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Micro-Computed Tomographic Evaluation of Dentinal Cracks Caused by Various Recent File Systems

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Research Article

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ABSTRACT

Objectives: The purpose of present study was to evaluate the incidence of dentinal micro-cracks observed after the use of ProTaper Gold (PTG), WaveOne Gold (WOG), OneShape New Generation (OSNG), K3XF nickel-titanium (NiTi) instrumentation systems.
Materials and Methods: Sixty extracted human mandibular first molars were randomly assigned to four groups (*n* = 15). The root canals were instrumented with PTG, WOG, OSNG, and K3XF systems. The cross-sectional images of the roots were screened using high-resolution micro-computed tomography imaging before and after preparation to detect the presence of dentinal cracks.
Results*:* Although there was no statistically significant difference between PTG and WOG systems, WOG caused lesser micro-crack among all groups. K3XF showed statistically fewer cracks than OSNG. K3XF and OSNG systems caused statistically more dentinal micro-cracks than both Gold systems. WOG and PTG systems caused lesser micro-cracks formation among the systems evaluated in present study.
Conclusions: All used systems have caused different degrees of crack formations. Furthermore, WOG and PTG systems have shown superior features in terms of creating dentinal cracks according to OSNG, and K3XF systems. Preferring PTG and WOG systems during root canal shaping may minimize microcracks.

Keywords: Endodontics, Microcomputed Tomography, Root Canal Preparation.

Çeşitli Yeni Eğe Sistemlerinin Neden Olduğu Dentin Çatlaklarının Mikro Bilgisayarlı Tomografik Değerlendirilmesi

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ÖZ

Amaç: Bu çalışmanın amacı, ProTaper Gold (PTG), WaveOne Gold (WOG), OneShape Yeni Nesil (OSNG), K3XF nikel-titanyum (NiTi) enstrümantasyon sistemlerinin kullanımından sonra gözlenen dentin mikro çatlaklarının insidansını değerlendirmektir.
Gereç ve Yöntem: Altmış adet çekilmiş insan mandibular birinci molar dişi rastgele dört gruba ayrıldı (n = 15). Kök kanalları PTG, WOG, OSNG ve K3XF sistemleri ile enstrümante edildi. Köklerin kesit görüntüleri, dentin çatlaklarının varlığını tespit etmek için hazırlıktan önce ve sonra yüksek çözünürlüklü mikro bilgisayarlı tomografi görüntüleme kullanılarak tarandı.
Bulgular: PTG ve WOG sistemleri arasında istatistiksel olarak anlamlı bir fark olmamasına rağmen, WOG tüm gruplar arasında daha az mikro-çatlamaya neden oldu. K3XF, OSNG'den istatistiksel olarak daha az çatlak gösterdi. K3XF ve OSNG sistemleri, her iki Gold sisteminden istatistiksel olarak daha fazla dentin mikro çatlaklarına neden oldu. WOG ve PTG sistemleri, bu çalışmada değerlendirilen sistemler arasında daha az mikro çatlak oluşumuna neden olmuştur.
Sonuçlar: Kullanılan tüm sistemler farklı derecelerde çatlak oluşumlarına neden olmuştur. Ayrıca WOG ve PTG sistemleri, OSNG ve K3XF sistemlerine göre dentin çatlakları oluşturma konusunda üstün özellikler göstermiştir. Kök kanal şekillendirmesi sırasında PTG ve WOG sistemlerin tercih edilmesi mikro çatlakları en aza indirebilir.

Anahtar Kelimeler: Endodonti, Mikrobilgisayarlı Tomografi, Kök Kanal Hazırlığı.

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Introduction

Root canal preparation is one of the most important steps in endodontic procedures.[1]{Hübscher, 2003 #1} Properly prepared root canals provide enhanced irrigation as well as obturation. Thus, mechanical preparation plays a crucial role in the success of endodontic treatment.[2] However, during mechanical preparation, root canal walls can be exposed to instantaneous stress concentrations through dentine, which causes perforations, zips, iatrogenic defects, dentinal defects and micro-cracks or craze lines, especially in curved canals.[1,3] Minimizing the fractures and micro-cracks became one of the main goals of root canal preparations because these are significant disadvantages of preparations. For this purpose, many instrumentation systems have been introduced and developed in the endodontic field. The K3XF (SybronEndo, Orange, CA) system is an upgraded level of K3 system and one of the most recent instrumentation systems in endodontics. The K3XF system ensures clinicians enhanced flexibility and strength to cyclic fatigue through exclusive R-phase technology, in addition to the core features of the original K3 system. Another recent file system that applies traditional constant rotational movement is OneShape New Generation (OSNG; MicroMega, Besancon, France). The manufacturer of the OSNG files demands that it increases the available volume to eliminate upstream residuals and debris in the root canal system because of its asymmetrical section geometry and larger pitch.[4,5]

The new rotary system called ProTaper Gold (PTG, Dentsply Sirona, Ballaigues, Switzerland) contains a convex triangular cross-section and a changeable progressive pitch. The design of PTG provides high resistance to cyclic fatigue with enhanced flexibility.[4] The manufacturer also asserts that the design of PTG may perform an asymmetric rotary movement aimed to decrease the screwing effect by minimising the contact zone between the file and the dentinal wall. WaveOne Gold (WOG, Dentsply Sirona, Ballaigues, Switzerland) is the modification of the WaveOne single-file reciprocating system. It has been claimed by the manufacturers of WOG that the M-Wire NiTi technology offers an increased cyclical fatigue resistance and lowered screwing effect. The design of WOG is claimed to increase cutting efficiency due to its parallelogram design which contains a triangular-shaped predecessor with one or two cutting edges depending on the location throughout the file. Nonetheless, various features of nickel-titanium (NiTi) files can significantly impact microcrack formation. The relationship between dentinal micro-cracks and the thermal metallurgy and kinematics of new PTG and WOG endodontic instruments has not been examined. Therefore, this study aimed to compare root cracks on the root canals that instrumented with the PTG, WOG, OSNG, and K3XF systems using high-resolution micro-computed tomographic (micro-CT) analysis.

Materials and Methods

Sample Selection and Preparation of Specimens

Approval for the present study was obtained from the Clinical Research Ethics Committee of X University in X, X (2021-08/44). We selected eighty-five mandibular molars with no dentinal fractures extracted for reasons not related to this study. The teeth were extracted both for orthodontic or periodontal reasons. Sixty teeth with no resorptions or visible defects were selected. Possible root canal obstructions, curvature angle of the mesial roots, pre-existing craze lines, and micro-cracks were detected using preoperative micro-CT images. The teeth were examined with Schneider's method and the curvature of mesial roots were ranged between 10°-20°.[6] Extracted teeth were stored at 0.1% thymol until used which is one month after following the removal of surface remnants. According to De-Deus procedure, distal roots were removed by a low-speed saw (Isomet; Buhler Ltd, Lake Bluff, NY). Thus, the mesial root was separated from the tooth.[6] Canal patency has been conducted with a 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until the tip was visible from apical foramen and the working length (WL) was 1mm lower than this measurement. After keeping all the specimens in 0.01% thymol, all the roots were covered using a polyether impression material (Impregum F, 3M/ESPE, Seefeld, Germany) as a periodontal ligament space and inserted in acrylic blocks.[7]

Root Canal Instrumentation

The specimens were allocated to 1 of 4 groups: PTG, WOG, OSNG, and K3XF (15 teeth in each group). All the root canal preparations were completed by only one operator, and the instrumentation sequences used were as follows;

PTG Group

The PTG instruments used in a sequence of SX (1/2 of the WL), S1 (size 17, .02 taper; 2/3 of the WL), S2 (size 20, .04 taper; 2/3 of the WL), F1 (size 20, .07 taper; full WL), F2 (size 25, .08 taper; full WL) files. All the PTG instruments were used at 300 rpm with a torque of 3 Ncm for SX and S1 instruments, 1.5 Ncm for F1 instruments, and 2 Ncm for F2 instruments.

WOG Group

The WOG file with a size 25 and taper .08 was used in WO all program. 6: 1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) was chosen for this method.

OSNG Group

OSNG (Micro-Mega) instruments (size 25, .06 taper) were used with a torque-controlled endodontic motor (X-Smart, Dentsply Maillefer). The instruments were worked using in-and-out movements and minimal pressure with 2 Ncm torque and 400 rpm at the WL.

K3XF Group

Sybron Elements motor was chosen with K3XF (SybronEndo) instruments to size 25 taper .10 file at the orifice level and the half of WL, at WL, size 25 taper .04 and .06 were used. The speed of the selected motor was 400 rpm and the torque was 3 Ncm. The selected teeth were prepared with a total of 10 ml 5.25% NaOCl solution using a 29-gauge side-vented NaviTip needle (Ultradent, South Jordan, UT, USA). The needle was asserted into the root canals until 1 mm lower than WL.

Dentinal Microcrack Evaluation

Analysis of microcracks before and after root canal instrumentation was carried out by the two examiners. Samples were scanned with micro-CT (Bruker-MicroCT 1172, Belgium) with 100kVa force being used. All samples were scanned using 1000ms exposure time, 0.4 rotation through 360o, and an Aluminum 0.5 mm filter was used. Samples were scanned with 13.7 µm/pixel. All images were taken using 3 frame average. Data were reconstructed with NRecon (Bruker-MicroCT 1172, Belgium) and analysed with CTan (Bruker-MicroCT 1172, Belgium) software. Data viewer (Bruker-MicroCT 1172, Belgium) was used to detect the defect site. To detect the dentinal micro-cracks, 3 pre-calibrated investigators were used in furcation level to apex (n=45 840). When the before and after cross-sectional images of root canal preparations were examined, the dentinal micro-cracks were recorded.

Statistical Analysis

The micro-crack incidence data were analysed using the SPSS statistical software program (version 14.0, SPSS Inc., Chicago, IL). A three-way ANOVA was applied to compare the evaluated NiTi systems in terms of dentinal micro-crack formation. ANOVA with post hoc Tukey's test was used for statistical analysis with a p-value at 0.05.

Results

The mean, standard deviation, and statistical analysis of dentinal defects observed after instrumentation are shown in Table 1. The micro-CT images of dentinal micro-cracks formed in the coronal, middle, and apical thirds of roots are shown for K3XF, OSNG, PTG, and WOG respectively, in Figures 1, 2, and 3. A kappa test was performed and showed 94.6% inter-examiner agreement on the examination of micro-crack formation. Cross-sectional images were examined to compare the condition of the dentinal defect observed in the pre and post instrumentation. The comparison of pre-instrumentation micro-crack observations showed no statistically significant differences among root regions and instrumentation systems (p>0.05). The WOG system produced statistically fewer micro-cracks than any other system (p>0.05).

OSNG caused statistically more cracks formation than the K3XF system (p>0.05). Moreover, K3XF and OSGN exhibited statistically more dentinal cracks than PTG and WOG systems (p>0.05). Furthermore, although there was no statistically significant difference between PTG and WOG systems (p>0.05), considering its average value PTG caused more dentinal micro-crack formation than WOG throughout the entire length of the root canal.

As a result of cross-sectional image examination, the incidence of cracks was higher in the apical thirds than the middle and coronal thirds for the WOG, PTG, OSNG, and K3XF groups (p>0.05).

Discussion

Dentine cracks that do not reach the pulp cavity and on the external surface of roots may be formed as linear micro-cracks. Linear micro-cracks may form from the stress that occurs during mechanical shaping due to excessive tensile strength of the collagen matrix. If the applied force transmitted to the external surface during canal preparation exceeds the force that holds the root dentine together, cracks may form from the dentine to the external root surface.[7] It's been reported that NiTi rotary systems may cause fractures on the dentinal surface.[8,9] Four selected different NiTi systems were compared in the present study and concluded that instrumentation causes micro-cracks depending on the process of producing these instruments. Therefore, the thermomechanical treatment and kinematic features of instrumentation systems must be evaluated in terms of root dentine cracks that occur during preparation. However, no study compared PTG, WOG and OSGN instrumentation systems through their incidence of causing dentinal micro-cracks.

Table 1. The mean, standard deviation and statistical analysis of dentinal defects observed after instrumentation.

	Apical 1/3		Middle 1/3		Coronal 1/3	
	Before Preparation Micro-crack (%)	**After Preparation** Micro-crack (%)	**Before Preparation** Micro-crack (%)	**After Preparation** Micro-crack (%)	**Before Preparation** Micro-crack (%)	**After Preparation** Micro-crack (%)
OSNG	32.25 (1.54)^{aA}	**54.43 (1.80)^{Aa}**	31.16 (1.48)^{aA}	**50.41 (1.21)^{Ba}**	30.12 (1.41)^{aA}	**49.11 (1.21)^{Ba}**
K3XF	31.65 (1.52)^{aA}	**42.35 (2.48)^{Ab}**	30.74 (1.42)^{aA}	**39.15 (1.15)^{Bb}**	29.64 (1.38)^{aA}	**38.73 (1.61)^{Bb}**
PTG	31.05 (1.48)^{aA}	**36.14 (0.94)^{Ac}**	30.55 (1.40)^{aA}	**33.75 (0.77)^{Bc}**	29.48 (1.24)^{aA}	**33.47 (0.85)^{Bc}**
WOG	31.20 (0.83)^{aA}	**35.92 (0.96)^{Ac}**	30.24 (1.28)^{aA}	**33.63 (0.97)^{Bc}**	29.32 (1.18)^{aA}	**33.41 (1.11)^{Bc}**

By the three way ANOVA, F = 283.435; p=0.000 (p>0.05), Different superscript uppercase letters in the same row (same rotary system in different thirds) indicate a statistically significant difference (p>0.05), Different superscript lowercase letters in the same column (different rotary systems in the same third) indicate a statistically significant difference (p>0.05).

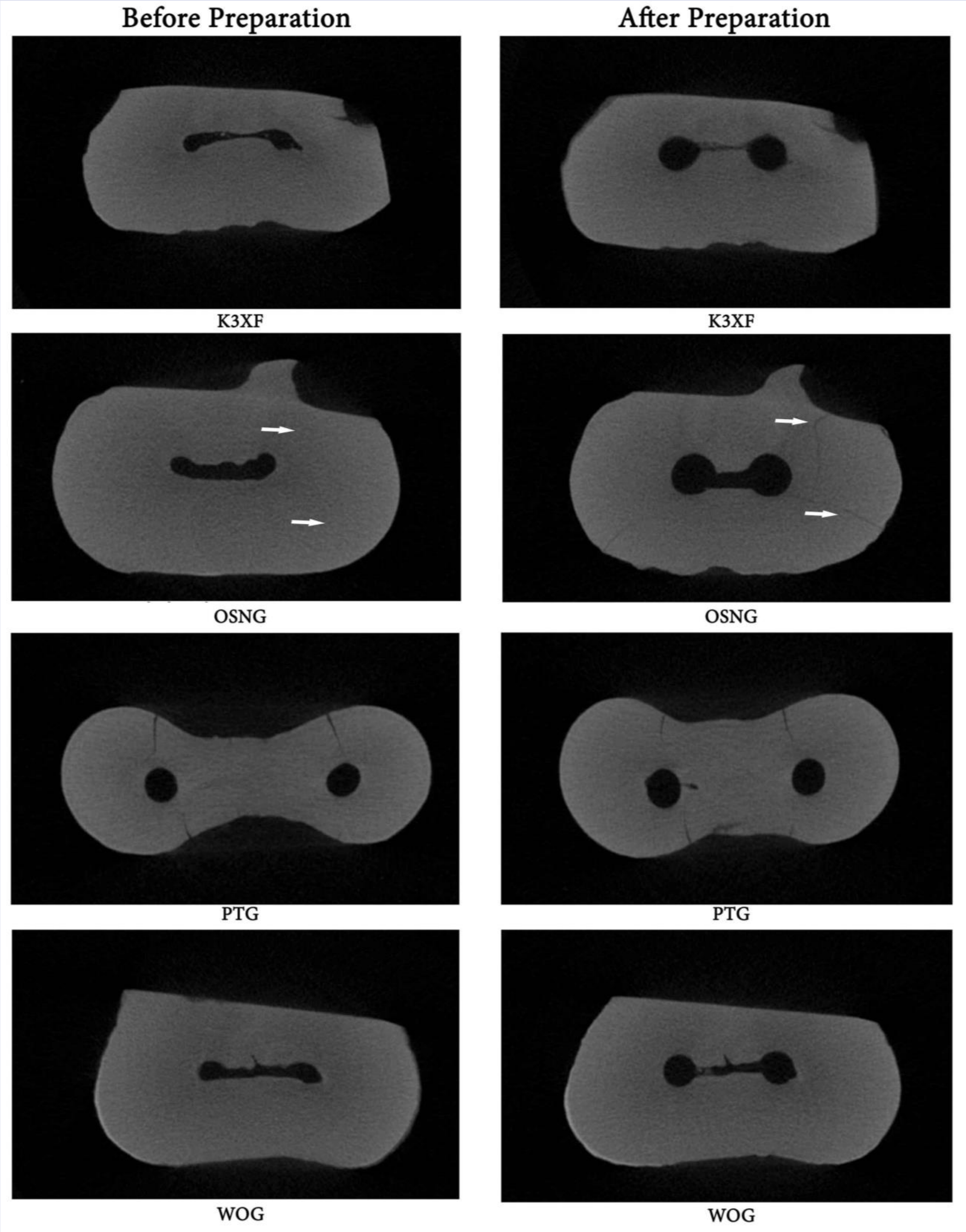

Figure 1. The representative micro-computed tomographic images obtained from the coronal third of roots before and after preparation using instrumentation systems

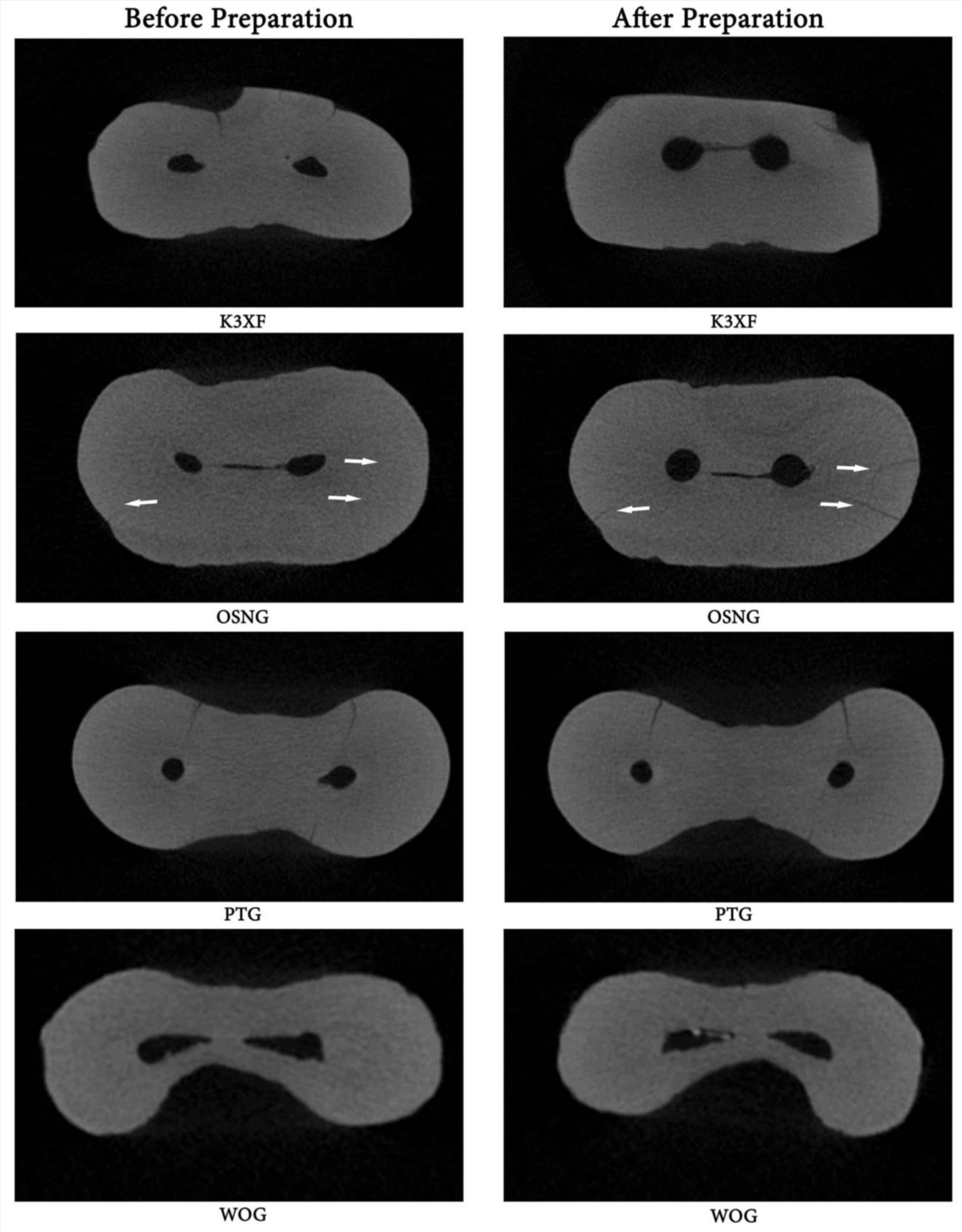

Figure 2. The representative micro-computed tomographic images obtained from the middle third of roots before and after preparation using instrumentation systems

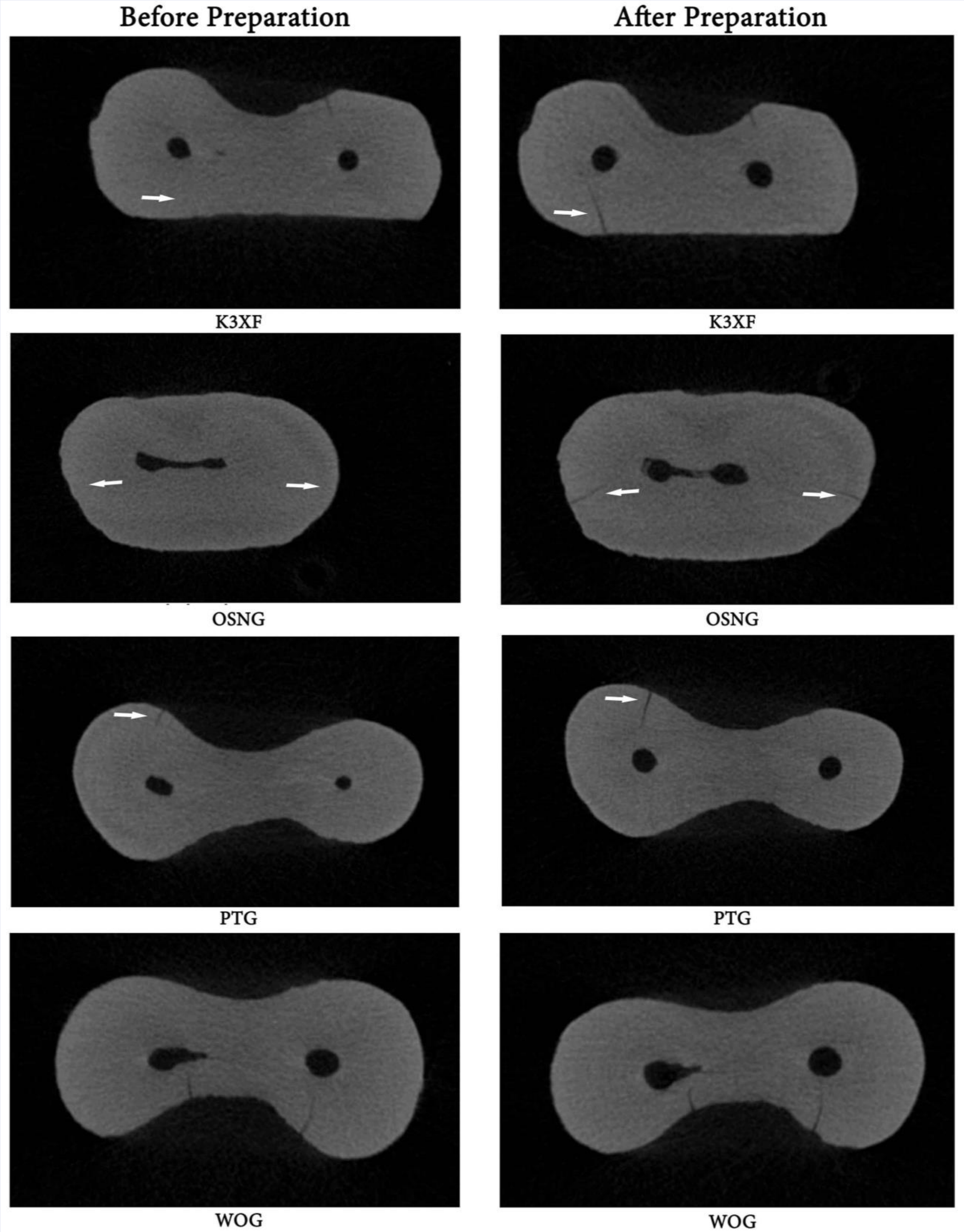

Figure 3. The representative micro-computed tomographic images obtained from the apical third of roots before and after preparation using instrumentation systems

As known, the increase of apical stress and strain may depend on the file design.[10] It's been reported that the PTG and WOG systems cause fewer dentinal micro-cracks at the coronal, middle, and apical thirds compared with the OSNG and K3XF in the present study. The PTG group showed significantly lower micro-cracks than the other groups because the convex triangular cross-section design of PTG instrumentation allows minimal contact of the file on the dentinal walls. Moreover, the micro-crack formation was not reported in the WOG group because of its offset parallelogram-shaped cross-section design that limits the engagement zone that ensures fewer dentinal crack formations.

As the NiTi systems and instruments develop with the new technologies, the developed NiTi systems became available for usage in different areas as well as different kinematics and alloys. Moreover, it has been claimed that the new systems significantly increase the dentinal micro-cracks with the instrumental origin.[11,12] Also, it has been reported that the reciprocating motion of the file systems causes significantly less damage and micro-cracks than the continuous and rotational motion. Interestingly, middle and coronal thirds were affected less than apical thirds and fewer dentinal micro-cracks were observed. Moreover, continuous rotation produced more micro-cracks in the apical third than in the coronal and middle thirds.[8,13] Comparison of root dentinal crack formation from continuous rotating and reciprocating root canal preparation methods revealed that root canal instruments with reciprocating movements gained better results in terms of dentinal micro-crack formation than instruments with a continuous rotation movement.[14] Nevertheless, continuous rotational movements on root canals can cause micro-cracks and craze lines in root dentine.[15] Also, the continuous rotational motion of the OSNG, K3XF, and PTG caused more micro-cracks to form than the reciprocating motion of the WOG system, which has been designed clockwise and anticlockwise angles. This movement causes stress especially in the apical area of roots and eventually creates micro-cracks at this level. In contrast, continuous rotation of the other instruments may have increased the stress concentration because greater rotational force was adopted to the root canal walls, resulting with more cracks.

The ongoing metallurgic developments in the manufacture of NiTi instrument systems have played a crucial role in improving both flexibility and reducing crack formation. Thermomechanical treatment of NiTi files has been performed using various methods. In time, endodontic instruments have been produced using different metallurgical techniques as M-Wire, then Blue Wire, and recently Gold Wire technology. In the current study, OSNG caused a higher percentage of cracks than the K3XF. In terms of metallurgical evaluation, although OSNG was manufactured conventionally for treated NiTi wire, K3XF was manufactured with R-phase. R-phase is associated with enhanced flexibility and fatigue resistance to instruments. It's the process of heating and cooling until obtaining the final shape of the file which is a twistable and elastic form of NiTi instruments.[16,17] The manufacturer claims that developed NiTi systems are more advantageous than the traditional systems due to their phase transformation according to temperature.[18] This may be the advantage of the K3XF system, which caused fewer microcracks than the OSNG system. Also, several studies support the previous study.[19,20]

PTG and WOG systems were manufactured using the latest metallurgical technology which contains a following heating and cooling process that causes reversing between martensite and austenite. In the present study, both systems caused fewer dentinal cracks compared to the other systems. According to the metallurgical assessment, in both gold systems (PTG & WOG) the phase-transition point between martensite and austenite through heating and cooling cycles was higher compared to previous methods. One of the reasons that make PTG and WOG files more elastic is the Gold Wire alloy material which makes new files more advantageous than traditional NiTi wires. The enhanced flexibility of new systems also promises a better quality of preparation and fewer micro-crack formations during preparation with the PTG system. The PTG systems also show a great ability on more restrictive canals such as curved and long canals.[21] In the present study, the micro-computed tomography experimental model was selected to examine dentinal micro-cracks because it is capable of a qualitative and quantitative assessment of a root canal in three dimensions and a better visualization of root canal morphology.[22] This technique produces highly accurate and clear images.[23] This superior visualisation technology assesses pre and postoperative conditions of root dentine in terms of the presence of cracks. Moreover, the most crucial difference of this approach compared to methods used in previous studies is that roots do not need to be cut for micro-CT evaluation.

Conclusions

Within the limitations of the present study, the WOG system caused the least crack formation amongst the other systems used in the present study. The incidence of dentinal cracks may vary depending on the design of the instrument through kinematic and metallurgic properties.

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None to declare

Conflicts of Interest Statement

The authors declare that they have no conflicts of interest in relation to this study.

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