Keywords
Continuous rotation; Dentinal defects; Dental materials; Dentinal microcracks; Endodontic instrumentation; Nickel-titanium instruments; Prosthodontic prognosis; Root canal preparation; Reciprocating motion Vertical root fracture.

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Received: 09.12.2025
Revised: 05.02.2026
Accepted: 08.04.2026
Doi:
10.1922/ejprd.v34i2.1382

Tooth Microcracks Comparison Of Continuous Rotating And Reciprocating Rotary Files During Root Canal Biomechanical Preparation: In-Vitro Study

ABSTRACT
Newly developed nickel-titanium alloy (NiTi) instruments enable the instrument to be used with remarkable flexibility in root canals, such that the instrument can safely prepare curved root canals without the need to straighten them. There are two kinds of motion systems used when NiTi rotary instruments are applied: continuous rotating and reciprocating. In the process of biomechanical preparation, high stress concentrations inside the apical dentin create microcracks or craze lines when tools come into contact with the dentin wall surface. The study aimed to observe the effect and differences between continuously rotating and reciprocating rotary instruments on the incidence of microcrack formation on the dentin surface of tooth root canals. Thirty-two extracted mandibular and maxillary first premolar teeth were collected and divided into two groups (n=16) as per the instrumentation protocol: group I: Continuous rotating (Protaper Universal file) and group II: Reciprocating (Wave One file). Each group was subsequently instrumented with the standardized working length assigned file system. The samples were collected to be tested following instrumentation and cut to identify the microcracks under 18-24x magnification under the microscope. Pearson Chi-Square test was used to statistically analyze the data. There is no statistically significant difference in the microcrack levels for both groups, which have p = 0.110 > 0.05. The rate of microcrack in the continuous rotating and reciprocating groups was not significantly different. Most incidence of the microcracks was experienced in the apical part (9mm) in both the continuous rotating and reciprocating groups, as opposed to the coronal (3mm) and middle (6mm) parts.

INTRODUCTION
The goals of root canal treatment are to preserve the oral cavity tooth's appearance and functionality, to get rid of bacteria and their byproducts from the root canal system, manage pain, control sepsis and abnormalities in the pulp and surrounding periapical tissue, and use the surrounding tissue to heal the damaged tooth and return it to a healthy state.[1-2] The "endodontic triad" is a three-phase root canal treatment that includes biomechanical treatment (cleaning and shaping), sterilization (irrigation and disinfection), and root canal filling.[1-3] Chemo mechanical root canal preparation, the process of eliminating bacteria from the root canal using mechanical instruments and antibacterial irrigation.[1-4]

In the mid-1800s, the first endodontic file was made, which was a standard stainless steel K-File, the kind used mostly in dental clinics, that was manually operated.[5] Subsequently, in 1963, W.F.Buehler, a metallurgist at the Naval Ordnance Laboratory in Silver Springs, Maryland, USA, discovered “nitinol”, an abbreviation for nickel (56%), titanium (44%), and Naval Ordnance

Laboratory (nol).[6] Nitinol's exceptional shape memory and flexibility allow it to properly prepare curved root canals without the need for straightening.[2,7]

Protaper Universal file system has a non-cutting, triangular cross-sectional guiding tip on its file system which improves cutting flexibility and efficiency. Three shaping files (two major shaping files, S1 and S2), one extra shaping file, SX, and five finishing files (F1, F2, F3, F4, and F5.5) make up the Protaper Universal file system.[5]

The transition of the manual to rotary preparation has taken place ever since the introduction of the NiTi rotary instruments in 1988. The invention of reciprocating NiTi files for root canal treatment in the 1950s by a French dentist paved the way for the creation of the fourth generation of NiTi rotary devices.[8] As a result, WaveOne (Dentsply Sirona), a new reciprocating instrument for single-file processing, was created using M-Wire alloy.[9]

Two distinct motion systems are used with NiTi rotary instruments: continuous rotation, which constantly revolves in 360° clockwise rotations. In addition to kinematics, the metallurgical properties and design characteristics of NiTi instruments, including alloy processing, cross-sectional geometry, and taper, influence stress distribution within root dentin. Variations between conventional NiTi and thermally treated alloys, such as M-Wire, may alter torsional and flexural behaviour, thereby affecting dentinal crack formation during instrumentation. The reciprocating file system moves in a repeated, bending-like back-and-forth action. The pressure on the instrument is decreased by rotating it counterclockwise 90° (cutting action) and clockwise 30° (release of instrument).[9] The purpose of endodontic instrumentation is to create canals that allow for appropriate closure and enlarge the diameter to remove tissue, debris, and bacteria. Complications such as perforation, ledge development, canal displacement, zip formation and separation of instruments are common. Nevertheless, the process of preparation may harm the root dentin, leading to microcracks or vertical root fractures (VRF).[10,11]

Dentinal microcracks formed during biomechanical preparation may compromise the structural integrity of endodontically treated teeth. These defects can propagate under functional occlusal forces, particularly after post placement or full-coverage restorations, potentially leading to catastrophic vertical root fracture. Therefore, preservation of dentinal integrity during canal preparation is essential not only for endodontic success but also for long-term restorative and prosthodontic prognosis.

During biomechanical preparation, the stress concentration between instruments and the apical dentin wall surface results in the formation of microcracks or craze lines. This might be associated with the increase in microcracks caused by the pressure from recurrent occlusal stresses, high concentration of sodium hypochlorite, tooth anatomy, placement of prosthetic posts, and root canal obturation technique.[12-14] Ageing may also change the evolution of the crack in the tooth; in fact, in young people, microcracks spread throughout the intertubular dentin, while in old people, throughout the peritubular dentin.[15]

Ravi AB et al. compared the frequency of dentin surface cracks in root canal treatment performed using two techniques: continuous rotation (ProTaper Universal and ProTaper Next) and reciprocating rotation (Reciproc and WaveOne). A high probability of microcracks develops with aggressive twisting movements that produce significant stress concentrations in the root canal walls,[12] but Yan W et al. study says continuous rotation instruments do not create nearly as many microcracks as reciprocating instruments.[16] According to Sharma S. et al., studied the effects of reciprocating and continuous rotation root canal instruments on apical dentin weakening. The outcome demonstrates that reciprocating and continuously rotating devices produced weak apical dentin.[17]

Earlier reports have related root canal operations with the emergence of dentinal defects mainly on the basis of sectioning the root and direct observation under the stereomicroscope. The cracks on the dentin that were seen in these methods may have developed during a tooth resection surgery or may have been existing before. Methylene blue dye can be a useful aid in endodontic surgery, and it's a preferred technique for assessing dentinal cracks.[15] Considering the importance of maintaining root strength to support subsequent restorative and prosthodontic procedures, evaluating the impact of different instrumentation systems on dentinal integrity is clinically relevant.

The study aimed to observe the effect and differences between continuously rotating and reciprocating rotary instruments on the microcrack formation of the dentinal wall.

MATERIAL AND METHODS

Thirty-two first premolar teeth extracted with one root from the mandible and maxilla were picked and stored in purified filtered water. The sample was calculated using past related in-vitro research conducted on the same, investigating the formation of dentinal microcracks and making sure that the power used was adequate to identify differences among groups. Teeth that are severely curved in the root, broken crown, caries and restoration were eliminated. A stereomicroscope was examined under 18-24x to identify any existing craze lines or cracks in all roots. The canals were catheterized with a #10 K-File (Denstply) into the canals. Then all teeth were dented in a block of gypsum up to cemento enamel junction. The method of making the root canals was the crown-down pressureless method. The teeth represented were also split into two groups (n=16) as follows:

In group I, the following sequence of NiTi Protaper Universal Shaping file (Dentsply, Sirona, USA): S1

(250rpm, 3-4 Ncm with *torque limit* 17) to prepare the coronal part root canal and S2 (250rpm, 1-1.5 Ncm with *torque limit* 20) to prepare and enlarge the middle part of the root canal, then Protaper Universal *Finishing* file (Dentsply, Sirona, USA): F1 (250rpm, 1.5-2 Ncm with *torque limit* 20), F2 (250rpm, 2-3 Ncm with *torque limit* 25) and F3 (250rpm, 2-3 Ncm with *torque limit* 30) was used to finish the root canal without further enlarging the coronal part of the root. The canals were prepared up to working length by means of PTU shaping and finishing, which is file number #25 with a taper of 0.06 at the apical area.

In group II, a primary reciprocating file NiTi WaveOne (Dentsply, Sirona, USA), where the file size is determined from the glide path size of the NiTi K-file: (06/20 - F15) and (06/40 - F25). The slow in and out pecking action of the contra-angle handpiece was performed by WO files and operated with an endomotor at a low-speed. Repeat K-File no.10 by making changes to the Protaper Universal and Wave One file.

Irrigation was done with saline and 3% sodium hypochlorite during and after root canal preparation. That irrigation solution was next activated using a sonic endo activator, and it was then neutralized with saline. Following a minute of irrigation with 17% EDTA, a saline solution was used to neutralize it. Paper point #25 was used to dry the canals after every irrigation. The randomization was done for the two groups in the two specimens randomly, through a computer-generated method to reduce allocation bias. The same experienced operator did all the procedures in order to make it standardized and minimize variability among operators.

Sectioning and Stereomicroscope Analysis

A 30-gauge irrigation syringe of 200 L of 1% ethylene blue dye was irrigated into the root canals of the teeth of the two groups in 24 hours. All roots were cross-sectioned into three (horizontal) sections at 3 mm (coronal), 6 mm(middle), and 9 mm (apical) using a low-speed saw and cooled in water. Each section was scanned at 18-24x with a Stereomicroscope (SZX16; Olympus, Tokyo, Japan) to obtain a digital image of each section. Dentinal defect assessment was conducted using two blinded examiners. Where there was a disagreement, consultation was made through discussion. Dentinal defects were assessed according to the description presented by Burkleain S. et al. (2013), Cicek E. et al. (2014) and Sharma S. et al. (2017). No defects were described as root dentine, which lacked craze lines or microcracks on the outer surface of the root and on the inside of the root canal. Defects (e.g., the score 1: a craze line, score 2: a partial crack, score 3: a complete crack) were scored. In each group, there were 48 slices calculated in 96 sections.

Score	Meaning
0	"No cracks: root dentin without lines or no cracks on the outer surface or walls of the root canal"
1	"Craze line: a line extending from the outer surface into the dentin but not reaching the root canal"
2	"Partial crack: a line extending from the root canal wall to the dentin without reaching the outer surface."
3	"Complete crack: a line extending from the root canal wall to the outer surface."

Statistical Analysis

The statistical data were analyzed with the help of statistical software SPSS 25.0. The statistics were described in frequency and percentage. The Pearson Chi-Square test that was used to test the difference between the two groups found the difference significant in terms of the p-value of less than 0.05.

RESULTS

Four categories are identified with corresponding scores of 0-3 based on the continuous rotating (Figure 1-4) and reciprocating (Figure 5-8) pictures captured by the stereomicroscope. The arrows indicate the formation of microcracks on the tooth section.

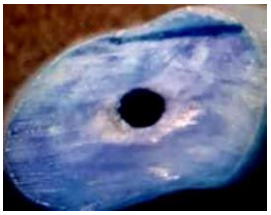


Figure 1. Score 0

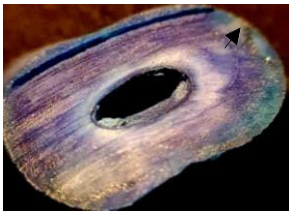


Figure 2. Score 1

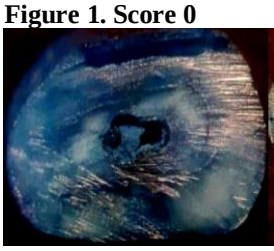


Figure 3. Score 2

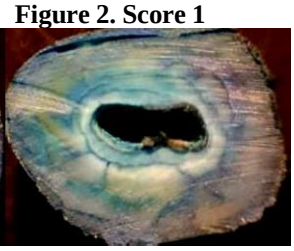


Figure 4. Score 3

Figure 5. Score 0

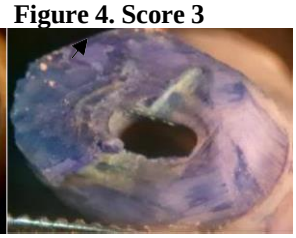


Figure 6. Score 1

Figure 7. Score 2

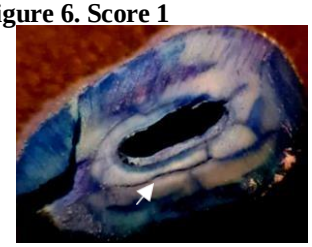
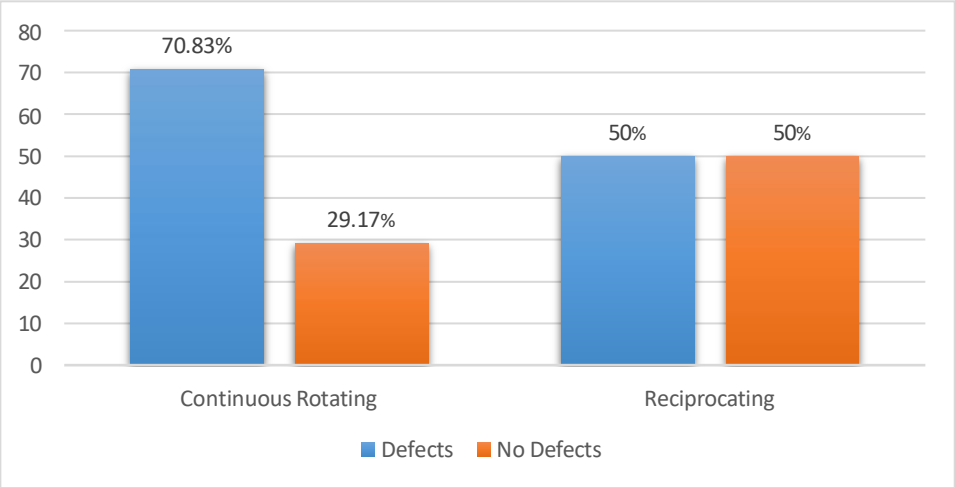


Figure 8. Score 3

Based on Table 1 and Graph 1, the data of the continuous rotating group indicates that 29.17% of the teeth did not have microcracks, but 70.83% of the teeth had microcracks. According to the reciprocating group, 50% of the teeth exhibited microcracks, while the other 50% of the teeth did not show any microcracks.

Table 1. Differences in the frequency and percentage of teeth showing microcracks between the continuous rotating and reciprocating groups.

Treatment groups/ Microcrack	Continuous Rotating n (%)	Reciprocating n (%)
Defect	34 (70.83)	24 (50)
No Defect	14 (29.17)	24 (50)
Total	48 (100)	48 (100)



Graphic 1. Differences in the percentage of teeth showing microcracks between the continuous rotating and reciprocating groups.

Table 2 shows that the coronal third of the tooth roots had the largest distribution of microcracks in the continuous rotating group, with a score of 0, 56.25%, and the lowest score of 2, representing no teeth. The middle section of the tooth root, 37.5%, had a microcrack score of 1, and 18.75% had the lowest values, which were scores 0 and 2, respectively. The highest microcrack scores for the apical section were 3, 62.5%, and 6.25% score 1. Furthermore, in the reciprocating group, the coronal third of the tooth roots had the greatest variation in microcracks, scoring 0, 75%, and the lowest score of 2, indicating no presence of any teeth. 50% of the middle section had a score of 0, while the lowest values, scoring 1, were found at 6,25%. In the apical section, the greatest microcrack scores were 2, 31,25%, and 18,75% score 1.

Table 2. Variations in the microcrack score distribution in one-third of the tooth roots

One-third of teeth roots with score/ Treatment groups	Continuous Rotating n (%)	Reciprocating n (%)
Coronal		
0	9 (56,25)	12 (75)
1	3 (18,75)	3 (18,75)
2	0	0
3	4 (25)	1 (6,25)
Middle		
0	3 (18,75)	8 (50)
1	6 (37,5)	1 (6,25)
2	3 (18,75)	2 (12,5)
3	4 (25)	5 (31,25)
Apical		
0	2 (12,5)	4 (25)
1	2 (6,25)	3 (18,75)
2	2 (12,5)	5 (31,25)
3	10 (62,5)	4 (25)

Based on Table 3 results show that, for the continuous rotating group, score 3 has the highest value, 64.3% of teeth have full cracks, while score 0 has the lowest, 36.8% of teeth have no cracks. According to the study's findings, the reciprocating group with the highest value, score 0, had 63.2% of teeth without cracks, while the group with the lowest value, score 3, had 35.7% of teeth with complete cracks. The microcrack scores of the continuous rotating and

reciprocating groups do not differ significantly according to the results of the Chi-Square test, with a significant p = 0.110 > 0.05.

Table 3. Analysis of differences in microcrack scores in the two treatment groups

Microcrack score/Treatment groups	0	1	2	3	p-value
	n (%)	n (%)	n (%)	n (%)	
Continuous rotating	14 (36,8)	11 (61,1)	5 (41,7)	18 (64,3)	p = 0,110
Reciprocating	24 (63,2)	7 (38,9)	7 (58,4)	10 (35,7)	
Total	38 (100)	18 (100)	12 (100)	28 (100)	

Although differences in percentage distribution were observed between the groups, these variations were not statistically significant, indicating comparable effects of both instrumentation systems on dentinal microcrack formation.

DISCUSSION

Preservation of dentinal integrity during root canal preparation is critical for maintaining the long-term structural stability of endodontically treated teeth. Dentinal defects created during instrumentation may act as stress concentration points that predispose teeth to fracture under functional loading, particularly after restorative or prosthodontic rehabilitation.

The present study showed that 70.83% of teeth prepared with a continuous rotating system showed dentinal defects, which is more than dentinal defects created by the reciprocating system (50%), which is in accordance with the study done by Sharma S. et al. The incidence of dentinal cracks was due to the reciprocating motion, different file design, and shorter preparation of the root canal.[17]

Our study indicated that there was the highest rate of microcrack formation when ProTaper Universal (PTU) was used to create a continuous rotating system. Similarly, Ted MC et al. observed more microcracks with the use of ProTaper Universal than ProTaper Next and Reciproc.[18] In another similar study conducted by Li S et al., observed more microcracks with the use of the ProTaper Universal and OneShape systems than with the use of the Reciproc and self-adjusting file systems.[19]

The PTU files have their convex triangle shape in the transversal plane; this gives the files a reduced efflux of debris on enlargement. Moreover, the files do not contain radial area; hence more deviation around the centre of the root. The feature could enhance the formation of microcracks as it causes additional stress on the dentin.[18]

The cross-sectional design, taper, and metallurgical characteristics of NiTi instruments influence the magnitude and distribution of stresses transmitted to root dentin. Instruments with greater taper may remove more dentin, potentially weakening root structure and increasing susceptibility to crack initiation. Additionally, thermally treated alloys such as M-Wire are designed to improve flexibility and reduce cyclic fatigue, which may contribute to altered stress patterns during instrumentation.

The NiTi instrument's kinematics of movement can affect the development of dentinal cracks. When cutting and shaping the root canal, reciprocal motion appears to permit the continuous release of the file interacting with the inner surface of the root canal. Repeat clockwise and counterclockwise rotations decrease flexural and torsional stresses in the dentin since the counterclockwise rotation disengages the instrument blades and decreases stress. Even though the reciprocating motion of the WaveOne system might also reduce the occurrence of dentinal cracks, its one-time usage and high taper size can still lead to the emergence of multiple dentinal defects. Single-use of 1 file is economical, and there are no chances of prion cross-contamination, file fatigue, and the time taken by practitioners to learn and acquire a new method is minimized.[18,19]

In a work where enlargement was effected by the use of the unique motion kinematics of rotary file systems, Priya et al. determined that the ProTaper Universal system produced more microcracking compared to the Reciproc, which was consistent with our results. However, some authors performed coronal enlargement with the presence of a Gates-Glidden drill and then used rotary file systems. We do believe that the findings of the research may differ due to the differences in methods used.[20,18]

Based on the study's results, more than half of the teeth in two groups had coronal and middle region scores of 0, and only 62,5% of the apical section in the continuous rotating group had a score of 3. The findings of this study are not similar to the study done by Sharma S. et al. and Monga P. et al.[17,21.] Continuous rotating system causes more dentinal defect is because the files have a triangular or modified triangular cross-section, which reduces the space available for the collection of dentine chips and causes stresses to be generated on the root dentinal wall. Additional stress may also result from its 7–9% taper of different files from F1 to F3.[17,21.]

According to Table 2, the reciprocating group of the coronal section has the highest number of teeth that do not have a microcrack, which is 75%. This result is almost the same with The findings of this study is almost similar with the study done by Sharma S et al.[17] It was found that the reciprocating movement is claimed to relieve stress on the instrument by special counterclockwise (cutting action) and clockwise (release of instrument) movements, and it is assumed that this movement reduces the risk of cyclic fatigue caused by tension and compression.[13]

A significant determinant of vulnerability to fractures is a decrease in the dentin wall thickness. In terms of the prosthodontic consideration, dentinal microcracks can undermine the retention and resistance form of post-core systems and have an increased tendency of vertical root fracture following the placement of the crowns.

Intracanal post-restored teeth experience greater functional stresses, which can propagate the already existing microcracks to complete fractures, eventually influencing the long-term treatment prognosis. Mostly, fractures were located in the apical and mid-root area, due to higher load located under the cemento-enamel junction.[17] The reciprocating instruments revealed fewer dentinal defects than the continuously rotating group. The results were statistically insignificant (p = 0,110 > 0,05), indicating that there is no significant difference between the two groups in terms of microcrack production. Similar findings were shown in the study done by Sharma S et al. with a p = 0,262 > 0,05. The absence of periodontal cushioning in produced samples, operator competence, and storage circumstances can all lead to the creation of root dentinal cracks. Clinical treatments such as post space preparation techniques or forces caused by obturation methods have the potential to further propagate these cracks. Simple masticatory pressures, parafunctional behaviours like bruxism, and occlusal stress can also have an impact on the development of partial cracks into complete root fractures.[17,19,21] Nonetheless, elimination of irregularities in the canal wall and creation of a smooth, round canal shape throughout the length of the canal should result in a more uniform stress distribution and lower overall stresses.[22]

The constraint of the current study was that the various teeth within the two jaws with varied root dentin thickness were not compared, which may indicate a great variation in findings because of the variations in strength and reaction to stresses when preparing the canals. The time of preparation was not taken into account either. Better results will be obtained when standardised protocols are used in further research.

CONCLUSION

According to the findings of this study, the difference in the incidence of microcracks was found to be higher in the group of carrying the continuous rotating rotary files than the reciprocating system though not significantly different. Microcracks were more common in the apical third (9 mm) than in the coronal (3 mm) and middle (6 mm) sides in both groups. Dentinal integrity is also of significance in biomechanical preparation to ensure the structural stability of the tooth under endodontic treatment even in cases where the tooth is to receive further restoration or prosthodontic restoration.

Acknowledgement:
The authors would like to thank Universitas Sumatera Utara for the Research Fund, Contract No. 512596/UN5.2.6.D/PT/2025

Declaration:
This study was approved by the Human Research Ethics Committee of Universitas Sumatera Utara and was performed in accordance with the tenets of the Declaration of Helsinki.

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