Rotary Continuous and Reciprocating Single-File Nickel–Titanium Instruments in the Induction of Dentinal Cracks

Mettasari Puspa Wardoyo[1], Dewa Ayu Nyoman Putri Artiningsih[2]*, Munyati Usman[2], Kamizar Nazar[2], Stiza Tanita Wiranatakusumah[2]

1. Conservative Dentistry Residency Program, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia.
2. Department of Conservative Dentistry, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia.

Abstract

Root canal preparation with a nickel–titanium (NiTi) rotary instrument may induce cracks in the root canal wall. This study sought to evaluate and compare the incidence of cracking in the root canal wall after root canal preparation using single-file NiTi rotary instruments with rotary continuous and reciprocating movements via micro-computed tomography (micro-CT) analysis. Thirty-two single root canal samples were randomly assigned into two groups—reciprocating instruments and rotary continuous instruments (n = 16 per group)—according to the system used for root canal preparation. The samples were scanned by high-resolution micro-CT imaging to evaluate for cracks before and after root canal preparation. Comparisons were analyzed statistically using Fisher's exact test. Post instrumentation cracks were detected in both the reciprocating group (12.5%) and rotary continuous group (25%) and there was no significant difference in the number of cracks between the two (P > .05). Cracks were most often found in the apical one-third of the root canal. Root canal preparation with single-file NiTi rotary continuous and reciprocating instruments can induce dentinal cracks in the root canal wall with no significant differences in the cracks induced between the two types of movement.

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Introduction

Root canal treatment aims to treat the microbial contamination of pulp and root canal systems so that patients can retain the function and aesthetics of their natural teeth.[1] Root canal instrumentation is accomplished by the use of endodontic instruments and irrigating solutions under aseptic working conditions. Endodontic instruments can be classified into handheld instruments and nickel–titanium (NiTi) rotary instruments.[2] The NiTi rotary system currently boasts two types of movements; rotary continuous movements and reciprocating movements.[3] Rotary continuous movement is defined as a 360° clockwise (CW) rotating motion that employs a rotary engine.[4] In comparison, reciprocating movements are repetitive up-and-down or back-and-forth motions, also known as CW and counterclockwise (CCW) movements.[2,5] The current NiTi rotary instrument system can further be stratified as full-sequence and single-file systems. The newer single-file technique was recently introduced to simplify instrumentation protocols, reduce stresses, and avoid the risk of cross-contamination.[6] Existing single-file NiTi rotary instruments are available with either rotary continuous or reciprocating motion.[2] Reciproc Blue® (VDW GmbH, Munich, Germany), a thermally treated single-file NiTi instrument with reciprocating movements, is an improved version of the original Reciproc instrument.[7] One Curve®, a thermally treated single-file NiTi instrument with rotary continuous movements, is an improved version of the One Shape® instrument.[8]

Root canal instrumentation with NiTi rotary instruments could result in some complications such as perforation, canal transportation, ledge and zip formation, instrument separation, and dentinal cracks in the root canal wall.[9–13] Root canal instrumentation may also weaken the root structure and increase its susceptibility to defects such as cracks in the

Corresponding author:
Dewa Ayu Nyoman Putri Artiningsih
Department of Conservative Dentistry,
Faculty of Dentistry, Universitas Indonesia
E-mail: dewaayunpa@yahoo.co.id

dentine. Dentinal defects may possibly lead to vertical root fractures (VRFs) during obturation, retreatment, and postplacement or simply because of masticatory forces.[14,15] VRFs can lead to tooth or root extraction.[9,16,17] VRFs attributed to endodontic procedures were found in 3.69% of endodontically treated teeth.[15] Shemesh et al. reported that excess removal of root dentine during root canal instrumentation resulted in a weakening of the root that could lead to VRFs.[14] These authors also determined that the incidence of VRFs increased when the application of root canal instrumentation was followed by obturation and/or retreatment procedures.[14] Clinically, microorganisms may proliferate in crack lines, leading to the establishment of biofilm on the root surface.[18]

Bier et al. reported that manual instruments did not cause cracks in the root canal walls, while first-generation NiTi rotary instruments (Greater Taper and ProFile) and second-generation (ProTaper) did induce cracks.[19] Priya et al. (2014)revealed in their study that manual instruments did not cause major damage to the root canal wall, while all NiTi rotary instruments with both rotary continuous and reciprocating movements induced cracks.[20] Several studies also reported that the use of NiTi rotary continuous instruments induced more cracks than as seen with NiTi reciprocating instruments.[11,16] However, there are also notable observations to consider from Burklein et al. and Gergi et al., who found that NiTi reciprocating instruments induced more cracks than NiTi rotary continuous instruments.[12,21] Thus, the exact influence of the movement of different NiTi rotary instrumentation (i.e., rotary continuous and reciprocating) on the formation of cracks in the root canal wall remains a controversial topic.

In the last few years, micro-computed tomography (micro-CT) has opened up new possibilities for endodontic research because of its highly accurate and nondestructive properties, which facilitate the making of accurate assessments before and after different endodontic procedures.[22,23] Thus, the present study was designed to compare the incidence of cracking in the root canal wall after root canal preparation using single-file NiTi rotary instruments with either rotary continuous or reciprocating movements using micro-CT analysis.

Materials and methods

This study was approved by the Ethics Committee of Universitas Indonesia (protocol no. 051181218). All laboratory procedures were performed by the same operator.

Intact human maxillary molars were obtained from the collections of the Department of Oral Surgery, Faculty of Dentistry, Universitas Indonesia. Maxillary molars with mesiobuccal/distobuccal roots, mature apices, and less than 5^{o} root curvature were selected. All teeth were cleaned and stored in saline solution at 4^{o}C. The coronal portion of the teeth was removed with a diamond bur, leaving behind samples of 9 mm in length. Root canal patency was confirmed with a size 10 k-file until the tip was visible at the apical foramen. The glide path up to the WL (0.5 mm short of the length of the teeth) was established with a size 15 NiTiFlex k-file. All samples were scanned at an isotropic resolution of 6.06 μm using a micro-CT scanner (SkyScan 1173; Bruker, Kontich, Belgium) at 50 kV and 90 μA. Scanning was performed by 360^{o} rotation around the vertical axis with a rotation step of 0.5^{o}.

As described previously by Liu et al., each sample was wrapped with a single layer of aluminum foil and then embedded in acrylic resin. The sample wrapped in aluminum foil was then removed and the aluminum foil was peeled off. A hydrophilic polyvinyl siloxane impression material filled the space created by the aluminum foil to simulate the periodontal ligament, and the sample was immediately repositioned. The apical 3 mm of the root was exposed and immersed in water during instrumentation.[11]

Samples were randomly assigned into two groups (n = 16 per group) according to the system used for root canal preparation. In the reciprocating instrument group, root canal preparation was performed with the Reciproc Blue® R25 (25/8%) driven with the X-Smart plus motor in a reciprocating pattern. The Reciproc Blue® instrument was moved in the apical direction using a slow in-and-out pecking motion with an amplitude of 3 mm until WL was reached. In the rotary continuous instrument group, root canal preparation was performed with One Curve® (25/6%) driven with the X-Smart plus motor in a rotary continuous pattern with a speed of 300 rpm and 2.5 Ncm torque. One Curve instrument was moved in the apical direction using an in-and-out movement without any pressure to reach two-thirds of the WL, 3 mm short of the WL, and the WL. Each sample was irrigated with 10 mL of 2.5% NaOCl and 2 mL of aquabides.

After root canal preparation, the sample was scanned with micro-CT. The micro-CT findings before and after root canal preparation were compared to determines the number of teeth that developed cracks after root canal preparation. The locations where cracks occurred were evaluated to see the number of cracks in the apical, middle, and coronal areas. The types of cracks in the root canal wall were also evaluated to elucidate the number of incomplete cracks, complete cracks, and craze lines defined as a crack extending from the root canal wall to the outer surface of the root; a crack extending from the root canal into the dentin without reaching the outer surface of the root; and a crack extending from the outer surface of the root into the dentin without reaching the root canal wall, respectively.[18,23] An evaluation of the cross-sectional images was performed before and after root canal preparation using the ImageJ software (National Institutes of Health, Bethesda, MD, USA). Images before and after root canal preparation (n = 96,000) were analyzed for the presence of dentinal cracks in the apical, middle, and coronal portions.

Collected data were statistically analyzed using the Statistical Package for the Social Sciences version 22.0 for Windows software program (IBM Corp., Armonk, NY, USA). Differences in the number of samples that developed various cracks after instrumentation between the two groups were assessed using Fisher's exact test. A *P* value of less than.05 indicated that the differences were statistically significant.

Results

Considering a total of 32 samples, cracks were detected in both the reciprocating instrument group (12.5%) and rotary continuous instrument group (25%). Even though there were differences in the percentage of samples that developed cracks between the two groups, no significant differences were observed ($P > .05$) as seen in Table 1.

Group	N	No crack	Crack	*P* value
Reciprocating instrument	16	14 (87.5%)	2 (12.5%)	.654
Rotary continuous instrument	16	12 (75%)	4 (25%)	

Table 1: The number of teeth in which cracks were observed.
*Fisher's exact test, P < .05

In the preoperative scans, preexisting cracks in the root canal wall were found in 16 samples. Conversely, postoperatively, in the reciprocating instrument group, four cracks were found in the apical sections of the two samples that developed cracks, while, in the rotary continuous instrument group, eight cracks were found in the apical portions of the four samples that developed cracks. Thus, cracks formed after root canal preparation conducted with both reciprocating instruments and rotary continuous instruments, most commonly in the apical one-third of the root canal. In both groups, only incomplete cracks were observed, including four cracks in the reciprocating instrument group and eight cracks in the rotary continuous instrument group (Figure 1).

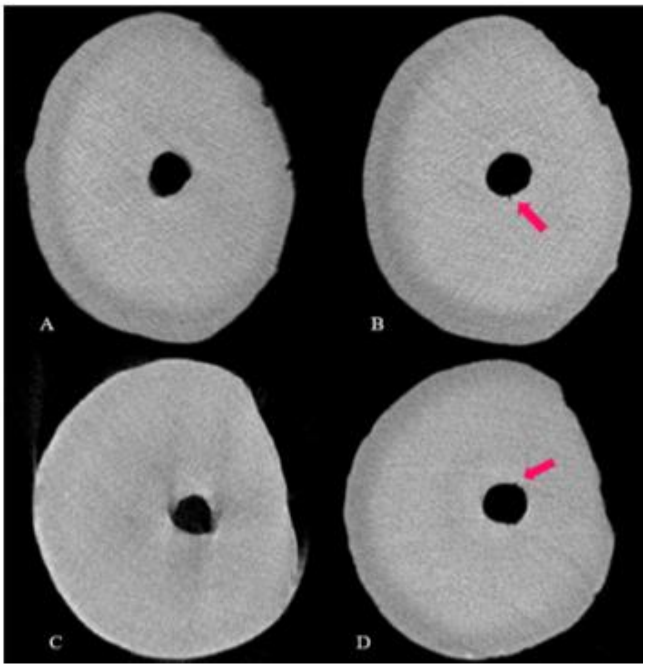

Figure 1: Micro-CT images demonstrating cracks in the apical one-third prior to and following root canal preparation with different systems. (A) No cracking was found prior to root canal preparation with the reciprocating instrument. (B) Incomplete cracks were found following root canal preparation with the reciprocating

instrument as pointed out by the red arrow. (C) No cracking was found prior to root canal preparation with the rotary continuous instrument. (D) Incomplete cracks were found following root canal preparation with the rotary continuous instrument as pointed out by the red arrow.

Discussion

The results of this study revealed that both types of NiTi rotary instruments tested induced crack formation in the root canal wall, ultimately affecting 12.5% of the reciprocating instrument group and 25% of the rotary continuous instrument group (Table 1). The results of this study are in accordance with those of previous studies by Burklein et al., Kansal et al., Priya et al., Pop et al., and Ceyhanli et al., who reported that NiTi rotary instruments with both reciprocating and rotary continuous movements may cause cracks in the dentin of the root canal wall.[12,16,17,20,24] During root canal preparation, a canal is shaped by the contact between instruments and the dentin of root canal walls. These contacts create many momentary stress concentrations in the dentin, which may induce cracks in the root canal wall.[16]

In this study, there were no significant differences between the reciprocating instrument group and the rotary continuous instrument group, although there were differences in the percentage of cracks between the two groups in that a higher percentage was recorded in the rotary continuous instrument group than in the reciprocating instrument group.

Reciprocating movements consist of repetitive CW and CCW motions, enabling the continuous release of the instrument when it is engaged in the inner surface of the root canal during the cutting and shaping procedure. Further, the CW motion disengages the blades of the instrument from the dentin wall, thus reducing the flexural and torsional stresses acting on the dentin, which could help to prevent the formation of dentinal defects. Reciprocating motion avoids continuous rotational stress and the constant torque that is generated from traditional rotary continuous motion on the inner surfaces of root canal walls.[16,25]

Continuous rotating movement results in a high level of stress concentrations in root canal walls because of the greater rotational forces and constant torque applied to the walls. Thus, more cracks are expected in the rotary continuous group.[9,16]

In this study, ultimately, cracking in both the reciprocating instrument group and rotary continuous instrument group was only found in the apical section. The apical part rapidly expands from size 15 to size 25 using a single-file system, which may have predisposed cracks to appear in this part.[23]

The type of crack found in this study was incomplete crack. According to Li et al., different morphologies of dentinal cracks, including incomplete crack, complete crack, and craze line, are associated with the stress intensity, concentration zone, and root canal wall thickness.[23]

Other than the motion of the instrument, the design of the instrument may also influence the formation of cracks in the root canal wall. According to research from Burklein et al. and Gergi et al., the formation of cracks may also be a result of the cross-sectional design of instruments, where the S-shaped cross-sectional design with sharp cutting edges led to more cracks than triangular or modified triangular cross-section.[12,21] In contrast with the results of this study, use of a NiTi rotary instrument with triangular cross-sections (One Curve®) generated more cracks relative to use of a NiTi rotary instrument with an S-shaped cross-section (Reciproc Blue®). Although the two single-file systems had the same D0, they had different cross-sections (S-shape and triangular shape for Reciproc Blue® and One Curve®, respectively). Between the two, the triangular shape includes a larger cross-sectional area; this is key because instruments with greater cross-sectional area make contact with larger areas of the root canal wall, remove more dentin, and generate more pressure on the root canal wall.[25] Triangular cross-section application also decreases the cutting efficiency and provides less space for dentine chips, thus generating more stress on root canal walls.[26]

In this study, cracks formed after root canal preparation using rotary continuous and reciprocating single-file NiTi instruments appeared as microcracks. Microcracks do not possess a high risk of developing into VRFs.

In this study, periodontal ligament simulation was conducted using polyvinyl siloxane impression materials to prevent cracks as seen in previous studies by De-Deus et al., Karatas et al., Oliveira et al., and Cassimiro et al.[9,10,18,22,27,28] The periodontal ligament serves to absorb tensions associated with the root canal preparation and limit the movement of the tooth while preventing external forces against the root.[28] A study by Rose and Svec suggested that the presence of natural periodontal structures may have absorbed the instrumentation impact, thus preventing cracks.[18,29] The periodontal ligament simulation could have prevented the formation of dentinal defects after the preparation as was observed in various other studies.[9,10,13,22,28] Unfortunately, there is no artificial material capable of absorbing forces on teeth that is as sufficient as the natural periodontal ligament in the clinical condition.[14,15,18,30,31] Furthermore, impression material used as a replacement for the periodontal ligament may collapse and permit direct tooth-to-acrylic contact, which never occurs in vivo (i.e., with bone).[10,29,32]

All samples were scanned before and after root canal preparation using micro-CT. Micro-CT using microfocal spot X-ray sources and high-resolution detection allows for projections to be rotated through multiple viewing directions to produce three-dimensional reconstructed images of samples.[33] Micro-CT provides three-dimensional and high-resolution scanning; thus, dentinal microcracks can be accurately analyzed.[17,23,27] This nondestructive scanning method also facilitates root canal visualization before and after root canal preparation, thus increasing the internal validity of the study because each sample served as its own control.[18,22,23,27,28] The initial scan enabled the detection of preexisting cracks and the precise region in which they were propagated.[22,23,27,28] In the present study, preexisting cracks in the root canal wall were found that could be associated with the patient's age, occlusion force, occlusion habit, or the tooth extraction process.[23,28,31,34,35] Micro-CT imaging enabled the evaluation of hundreds of slices per sample in contrast with previous studies that used stereomycroscopes and scanning electron microscopy, presenting many limitations such as (1) the necessary destructive root-sectioning method could cause crack formation; (2) samples could not be evaluated prior to root canal preparation to detect preexisting cracks; (3) only a few slices per sample can be evaluated, with the possibility of missing several cracks along the sample; (4) it is possible that the same crack extended to different levels of the root and were counted as separate cracks; and (5) it was not possible to evaluate at which point during the instrumentation procedures the cracks were produced.[22,23,27,36] However, this technique also poses some disadvantages, such as being a tedious, time-consuming, and expensive task.[23]

With an awareness of the potential of cracks to occur in the root canal wall induced by NiTi rotary instruments with both reciprocating and rotary continuous movements, root canal instrumentation should be applied carefully regardless of the type of NiTi rotary instrument used.

Conclusions

NiTi rotary instruments can cause cracks in the root canal wall. NiTi rotary continuous instrumentation creates more cracks in the root canal wall relative to reciprocating instruments, but there is no significant difference between the two outcomes. Cracks that occurred after root canal preparation were found most frequently in the apical one-third of the root canal. The type of crack most often found was incomplete crack. The cracks that appeared postoperatively were generally microcracks that did not possess a high risk of vertical root fracture.

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Declaration of Interest

The authors deny any conflicts of interest exist related to this study.

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