The Saudi Dental Journal 36 (2024) 1369–1375

Contents lists available at ScienceDirect

The Saudi Dental Journal

journal homepage: www.ksu.edu.sa
www.sciencedirect.com

Original Article

Impact of using single-file reciprocating system on the quality of root canal treatment treated by undergraduate students

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ARTICLE INFO

Keywords:
Root canal quality
Single rotary file system
Undergraduate students
WaveOne gold
Root filling

ABSTRACT

Background: This study aimed to evaluate the use of a single-file reciprocating system on the technical quality of root canal filling and treatment by radiographic assessment of cases treated by undergraduate dental students.
Materials and methods: This was a retrospective cross-sectional clinical study of endodontically treatments conducted by fourth-year undergraduate students during the academic year 2021–2022. Root canal preparation was performed using the WaveOne Gold system with matching single-cone gutta-percha. The collected data included sex, tooth position, number of canals, and treatment time (first or second semester). The quality of the root canal filling was assessed based on the root canal filling length, density, and taper. The presence of ledges, apical transportation, perforation, and instrument separation were recorded. Data were analyzed using SPSS version 28. Chi-square tests were used, and the statistical significance level was set at $P < 0.05$.
Results: A total of 601 teeth were included. The length of the root canal filling was adequate in 93.51 % of the teeth, underfilled in 2.82 %, and overfilled in 3.66 %. The density and taper were adequate in 96.5 % and 98.16 % of the teeth, respectively. There were no significant differences among the parameters of length, taper, density, or procedural errors relative to the arch type. However, there was a significant difference between the anterior and premolar teeth in terms of taper, density, and overall quality of the root canal filling. The overall quality of root canal treatment was acceptable in 527 teeth (87.68 %), with no significant difference between teeth ($P = 0.256$).
Conclusion: The quality of root canal treatment performed by undergraduate students using a single-file reciprocating system is good or acceptable.

1. Introduction

Root canal treatment is a fundamental procedure in dental care (American Association of Endodontists, 2018). The aim of root canal filling is to allow the healing of periapical tissues by providing a hermetic seal and preventing reinfection of the root canal space after adequate chemo-mechanical preparation (Sagsen et al., 2006). With adequate coronal restoration, the long-term retention of a functional endodontically treated tooth is expected (European Society of Endodontology, 2006; Medina-Torres et al., 2024).

Pulp and periapical diseases are microbial in nature, and the success of root canal treatment relies on proper cleaning and disinfection of the root canal system followed by adequate coronal and apical sealing to prevent reinfection (Al Shehadat et al., 2023). Adequate techniques and the absence of procedural errors throughout the treatment will ensure proper cleaning, disinfection, and sealing. Hence, the technical standards of root canal treatment are closely related to treatment outcomes. The European Society of Endodontology (ESE) and the American Association of Endodontists (AAE) have declared that the technical quality of root canal fillings, assessed radiographically, can enhance success (Er et al., 2006). In other words, radiographs that show properly shaped canals with a consistent coronal to apical taper, absence of procedural mishaps, proper filling density with absence of voids at the canal walls, and a precise distance at the canal's apical constriction (within 0.5–2 mm from the radiographic apex) have a higher chance of success (European Society of Endodontology, 2006; Medina-Torres et al., 2024).

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https://doi.org/10.1016/j.sdentj.2024.08.011
Received 22 April 2024; Received in revised form 18 August 2024; Accepted 21 August 2024
Available online 29 August 2024

The technical quality of root canal fillings undertaken by undergraduate students has been investigated in a number of previous studies based on the evaluation of radiographic images of endodontically treated teeth (Al Shehadat et al., 2023; Elsayed et al., 2011; Alsaleh et al., 2012; Chueh et al., 2003; Hayes et al., 2001; Moradi and Gharechahi, 2014; Khabbaz et al., 2010; Barrieshi-Nusair et al., 2004; Patel et al., 2021; Lynch and Burke, 2006; Unal et al., 2011; Rafeek et al., 2012; Smadi et al., 2015). Several studies have reported variations in the quality and outcomes of endodontic treatment performed by undergraduate dental students (Alsaleh et al., 2012; Barrieshi-Nusair et al., 2004; Qualtrough, 2014). Unfortunately, the quality of root canal treatments performed by undergraduate dental students has been reported to be inadequate in many countries (Alsaleh et al., 2012; Alsulaimani et al., 2015; Barrieshi-Nusair et al. 2004; Elsayed et al., 2011; Habib et al., 2018; Rafeek et al., 2012; Ribeiro et al., 2018; Qualtrough, 2014). This could be attributed to a variety of reasons, including the undergraduate laboratory and clinical facilities, training hours, dominant techniques taught, instruments used, staff-to-student ratio, and the type and location of treated teeth inside the oral cavity (Barrieshi-Nusair et al., 2004).

With the current advancements in metallurgy and kinematics, nickel-titanium (NiTi) instruments have become indispensable, and the use of machine-assisted endodontic instruments allows for easier, faster, and better root canal shaping, as well as greater resistance to fracture (Balto et al., 2010). Hence, the use of engine-driven NiTi techniques is suggested in the preclinical and clinical training of undergraduate students. At the Ajman University (AU) Dental College, in addition to manual step-back root canal preparation, the reciprocating WaveOne Gold (WOG) file has been introduced in preclinical undergraduate training in the last few years and has become the predominant technique used in undergraduate dental clinics (Silva et al., 2023; Elashiry et al., 2020).

The WOG system is particularly advantageous for teaching root canal treatments in undergraduate education. Employing a single-file technique, it streamlines the procedure by reducing both complexity and time without compromising quality (Plotino et al., 2015). The reciprocating motion of the WOG file minimizes torsional stress and the risk of file breakage, which are critical factors for novices who may lack refined tactile sensitivity. The simplicity and effectiveness of the WOG system make it a useful tool for educational purposes. This allows students to achieve predictable and reproducible results, thus building confidence and competence in endodontic procedures (Pedullà et al., 2014).

Certain questions in health care research have been investigated through observational studies (von Elm et al., 2018). Beyond being an effective tool for clinical governance, clinical audits can help dental educators identify and address curriculum deficiencies, methodological issues, and problems with instruments or materials. Repeating the clinical audit cycle at appropriate intervals is crucial for evaluating the implementation of changes and providing essential feedback that ensures continuous improvement and consistent quality, ultimately optimizing patient outcomes. Therefore, it is imperative to continuously review the outcomes of clinical training for undergraduate dental students (Fong et al., 2018).

The current study aimed to radiographically assess and evaluate the technical quality of root fillings performed by fourth year undergraduate students using the WOG single-reciprocating file system in terms of filling length, density, and taper, and to assess the influence of the use of engine-driven files on root canal preparation mishaps and iatrogenic errors. The STROBE statement checklist was followed while reporting the current study.

2. Materials and methods

This retrospective cross-sectional clinical study of intraoral periapical radiographs of root canal treatments performed at the College of Dentistry, Ajman University (AU), United Arab Emirates (UAE), during the academic year 2021–2022. Ethical approval was obtained from the Ethical Approval Committee of Ajman University (D-F-H-6-Feb).

Due to the retrospective nature of this study, patient consent was waived, as data were collected as part of routine dental hospital procedures. Furthermore, the investigators ensured that all data were anonymized without any reference to the patients' identities.

2.1. Case selection

Endodontic patients treated by fourth-year undergraduate students, who had preclinical training only, were included in this study. Case selection included anterior teeth or premolars with fully formed apices and minimal root curvature that received primary root canal treatment.

Molar teeth, anterior teeth, and premolars with anatomical variations or signs of root resorption or possible fracture were excluded. Teeth with previously initiated root canal treatment or retreatment cases were excluded from the study. Root canals that were prepared or obturated using techniques other than the WOG file system were also excluded.

2.2. Root canal treatment protocol

Endodontic treatment was performed in an aseptic environment using rubber dam isolation. After accessing the cavity, a standard glide-path to the full working length was established with a stainless steel K-file (Dentsply Sirona, Maillefer, Switzerland), mainly size 10 or 15, with the aid of 17 % Ethylenediaminetetraacetic acid lubricant gel (Glyde File Prep, Dentsply-Maillefer, Ballaigues, Switzerland).

Working lengths were determined using an apex locator Root ZX II (J. Morita, Tokyo, Japan) and intraoral digital periapical working length radiographs. A working length 0.5–1 mm away from the radiographic apex was considered acceptable. The initial apical file was determined, followed by instrumentation using the WOG reciprocating system, and the file size was selected according to the manufacturer's instructions. Standard clinical protocols, such as recapitulation (patency) file between each successive file (stainless steel K-File size #10), copious canal irrigation with 2.5 % sodium hypochlorite, and saline as the final irrigation, were performed. The canals were dried using WOG paper points (Dentsply Sirona, Maillefer, Switzerland).

Root filling was performed using Wave-One gutta-percha (Dentsply Sirona, Maillefer, Switzerland) according to the size of the last file used for instrumentation, either primary, medium, or large, with a single-cone root filling technique using a bioceramic sealer (NeoSEALER® Flo, Avalon Biomed Division of NuSmile Ltd., USA). The root canal treatment in the majority of cases was accomplished in a single session unless canal obturation was not advised due to a treatment factor or a time constraint, in which case another session was scheduled to complete the treatment.

All radiographs were taken by undergraduate students using photostimulable phosphor plates using both the bisecting and parallel angle techniques. Radiographs were obtained using an X-ray machine with the manufacturer and serial number CEFLA (Italy) – 705018180, and X-ray tube serial number 70501818. The exposure settings of 70 kVp and 8 mA were fixed for all intraoral images. The plates were scanned with DIGORA® Optime DXR-60. All images were saved automatically to the patient records with the dental operator software SCANORA® 3D (Soredex). Radiographs were evaluated by two calibrated, experienced examiners: an endodontist with 20 years of experience and an endodontic postgraduate student with ten years of experience. Prior to the study, the examiners were calibrated by assessing a few selected cases. The inter- and intra-examiner reliabilities were determined by scoring 25 random radiographs ($\kappa = 0.89$). Radiographs were evaluated twice by the same examiners; the first stage involved inter-examiner reliability, followed by intra-examiner reliability 4 weeks later. These radiographs were included in the main study. Records and digital radiographs were accessed and retrieved for this study. Good-quality radiographs showing at least 3 mm beyond the radiographic apex

were included, while poor-quality radiographs with inadequate data were excluded. All radiographs taken during the root canal treatment for the 601 patients included in the study were viewed on the computer screen using the SCANORA® 3D software. The images were enhanced using the tools available in the software.

Data collected included sex, tooth position, number of canals, and time of treatment (in the first or second semester) to test the effectiveness of the student experience.

2.3. Assessing the technical quality of root fillings and detecting iatrogenic errors

Barrieshi-Nusair et al. (2004) and Eleftheriadis and Lambrianidis (2005) established criteria for assessing instrumentation and obturation mishaps in endodontics. These criteria encompass various critical aspects for evaluating the technical quality of root canal treatments. Instrumentation-related mishaps include ledges, where files or obturation materials deviate from the canal's original curvature; zipping, identified by an elliptical shape at the apical end of the canal; instrument separation, noted by the presence of a separated radiopaque instrument; strip perforation, seen as extrusion on the inner wall of multi-rooted teeth; root perforation, which involves material extrusion into any part of the root, including the apex; apical transportation, identified when the filling material is located on the outside curve of the apical third of the canal; and floor damage, recognized as irregularities on the access cavity floor and walls in multi-rooted teeth without perforation.

Regarding obturation-related mishaps, criteria included root canal filling length, considered acceptable within 0.5–2 mm of the radiographic apex; unacceptable lengths were classified as underfilling (>2 mm short) or overfilling (beyond the apex). Density was considered acceptable if it was uniform and had no voids, whereas poor density with visible voids was deemed unacceptable. The taper was considered adequate when it was consistently shaped from the orifice to the apex; inadequate tapering included inconsistent or insufficient shaping. These guidelines ensured systematic assessment of root canal treatment quality, encompassing both procedural techniques and final outcomes.

2.4. Statistical analysis

Data were entered into a Microsoft Excel spreadsheet and analyzed using SPSS version 28 (Chicago, Illinois, United States). Data on patient sex, student experience, number of canals, tooth position, root filling length, density, taper, and procedural mishaps such as ledge, apical transportation, fractured instrument, perforation, and zipping were expressed as frequencies and percentages. Chi-square tests were used to analyze the relationships between independent variables (tooth position and student experience) or categorical variables (length, density, and taper) and procedural errors. Cohen's kappa (κ) values for inter-examiner agreement were analyzed using the data of all evaluated cases. The statistical significance level was set at $p < 0.05$.

Multivariable logistic regression was performed with tooth position as the independent variable to compare its effect on length, density, taper, and procedural errors as dependent variables.

3. Results

The total sample size of the teeth examined was 616, representing the total number of cases completed by fourth-year students during the first and second semesters of the 2021–2022 academic year. Fifteen samples were excluded from the study because of poor-quality radiographs with inadequate data.

The total number of teeth included in this study was 601, comprising 386 males and 215 females, representing 64.2 % and 35.8 %, respectively. The most frequently treated teeth were maxillary premolars (n = 310, 51.58 %), whereas the least frequently treated were mandibular anteriors (n = 16, 2.66 %). Approximately half of the teeth in this study received single-tooth root canals (49.9 %) (Fig. 1).

The study revealed that the length of the root canal filling was adequate in 93.51 % of the teeth, underfilled in 2.82 %, and overfilled in 3.66 %. The densities of the root filling and taper were adequate in 96.5 % and 98.16 % of the teeth, respectively (Fig. 2).

The percentages of procedural mishaps (ledge, apical transportation, perforation, separated instrument, zipping, and floor damage) are presented in Table 1. The results indicated a low frequency of procedural errors. No perforations were observed in the coronal or middle portion of the root. However, any master cone that extended beyond the radiographic apex during the try-in stage was considered an apical perforation, and this accounted for the highest number of mishaps in this study (14.6 %). The effect of apical perforation on the quality of root canal filling length was reduced to 2.66 % after correction of the master cone during obturation.

Statistical analysis showed no significant differences among the parameters of length, taper, density, and all procedural errors relative to the arch type. However, there was a significant difference between the anterior and premolar teeth in terms of taper, density, and overall quality of the root canal filling ($P < 0.05$).

The quality of root canal treatment was categorized as acceptable when all variables (length, taper, and density) were adequate and there were no mishaps (ledge, apical root perforation, floor damage, apical transportation, zipping, or separated instruments). When the master cone was adjusted after the apical perforation and the canals were obturated to an adequate length, the treatment was classified as acceptable.

The results of this study showed that 527 teeth (87.68 %) had acceptable overall root canal quality. Maxillary premolar teeth had the highest overall quality (89.7 %), followed by mandibular premolars (88.1 %) and mandibular anterior teeth (87.5 %), and the lowest overall quality was for maxillary anterior teeth (83 %), with no significant differences between the teeth ($P = 0.256$).

However, when examining the correlation between student experience and the quality of root filling, the overall quality of teeth treated by undergraduate students in the first and second semesters was comparable (86.33 % and 89.03 %, respectively) and no statistically significant difference was found ($P = 0.324$) (Tables 2 and 3).

In multivariable logistic regression, the density and the taper of maxillary anterior teeth are four times more inadequate than other groups, odds ratio [OR] 4.423, 95 % confidence interval [CI] 1.230–15.901, $P = 0.02$ and OR 4.450, 95 % CI 0.942–21.010, $P = 0.05$, respectively (Table 4).

4. Discussion

This study retrospectively evaluated the quality of root canal treatments performed by undergraduate dental students by inspecting intraoral periapical (IOPA) radiographic images. The key parameters assessed were the length of the filling material relative to the radiographic apex, the taper and density of the filling material, and the incidence of procedural errors. As per the identification criteria selected, all overextended master cone radiographs were counted as procedural errors of apical perforation, except if the overall postoperative obturation radiograph revealed an adequate length.

Although 2D-view IOPA images are known to have limitations such as overlapping anatomical structures and geometrical distortions (Kazzi et al., 2007), many studies have utilized them to assess the technical quality of root fillings and audit the overall quality of treatment and procedural errors conducted by undergraduate students in dental schools worldwide using similar parameters (Al Shehadat et al., 2023; Elsayed et al., 2011; Alsaleh et al., 2012; Chueh et al., 2003; Hayes et al., 2001; Moradi and Gharechahi, 2014; Khabbaz et al., 2010; Barrieshi-Nusair et al., 2004; Patel et al., 2021; Lynch and Burke, 2006; Unal et al., 2011; Rafeek et al., 2012; Smadi et al., 2015). These parameters are considered acceptable indicators of the overall quality of root canal

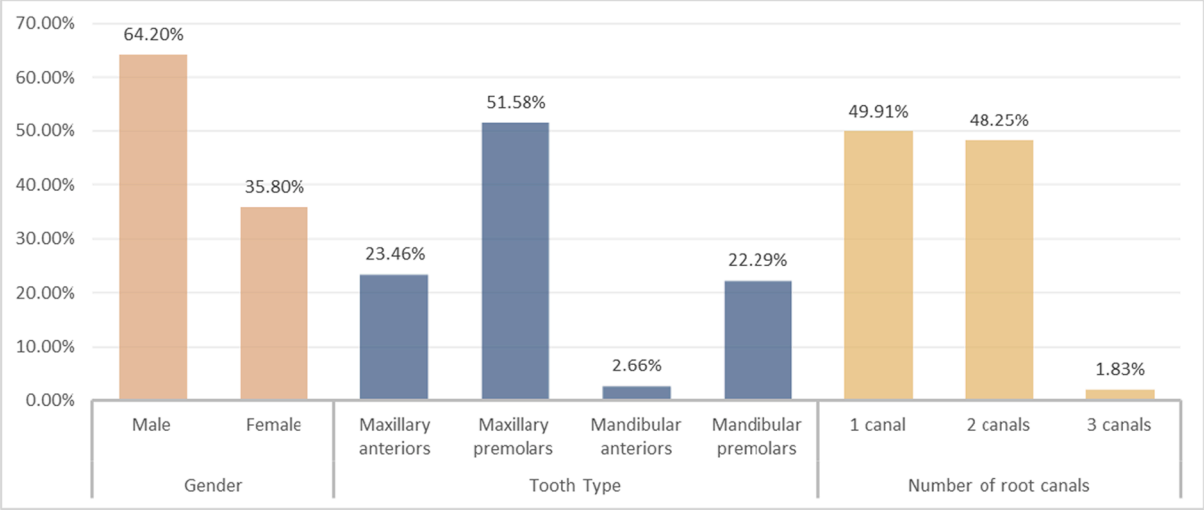

Fig. 1. Distribution of teeth according to gender, tooth type, and number of root canals.

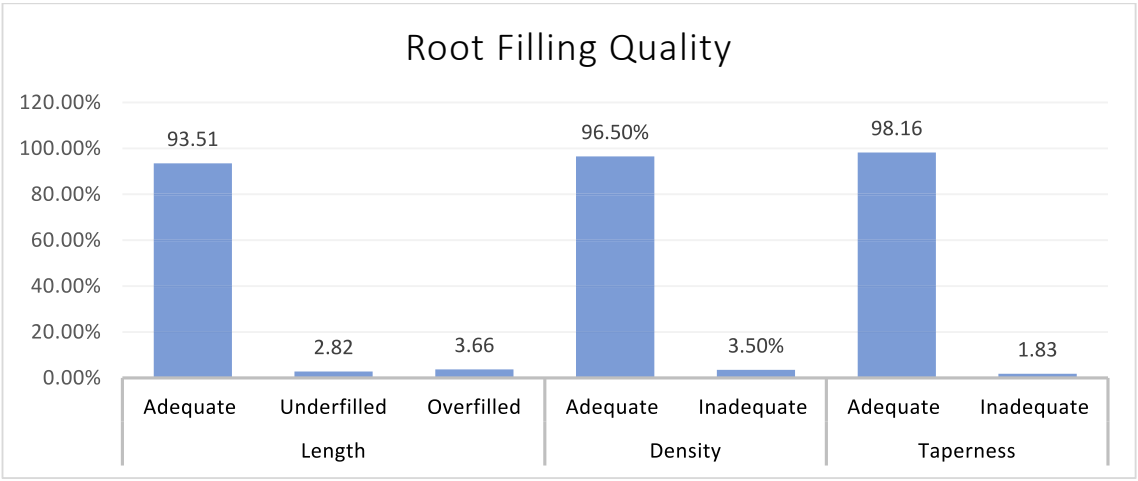

Fig. 2. Quality of root canal filling related to length, density, and taper.

treatments (Qualtrough, 2014).

The American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology have suggested the use of images with higher accuracy and resolution (limited field of view cone-beam computed tomography [CBCT]) to evaluate the factors that impact the outcomes of root canal treatment (Moussa-Badran et al., 2008). However, such data are currently not available for auditing purposes because CBCT images are not routinely prescribed in undergraduate clinics.

In this study, all the assessed teeth were anterior teeth and premolars treated by fourth-year students in the period between 2021 and 2022. Of the 601 treated maxillary and mandibular teeth, 87.68 % (n = 527) showed acceptable overall quality of root canal treatment. A previous audit conducted at AU in 2009 reported a much lower frequency of 19.2 % (unpublished data).

The acceptable overall quality results from our study are higher than those of other schools worldwide, which range from 23 % to 85 % in different countries, including Sharjah University/United Arab Emirates (Al Shehadat et al., 2023; Elsayed et al., 2011; Alsaleh et al., 2012; Chueh et al., 2003; Hayes et al., 2001; Moradi and Gharechahi, 2014; Khabbaz et al., 2010; Barrieshi-Nusair et al., 2004; Patel et al., 2021; Lynch and Burke, 2006; Unal et al., 2011; Rafeek et al., 2012; Smadi et al., 2015).

In addition, the current results showed higher frequencies of root canal fillings with adequate length, density, and taper (93.5 %, 96.5 %, and 98.2 %, respectively), which are clearly higher than those reported in all previously mentioned studies.

According to the undergraduate curriculum at the AU Dental College, dental students have been taught endodontic courses in the DDS program for over three years. The third-year syllabus incorporates laboratory training exercises in which students perform root canal treatment on different types of simulated plastic teeth on a dental manikin as well as extracted teeth over two semesters. The time dedicated to preclinical endodontic practical training at AU Dental College is 42 h per semester (84 h per year), which is the highest compared to other universities, [Wits University (60 h), Cork (48 h), Glasgow (32 h), West Indies (54 h), and Jordan (56 h)] (Lynch and Burke, 2006). The preclinical staff: student ratio is 1:8, and students are required to complete full root canal treatment on at least 16 extracted and plastic teeth before proceeding to the clinical phase.

Differences in the results among studies may be attributed to different study designs, such as the type of teeth treated (posterior or anterior teeth), whether single-tooth or multiple-teeth root canals were evaluated, the education level of students involved, and the criteria used to evaluate the quality of the treatment. Additionally, differences in root canal preparation and obturation techniques may have contributed to

Table 1
The incidence of measured parameters related to length, taper, density, ledge, apical root perforation, floor damage, apical transportation, zipping, and separated instrument in both arches with their significance level.

Parameter/Mishaps		Anterior Teeth	Premolar teeth	P value
Length	Adequate	150 (95.5)	412 (93.5)	0.156
	Underfilled	1 (0.6)	16 (3.6)	
	Overfilled	6 (3.8)	16 (3.6)	
Taperness	Adequate	148 (94.3)	442 (99.5)	<0.001
	Inadequate	9 (5.7)	2 (0.5)	
Density	Adequate	142 (90.4)	438 (98.6)	<0.001
	Inadequate	15 (9.6)	6 (1.4)	
Ledge	Present	0 (0)	5(1.1)	0.219
	Absent	157 (100)	439 (98.9)	
Apical Root Perforation	Present	29 (18.5)	59 (13.3)	0.076
	Absent	128 (81.5)	385 (86.7)	
Floor Damage	Present	0 (0)	4 (0.9)	0.297
	Absent	157 (100)	440 (99.1)	
Apical Transportation	Present	0 (0)	0(0)	1
	Absent	157 (100)	444 (100)	
Zipping	Present	0 (0)	2 (0.3)	0.545
	Absent	157 (100)	442 (99.7)	
Separated Instrument	Present	0 (0)	2 (0.3)	0.545
	Absent	157 (100)	442 (99.7)	
Overall quality	Accepted	131 (83.4)	396 (89.2)	0.043
	Not accepted	26 (16.6)	48 (10.8)	

Table 2
The overall quality of root canal filling in relation to arch, semester, tooth position, and tooth type, along with its significance level.

			Acceptable	Not Acceptable	P value
Quality	Arch	Maxillary	395 (87.6 %)	56 (12.4 %)	0.893
		Mandibular	132 (87.8 %)	18(12.2 %)	
	Semester	1st Semester	259 (86.33 %)	41(13.66 %)	0.324
		2nd Semester	268 (89.03 %)	33(10.96 %)	
	Tooth Position	Anteriors	131 (83.43 %)	26 (16.56 %)	0.05
		Permolars	396 (89.18 %)	48 (10.81 %)	
	Anterior teeth	Upper Anteriors	117(83 %)	24(17 %)	0.369
		Lower Anteriors	14(87.5 %)	2(12.5 %)	
	Premolar Teeth	Upper Premolars	278(89.7 %)	32(10.3 %)	0.718
		Lower Premolars	118(88.1 %)	16(11.9 %)	

the variation in the results (Nagaraja, 2015).

The engine-driven NiTi root canal instruments were introduced to our undergraduate training in September 2019. Besides implementing this revolutionary step, the higher frequency of adequate quality of root filling and fewer incidence of procedural errors reported in this study might be attributed to the study design, in which only minimally complicated teeth (anterior and premolars) were included. Canal curvature is a significant challenge for operators, especially beginners. Several studies have claimed that the occurrence of unacceptable root filling increases significantly as the tooth position moves posteriorly (Cheung and Liu, 2009, Subramanian et al., 2023).

A meta-analysis reviewed 24 international studies that assessed the quality of root canal treatments performed by undergraduate students using manual root canal preparation techniques. It revealed a lower frequency of acceptable root fillings performed by undergraduate students (48.75 %) (Qualtrough, 2014).

According to Cheung and Liu (2009), manual root canal preparation using stainless steel results in a greater incidence of procedural errors and is associated with a lower healing rate than NiTi rotary shaping in primary root canal treatments performed in a dental teaching setting (Dadresanfar et al., 2008).

Ledge formation is the most common error assessed radiographically in root fillings performed by undergraduate students who implement manual step-back preparation, especially in curved canals, followed by apical transportation and apical perforations (American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology, 2015; Arias and Peters, 2022; Rafeek et al., 2012; Saunders et al., 1997; Patel et al., 2021). However, ledge formation was observed in only five of the 601 teeth, and no apical transportation was reported in the present study (Table 1). By contrast, apical root perforation was the most frequently observed procedural error (14.6 %), mostly occurring in maxillary anterior teeth (Table 1).

Furthermore, previous studies have shown that the most frequent cause of inadequate root filling was related to filling density (Qualtrough, 2014). In the present study, the predominant cause of unacceptable root filling was related to overextended master cone and apical overpreparation/perforation.

This problem could be linked to inadequate working length determination and/or the disregard of the canal apical constriction during instrumentation and the inability of students to confine the instrumentation within the canal, possibly owing to low control of the rotary file motion at the apical area. In addition, this problem mostly occurred in maxillary anterior teeth, which inherently possess a large apical diameter that does not match the largest instrument size available in the WOG reciprocating file system. Eventually, this makes customizing the correct master cone challenging for inexperienced dental students.

Although there is no consensus on which technique or instrument design is clinically superior (de-Figueiredo et al., 2020), similar success rates after root canal treatment were reported with reciprocating single-file instrumentation and matching single-cone root filling or hand-file instrumentation and lateral compaction in a 12-month randomized clinical trial (Hamid et al., 2018). However, the present study showed a significantly higher frequency of acceptable overall quality of root fillings, mainly in premolars, which might reflect better matching of the WOG file size and design with the root canal size and shape in premolar teeth.

Regarding the influence of students' experience on their performance, no differences were observed in their performance in the second semester (86.33 %) compared to the first semester (89.03 %). This is compatible with the concept that the single-reciprocating instrumentation technique can shorten the learning curve of newly trained students (Pettigrew et al., 2007).

The influence of the quality of student guidance and the staff-student ratio are also important when considering the outcomes of patient treatment under supervision (Arias and Peters, 2022). The clinical staff-student ratio in the fourth-year undergraduate endodontic clinic at AU College of Dentistry is 1:3, including two specialists, one senior dental practitioner, and two junior dental practitioners. This ratio is lower than that of several other universities (American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology, 2015; Al Shehadat et al., 2023; Barrieshi-Nusair et al., 2004; Elsayed et al., 2011; Lynch and Burke, 2006; Nagaraja, 2015). It seems that the aforementioned quotas and ratios had an obvious positive influence on the results of this study.

Within the limitations of this study, the clinical audit feedback cycle is deemed a useful tool when applied in undergraduate endodontic training and has the potential to enable educators to identify areas of weakness for improvement.

To ensure reliability and consistency, a re-audit is suggested to assess the quality of the endodontic treatment performed by undergraduate students in both the anterior and posterior teeth with varying degrees of difficulty, involving a larger sample size for all types of teeth and

Table 3
The correlation between student experience in first and second semester and the quality of the root filling.

				Acceptable	Not Acceptable	P value
Quality	1st Semester	Arch	Maxillary	190 (86.36 %)	30 (13.63 %)	0.980
			Mandibular	69 (86.25 %)	11 (13.8 %)	
		Tooth Position	Anteriors	57(81.42 %)	13 (18.57 %)	0.172
			Permolars	202 (87.82 %)	28(12.17 %)	
		Anterior teeth	Upper Anteriors	50 (80.64) %)	12 (19.35 %)	0.185
			Lower Anteriors	7 (87.5 %)	1 (12.5 %)	
		Premolar Teeth	Upper Premolars	140 (88.6 %)	18 (11.4 %)	0.594
			Lower Premolars	62 (86.1 %)	10 (13.9 %)	
	2nd Semester	Arch	Maxillary	205(88.74 %)	26 (11.25 %)	0.768
			Mandibular	63 (90 %)	7 (10 %)	
		Tooth Position	Anteriors	74 (85.05 %)	13 (14.94 %)	0.159
			Permolars	194 (90.65 %)	20 (9.34 %)	
		Anterior teeth	Upper Anteriors	67 (84.8 %)	12 (15.19 %)	0.581
			Lower Anteriors	7 (87.5 %)	1 (12.5 %)	
		Premolar Teeth	Upper Premolars	138 (90.79 %)	14(9.21 %)	0.912
			Lower Premolars	56 (90.32 %)	6 (9.67 %)	

Table 4
Logistic regression: Factors affecting the prevalence of procedural errors.

Outcomes	Tooth position (Comparing to Maxillary Anterior Teeth)	
	Odds ratio (95 % CI)	P-Value
Density	4.423 (1.230–15.901)	0.02
Taper	4.450 (0.942–21.010)	0.05
Length	1.677 (0.629–4.471)	0.301
Floor damage	0.00	1
Overall quality	1.522 (0.769–3.013)	0.228
Fractured instrument	0.970 (0.000)	1
Zipping	1.097 (0.000)	1
Apical perforation	1.379 (0.730–2.605)	0.322
Ledge	0.00	0.996

different levels of students.

5. Conclusions

The results of the present study indicate that the quality of root canal treatment performed by fourth year undergraduate students was adequate and higher than that recorded in other similar studies.

The changes implemented in the students' practical training in 2019 were justified and had a positive influence on the outcomes of the selected root canal treatments performed by the fourth-year undergraduate students. However, students tended to mismanage the apical constriction, especially in the maxillary anterior teeth, which requires further attention.

6. Declaration

Ethics approval and consent to participate: The study was approved by the Ethics committee of Ajman University (D-F-H-6-FebEthics approval and consent to participate.

Informed written consent from the patient to participate was waived from the consent of the patient to be treated at Ajman University Undergraduate Students Clinics by the Ethics Committee of Ajman University (D-F-H-6-Feb).

All methods were performed in accordance with relevant guidelines and regulations.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

MM: Conceptualization, Data collection, reviewing, and writing. **DH:** Writing, and reviewing. **MA:** Writing and reviewing. **As:** Conceptualization, writing, reviewing.

Funding: **No funding was received for this manuscript**

Authors' contributions: All authors contributed to this study:

1- Marwa Ameen and Dunia Alhadi: Did the data collection.
2- Marwa Ameen, Abdul Rahman Saleh and Manal Almaslamani: Data analysis.
3- Dunia Alhadi, Abdul Rahman Saleh, and Manal Almaslamani: Writing the manuscript.
4- Manal Almaslamani: Corresponding Author.

Acknowledgements: Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2024.08.011.

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