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Original Article

Comparative Efficacy of Manual vs. Rotary/Reciprocating NiTi Instrumentation by Novice Dental Students on Simulated Root Canals

Ethan Smith[1]*, Olivia Davis[1]

[1]Department of Endodontology, Kornberg School of Dentistry, Temple University, Philadelphia, Pennsylvania, USA.

***E-mail** ✉ ethansmith2025@outlook.com

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ABSTRACT

In previous decades, root canal shaping was primarily achieved with manual stainless steel files. The development of nickel–titanium (NiTi) mechanical instruments has since offered the potential for more efficient and predictable canal preparation. Despite these advancements, the use of NiTi systems in undergraduate training remains limited. This study aimed to compare three root canal preparation approaches—manual instrumentation using stainless steel hand files, continuous rotary motion with ProTaper Gold (PTG) files, and reciprocating motion with WaveOne Gold (WOG) files—on endodontic resin blocks, evaluating both preparation quality and instrumentation time. Thirty-six third-year dental students with no prior endodontic experience were randomly assigned to six groups to prepare 108 resin blocks, each student working on three. Standardized photographs were obtained at preoperative, intraoperative, and postoperative stages to analyze resin removal, apical transportation, and mid-cervical wear. Additionally, questionnaires were distributed to assess students' satisfaction and subjective experiences. Data were analyzed using the Friedman test, Wilcoxon test with Bonferroni correction, and Kruskal–Wallis test followed by the Mann–Whitney U test, with statistical significance set at $p < 0.05$.

The PTG group demonstrated significantly less apical deviation (0.073 ± 0.003) than both the WOG and manual groups ($p < 0.001$). A significant difference in mid-cervical wear was noted only between PTG and manual techniques. Manual instrumentation showed greater inconsistency and required approximately five times longer to complete. Overall, 90% of students preferred mechanical over manual instrumentation. Mechanical systems, especially the PTG, were markedly faster and produced superior canal shaping quality. These findings support the integration of mechanical instrumentation into undergraduate dental curricula.

Keywords: Endodontics, Dental students, Dental education, Nickel–titanium, Stainless steel

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Introduction

Successful endodontic therapy depends on thorough cleaning, precise shaping, and effective three-dimensional obturation of the canal system [1, 2]. The cleaning and shaping phase aims to remove all organic material and create a consistently tapered canal form while preserving the natural canal curvature [3]. Mastery of instrumentation requires clinical skill and understanding of each instrument's design and movement pattern [3]. Historically, root canal preparation relied heavily on stainless steel hand files until the introduction of NiTi rotary systems revolutionized the process. Numerous studies have demonstrated the advantages of NiTi files, including enhanced cutting performance and the ability to create conservative preparations [3–5]. Despite these benefits, their use is still predominantly limited to postgraduate or experienced practitioners, with minimal exposure at the undergraduate level [6].

Accreditation authorities and professional organizations such as the European Society of Endodontology (ESE) and the Association for Dental Education in Europe (ADEE) emphasize the inclusion of comprehensive theoretical, pre-clinical, and clinical training within dental education [7]. These programs aim to prepare students for uncomplicated endodontic treatments. Since today's students represent future clinicians, it is crucial that they receive technically advanced instruction that enables them to deliver optimal care [7, 8]. Thus, incorporating contemporary techniques and efficient instruments into undergraduate teaching is essential to enhance students' confidence and competence in modern endodontic practice [9, 10].

Despite well-documented benefits of NiTi rotary systems, many dental schools still emphasize manual stainless steel instrumentation. Reluctance to adopt mechanical methods often stems from concerns about instrument fracture and the costs of new equipment [10]. However, growing evidence supports the safe and effective use of NiTi instruments by undergraduate students, leading to better outcomes and greater efficiency [6, 11–16].

Still, there is limited data exploring how different training sequences influence learning curves and preparation quality, or whether mastering manual methods before mechanical systems is necessary. Consequently, this study sought to assess three instrumentation techniques—manual (stainless steel), rotary (ProTaper Gold), and reciprocating (WaveOne Gold)—performed by third-year students with no previous endodontic experience, comparing preparation quality, procedural time, and user preference. The null hypothesis proposed no significant differences among the techniques regarding preparation accuracy, duration, or satisfaction.

Materials and Methods

All third-year dental students (n = 36) from the Faculty of Dental Medicine, University of Lisbon (FMDUL), were recruited for this study. The sole inclusion criterion was the absence of any previous experience with the instruments or methods under evaluation. Before commencing the practical component, participants attended a theoretical session covering the design, physical characteristics, and operation of both stainless steel and nickel–titanium (NiTi) systems, along with the specific instrumentation protocols to be applied. Participation was voluntary, and as the study did not affect academic grading, formal ethics approval was not required (protocol no. CEBD202402).

To maintain impartiality, students were randomly distributed into six groups using a concealed and blinded allocation process, hidden from the primary evaluator (KB) responsible for image and data assessment. Across all groups, 108 simulated resin canals (about 18 per group) were prepared in a fixed rotation sequence incorporating the three techniques—stainless steel (SS), ProTaper Gold (PTG), and WaveOne Gold (WOG). The assigned instrumentation sequences were: Group I: SS-PTG-WOG; Group II: SS-WOG-PTG; Group III: PTG-SS-WOG; Group IV: PTG-WOG-SS; Group V: WOG-SS-PTG; and Group VI: WOG-PTG-SS. Each participant worked with all three techniques on separate laboratory days conducted over three consecutive weeks, with one-week intervals between sessions.

During each practical session, every student received an individualized kit containing the specific files for the assigned technique, a millimetre ruler, a 5 mL syringe (Luer Lock) with a 27-gauge side-vented needle, an alcohol container, an endodontic resin block (ISO 15, Endo-Training-Bloc-S. 02 Taper; Dentsply-Maillefer, Ballaigues, Switzerland), and written instructions outlining the laboratory procedure. The resin blocks measured 16.5 mm in total length, with a 0.02 taper and an apical foramen diameter of 0.15 mm. The working length for all samples was standardized at 16.0 mm. Canal patency was confirmed prior to preparation using a size 10 K file. Students used stopwatches to record the duration of canal instrumentation, including cleaning and irrigation, while pausing timing during file changes in the manual and PTG procedures.

Manual shaping with SS files (sizes 10, 15, 20, and 25 K) followed the FMDUL Endodontics training protocol using the balanced force technique in a crown-down approach. This involved three phases: enlargement of the cervical and middle thirds with Gates–Glidden burs, widening of the apical third, and establishing a continuous taper throughout the canal. Alcohol irrigation and patency checks were performed after each instrument change.

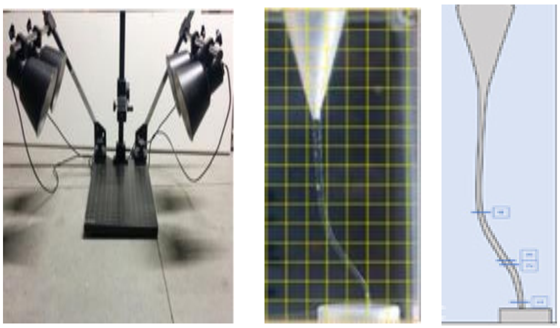
The continuous rotation technique with PTG files (Dentsply Sirona-Maillefer, Ballaigues, Switzerland) adhered to manufacturer guidelines and preset endomotor parameters. The canal was initially irrigated with alcohol, and files (SX, S1, S2, F1, F2) were introduced passively. SX, S1, and S2 were used with brushing and cutting actions at canal entry, whereas F1 and F2 were used in gentle inward and outward motions without lateral pressure.

For the reciprocating method using WOG Primary files (Dentsply Sirona-Maillefer, Ballaigues, Switzerland), preparation followed manufacturer instructions with a motor programmed for reciprocating motion. Files were advanced with short pecking movements of no more than 3 mm, and after every three pecks, the file was withdrawn, cleaned, and the canal irrigated, with patency checked using a size 10 K file. All preparations were completed to an apical diameter of size 25 for consistency across groups.

Imaging

A total of 108 resin blocks were photographed during preoperative, intraoperative, and postoperative stages. High-resolution images were taken with an Olympus E500 digital camera (Olympus, Tokyo, Japan) equipped with a macro lens, using a shutter speed of 1.6 s and aperture f/22. A fixed reproduction table with a millimetre scale and constant focal distance ensured standardization **(Figure 1a)**.

In the manual groups, three photo sets were taken: preoperative, intraoperative (after coronal enlargement with a Gates–Glidden drill), and postoperative. For the PTG groups, three images were recorded—preoperative, intraoperative (after the S2 file), and postoperative. In contrast, for the WOG groups, two images—pre- and postoperative—were obtained.



a) b) c)

Figure 1. (a) Photography setup and fixed mounting platform, (b) grid superimposition, and (c) measuring reference points 1–4.

All photographs were processed in Image-Pro 10 (Media Cybernetics, Rockville, MD, USA) by a single trained evaluator (KB). The software was calibrated to convert pixel values into millimetres and configured to record precise spatial measurements. A digital grid was added to each baseline image **(Figure 1b)** to identify standard reference zones. Three evaluation points were chosen: the first, 1.0 mm short of the working length, representing apical deviation; the second, at the area of the second curvature, where both minimal and maximal resin loss were determined; and the third, above the first, corresponding to the average wear at the cervical level **(Figure 1c)**. Image alignment was achieved with a registration function that marked four reference points—green from image 1 and red from image 2—to ensure overlap accuracy **(Figure 2a)**. The image comparison module then produced a combined image displaying the calculated dimensional differences **(Figure 2b)**.

a)

b)

Figure 2. (a) Registration points 1–4 for alignment (green = base image, red = comparison image), and (b) final overlay result used for analysis.

Upon finishing the laboratory work, participants completed a validated, self-administered questionnaire. Each student submitted three questionnaires, one for each session, regardless of the method used that day. Responses were anonymous, indicating only group and date. The form consisted of five multiple-choice items assessing perceived difficulty, file quantity, working phase, and satisfaction. The aim was to record the participants' subjective impressions regarding the three instrumentation systems.

Statistical analysis

Data were processed using SPSS version 24 (IBM Corp., Armonk, NY, USA). Dependent outcomes—including apical deviation, volume of resin removed, mid-cervical wear, and total instrumentation time—were examined with the Friedman test, followed by Wilcoxon paired tests corrected by the Bonferroni method. Differences in satisfaction and preference were analysed using the Kruskal–Wallis and Mann–Whitney U tests. The probability threshold for significance was set at $p < 0.05$.

Results and Discussion

Marked distinctions were identified between the three preparation systems regarding canal shaping. The ProTaper Gold (PTG) group displayed the smallest mean apical deviation (0.073 ± 0.003) compared to stainless steel (SS) (0.085 ± 0.005; $p < 0.001$) and WaveOne Gold (WOG) (0.081 ± 0.003; $p < 0.001$). Minimum resin removal (QMin) values were lowest and most inconsistent with SS (0.259), whereas PTG (0.3) and WOG (0.299) produced significantly greater and more uniform removal ($p < 0.001$). The maximum resin removal (QMax) mirrored these results: SS averaged 0.521, while PTG and WOG recorded 0.574 and 0.572, respectively ($p < 0.001$). Differences in mid-cervical wear (MCW) were statistically relevant between PTG and SS ($p < 0.05$) and between PTG and WOG ($p < 0.001$), as displayed in **Table 1**.

Table 1. Statistical comparison of measured parameters according to technique.

Parameter	Stainless Steel (SS) Mean (SD) [Min, Max]	ProTaper Gold (PTG) Mean (SD) [Min, Max]	WaveOne Gold (WOG) Mean (SD) [Min, Max]	p-value	Multiple Comparisons
Apical Deviation (AD, mm)	0.085 (0.005) [0.005, 0.076]	0.073 (0.003) [0.067, 0.078]	0.081 (0.003) [0.074, 0.088]	<0.001	SS–PTG *** PTG–WOG ***
Minimum Canal Width (QMin, mm)	0.259 (0.032) [0.032, 0.196]	0.300 (0.005) [0.287, 0.308]	0.299 (0.004) [0.293, 0.305]	<0.001	SS–PTG *** SS–WOG ***
Maximum Canal Width (QMax, mm)	0.521 (0.047) [0.047, 0.401]	0.574 (0.003) [0.568, 0.581]	0.572 (0.004) [0.565, 0.579]	<0.001	SS–PTG *** SS–WOG ***
Mid-Cervical Wear (MCW, mm)	0.449 (0.058) [0.058, 0.377]	0.492 (0.002) [0.488, 0.498]	0.485 (0.003) [0.479, 0.491]	<0.001	SS–PTG * PTG–WOG ***

Multiple comparisons (MC) derived from Wilcoxon test with Bonferroni correction.
Abbreviations: SS = stainless steel; PTG = ProTaper Gold; WOG = WaveOne Gold; x̄ = mean; SD = standard deviation; AD = apical deviation; QMin = minimal resin loss; QMax = maximal resin loss; MCW = mid-cervical wear; * $p < 0.05$; *** $p < 0.001$.

Procedure duration differed greatly between methods. The SS technique took the longest, averaging 33 min 15 s (±08:43), which was considerably slower than PTG (06:27 ± 02:11; $p < 0.001$) and WOG (06:34 ± 02:21; $p < 0.001$), as summarized in **Table 2**.

Table 2. Comparison of working time by instrumentation approach.

Parameter	Stainless Steel (SS) Mean (SD) [Min, Max]	ProTaper Gold (PTG) Mean (SD) [Min, Max]	WaveOne Gold (WOG) Mean (SD) [Min, Max]	p-value	Multiple Comparisons
Instrumentation Time (min:sec)	33:15 (08:43) [19:37; 55:43]	06:27 (02:11) [02:39; 14:36]	06:34 (02:21) [03:22; 13:00]	<0.001	SS–PTG *** SS–WOG ***

SS: stainless steel; PTG: ProTaper Gold; WOG: WaveOne Gold; x̄ = mean; SD = standard deviation; *** $p < 0.001$.

Student feedback revealed distinct tendencies among the systems. Cohen's kappa coefficients indicated no correlation between instrumentation type and difficulty perception, operative phase, or satisfaction. The apical third was identified as the most demanding region. The shaping phase was the most challenging for SS and WOG users, whereas PTG was favoured during finishing. PTG achieved the highest satisfaction ratings, followed by WOG, while SS received the lowest. Over 90% of participants expressed preference for mechanical systems, in contrast to 61.1% supporting SS. Statistically significant gaps were found between manual and mechanical groups ($p < 0.01$ for SS vs. PTG; $p < 0.001$ for SS vs. WOG). Almost 47.2% of participants felt that SS required too many files, compared with only 2.8% for PTG or WOG. Most students deemed the number of files in mechanical systems adequate, though 13.9% believed WOG used too few, a concern absent for PTG. No meaningful difference was found between PTG and WOG overall **(Tables 3 and 4)**.

Table 3. Questionnaire-based descriptive statistics by technique.

Questionnaire Item	Response	Stainless Steel (SS) n (%)	ProTaper Gold (PTG) n (%)	WaveOne Gold (WOG) n (%)	p-value	Cohen's κ (Pairwise)		
						SS vs. PTG	SS vs. WOG	PTG vs. WOG

Most Difficult Zone	None	0 (0%)	12 (33.3%)	11 (30.6%)	0.341 ***	0.039	0.129	0.261
	Cervical	2 (5.6%)	0 (0%)	0 (0%)				
	Middle	9 (25%)	1 (2.8%)	2 (5.6%)				
	Apical	25 (69.4%)	23 (63.9%)	23 (63.9%)				
Easiest Phase	None	0 (0%)	1 (2.8%)	2 (5.6%)	0.282 **	0.123	−0.129	−0.050
	Shaping	23 (63.9%)	7 (19.4%)	15 (41.7%)				
	Finishing	8 (22.2%)	17 (47.2%)	9 (25%)				
	Shaping + Finishing	5 (13.9%)	11 (30.6%)	10 (27.8%)				
Number of Files Used	Insufficient	1 (2.8%)	0 (0%)	5 (13.9%)	0.427 ***	0.057	0.019	0.118
	Sufficient	18 (50%)	35 (97.2%)	30 (83.3%)				
	Excessive	17 (47.2%)	1 (2.8%)	1 (2.8%)				
Technical Satisfaction (1–5)	1	3 (8.3%)	0 (0%)	1 (2.8%)	0.540 ***	0.025	−0.041	0.118
	2	13 (36.1%)	0 (0%)	2 (5.6%)				
	3	11 (30.6%)	0 (0%)	3 (8.3%)				
	4	8 (22.2%)	6 (16.7%)	9 (25%)				
	5	1 (2.8%)	30 (83.3%)	21 (58.3%)				

(Cramer's V and multiple comparisons (MC) using Cohen's κ).
SS = stainless steel; PTG = ProTaper Gold; WOG = WaveOne Gold; n = frequency; % = percentage; ** p < 0.01; *** p < 0.001.

Table 4. Comparison of overall satisfaction scores across instrumentation systems.

Group	Parameter	Stainless Steel (SS) Mean (SD) [Min; Max]	ProTaper Gold (PTG) Mean (SD) [Min; Max]	WaveOne Gold (WOG) Mean (SD) [Min; Max]	p-value (Between Techniques)	Multiple Comparisons
I		2.8 (0.8) [2, 4]	5.0 (0) [5, 5]	4.7 (0.5) [4, 5]	0.006	SS–PTG *
II		2.3 (1.2) [1, 4]	5.0 (0) [5, 5]	5.0 (0) [5, 5]	0.002	SS–PTG * SS–WOG *
III		3.2 (1.5) [1, 5]	5.0 (0) [5, 5]	5.0 (0) [5, 5]	0.007	—
IV		3.5 (0.8) [2, 4]	4.3 (0.5) [4, 5]	3.2 (1.2) [2, 5]	0.157	—
V		2.2 (0.4) [2, 3]	5.0 (0) [5, 5]	4.7 (0.5) [4, 5]	0.004	SS–PTG *
VI		2.5 (0.5) [2, 3]	4.7 (0.5) [4, 5]	3.3 (1.2) [1, 4]	0.006	SS–PTG **
p-value (Across Groups)		0.149	0.006	—	—	—
Multiple Comparisons (Across Groups)		—	IV–I * IV–II * IV–III * IV–V *	VI–II * VI–III *	—	—

pA = significance among six test groups; pB = comparison between systems.
Tests used: Kruskal–Wallis and Mann–Whitney U with Bonferroni adjustment.
SS = stainless steel; PTG = ProTaper Gold; WOG = WaveOne Gold; $\bar{x}$ = mean; SD = standard deviation; * p < 0.05; ** p < 0.01.
Group I: SS-PTG-WOG; Group II: SS-WOG-PTG; Group III: PTG-SS-WOG; Group IV: PTG-WOG-SS; Group V: WOG-SS-PTG; Group VI: WOG-PTG-SS.

The different phases of endodontic therapy are interdependent, with each step contributing significantly to the overall treatment outcome. Among these, biomechanical preparation, which integrates both mechanical and chemical procedures, is particularly fundamental. This stage utilizes endodontic tools, files, and irrigants to establish optimal conditions for sealing the root canal system [17]. The development of nickel–titanium (NiTi) instruments has greatly simplified the mechanical shaping process [18]. Numerous publications have highlighted its relevance, investigating aspects such as the characteristics of various instruments [19–22], instrumentation movements and techniques [22, 23], and the final canal design [5, 14, 24, 25].

Based on the findings of this investigation, the null hypothesis stating that no differences exist among instrumentation approaches regarding preparation quality, operation time, and user satisfaction is rejected. One of the analyzed parameters was the quality of canal shaping performed on resin blocks by students. When evaluating changes in the original canal configuration, both the maximum and minimum resin removal exhibited comparable outcomes, showing significantly lower values ($p < 0.001$) for stainless steel (SS) instrumentation compared to other groups. This may be linked to the design of SS files, which typically create a more cylindrical shape due to their 2% taper. Additionally, significant distinctions observed between ProTaper Gold (PTG) and SS, as well as between PTG and WaveOne Gold (WOG), are consistent with prior reports indicating that PTG better preserves canal anatomy with minimal apical deviation, as confirmed here, though it has also been associated with greater debris extrusion and reduced cutting capacity [25–29]. However, the lower apical deviation recorded in this study contrasts with Algar *et al*. [30], who noted higher apical transportation using PTG, possibly because their comparison involved a system with less taper, which enhances file flexibility. Although the WOG system is also known to maintain canal curvature, it generally induces more dentinal wear [31]. This may explain the greater cervical wear detected in both WOG and SS groups—WOG files, with their larger cervical diameter, apply more cutting stress in that region, while the SS results could stem from the use of Gates–Glidden (GG) drills, which actively remove material from the coronal and middle thirds.

Although the learning order for the six student groups was not a formal variable, additional analysis examined whether sequence influenced results. The pattern matched those found for isolated variables: significant differences appeared only in the manual SS group regarding apical deviation, minimal resin removal, and wear in the middle–cervical region. This suggests that the order of learning or technique had little impact on preparation quality, consistent with Sonntag *et al*. [32], who observed that previous experience with one method did not influence another. Specifically, the PTG system outperformed SS and WOG in minimizing apical deviation, confirming earlier findings that it helps maintain the original apical foramen position [25].

In terms of instrumentation time, the SS method required 33 minutes and 15 seconds on average, roughly five times longer than PTG and WOG. The superior time efficiency of mechanical systems, also highlighted in prior research [12–15, 33], not only shortens endodontic procedures but may also reduce the number of visits needed for completion [28]. Both NiTi-based and rotary techniques show a short learning curve, allowing even beginners to shape simulated canals accurately and predictably in a reduced timeframe [15, 28, 34], without extensive prior training in manual methods.

In the final stage, student feedback was collected to evaluate perceptions of each system. Their responses revealed consistent challenges in the apical third, though opinions varied on the easiest phase. With SS and WOG, "shaping" was identified as most manageable, while with PTG, students preferred the "finishing" step. A notable difference in perceived number of files was found between manual and mechanical methods: about 47.2% of participants felt SS instrumentation required too many files, whereas most judged the number in mechanical systems to be sufficient. Satisfaction levels were significantly higher with PTG and WOG than with SS, with over 90% favoring mechanical instrumentation. This trend persisted across group and learning sequence comparisons, echoing earlier findings [10, 32, 35, 36]. The prevailing preference for PTG, followed by WOG and lastly SS, may stem from shorter working times, ease of handling, and refined design of mechanical instruments. Student opinions and feedback are vital for continuous curriculum development and enhancing teacher–student interaction [37]. This is especially important in demanding areas such as endodontics, where complex root canal morphology increases difficulty [38]. Thus, fostering confidence and integrating innovative techniques through practical laboratory training during undergraduate education is essential for building lifelong learning habits [39]. The present findings emphasize the competence of novice clinicians using modern rotary systems and support their integration into dental training programs.

While the introduction of NiTi alloy and the subsequent adoption of mechanical methods for root canal shaping have undeniably represented a major advancement in endodontics [19], it is important to recognize that the continuous emergence of novel approaches aimed at simplifying canal instrumentation still poses challenges for both dental practitioners and students [10]. The present investigation concentrated on evaluating three distinct root canal preparation techniques by employing resin training blocks. These blocks, featuring S-shaped canals, imitate natural canal curvature while avoiding the intricate details that often lead to instrument fracture or blockage. Notably, these artificial models meet the technical complexity requirements set by the European Society of Endodontology (ESE) [7]. Although simulated canals differ qualitatively from real teeth, they remain highly beneficial for standardized laboratory assessments of various preparation systems [40, 41].

Several limitations should be acknowledged in this research. The image evaluation was carried out using ImagePro software, which, despite having features to align and overlay images, still contains a degree of operator subjectivity. To minimize this influence, image analysis was performed by one blinded operator, with grouping and labeling managed separately by another individual who was unaware of the assessment schedule. This approach reduced potential observer bias. Moreover, the study did not examine procedural errors such as ledges, zipping, elbows, or instrument separation, all of which may influence both instrumentation quality and working time. Additionally, the student questionnaires were completed by participants without prior endodontic training, which may have impacted the precision of their responses.

Furthermore, the observation that continuous rotation systems demonstrated better performance than reciprocating motion is specific to the parameters evaluated and to feedback obtained from novice operators. Hence, these results should be interpreted cautiously, as outcomes could differ in student groups with prior experience. Future investigations should consider employing alternative evaluation methods and including students with clinical exposure, to further analyze how previous training and familiarity affect technique preference and instrument handling perception.

Conclusion

Within the scope of this study, mechanical instrumentation conducted by undergraduate students without prior endodontic experience resulted in shorter working times and less apical deviation. Compared to manual methods, mechanical techniques achieved superior canal shaping quality. These findings highlight the educational value of incorporating rotary and mechanical instrumentation into undergraduate dental programs, as they enhance both efficiency and performance in root canal preparation.

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