire (EOF) files, are systematically summarized. The metrics for surface roughness yielded an Average Roughness (Ra) of 150 ± 10, reflecting a smoother finish compared to Group 2. The Root Mean Square Roughness (Rq) was measured at 140 ± 12, while Maximum Peak Height (Rp) was recorded at 300 ± 14. Statistical evaluation for this group also utilized the Pearson Chi-Square test, underscoring the consistency in data analysis methods. To provide a comprehensive comparison of the effectiveness of the various rotary file systems on the resulting surface roughness of the prepared roots across all groups, Table 5 presents a detailed analysis utilizing one-way ANOVA. This comparative assessment aims to deepen our understanding of how each rotary file system influences the final surface characteristics of the shaped roots, ultimately contributing valuable insights to the realm of

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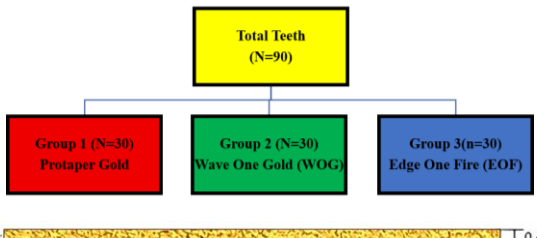
endodontics and enhancing clinical practices surrounding root canal therapy.

**Table 1:** The total number of teeth has been categorised into three distinct groups




**Picture 1:** Microscopic images captured using *Atomic Force Microscopy* showcases reciprocating files before they undergo instrumentation, with the image representing a scale of 10 micrometers by 10 micrometers. The images feature: ProTaper Gold, recognized for its innovative design. This file intricate details are highlighted at the microscopic level (µm=micrometers)

**Picture 2:** Microscopic images captured using *Atomic Force Microscopy* showcases reciprocating files before they undergo instrumentation, with the image representing a scale of 10 micrometers by 10 micrometers. The images feature: WaveOne Gold (WOG), known for its efficiency. This files intricate details are highlighted at the microscopic level (µm=micrometers)

**Picture 3:** Microscopic images captured using *Atomic Force Microscopy* showcases reciprocating files before they undergo instrumentation, with the image representing a scale of 10 micrometers by 10 micrometers. The images feature: EdgeOne Fire (EOF), which is engineered for optimal performance in endodontic procedures. This files intricate details are highlighted at the microscopic level (µm=micrometers)

**Table 2:** Group 1 (n=30) extracted maxillary first premolars. The biomechanical preparation was performed using ProTaper Gold instruments. The surface roughness of ProTaper Gold was assessed using atomic force microscopy, focusing on three measurements: average roughness (Ra), root mean square roughness (Rq), and maximum peak height (Rp). A statistical analysis was conducted using the Pearson Chi-Square test to evaluate the significance of the results

| Parameters | Value (nm) | Stat. Mean | Std. Dev. | Std. Error | 95% CI | Pearson Chi-Square Value | df | p value |
|---|---|---|---|---|---|---|---|---|
| Average Roughness (Ra) | 160±10 | 2.24 | 2.226 | 2.023 | 2.13 | 2.26 | 1.3 | 0.06 |
| Root Mean | 170±13 | 2.26 | 2.034 | 2.053 | 2.24 | 2.25 | 1.2 | 0.01* |

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|---|---|---|---|---|---|---|---|---|
| Square Roughness (Rq) | | | | | | | | |
| Maximum Peak Height (Rp) | 310±20 | 2.30 | 2.046 | 2.054 | 2.64 | 2.30 | 1.0 | 0.04* |
| *p<0.05 significant | | | | | | | | |

**Table 3:** Group 2 (n=30) extracted maxillary first premolars. The biomechanical preparation was performed using Wave One Gold (WOG) instruments. The surface roughness of Wave One Gold (WOG) was assessed using atomic force microscopy, focusing on three measurements: average roughness (Ra), root mean square roughness (Rq), and maximum peak height (Rp). A statistical analysis was conducted using the Pearson Chi-Square test to evaluate the significance of the results

| Parameters | Value (nm) | Stat. Mean | Std. Dev. | Std. Error | 95% CI | Pearson Chi-Square Value | df | p value |
|---|---|---|---|---|---|---|---|---|
| Average Roughness (Ra) | 220±10 | 2.32 | 2.023 | 2.027 | 2.28 | 2.09 | 1.0 | 0.05* |
| Root Mean Square Roughness (Rq) | 240±15 | 2.34 | 2.045 | 2.035 | 2.33 | 2.18 | 1.0 | 0.04* |
| Maximum Peak Height (Rp) | 350±20 | 2.37 | 2.056 | 2.056 | 2.45 | 2.48 | 1.0 | 0.06 |
| *p<0.05 significant | | | | | | | | |

**Table 4:** Group 3 (n=30) extracted maxillary first premolars. The biomechanical preparation was performed using Edge One Fire (EOF) instruments. The surface roughness of Edge One Fire (EOF) was assessed using atomic force microscopy, focusing on three measurements: average roughness (Ra), root mean square roughness (Rq), and maximum peak height (Rp). A statistical analysis was conducted using the Pearson Chi-Square test to evaluate the significance of the results

| Parameters | Value (nm) | Stat. Mean | Std. Dev. | Std. Error | 95% CI | Pearson Chi-Square Value | df | p value |
|---|---|---|---|---|---|---|---|---|
| Average Roughness (Ra) | 150±10 | 2.20 | 2.098 | 2.047 | 2.10 | 2.08 | 1.3 | 0.01* |
| Root Mean Square Roughness | 140±12 | 2.22 | 2.106 | 2.055 | 2.23 | 2.10 | 1.4 | 0.02* |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Rq) | | | | | | | | |
| Maximum Peak Height (Rp) | 300±14 | 2.23 | 2.112 | 2.059 | 2.34 | 2.20 | 1.5 | 0.06 |
| *p<0.05 significant | | | | | | | | |

**Table 5:** Estimation amongst all studied groups using one-way ANOVA

| Variables | Degree of Freedom | Sum of Squares ∑ | Mean Sum of Squares m∑ | F | Level of Sig. (p) |
|---|---|---|---|---|---|
| Between Groups | 3 | 2.420 | 2.126 | 1.2 | 0.01* |
| Within Groups | 18 | 2.256 | 2.162 | – | |
| Cumulative | 224.33 | 18.103 | *p<0.05 significant | | |

**Discussion**

Rai A et al reviewed in their study that dental caries, commonly known as tooth decay, is a widespread and significant oral health issue characterised by both the pathological changes occurring in the dental tissues and the resulting lesions that form as a consequence. This condition is multifaceted, primarily stemming from an imbalance in the oral microbial that shifts toward an acid-producing (acidogenic) and decay-causing (cariogenic) environment.[15,16] Pitts NB et al included in their study that the shift is predominantly driven by the frequent consumption of sugars and refined carbohydrates, which serve as fermentable substrates for the bacteria present in the oral cavity. The metabolic processes initiated by these bacteria result in the demineralisation of enamel and dentin, leading to the development of observable carious lesions.[17,18] Lambrianidis T et al showed in their study that caries can be classified as a dietary-microbial disease; it necessitates not only the presence of a cariogenic biofilm—a complex community of bacteria formed on the tooth surface—but also an adequate supply of fermentable carbohydrates that fuel this microbial ecosystem. The protective role of fluoride in the prevention of dental caries is paramount; exposure to fluoride helps in remineralising early carious lesions and enhances enamel resistance to acidic attacks. Conversely, insufficient fluoride exposure can significantly increase an individual's susceptibility to the onset and progression of caries.[19,20] Kaur J et al reviewed in their study that in the field of endodontics, the standard therapeutic protocol for managing infected teeth involves the careful removal of the infected pulp tissue. This process is followed by the thorough disinfection of the internal tooth structure and the placement of a biocompatible filling material, typically gutta-percha, to seal the root canal system. Finally, a crown or filling is applied to restore the tooth's function and strength. A key aspect of successful root canal therapy (RCT) is the biomechanical preparation of the root canal system, a critical process that includes the precise shaping of the canal. This preparation is essential to ensure the complete removal of necrotic tissue while employing suitable irrigants that facilitate disinfection, thus effectively combining mechanical (instrumentation) and chemical (irrigation) methodologies to achieve an optimal outcome.[21-23] Relvas JB et al included in their study that the introduction of nickel-titanium (NiTi) rotary instrumentation has revolutionised endodontic practices by providing superior mechanical properties compared to conventional stainless steel instruments. NiTi

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instruments exhibit increased flexibility and strength, enabling them to navigate the complexities of root canal anatomies more effectively. However, their use does come with certain risks, including the potential for unexpected instrument separation, which can pose challenges during treatment.[24] Hieawy A et al reviewed in their study that the discussion will also explore advanced NiTi alloy technologies relevant to rotary instrumentation, with a focus on specific systems. For instance,WaveOne Gold (WOG) is an innovative single-file system that employs reciprocating motion and includes four specifically designed file sizes that help preserve the integrity of the dentin during canal preparation. ProTaper Gold, another advanced system, utilizes a proprietary gold heat treatment process that enhances cutting efficiency while simultaneously reducing frictional resistance during use. Additionally, EdgeOne Fire files are notable for their operational efficiency and flexibility, presenting a more economical option in the clinical setting, though they require the establishment of a glide path in complex canal anatomies to ensure safe and effective navigation. [25,26] Tsenova-Ilieva I et al showed in their study that endodontic research has illuminated the innovative application of atomic force microscopy (AFM) for a detailed quantitative analysis of the surface roughness of both dentin and nickel-titanium (NiTi) instruments. These cutting-edge studies delve into the intricate effects of various irrigants and the mechanical wear experienced by these surfaces, providing crucial insights that can significantly enhance the efficacy of endodontic procedures.[27] Karunakar P et al reviewed in their study that employing ultrasonic activation markedly increases the roughness of dentin surfaces. This increase in roughness carries substantial implications for the overall effectiveness of cleaning and shaping during root canal treatments. By gaining a deeper understanding of these interactions, clinicians are empowered to refine their techniques and select the most suitable materials, ultimately leading to improved patient outcomes in endodontic care. The ongoing exploration of these factors underscores the importance of integrating advanced microscopy techniques into routine dental practice to continually elevate the standards of care continually.[28]

**Conclusion**

This study provides a detailed evaluation of the nano-scaled surface topographies of three commercially available rotary file systems that are commonly used for the biomechanical preparation of maxillary premolars. Utilising advanced atomic force microscopy (AFM) techniques, the research unveils significant variations in the surface characteristics of these rotary files, which may profoundly affect their performance during root canal procedures. The findings revealed and concluded that WaveOne Gold files exhibit a greater degree of surface roughness in comparison to both ProTaper Gold and Edge One Fire (EOF) files. This increased roughness could potentially impact the effectiveness of these instruments in cleaning and shaping the root canal system. Furthermore, the analysis highlights a concerning trend: with clinical use, the surface characteristics of these rotary files tend to deteriorate markedly. This degradation often results in enhanced roughness due to the inevitable wear and tear experienced during procedures. These results point to a pressing need for extensive future research aimed at deepening our understanding of the performance dynamics of rotary files. Such studies will be vital for refining their application in clinical settings, ultimately contributing to improved patient outcomes and the development of more effective treatment strategies in endodontics.

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