Original Article

The Frequency of Dentinal Cracks Caused by Root Canal Preparation with Reciproc Blue, Reciproc, ProTaper Next and ProTaper Universal

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KEY WORDS
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ABSTRACT

Background: Nickel-titanium rotary and reciprocating systems may generate stresses in root dentin during canal preparation, potentially contributing to dentinal crack formation. Although several systems have been investigated, evidence regarding crack formation associated with Reciproc Blue remains limited, particularly using stereomicroscopic sectioning methods.

Purpose: This study aimed to compare the frequency of dentinal cracks caused by root canal preparation with ProTaper Universal (PTU), ProTaper Next (PTN), Reciproc, and Reciproc Blue (RB).

Materials and Method: In this *in vitro* study, 75 single-canal mandibular premolars were randomly assigned to 5 groups (n=15) for root canal instrumentation with PTU, PTN, Reciproc and RB; the fifth group served as the control group (no instrumentation). Root canal irrigation was performed with full strength sodium hypochlorite after using each file. After instrumentation, the roots were sectioned perpendicular to the longitudinal tooth axis at 3-, 6-, and 9-mm distances from the apex by a diamond saw under water coolant. The sections were inspected under a stereomicroscope at 25× magnification for dentinal cracks. Data were analyzed by the Chi-square and Monte Carlo tests (alpha= 0.05).

Results: The highest crack frequency occurred in the PTU group at 6 and 9 mm from the apex, whereas no cracks were observed in the control group at any level. The frequency of cracked sections in the PTU, PTN, Reciproc, and RB groups was 19/45, 15/45, 8/45, and 5/45, respectively, indicating significantly more cracks in PTU and PTN than in Reciproc and RB (p Value< 0.05), while no significant differences were found among the systems at 3, 6, or 9 mm individually (p> 0.05).

Conclusion: Within the limitations of this in vitro study, all tested instrumentation systems produced dentinal cracks. Reciproc Blue generated the lowest overall crack frequency and may represent a favorable alternative to the other tested systems, particularly when preservation of root dentin integrity is a concern.

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Introduction

Nickel-titanium (NiTi) rotary files offer superior advantages over stainless-steel files due to their superelastic properties, allowing them to regain their original shape after deformation [1-2]. These NiTi files provide numerous benefits, such as preserving the natural geometry of the root canal, preventing the development of abnormalities, and reducing procedural errors compared to hand files [3-4]. The increasing use of endodontic rotary systems necessitates a correct and thorough understanding of their characteristics and limitations [1]. Several rotary systems are currently available on the market. ProTaper Universal (PTU) rotary instruments are constructed from NiTi alloy and come in a range of sizes to accommodate different clinical needs. They have variable taper along the blade, and a triangular cross-section [5]. ProTaper Next (PTN) rotary files are made of NiTi alloy and have an eccentric rectangular cross-section, as well as high flexibility and fracture resistance [4, 6]. Reciproc is a single-file endodontic system manufactured from M-wire [7]. These files exhibit enhanced flexibility and feature a non-cutting tip, an S-shaped cross-section, and sharp cutting edges that form the canal with reciprocal movement [4]. Reciproc Blue (RB) is the advanced type of Reciproc with superior flexibility and high resistance to cyclic fatigue [8]. According to the manufacturer, both Reciproc and RB are effective in cleaning the root canal walls thoroughly and adapt to its anatomical complexities due to their high flexibility. Also, according to the manufacturer, they apply much lower stress to canal walls due to their reciprocal movement, compared with the conventional rotary systems [9-10]. Moreover, some authors have reported higher cleaning efficiency of single-file systems with less damage to canal walls, compared with multi-file systems; furthermore, they save time and cost [4]. Crack formation due to root canal instrumentation with rotary systems is also a common concern [11]. Application of endodontic rotary systems may compromise the integrity of dentin, cause cracks in root dentinal walls [12], decrease the fracture resistance of teeth, and even lead to vertical root fractures necessitating tooth extraction [13]. Longitudinal tooth fractures include a spectrum of defects that extend along the long axis of the tooth and may involve the crown, root, or both. They can occur as a result of occlusal forces, parafunctional habits, trauma, or dental procedures. Based on the extent and location of the defect, longitudinal tooth fractures are commonly classified as craze lines, fractured cusp, cracked tooth, split tooth, and vertical root fracture. Considering the availability of several types of rotary systems in the market, comparison of their characteristics with each other is imperative to find the most efficient system with the lowest rate of complications such as dentinal cracks for a conservative endodontic treatment. Several studies have assessed stress generation in root dentin and micro-crack formation as the result of root canal instrumentation by rotary systems [14-15]. Although several studies have evaluated dentinal defects after root canal preparation with rotary and reciprocating systems, evidence regarding RB remains limited. Previous studies evaluating RB mainly used micro-computed tomography (μCT), whereas many earlier investigations of other systems used stereomicroscopic sectioning. Because differences in assessment methods may affect reported crack frequency, further evaluation using a standardized sectioning model is warranted [16-20]. Therefore, this *in vitro* study aimed to compare the frequency of dentinal cracks after canal preparation with PTU, PTN, Reciproc, and RB using a periodontal ligament simulation model.

Materials and Method

The research protocol received approval from the Ethics Committee of Ardabil University of Medical Sciences (IR.ARUMS.REC.1398.156). Informed consent in a written form was obtained from all participating patients prior to extraction by one of the authors (Fateme Vaseghi), specifying that their teeth could be used for research purposes, and their consent was added to the patients' charts.

This *in vitro*, experimental study was conducted on 75 human mandibular premolars extracted for purposes or reasons unrelated to the research such as orthodontic treatment. The inclusion criterion was single rooted with one canal extracted human mandibular premolars. Teeth exhibiting curved canals, two canals, calcified canals, open apex, internal/external root resorption, and developmental anomalies were excluded.

Based on a previous study by Khoshbin *et al.* [4] the sample size was determined to be 15 teeth per file type, assuming a significance level (alpha) of 0.05, error of 0.15, 95% confidence interval, and frequency of cracks caused by PTU to be 92%.

Seventy-five extracted mandibular premolars were gathered for the study from dental clinics, and thoroughly cleaned to remove any remaining soft tissue, calculus, and debris by a periodontal scaler. The teeth were then inspected macroscopically and radiographically to ensure eligibility criteria. Finally, they were inspected using a stereomicroscope (SZX18, Olympus, Japan) at 25× magnification to confirm no superficial defects. The selected teeth were stored in 0.5% chloramine T solution at 4°C until the experiment to prevent dehydration. For standardization, the teeth were decoronated by a diamond disc at low speed (Isomet, Buchler, Lake Bluff, USA) with water coolant. This step set the remaining root length to 15 mm. All root surfaces underwent a final inspection with a stereomicroscope at 25× magnification to verify that no craze lines or cracks were present.

Pulp tissue was then removed using a barbed broach (Mani Inc., Japan). A #15 K-file (Mani Inc., Japan) was advanced into the canal until its tip was visible at the apex to establish the working length. This length was recorded as 1 mm less than the point of apical visibility.

To simulate the periodontal ligament following method was used. To coat the roots with a 0.2- to 0.3-mm thick wax layer, the teeth were immersed in melted wax up to 2.0 mm below the cementoenamel junction and then allowed to cool. Then roots mounted in auto-polymerizing acrylic resin blocks. Following acrylic resin's polymerization, the teeth wrapped in foil were removed from the acrylic block, the wrapping was removed, and the teeth were dipped in condensation silicone impression wash material (C-Silicone; Speedex, Coltene, Switzerland) and placed back in the acrylic block. The blocks were then immersed in distilled water [10, 18-19].

A random assignment placed the teeth into 5 distinct groups (n=15) of PTU, PTN, Reciproc, RB, and control (no instrumentation). In each group, the teeth were instrumented as instructed by manufacturers. Also, a #25 master apical file was used to standardize apical preparation in all groups.

Root canal instrumentation in PTU group

The root canals instrumentation was performed with P-TU files (Dentsply, Maillefer) as instructed by the manufacturer. For this purpose, coronal flaring was first performed by the SX file, and then the canals were instrumented with S1 and S2 files passively. Shaping was then performed with F1 and F2 files. An endo-motor (V-DW, Reciproc Silver, Germany) operating at 300rpm was used for SX, S1 and S2 files with 3N/cm torque, for F1 with 1.5N/cm torque, and for F2 with 2N/cm torque.

Root canal instrumentation PTN group

The teeth were instrumented with PTN (Dentsply, Maillefer) as instructed by the manufacturer. X1 followed by X2 files were operated using an endo-motor (VDW, Reciproc Silver, Germany) operating at 300 rpm with a torque setting of 3 N/cm.

Root canal instrumentation Reciproc and RB groups

The teeth preparation with Reciproc (VDW, Munich, Germany) and RB (VDW, Munich, Germany) files was done as instructed by the manufacturer. The R25 file was used to prepare root canals in both groups. The endo-motor (VDW, Reciproc Silver, Germany) was put on the Reciprocation mode to adjust the speed and torque automatically.

In all groups, a K-file (#10) (Mani Inc., Japan) was utilized to ensure patency following using each file. Also, root canal irrigation with full strength NaOCl was performed after using each file in all groups.

Following root canal preparation, a diamond saw with water coolant was used to section all roots perpendicular to their longitudinal axis, creating sections at 3, 6, and 9mm from the apex. Each section was then photographed and evaluated using a stereomicroscope (SZX18, Olympus, Japan) with 25× magnification (Figures 1-5).

Each photograph was inspected by two endodontists

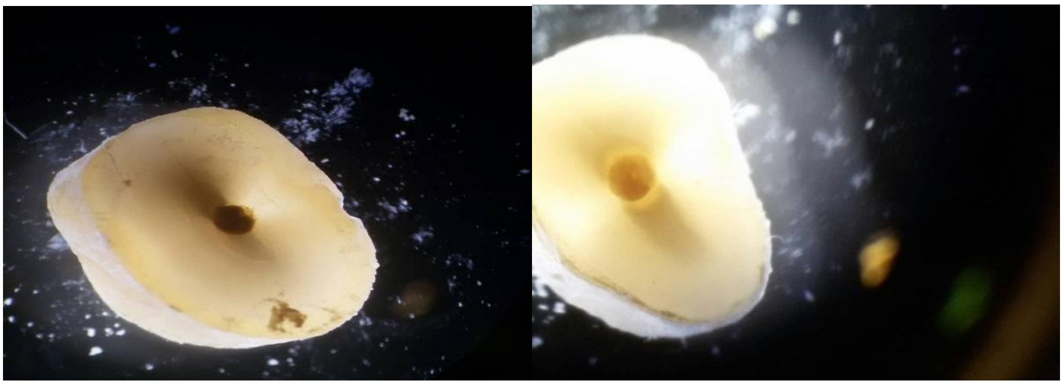

Figure 1: A representative specimen instrumented with ProTaper Universal under a stereomicroscope at 25× magnification: (left) a specimen with crack; (right) a specimen without crack

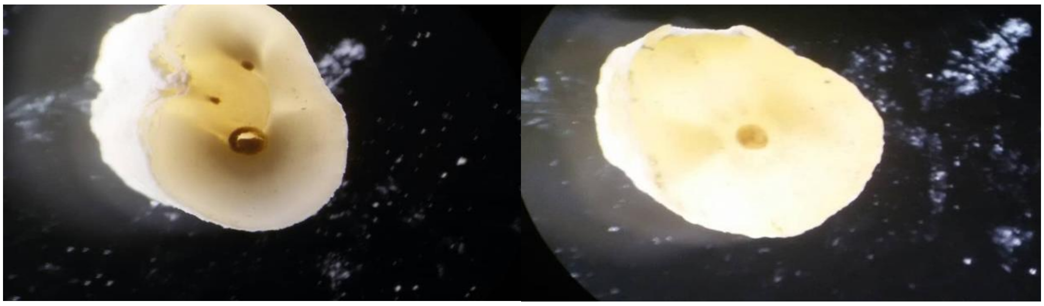

Figure 2: A representative specimen instrumented with ProTaper Next under a stereomicroscope at 25× magnification: (left) a specimen with crack; (right) a specimen without crack

in terms of presence of dentinal cracks, and categorized into three groups (based on the type of defect) as (I) No defect/crack, (II) A fracture, characterized by a crack running from the root canal surface entirely through to the outer root surface, and (III) Defected canals were characterized by incomplete cracks or crack lines originating from the canal but not extending to the outer surface.

The frequency of cracks caused by each rotary system was calculated and reported. Intra-examiner reliability was confirmed by re-evaluating a random 25% of the images 10 days after their primary assessment. Cohen's Kappa indicated perfect agreement (Kappa=1) between the two evaluations.

SPSS version 23 (SPSS Inc., IL, USA) was used for data analysis. Statistical significance was determined using the Chi-square test and Monte Carlo test at $p < 0.05$.

Results

The frequency distribution of dentinal cracks within each of the five groups, measured at 3, 6, and 9mm from the apex, is shown in Table 1. As demonstrated, the PTU group displayed the most dentinal cracks, with the highest frequencies occurring at 6mm and 9mm from the apex. Conversely, Reciproc and RB groups had the fewest cracks at the 3mm mark. A clear pattern emerged where crack frequency diminished moving from the coronal to the apical area. The control group showed no cracks at any of the measured apical distances.

These data demonstrated that all rotary files caused dentinal cracks and all cracks were incomplete.

Comparison of the four rotary files regarding the frequency of dentinal cracks at 3, 6, and 9 mm from the apex showed no significant difference (p Value > 0.05, Chi-square test). The frequency of cracked sections in the PTU, PTN, Reciproc, and RB groups was 19/45, 15/45, 8/45, and 5/45, respectively, and this difference was statistically significant (p Value < 0.05, Chi-square test with Monte Carlo correction). No other statistically significant differences were found among the groups (Table 2).

Discussion

RB is a recently developed NiTi file that undergoes a specialized heat treatment, resulting in a visible blue oxide layer on its surface [21]. Its design resembles the M-Wire Reciproc file, but studies have shown that RB exhibits higher resistance to cyclic fatigue and improved flexibility compared to the M-Wire Reciproc [22–24]. However, there is limited data available regarding the formation of cracks in the root canal system when using

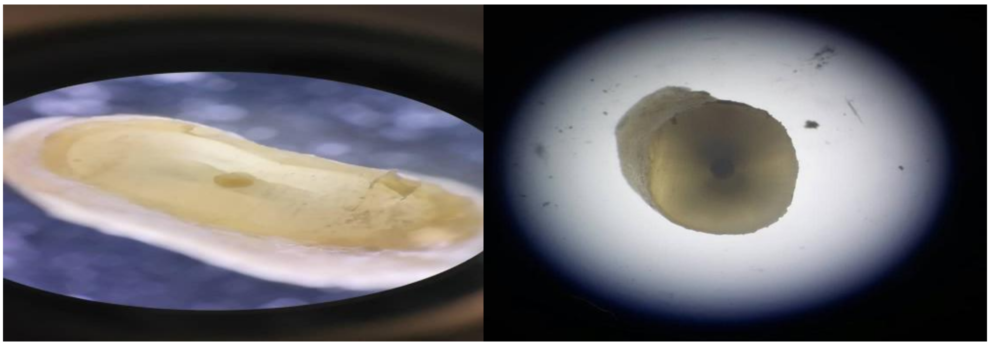

Figure 3: A representative specimen instrumented with Reciproc Blue under a stereomicroscope at 25× magnification: (left) a specimen with crack; (right) a specimen without crack

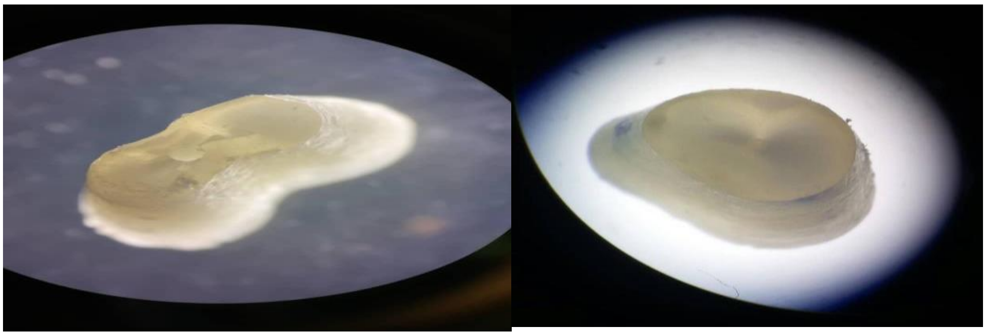

Figure 4: A representative specimen instrumented with Reciproc under a stereomicroscope at 25× magnification: (left) a specimen with crack; (right) a specimen without crack

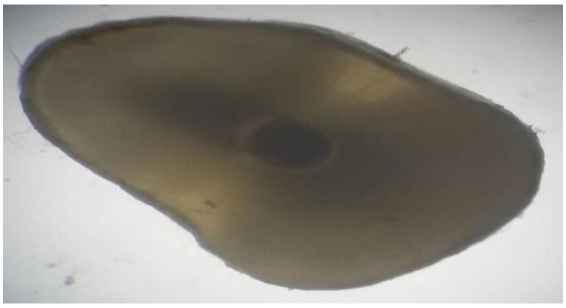

Figure 5: A representative specimen (3mm from the apex) of the control group under a stereomicroscope at 25× magnification

RB files. Our *in vitro* research focused on evaluating and comparing the occurrence of dentinal cracks caused by root canal preparation using PTU, PTN, Reciproc, and RB, utilizing a standard model for simulating the periodontal ligament.

Table 1: Frequency distribution of dentinal cracks in the five groups at 3, 6, and 9mm from the apex

		3mm	6mm	9mm	*p* Value
PTU	No defect	11	7	8	0.306*
	Cracked	4	8	7	
PTN	No defect	10	10	10	1.000*
	Cracked	5	5	5	
Reciproc	No defect	14	11	12	0.495**
	Cracked	1	4	3	
RB	No defect	14	13	13	1.000**
	Cracked	1	2	2	
Total	No defect	49	41	43	0.224*
	Cracked	11	19	17	

*Pearson Chi-Square; ** Monte Carlo; PTU = ProTaper Universal; PTN= ProTaper Next; RB = Reciproc Blue

The control group in this study showed no crack formation, which is consistent with similar previous studies [25–27]. This not only confirms that no cracks were introduced during the cutting process and that the pre-experiment evaluation of cracks was accurate but also indicates that the cracks were a result of the instrumentation process.

Although a recent critical analysis of research methods suggested that dentinal microcracks in extracted teeth might be an artifact of laboratory settings due to dehydration and storage conditions, and should not be considered as the starting point for vertical root fractures [28], different studies have shown that both hand NiTi and stainless steel K-files, along with the control groups, resulted in no microcracks at any root canal level, highlighting the role of rotary instruments in this side effect [29-30].

The frequency of cracked sections in the PTU, PTN, Reciproc, and RB groups was 19/45, 15/45, 8/45, and 5/45, respectively, and this difference proved statistically significant ($p< 0.05$). PTU resulted in the highest number of cracks at 9- and 6-mm levels, while Reciproc and RB yielded the lowest frequency of cracks at 3mm.

Several potential factors might contribute to these differences, including variations in taper, flexibility, cross-sectional design, manufacturing technology, and other characteristics of the files [4]. Differences in alloy

Table 2: Frequency of cracked sections in different root levels and overall according to the examined groups

		Protaper universal	Protaper next	Reciproc	Reciproc blue	*p* Value
3 mm	No defect	11	10	14	14	0.181**
	Cracked	4	5	1	1	
6 mm	No defect	7	10	11	13	0.123*
	Cracked	8	5	4	2	
9 mm	No defect	8	10	12	13	0.184*
	Cracked	7	5	3	2	
Total	No defect	26	30	37	40	0.003*
	Cracked	19	15	8	5	

* Pearson Chi-Square; ** Monte Carlo

composition and heat treatment (such as the M-wire technology used in PTN, Reciproc, and RB) increase instrument flexibility compared with conventional NiTi, which may help explain the lower crack frequencies observed with these systems, possibly by reducing the pressure transmitted to the dentinal walls [31]. Several previous studies have also reported a lower frequency of dentinal cracks during root canal instrumentation with rotary files fabricated using M-wire technology compared to conventional rotary files [32-33].

However, factors other than design, such as the motion of the instrument and the number of instruments, may be more important. An interesting study [34] compared a single reciprocating file system (WaveOne) utilizing M-wire with PTU F-2 file made of conventional NiTi alloy, both used in a single-file reciprocating motion, and found no statistically significant difference. However, cracks were significantly fewer compared to the full sequence of PTU in continuous rotary motion with the same apical enlargement size. Given that only motion kinematics differed among these groups, it implies that reciprocating motion is milder and results in less dentinal harm [34]. Our findings were consistent with their results.

Each file system evaluated in this study led to the formation of dentinal cracks, a result that reflects similar trends observed in prior *in vitro* research on root canal preparation [15, 26]. However, continuous rotational motion generates elevated stress levels on the root canal walls, which can contribute to the development of dentinal cracks [35]. Reciprocating motion has demonstrated improved centering ability within the root canal [36].Moreover, the alternating clockwise and counterclockwise movements in reciprocating motion enable the file to disengage repeatedly from the canal walls, preventing it from binding during the cutting and shaping process [37].Furthermore, flexural and torsional stresses on the dentin are minimized as the counterclockwise motion of reciprocating systems helps to release the instrument blades, thereby decreasing the overall mechanical strain [35].

The results of our study might also be due to the number of files used, as studies have shown that increased instrumentation within the canal may lead to a cumulative buildup of structural damage in the dentin [38-39]. Moreover, it should be noted that in most single-file systems, files possess a convex triangular cross-section near the coronal portion and, a tip with modified convex triangular design improving their flexibility [40]. However, more well-controlled studies are needed to confirm this conclusion.

The findings also indicated that there was no significant difference in crack frequency at various levels from the apex, but this frequency increased from apical to coronal sections. PTU resulted in the highest frequency at 9 and 6mm, while Reciproc and RB yielded the lowest frequency at 3 mm. Previous reports have indicated that during the instrumentation process, the stresses generated at 1 mm short of the apical foramen were merely one-third of the stress at more coronal levels [29]. This may also be due to an increase in the taper of various files towards the coronal third [29, 41]. However, a recent meta-analysis found insufficient evidence to confirm whether variations in taper significantly influence root fracture resistance. Furthermore, there is a lack of randomized controlled trials with extended follow-up periods addressing this issue [42].

Aksoy *et al.* [17] suggested that new microcrack formation might not be associated with RB systems. The contrasting findings between the study by Aksoy *et al.* [17] and our study can be attributed to the limitations of μCT imaging. While Aksoy *et al.* [17] concluded that the RB system may not induce new dentinal microcracks in the mesial roots of mandibular molars; our study demonstrated the occurrence of dentinal cracks after using the RB system.

Other than the tooth type differences, one potential factor contributing to this discrepancy is the moisture content of the samples, which affect the visibility of dentinal microcracks in μCT imaging, potentially causing false-negative findings and underestimating the true incidence of cracks [43]. Additionally, artifacts arising from improper scanning and reconstruction parameters can significantly degrade image quality, making it difficult to accurately detect microcracks [28].

On the other hand, the high stress level caused by sectioning process might be the reason of higher incidence but if this was the reason there should be some cracks in control group too.

In contrast to μCT-based studies on rotary and reciprocating instrumentation that reported fewer or no new cracks, the present stereomicroscopic sectioning study demonstrated a measurable incidence of dentinal defects after instrumentation. Importantly, no cracks were detected in the control group, indicating that our sectioning protocol under water cooling did not introduce detectable defects and suggesting that, under these conditions, sectioning per se was not a source of microcrack artifacts.

Other than differences in tooth type, one potential explanation for the discrepancy is that microcrack detection in μCT depends heavily on voxel size, reconstruction parameters, and specimen hydration, which may reduce the visibility of fine defects and lead to underestimation of the true incidence of cracks. Moisture content profoundly influences microcrack detection as hydrated specimens reveal significantly fewer cracks than dried specimens, with detection increasing progressively as drying time extends from 2 to 24 hours [44]. This occurs because dehydration induces complex, inhomogeneous shrinkage and deformation of dentin, opening existing cracks above the resolution threshold of CT scanners, while rehydration can partially reverse this deformation and close some cracks below the detection limit [43]. Thus, divergences between μCT -based and sectioning studies should be interpreted in light of these methodological differences rather than being attributed solely to crack formation caused by the sectioning process itself. Comparative work has also shown that stereomicroscopy can detect a slightly higher proportion of defects than μCT, whereas scanning electron microscopy reveals even higher percentages (45.8% vs. 43.9%), underscoring the impact of the chosen detection method on reported defect rates [45].

Under the conditions of this study, reciprocating motion, single-file instrumentation, and M-wire or heat-treated alloy technology may have contributed to the lower frequency of dentinal cracks observed with Reciproc and RB. Nevertheless, since this study was conducted *in vitro*, caution is needed when applying the results to clinical practice. Simulating the periodontal ligament is essential in studies examining the impact of applied forces on crack development or fracture resistance [19]. As the periodontal ligament cannot be completely replicated in *in vitro* studies, further clinical research is needed to verify the present findings.

In line with recent methodological analyses, future research should aim to establish a standardized protocol for evaluating dentinal crack formation that combines high-resolution pre- and post-intervention μCT scanning with rigorous experimental controls on fresh cadaver models, followed by sectioning under controlled conditions when appropriate to validate imaging findings and minimize artifacts related to dehydration and sample handling. In addition, the incidence of cracks following various root canal obturation techniques should also be examined.

Conclusion

Considering the constraints of this study, the results demonstrated that all the tested rotary systems caused dentinal cracks. PTU yielded the highest and RB yielded the lowest number of dentinal cracks. RB appears to be a favorable alternative to the other rotary systems.

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None

Availability of data

The data used to support the findings of this study were supplied by the corresponding author under license, and the data will be available upon request. Requests for access to this data should be made to the corresponding author within 12 months of publication.

Authors' contributions

Study concept and design: R. F. and S. G.

Acquisition of data: F. V. and S. G.

Analysis and interpretation of data: K. N.

Drafting of the manuscript: S. N., A. N., and K. N.

Critical revision of the manuscript for important intellectual content: A. N. and R. F.

Study supervision: A. N., R. F.

Final review of the manuscript: A. N., R. F., S. G., F. V., S. N., and K. N.

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Conflicts of Interest

The authors declared that there is no conflict of interest regarding the publication of this paper.

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