Original paper

Micro-computed tomography evaluation of dentinal cracks after root canal preparation with different endodontic rotary files: An ex vivo study

Mohammed Mana Alzamanan[1,A–F], Abdullah Abdulrahman Albassam[2,A–F], Emad Mahmoud Khattab[2,A–F], Faisal Turki Alghamdi[3,B–F]

[1] Department of Endodontics, Najran Specialized Dental Center, Ministry of Health, Saudi Arabia
[2] Department of Endodontics, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia
[3] Department of Oral Biology, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia

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Address for correspondence
Mohammed Mana Alzamanan
E-mail: Dr.m.alzamanan@gmail.com

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Abstract

Background. The occurrence of dentinal cracks is rather frequent during root canal preparation and increases with some endodontic file systems. There have been few ex vivo studies on the incidence of the formation of microcracks after root canal preparation, using the micro-computed tomography (micro-CT) analysis.

Objectives. The aim of the present study was to compare the incidence of dentinal cracks after using the XP-endo® Shaper, TRUShape®, ProTaper Next™ (PTN), and ProTaper Universal™ (PTU) instruments in the preparation of mandibular premolar teeth with oval canals, using the micro-CT evaluation method.

Material and methods. Thirty-six extracted human mandibular premolars with single oval root canals were distributed randomly to 4 experimental groups ($n = 9$) for root canal preparation: group 1 – XP-endo Shaper; group 2 – TRUShape; group 3 – PTN; and group 4 – PTU. The teeth were scanned using micro-CT with high resolution, before and after mechanical root preparation. Then, the cross-sectional images of pre- and post-scanning were visualized simultaneously to detect new dentinal cracks. The number of dentinal cracks was determined as percentage for each group, and the results were statistically analyzed using the Wilcoxon signed rank test and the Kruskal–Wallis test.

Results. A total of 49,628 cross-sectional images were obtained from pre- and post-scanning with micro-CT. Dentinal cracks were observed in 11,223 (22.6%) of the images. No new dentinal cracks were formed after using XP-endo Shaper, TRUShape or PTN. New dentinal cracks were found in the PTU group, and the difference between the percentages of the pre- and post-preparation dentinal cracks was statistically significant (37.6% vs. 62.4%) ($p = 0.008$).

Conclusions. The use of the heat-treated nickel-titanium (NiTi) files (XP-endo Shaper, TRUShape, PTN) did not lead to the formation of new dentinal cracks. New dentinal cracks were formed while using the traditional NiTi file (PTU) only. Future studies are required to investigate the association between the formation of dentinal cracks and new endodontic file systems.

Keywords: root canal preparation, micro-computed tomography, dentinal microcracks, heat-treated nickel-titanium files, nickel-titanium file system

Highlights

- Different types of files cause varying levels of dentinal cracks during preparation.
- Micro-CT effectively detects dentinal cracks before and after tooth preparation.
- Heat-treated NiTi files (XP-endo, TRUShape, ProTaper Next) prevent the formation of new dentinal cracks.
- Traditional NiTi files (ProTaper Universal) lead to the formation of new dentinal cracks.

Introduction

Non-surgical root canal treatment (NSRCT) is a highly successful procedure, with significant chances to offer a favorable outcome.[1] Root canal preparation and chemical cleaning with the use of irrigants are the main steps in the endodontic treatment to control the success in NSRCT.[2] The main goal of root canal preparation is shaping the canal lumen, taking into consideration the original canal anatomy, to facilitate disinfection and decrease the count of microorganisms during endodontic therapy.[3] Byström and Sundqvist showed that instrumentation with saline irrigation reduced bacterial counts by 100–1,000 times.[4]

Nickel-titanium (NiTi) rotary instruments were introduced to the practice of endodontics by Walia et al. in 1988.[acc.5] In comparison with stainless-steel files, NiTi rotary instruments facilitate the mechanical preparation of root canals while respecting the canal anatomy.[6] The super-elasticity and shape memory of NiTi result from its transition from the austenite (A) to martensite (M) phases under mechanical stress and temperature changes.[7] Recent technological advancements in the mechanical properties of rotary NiTi instruments and their thermal treatment have introduced a new concept of a faster, easier and better shaping ability for root canals. Currently, new rotary instruments with asymmetrical movement inside the root canal are offered. These files have a three dimension (3D)-conforming design with an S-shape, e.g., TRUShape® (Dentsply Sirona, Tulsa, USA), others have off-centered geometry, like ProTaper Next™ (PTN) (Dentsply Maillefer, Ballaigues, Switzerland).[6,7]

The XP-endo Shaper file has been recently introduced as a single-file rotation tool with a unique design using Max-Wire (FKG Dentaire, La Chaux-de-Fonds, Switzerland). This 3D-conforming file demonstrates a higher flexibility and a greater fatigue resistance, with more dentin surface touched and less dentinal stress as compared to regular NiTi instruments.[8,9] As the manufacturer claims, the file has the ability to start shaping the canal at ISO diameter 15 until it achieves ISO diameter 30, and to increase the initial taper of 0.01 at the M phase through expanding inside the canal at body temperature up to 0.04 at the A phase, with the final preparation (30/.04). The XP-endo Shaper file is snake-shaped, with a triangular cross-section and the so called booster tip (BT) of unique geometry with 6 cutting edges, which makes canal shaping faster and easier.[10]

Some studies have found that patients with dental abnormalities are more predisposed to dental cracks in their incisor or molar teeth due to abnormal mineralization, often associated with syndromes or general disorders, such as oral-facial-digital syndrome (OFD)[11,12] or coronoid process hypertrophy (CPH).[13]

Initially, hand files were widely utilized for the root canal instrumentation of deciduous teeth and young permanent teeth.[14] Most hand files can cause microcracks in the root dentin, making it more susceptible to vertical root fractures, more often in deciduous teeth than permanent teeth, due to the intrinsic hardness of metal, which is exacerbated by the design of the instrument and the root canal morphology. When stainless-steel hand files are used in narrow curved canals, they tend to limit apical expansion, making obturation more difficult in child patients' deciduous teeth with open or closed apexes as compared to permanent teeth.[15,16] To overcome the challenges associated with using stainless-steel tools, NiTi instruments were developed for curved canals, with the intention not to induce aberrations.[14] A study by Barr et al. was the first investigation on the use of NiTi rotary files in the root canals of deciduous teeth.[17] A recently published study by Panda et al. compared the dentinal cracks which occurred in the extracted deciduous teeth after root canal preparation with hand and rotary files, and the self-adjusting file (SAF) technology.[18] The authors concluded that there were significant differences between the 3 instruments with regard to the formation of dentinal cracks.[18]

Cracked teeth can lead to complications, especially if left untreated. For example, in some advanced cases, infections may occur. The signs of infection involve increasing discomfort/pain,[19] hypersensitivity to heat/cold[20] and bad oral hygiene.[21] Some authors recommend a mouthwash for child patients with cracked teeth or oral thrush to enhance their oral hygiene.[22,23] Diagnosing cracked teeth has proven difficult for dentists, and is a cause of concern for both the dentist and the patient. Discomfort or pain might be improperly identified as the signs of other disorders, such as sinusitis, temporomandibular joint (TMJ) problems, headaches, ear pain, or unusual orofacial pain.[24–26]

During preparation with different NiTi files, dentinal cracks may appear as a result of stress on the dentin.[27]

These dentinal cracks can damage the root dentin and extend as vertical root fractures with unfavorable prognosis, possibly leading to tooth extraction.[28,29] Different methods can be used to evaluate dentinal cracks inside the teeth, including the sectioning methods[27,28,30–32] or the non-destructive method of micro-computed tomography (micro-CT).[33–36] The latter method offers better identification of cracks and prevents cracks that may be induced by applying the sectioning method.

In their study, Bayram et al. compared the incidence of cracks after the preparation of extracted mandibular molar teeth with the use of the XP-endo Shaper, SAF and ProTaper Gold™ files.[37] They found that none of the systems induced dentinal cracks.[37] Most of the studies compared the incidence of dentinal cracks in curved canals by micro-CT.[33,34] A recent review discussed the number of dentinal cracks when using different file systems and evaluation methods.[38] Three out of the 9 included micro-CT studies reported that new dentinal cracks were induced after root canal preparation with rotary file systems. This review confirmed that the number of dentinal cracks observed after root canal preparation varies, depending on the file system techniques and the assessment methodologies employed.[38]

No previous studies compared the incidence of dentinal cracks after using 3D-conforming files, such as XP-endo Shaper or TRUShape, in oval canals. Therefore, the aim of the present study was to compare the incidence of dentinal cracks after using the XP-endo Shaper, TRUShape, PTN, and ProTaper Universal™ (PTU) instruments in the preparation of oval canals, using micro-CT. The null hypothesis was that there would be no statistically significant differences between the experimental groups in terms of formation of dentinal cracks. The PTU file was considered as a reference for the regular design of NiTi files (the control group).

Material and methods

Sample selection

Freshly extracted, sound human permanent mandibular premolar teeth with single roots and oval canals, obtained from the Oral Surgery Clinic at the Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia, were selected for the experiment. The teeth were extracted for different reasons, not related to this study, and stored in a special solution (0.1% thymol solution) at 4°C for 1 week before the commencement of the experiment.

Initially, 50 mandibular premolars were collected. The teeth were examined under a stereomicroscope (EMZ-13TRD; Meiji Techno, Miyoshi, Japan) under ×12 magnification. The exclusion criteria comprised any teeth with the evidence of previous cracks or fracture along the root surface. The further evaluation of the teeth was performed using a digital radiograph from buccolingual and mesiodistal projections. The inclusion criteria were teeth with single oval root canals (<5°) with mature apices, and no evidence of internal resorption or calcification. The authors achieved a power of 0.92 with an alpha (α) level of 0.05 and a confidence level of 95%; a sample size of 36 was considered for the total sample.

Production of a mounting device

A mounting device or tube was fabricated to facilitate the positioning of the teeth inside the micro-CT equipment. It was a custom-made plastic tube with impression material for each tooth of the sample. After rinsing each tooth with tap water and drying it with gauze, polyvinylsiloxane (PVS) putty (Zhermack, Badia Polesine, Italy) was mixed according the manufacturer's recommendation. Then, the putty was placed inside the plastic tube and the subsequent selected tooth was submerged in the putty before the impression material was set. The tooth was inserted up to the level of or below the cementoenamel junction (CEJ) approximately.

Pre-root canal preparation scanning by micro-CT

Each tooth in the sample was pre-operatively scanned with the use of a micro-CT unit (SkyScan 1272; Bruker, Kontich, Belgium). The teeth were selected sequentially from the container box, dried gently with gauze and placed in their corresponding mounting tubes. The mounting tube was placed inside the Micro-CT unit. The scanning of the teeth was set at 100 kV and 100 µA with high resolution (15 µm). The rotational step was set at 0.6°, with a rotation of 360° around the vertical axis, 2,650-millisecond exposure time and the frame averaging of 3.

The SkyScan NRecon software, v. 1694 (Bruker), was used for the reconstruction of the images after tooth scanning with micro-CT. During image reconstruction, a 40% beam hardening correction, frame averaging and the reduction of ring artifacts were modified individually to the optimal value for each tooth in the sample. The field of interest was extended from CEJ up to the root apex for each tooth. Subsequently, a total of 600–800 axial cross-sectional images or slices were obtained for each tooth. After scanning, the teeth were placed back in the thymol solution at 4°C in a special box prior to mechanical instrumentation in the next step.[39]

Access cavity and the working length

For each tooth in the sample, a conventional endodontic access cavity was done, with a cross-section of an oval shape from the occlusal view. The access cavity was done using a high-speed round carbide bur (557 bur; Brasseler, Savannah, USA) and a high-speed air-driven handpiece

(KaVo North America, Charlotte, USA) under water cooling. Then, a K file #10 (Dentsply Maillefer) was inserted until it exited the canal and became visible to confirm the patency of the canal. If the root canal was not patent, the tooth was excluded from the study.

The working length (WL) was determined for each tooth by subtracting 1 mm from the length of the K file #10 in the major apical foramen.[40] The rubber stopper was used for the file in a stable reference point (the cusp tip). After the file was removed from the canal, WL was recorded. In order to remove the tissue and debris from the pulp chamber and the canal space, each tooth was filled with 3 mL of 3% NaOCl solution activated through passive ultrasonic irrigation (PUI) for 5 min, using a 27-gauge side-vented needle (Vista Apex Dental Products, Racine, USA). Then, the solution was suctioned using a high-suction tube in the dental unit. After irrigation with NaOCl, the saline solution was used in the same amount of 3 mL and the canals were left moistened to prevent any desiccation. All teeth were returned to the container box until the next step of root canal preparation.

Sample randomization

Thirty-six mandibular premolars were collected and randomly allocated to 4 experimental groups (n = 9 each) as follows:
– group 1: XP-endo Shaper (a triangular cross-section, MaxWire) (FKG Dentaire, La Chaux-de-Fonds, Switzerland);
– group 2: TRUShape (a triangular cross-section, heat-treated wire) (Dentsply Sirona, Tulsa, USA);
– group 3: ProTaper Next – PTN (a rectangular cross-section, M-wire) (Dentsply Maillefer, Ballaigues, Switzerland); and
– group 4: ProTaper Universal – PTU (conventional NiTi wire) (Dentsply Maillefer).

In all 4 groups, tooth preparation was done using the Dentsply X-Smart Plus EndoMotor engine (Dentsply Maillefer).[10] In addition, the preparation time was calculated for each group. The whole experiment was done by one operator (M.M.A.), and for each tooth in the experiment, a separate rotary file was used.

Root canal preparation and irrigation protocol

Group 1: XP-endo Shaper system

The sample teeth in this group were sequentially selected from the container box and dried gently with gauze for root canal preparation. At first, a glide path for the canal was created using a K file #15 (Dentsply Maillefer), and then irrigation with 1 mL of 3% NaOCl solution was performed. The XP-endo Shaper file was used to its full WL with the final preparation (30/.04), with a speed of 800 rpm and a torque of 1 N·m, as recommended by the manufacturer. First, the file tip was inserted until resistance was felt, and then the file was adapted in the motor and started the preparation of the canal. For each canal, 5 long gentle strokes were progressed to WL, without forcing the file or using the pecking motion. Once WL was reached, another 15 strokes to WL were done with the file, as recommended by the manufacturer.[10]

Group 2: TRUShape system

The sample teeth in this group were sequentially selected from the container box and dried gently with gauze for root canal preparation. At first, a glide path for the canal was created using a K file #15 (Dentsply Maillefer), and then irrigation with 1 mL of 3% NaOCl solution was performed. Then, the TRUShape file was used with a gentle in-and-out motion at a speed of 300 rpm and a torque of 3 N·m, as recommended by the manufacturer. The preparation of the canal was done by sequential enlargement toward WL, starting with size 20/.06, followed by sizes 25/.06 and 30/.06 in the full length of the canal (WL). The manner of canal preparation with the TRUShape file was the in-and-out passive motion with light apical pressure in an amplitude of 2–3 mm, without using the pecking motion while advancing toward WL.[41]

Group 3: PTN system

The sample teeth in this group were sequentially selected from the container box and dried gently with gauze for root canal preparation. At first, a glide path for the canal was created using a K file #15 (Dentsply Maillefer), and then irrigation with 1 mL of 3% NaOCl solution was performed. Then, each root canal was prepared with PTN with a gentle in-and-out motion at a speed of 300 rpm and a torque of 2 N·m, as recommended by the manufacturer. The preparation of the canal was done by sequential enlargement toward WL, starting with the X1 (17/.04) file, followed by the X2 (25/.06) and X3 (30/.07) files up to WL. The manner of canal preparation with PTN was a gentle in-and-out brushing motion against the canal.[42]

Group 4: PTU system

The sample teeth in this group were sequentially selected from the container box and dried gently with gauze for root canal preparation. At first, a glide path for the canal was created using a K file #15 (Dentsply Maillefer), and then irrigation with 1 mL of 3% NaOCl solution was performed. Subsequently, the enlargement of the coronal orifice and the preparation of ⅔ of WL was done using the SX instrument, followed by irrigation with 2 mL of 3% NaOCl solution. Thereafter, shaping files S1 (tip size 17) and S2 (tip size 20) were used for the preparation of WL. Full WL was prepared with finishing files F1 (20/.07), F2 (25/.08) and F3 (30/.09). The preparation manner involved using the crown-down technique for the PTU instruments at a speed of 300 rpm and a torque of 2 N·m, as recommended by the manufacturer. Shaping files SX, S1 and S2 were used with a brushing motion, while the finishing files (F1–F3) were used with a gentle in-and-out motion until the instrument reached WL.[43]

In each of the tested groups, the irrigation of the canals during instrumentation was performed using 2 mL of NaOCl activated through PUI for 5 min, using a 27-gauge side-vented needle, followed by 2 mL of the saline solution to remove the debris left after preparation. Then, each tooth in all the 4 tested groups was dried using an absorbent paper point (Meta Biomed, Colmar, USA) before rescanning with the use of the micro-CT device in the next step.

Post-root canal preparation scanning by micro-CT

Following mechanical preparation, all teeth from the 4 groups were placed in the corresponding mounting tubes for post-scanning with the micro-CT device. The scanning of the teeth was set at same parameters as before: 100 kV and 100 μA with high resolution (15 μm), the rotational step was set at 0.6°, with a rotation of 360° around the vertical axis, 2,650-millisecond exposure time and the frame averaging of 3.

The NRecon software was used for the reconstruction of the images after tooth scanning with micro-CT. During image reconstruction, a 40% beam hardening correction, frame averaging and the reduction of ring artifacts were modified individually to the optimal value for each tooth in the sample. The field of interest was extended from CEJ up to the root apex for each tooth. Subsequently, a total of 600–800 axial, cross-sectional images or slices were obtained for each tooth.

Evaluation of dentinal microcracks

After the reconstruction of all cross-sectional images, they were transferred to the SkyScan DataViewer program, v. 1524 (Bruker), using 3D imaging. A total of 49,628 cross-sectional images were obtained from pre- and post-scanning, with the area of interest extending from CEJ up to the apical foramen. All the cross-sectional images of the teeth before and after mechanical root canal preparation were evaluated.

Both the pre- and post-root canal preparation images were opened simultaneously by the DataViewer program and evaluated for the presence of microcracks. First, the post-root canal preparation cross-sectional image was evaluated for the presence of cracks, and then the pre-root canal preparation image was checked for the presence or absence of the same cracks. Any cross-sectional images with at least one microcrack were identified and marked.

Any new crack, craze line or propagated crack extending from the internal or external surface of the canal was defined as 'defect or cracks', while 'no defect' meant the absence of any crack or craze line in the micro-CT image.[30] Each sample was then checked for the presence of dentinal cracks. Two examiners, blinded to the micro-CT analysis, separately reviewed the samples. The Pearson correlation coefficient (PCC) was employed to determine agreement between the 2 examiners for dentinal crack findings, and it amounted to 0.942. For the observation of dentinal cracks, there was a significant positive correlation between the 2 examiners.

Assessment of the time required for root canal preparation

The operator performing the experiment used a digital timer to record the time required for root canal preparation. The beginning point was the first insertion of the file into the canal, and the end point was the completion of the final irrigation with distilled water. The time spent on changing the instruments was not taken into consideration.

Statistical analysis

The PCC was used to determine the agreement between the 2 examiners for dentinal crack observation. The total number of cracks per tooth was reported as percentage, and recorded in the Microsoft Excel sheet (Microsoft Corporation, Redmond, USA). Each tooth in all the 4 tested groups, with the related pre-and post-scanning images, was divided to 3 levels with regard to the root part: coronal; middle; and apical. The data for each sample was analyzed using IBM SPSS Statistics for Windows, v. 20.0 (IBM Corp., Armonk, USA).

The Wilcoxon signed ranks test (a non-parametric test) was used to determine statistically significant differences between the pre- and post-preparation cross-sectional images within all rotary system groups. The Kruskal–Wallis test (a non-parametric test) was used to explore statistically significant differences between the pre- and post-preparation cross-sectional images across the 4 groups, and to explore significant differences between the pre- and post-preparation cross-sectional images among the 3 root levels (coronal, middle and apical). The level of significance was set at $p < 0.05$.

Results

Percentages of dentinal cracks

Among the 49,628 pre- and post-root canal preparation images obtained, dentinal cracks were found in 22.6% ($n = 11{,}223$) of them. In the XP-endo Shaper group, 18.5% ($n = 2{,}076$ out of 11,223) of the pre -and post-preparation images showed dentinal cracks. In the TRUShape group, it was 24.7% (n = 2,774 out of 11,223), in the PTN group – 26.8% (n = 3,006 out of 11,223), and in the PTU group – 30.0% (n = 3,364 out of 11,223).

Regarding the occurrence of new cracks, the dentinal cracks which were observed in the post-preparation cross-sectional images were already present in the corresponding pre-preparation images with the same directions and extension in 3 groups – XP-endo Shaper, TrueShape and PTN. Thus, no new dentinal cracks were formed after preparation with these 3 tested file systems (Fig. 1). On the other hand, postoperative dentinal cracks were observed in 2,100 out of 3,364 cross-sectional images (62.4%) as compared to the corresponding preoperative dentinal cracks in 1,264 out of 3,364 cross-sectional images (37.6%) in the PTU group. Thus, new dentinal cracks were formed after preparation with the PTU system only (Fig. 1).

Statistical evaluation of dentinal cracks

The Wilcoxon signed ranks test showed a statistically significant difference only in the PTU group between the percentages of the pre-preparation dentinal cracks and post-preparation dentinal cracks (37.6% vs. 62.4%) (p = 0.008), whereas the other 3 groups presented the same numbers and percentages of dentinal cracks pre- and post-preparation, with no new dentinal cracks formed: the XP-endo Shaper group (n = 2,076) – 1,038 pre-preparation vs. 1,038 post-preparation (p = 1.000); the TrueShape group (n = 2,774) – 1,387 pre-preparation vs. 1,387 post-preparation (p = 1.000); and the PTN group (n = 3,006) – 1,503 pre-preparation vs. 1,503 post-preparation (p = 1.000).

The Kruskal–Wallis test showed statistically significant differences between different groups (XP-endo Shaper, TrueShape, PTN, and PTU) in the mean rank of dentinal cracks pre-preparation (p = 0.000) and post-preparation (p = 0.000) (Table 1). However, no statistically significant differences were found in the mean rank of dentinal cracks, either pre-preparation (p = 0.170) or post-preparation (p = 0.325), across the 3 root levels (coronal, middle and apical) according to the Kruskal–Wallis test (Fig. 2).

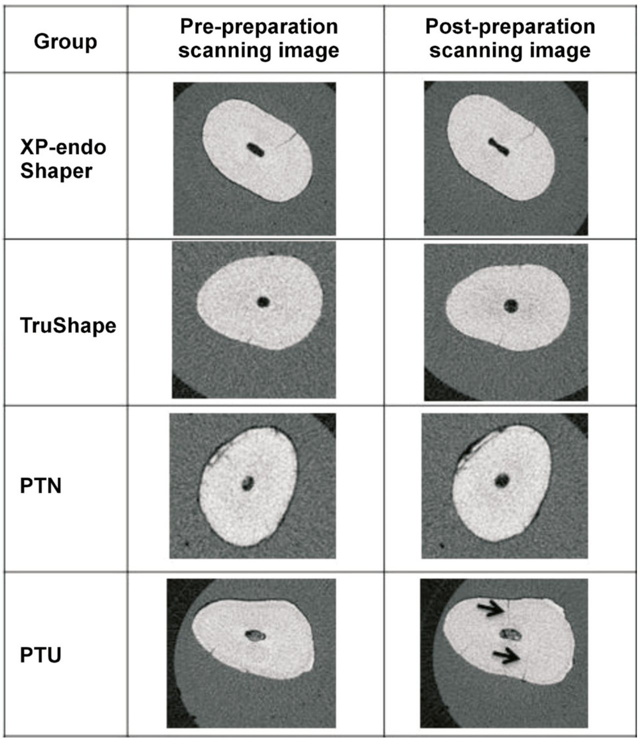

Fig. 1. Representative pre- and post-preparation scanning images for different groups tested

PTN – ProTaper Next; PTU – ProTaper Universal. Only in the PTU group, the post-preparation scanning image showed new dentinal cracks (black arrows).

Preparation time for different groups

The mean preparation time for the XP-endo Shaper, TRUShape, PTN, and PTU groups was 69.33 s, 151.56 s, 150.44 s, and 155.67 s, respectively. The one-way analysis of variance (ANOVA) showed a statistically significant difference between the 4 tested groups (p = 0.001), indicating that in the XP-endo Shaper group, root canal preparation required significantly less time as compared to the other 3 groups (Table 2, Fig. 3).

Table 1. Mean rank and χ^2 values regarding pre- and post-root canal preparation dentinal cracks for different groups tested (non-parametric Kruskal–Wallis test)

Groups		Mean rank	χ^2	Degrees of freedom	p-value
Pre-preparation	XP-endo Shaper	20.30	50.681	3	0.000*
	TRUShape	75.37			
	PTN	69.74			
	PTU	52.59			
Post-preparation	XP-endo Shaper	15.93	83.941	3	0.000*
	TRUShape	56.33			
	PTN	51.85			
	PTU	93.89			

* statistically significant.

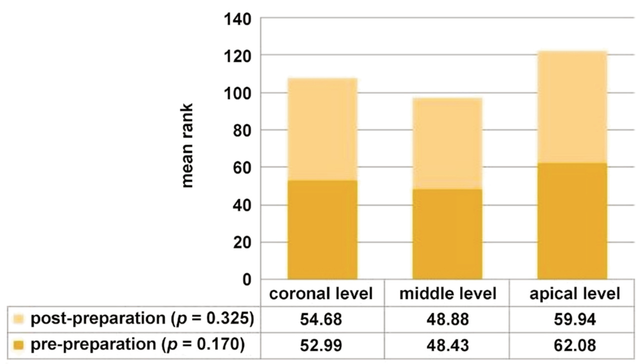

Fig. 2. Mean rank of dentinal cracks pre- and post-root canal preparation for 3 different root levels

Table 2. Mean preparation time for different groups tested (one-way ANOVA)

Groups	Preparation time [s]	*p*-value
XP-Endo Shaper	69.33 ±2.35	0.001*
TruShape	151.56 ±2.46	
PTN	150.44 ±1.88	
PTU	155.67 ±1.73	
Total	131.75 ±36.66	

Data presented as mean ± standard deviation (*M* ±*SD*).
* statistically significant.

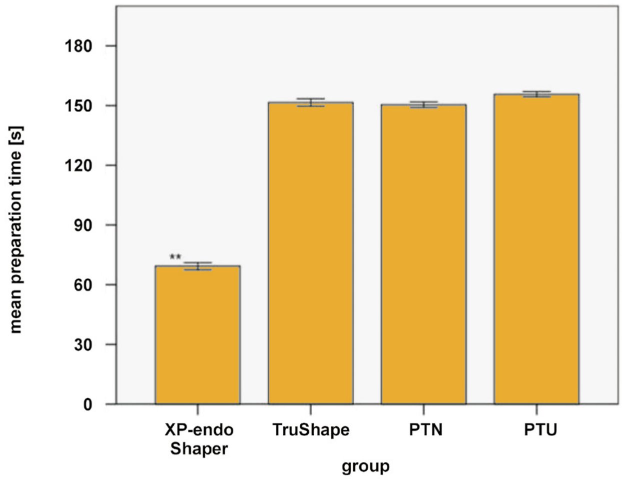

Fig. 3. Mean preparation time for different groups tested
** statistical significance ($p = 0.001$).

Discussion

This study evaluated the incidence of dentinal cracks after the preparation of mandibular premolars with oval canals, using the recently introduced 3D files (XP-endo Shaper, TRUShape and PTN) in comparison with the PTU file, by means of micro-CT scanning. Thirty-six freshly extracted teeth were selected for the study and divided equally into the 4 groups (9 teeth per group). In order to standardize the incidence results for all groups and to eliminate other contributing factors, mechanical preparation was finished with size 30 in all experimental groups in the study.

In previous studies on dentinal cracks which used the destructive (sectioning) method, the incidence of cracks varied between 4% and 80%.[44,45] However, the examination of dentinal cracks with the use of the sectioning method has many limitations, such as the creation of cracks after sectioning, and studying few slices of the root rather than the evaluation of the entire root. Using the micro-CT method to examine dentinal cracks is preferrable.[46,47] Micro-CT provides hundreds of slices to be evaluated for each tooth, showing the details of cracks, their location and extension in the dentin. In endodontic research, the advantages of micro-CT are numerous – less sample preparation, less damage to the teeth, no need to cut the teeth, and reliable results as compared to the sectioning method.[46]

In the present study, 3D files (XP-endo Shaper, TRUShape and PTN) were selected for the preparation of mandibular premolars with oval canals due to their ability to reach all canal walls with 3D asymmetrical rotation. The PTU system represented conventional NiTi files with symmetrical rotation. No previous study compared these 3D files with regard to the incidence of dentinal cracks after the mechanical preparation of oval canals.

At the beginning of our study, before root canal preparation, the teeth were evaluated under a stereomicroscope and no visible cracks were found in the samples. However, the pre-instrumentation micro-CT scanning images showed dentinal cracks in all study groups. This is in agreement with De-Deus et al., who reported that microcracks were present in all canal walls before the preparation of the examined teeth.[47]

The null hypothesis of the present study stated that there would be no statistically significant differences between the experimental groups in terms of formation of dentinal cracks. In the XP-endo Shaper, TRUShape and PTN groups, no cracks were formed after root canal preparation. However, in the PTU group, dentinal cracks occurred after preparation, and thus, the null hypothesis of the study was rejected (Fig. 1).

In the PTU group, the percentage of dentinal cracks observed postoperatively was high (62.4%) as compared to the percentage of dentinal cracks in the corresponding pre-preparation images (37.6%). The formation of dentinal cracks after the preparation of root canals with PTU was not surprising, and this finding was in agreement with previous studies.[27,36,37,44]

In root sectioning studies, the percentages of dentinal cracks after using PTU ranged from 16% to 56%.[8,27,44] With regard to micro-CT studies, 3 of them evaluated the dentinal cracks formed after using PTU,[36,37,48] and reported the percentages of 21%[36,37] and 42%.[48] Our results regarding post-instrumentation dentinal cracks in the PTU group were higher (62.4%) as compared to previous micro-CT studies.[36,37,48]

There is a limited number of micro-CT studies in the literature addressing the formation of dentinal cracks after using the XP-endo Shaper files in root canal preparation. Bayram et al. concluded that the XP-endo Shaper file had no effect on the formation of dentinal cracks after the preparation of mandibular premolars.[37] In the present study, XP-endo Shaper did not induce cracks after the preparation of mandibular premolars with oval canals, which is in agreement with Bayram et al.'s findings.[37] It can be explained by the flexibility of XP-endo Shaper, stemming from the alloy used and the design of the file.

TRUShape is a heat-treated NiTi file with a characteristic S-shape design and a decreased taper.[49] Again, micro-CT studies addressing the formation of dentinal cracks after using the TRUShape files in root canal preparation are scarce.[50,51] In 2017, Bayram et al. compared TRUShape with the Vortex Blue® and HyFlex™ files in terms of dentinal crack incidence after the preparation of mandibular incisors.[51] They concluded that none of the systems used induced new dentinal cracks after preparation.[51] Also, Zuolo et al. evaluated crack formation after using the TRUShape, SAF, BioRaCe™, and Reciproc® files, and concluded that none of the systems induced new dentinal cracks.[50] In our study, the TRUShape system did not induce cracks after the preparation of mandibular premolars, which is in agreement with previous studies.[50–52]

There are also few micro-CT studies in the literature regarding dentinal crack formation when using PTN.[47,53] De-Deus et al. compared PTN with the Twisted File (TF)™ Adaptive rotary systems with regard to the induction of dentinal cracks on mandibular molar teeth.[47] The authors concluded that the post-preparation cracks were already present in the pre-preparation scanning images, and none of the systems induced new dentinal cracks.[47] In our study, the PTN file did not induce cracks after the preparation of mandibular premolars, which confirms the results of some previous micro-CT studies,[47,53] and is in contrast with sectioning studies.[8,44] Although Choi et al. showed a variable range of vibrations inside the root canal, related to the use of PTN, no effects of these vibrations on crack formation was reported.[54]

In their recent research, Shantiaee et al. found that no new dentinal cracks were induced by rotary and reciprocal systems in curved canals during instrumentation, and they referred this outcome to the design of these instruments, which makes the files more flexible.[55] This finding in accordance with our results regarding the rotary files, with no dentinal cracks developed across the different section levels, as confirmed by micro-CT.

The variations in the preparation time between the 4 motorized techniques might be attributed to the mode in which each file was used to achieve WL. The tip of the XP-endo Shaper file has a unique shape that allows it to achieve WL quickly and with little pressure. The tip is subdivided into 2 parts. The apical portion of the tip features a non-cutting bullet form; it converts into 6 cutting blades that integrate into a thin shaft with a 0.01 taper. In comparison with the other 3 files evaluated, it appears that these attributes allow the XP-endo Shaper file to attain WL easily and rapidly with minimum resistance. The XP-endo Shaper file is not intended to shape the canal, but rather to clean it by accessing canal imperfections with each of the 15 lengthy pecking strokes suggested by the manufacturer.

There are some limitations to studies on dentinal cracks, such as the use of extracted teeth and the absence of the natural periodontal ligament (PDL) of the tooth during the experiment. In the present study, we used impression material to simulate PDL and allowing some freedom for the tooth movement. However, Soros et al. stated that impression material could collapse and get in direct contact with the teeth, which does not happen in bone environment.[56] During pre-preparation scanning with micro-CT, microcracks were found and the origin of these cracks could not be explained; they might have resulted from the extraction forces, the storage medium for the teeth or from the increased heat of scanning. Future studies on the issue of dentinal cracks after root canal preparation need to adopt an in vivo scenario, with the possibility to detect dentinal cracks clinically to avoid bias in the results. Some recent studies have tried to address cracks clinically, using strains gauges and infrared thermography.[57,58] In the present study, root canals were single oval canals, and future studies with curved or narrow canals may provide different results.

Conclusions

Within the limitations of the present study, none of the tested instrumentation systems led to the formation of new dentinal cracks in mandibular premolars with single oval canals, except one group (PTU). The formation of new cracks resulted from the mechanized instrumentation in one of the 4 groups, which is the traditional super-elastic NiTi PTU, and not from the sectioning procedure itself. Future studies are required to investigate the association between the formation of dentinal cracks after root canal preparation and new endodontic file systems.

Ethics approval and consent to participate

The study design was approved by the Research Ethics Committee at the Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia (approval No. 011-01-18).

Data availability

The datasets supporting the findings of the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Use of AI and AI-assisted technologies

Not applicable.

ORCID iDs

Mohammed Mana Alzamanan https://orcid.org/0000-0001-8266-8538
Abdullah Abdulrahman Albassam https://orcid.org/0000-0002-2596-7328
Emad Mahmoud Khattab https://orcid.org/0000-0003-0525-3544
Faisal Turki Alghamdi https://orcid.org/0000-0003-2086-0772

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