ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at:www.ijdsir.com

Volume – 9, Issue – 3, June – 2026, Page No. : 212 – 222

Incidence of Root Micro-Cracks Caused by 3 Different File Systems at Multiple Levels: A Stereomicroscopic Study

[1]C. Sunil Kumar, Professor and HOD, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

[2]Sreehitha Rajeswara Reddy, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

[3]Vamsee Krishna N, Associate Professor, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

[4]S. Sunil Kumar, Reader, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

[5]K. S. Chandrababu, Reader, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

[6]R. Bharathi Suma, Reader, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati

Corresponding Author: Sreehitha Rajeswara Reddy, Department of Conservative Dentistry and Endodontics, CKS Theja Institute of Dental Sciences and Research, Tirupati.

Citation of this Article: C. Sunil Kumar, Sreehitha Rajeswara Reddy, Vamsee Krishna N, S. Sunil Kumar, K. S. Chandrababu, R. Bharathi Suma, "Incidence of Root Micro-Cracks Caused by 3 Different File Systems at Multiple Levels: A Stereomicroscopic Study", IJDSIR – June – 2026, Volume – 9, Issue – 3, P. No. 212 – 222.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

The present in vitro study was conducted to evaluate and compare the incidence of dentinal microcrack formation associated with different endodontic file systems during biomechanical root canal preparation. Thirty-three freshly extracted human single-rooted permanent teeth with fully formed apices and intact root morphology were selected for the study. Standardized access cavity preparation and working length determination were performed for all specimens. The samples were randomly allocated into four groups and instrumented using group A (stainless steel hand K-files), group B (ProTaper Gold rotary files), group C (Neo Endo rotary files), and group D (WaveOne Gold reciprocating files) following their respective standardized protocols.

Following biomechanical instrumentation, all specimens were embedded in acrylic resin blocks and sectioned horizontally at the cervical, middle, and apical thirds. The sectioned samples were examined under a stereomicroscope at 40× magnification for assessment of dentinal microcracks. The data obtained were statistically analyzed using the Chi-square test, with a significance level set at $p < 0.05$.

The results demonstrated that samples in group B (Pro Taper Gold rotary files), exhibited the highest incidence of dentinal microcrack formation at the cervical and middle thirds, followed by group C (Neo Endo rotary files), group D (Wave One Gold reciprocating files). The samples in group A (stainless steel hand K-files) showed comparatively fewer dentinal defects across all levels. At the apical third, microcracks were observed only in the Neo Endo group. However, statistical analysis revealed no significant difference in the incidence of dentinal microcracks among the different instrumentation systems at cervical, middle, or apical levels ($p > 0.05$).

Keywords: Dentinal microcracks, root canal instrumentation, Pro Taper Gold, Wave One Gold, Neo Endo NiTi rotary systems, hand K-files

Introduction

Successful endodontic therapy relies on thorough cleaning, shaping, and disinfection of the root canal system while preserving the structural integrity of the tooth. Mechanical instrumentation is an essential step in root canal treatment; however, it inevitably generates stress within root dentin. This stress may lead to the formation of dentinal defects such as craze lines and microcracks, which are of clinical concern because they may propagate over time and compromise tooth integrity[1].

Dentinal microcracks are significant because they can act as precursors to vertical root fractures, which are among the most unfavorable complications in endodontically treated teeth. Once initiated, these microcracks may propagate under functional loading conditions, including mastication forces and occlusal stress, ultimately leading to catastrophic fracture and potential tooth loss. In addition, the presence of microcracks reduces the fracture resistance of root dentin by creating stress concentration zones that weaken the structural continuity of the tooth [2].

During biomechanical preparation, dentin is subjected to a combination of torsional stress, compressive forces, and tensile stress generated by rotating or reciprocating instruments. These stresses are influenced by several factors such as instrument taper, cross-sectional design, alloy properties, and kinematics of motion. Excessive dentin removal or uneven stress distribution along canal walls can increase the likelihood of crack initiation, particularly in the cervical and middle thirds of the root where instrumentation forces are generally higher [3].

Furthermore, dentinal defects may also affect the long-term prognosis of root canal-treated teeth by altering load distribution within the root structure. Microcracks can facilitate bacterial penetration and microleakage, potentially compromising the apical seal and contributing to reinfection. They may also propagate under cyclic loading conditions, especially in teeth restored with post-endodontic restorations, where additional functional stresses are applied [4].

The introduction of nickel–titanium (NiTi) rotary instrumentation has significantly improved shaping efficiency and flexibility compared to stainless steel hand instruments. However, despite these advantages, concerns remain regarding their potential to induce incidence of cracks due to continuous rotation or reciprocating motion, which may exert repetitive stress on canal walls [5].

Different NiTi file systems exhibit variations in design and motion. The ProTaper Gold system is a heat-treated rotary system designed to improve flexibility and cutting efficiency, while the WaveOne Gold system operates on a reciprocating motion intended to reduce continuous stress on dentin. The NeoEndo rotary system incorporates variable taper design aimed at balancing shaping efficiency and dentin preservation. However, the extent to which these systems influence dentinal microcrack formation remains unclear [6].

Stereomicroscopic evaluation has been widely used for identifying dentinal defects due to its ability to provide magnified visualization of root sections with reasonable accuracy. Sectioning methods combined with stereomicroscopy remain a reliable approach for assessing microcrack formation in experimental endodontic studies [7].

The present study aims to evaluate the incidence of dentinal microcrack formation observed in the root dentin following biomechanical preparation using stainless steel hand K-files, ProTaper Gold, NeoEndo, and WaveOne Gold instrumentation systems at cervical, middle, and apical root levels.

Materials and Methods

Study Design

The present in vitro study was designed to evaluate and compare the incidence of dentinal microcrack formation following biomechanical root canal preparation using different endodontic file systems.

This study was reviewed and approved by the Institutional Ethics Committee of C.K.S. Theja Institute of Dental Sciences and Research, Tirupati, Andhra Pradesh, India (Approval No. CKS/IEC-ENDO/2026/33).

Sample Selection

A total of thirty-three freshly extracted human single-rooted permanent teeth were selected for the study. Following extraction, all soft tissue remnants and calculus deposits were removed from the root surfaces using an ultrasonic scaler. The specimens were then disinfected and stored in normal saline solution at room temperature to maintain dentin hydration until further use.

Inclusion Criteria

Teeth fulfilling the following criteria were included:

- Completely formed apices
- Presence of a single root canal
- Intact root structure without visible defects

Exclusion Criteria

Teeth exhibiting any of the following conditions were excluded:

- Root caries
- Cracks or fractures
- Internal or external root resorption
- Calcified canals
- Previously endodontically treated teeth
- Teeth with open apices

Access Cavity Preparation and Working Length Determination

Standardized access cavity preparation was performed for all samples using an Endo Access bur mounted on a high-speed handpiece under continuous water cooling.

Canal patency was initially established using a size #10 K-file. Working length was determined by inserting the file into the canal until the tip was visualized at the apical foramen under magnification. One millimeter was subtracted from this measurement to establish the final working length for all specimens.

Grouping of Samples

The teeth were randomly allocated into four groups based on the file system used for biomechanical preparation.

Group A: Biomechanical preparation with stainless steel hand K-files up to size #40 using the step-back technique.

Group B: Biomechanical preparation with ProTaper Gold rotary files up to F2 following the manufacturer's recommended protocol.

Group C: Biomechanical preparation with Neoendo rotary file system up to size 20/.06 taper.

Group D: Biomechanical preparation with WaveOne Gold reciprocating file system up to Medium size.

Biomechanical Preparation

All biomechanical preparations were carried out by a single operator to ensure standardization and minimize operator-related variability.

During instrumentation, irrigation was performed using 3% sodium hypochlorite solution after each file change with a side-vented irrigation needle. A final rinse with normal saline was used to eliminate residual irrigant from the canal. EDTA gel was used as a lubricant throughout the procedure whenever required to facilitate smooth instrumentation.

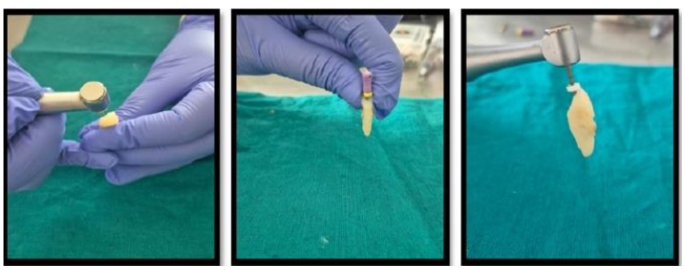


Figure 1: Root canal preparation done with respective file systems

Embedding of Specimens

After completion of biomechanical preparation, the external root surfaces were gently dried. Each tooth was then embedded vertically in self-cure acrylic resin blocks using cylindrical molds, ensuring that the coronal portion remained exposed. To simulate periodontal ligament conditions, a thin layer of silicone impression material was applied uniformly around the root surface before embedding the specimens in acrylic resin.

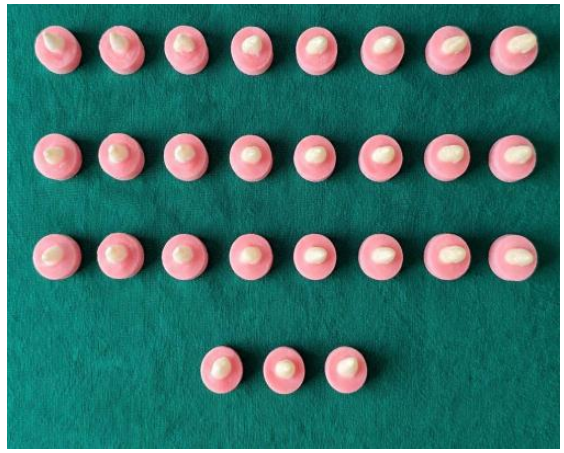


Figure 2: Prepared specimens were embedded in acrylic blocks

Sectioning Procedure

Horizontal sections were obtained from each specimen at the cervical, middle, and apical thirds using a hard tissue microtome under continuous water cooling. This procedure was performed carefully to avoid heat generation and to prevent the formation of artificial cracks. Each section was prepared to a uniform thickness of approximately 1 mm, ensuring minimal distortion and maintaining structural integrity.

Microscopic Examination

The sectioned specimens were examined under a stereomicroscope at 40× magnification to evaluate dentinal defects. Digital images were captured for documentation and analysis.

Dentinal conditions were classified as follows:

- **No defect:** Absence of craze lines or cracks within dentin.
- **Crack present:** Presence of a line extending from the root canal wall to the external root surface or vice versa.

All evaluations were performed by a blinded examiner to reduce observational bias.

Figure 3: All samples were sectioned with a uniform thickness of approximately 1 mm

Statistical Analysis

Data were analyzed using SPSS Version 21 (SPSS Inc., Armonk, NY, USA). Results were reported as the frequency of cracks in the 3 sections for each group. The Chi-square test was used to compare the frequency of cracks among the 4 groups, with $P < 0.05$ considered statistically significant

The collected data regarding dentinal crack incidence at cervical, middle, and apical levels were tabulated and statistically analyzed using appropriate tests.

Table 1: Comparison of Dentinal Crack Formation at Different Root Levels Using Various NiTi Instruments.

Instrument	Cervical n (%)	Middle n (%)	Apical n (%)
K-Files (n=9)	1 (33.3)	0 (0.0)	0 (0.0)
ProTaper Gold (n=30)	7 (70.0)	6 (60.0)	0 (0.0)
NeoEndo (n=30)	5 (50.0)	4 (40.0)	2 (20.0)
WaveOne Gold (n=30)	2 (20.0)	3 (30.0)	0 (0.0)
χ^2 value	5.304	4.100	4.897
p value	0.151	0.251	0.180

Chi-square test

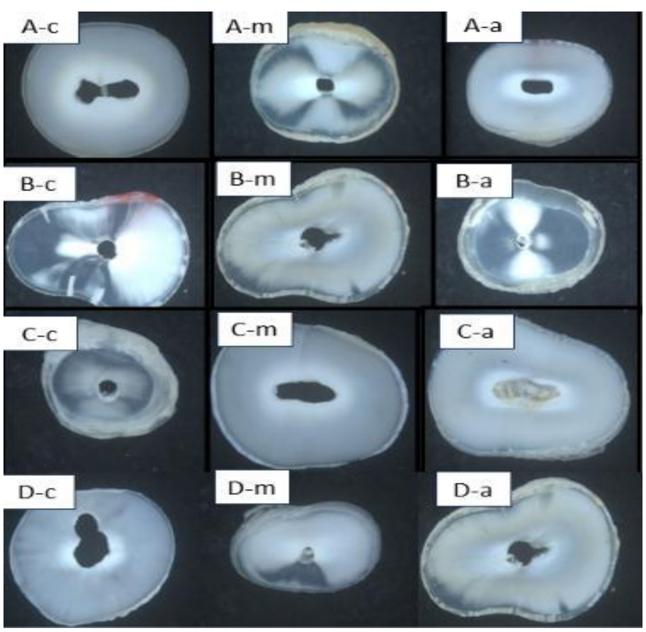
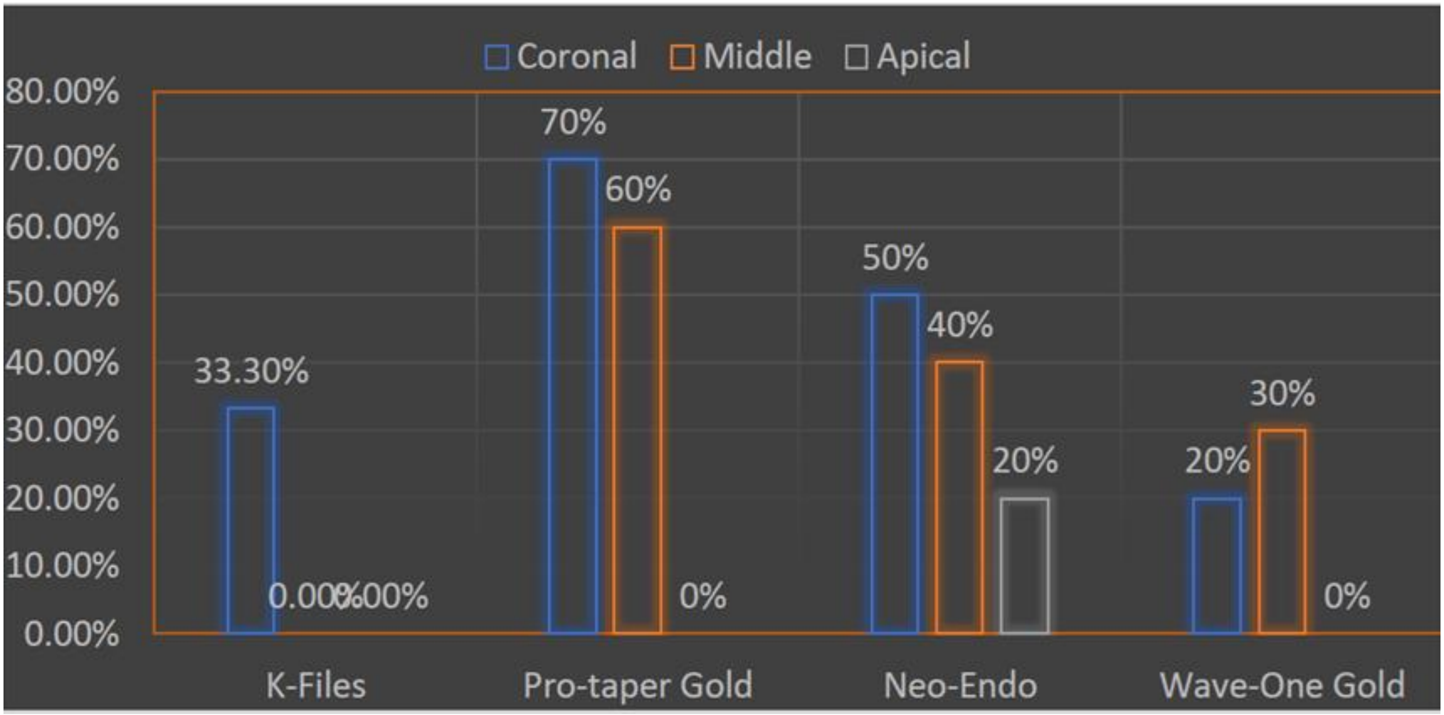


Figure 4: Digital image of each section at × 40 magnification using SEM (a) Hand File system; (b) pro tapered gold, (c) neo endo gold, (d) wave one gold. c- coronal, m-middle, a- apical



Graph 1: Percentage of dentinal crack at apical, middle and coronal third for all groups

The distribution of dentinal crack formation is presented separately for each instrument system in Table 1 and Figure 4.

Group A (K-files manual stainless steel file system):

K-Files showed dentinal crack formation in 1 sample (33.3%) at the cervical third, while no cracks were observed at the middle or apical thirds.

Group B (ProTaper Gold rotary file system):

ProTaper Gold demonstrated dentinal cracks in 7 samples (70.0%) at the cervical third and 6 samples (60.0%) at the middle third, with no crack formation at the apical third.

Group C (NeoEndo rotary file system):

NeoEndo exhibited dentinal crack formation in 5 samples (50.0%) at the cervical third, 4 samples (40.0%) at the middle third, and 2 samples (20.0%) at the apical third.

Group D (Wave One Gold reciprocating file system):

Wave One Gold showed dentinal cracks in 2 samples (20.0%) at the cervical third and 3 samples (30.0%) at the middle third, while no cracks were observed at the apical third.

At the apical level, dentinal cracks were observed only in Group C (Neo Endo rotary file system), whereas Groups A, B, and D showed no crack formation. Despite observable differences in crack incidence among the groups, statistical analysis using the Chi-square test revealed no significant differences at the cervical (χ^2 = 5.304, p = 0.151), middle (χ^2 = 4.100, p = 0.251), or apical levels (χ^2 = 4.897, p = 0.180).

Overall, although ProTaper Gold demonstrated the highest crack formation and WaveOne Gold the lowest, the differences among the four file systems were not statistically significant.

The results demonstrated varying degrees of crack formation among the tested instrumentation systems, with ProTaper Gold exhibiting the highest incidence of cracks, while WaveOne Gold and hand K-files showed comparatively lower crack formation.

Result and Discussion

Biomechanical preparation plays a fundamental role in successful endodontic therapy by facilitating adequate cleaning, shaping, and disinfection of the root canal system. Despite its importance, instrumentation procedures may generate stresses within root dentin that can lead to the development of dentinal defects such as craze lines and microcracks [7]. During root canal instrumentation using engine- driven instruments, high stress is concentrated on the walls of the root canal system which might lead to dentinal defects [3].

These defects are considered clinically significant because they may compromise the structural integrity of the tooth and predispose the root to vertical root fracture under functional loading conditions [8]. Dentinal microcracks may also reduce the fracture resistance of endodontically treated teeth by creating areas of stress concentration within the dentin [9]. Over time, repetitive occlusal and masticatory forces may contribute to propagation of these defects, eventually resulting in catastrophic root fracture and possible tooth loss [10]. Furthermore, microcracks may facilitate bacterial penetration and microleakage along dentinal walls, thereby affecting the long-term prognosis of root canal treatment [11].

The present in vitro study aims to evaluate and compare dentinal microcrack formation following biomechanical preparation using stainless steel hand K-files, ProTaper Gold rotary files, NeoEndo rotary files, and WaveOne Gold reciprocating files. The current study was conducted to evaluate the incidence of dentinal defects at cervical, middle, and apical thirds of the root using stereomicroscopic evaluation under 40× magnification.

In the present study, dentinal microcracks were observed in all experimental groups, although the differences among groups were statistically non-significant.

According to the findings from the current study the highest incidence of cracks was consistently observed at the cervical third, followed by the middle third, whereas the apical third demonstrated the least crack formation. This finding may be attributed to greater dentin removal and increased instrument contact in the coronal region during biomechanical preparation [12]. Larger canal diameter and greater taper preparation in the cervical region may result in increased tensile and compressive stress within root dentin [13].

In the current study the samples from group A (stainless-steel hand K-file) reported the least incidence of dentinal microcracks compared to BMP with other file systems. Crack formation was identified only at the cervical level, while no defects were observed at the middle or apical thirds. The lower incidence of cracks associated with hand instrumentation may be due to controlled nature of manual preparation techniques [7]. The step-back technique allows gradual enlargement of the canal with better tactile sensation and reduced rotational stress on canal walls. In comparison with rotary instrumentation systems, hand files remove dentin more conservatively and produce less torsional stress within root dentin [8].

Reduced engagement of the instrument with canal walls may therefore contribute to preservation of dentinal integrity [9].

The findings observed in the hand K-file group are in accordance with several previous investigations that reported fewer dentinal defects with manual instrumentation compared to rotary NiTi systems.

Previous studies have suggested that stainless steel hand files generate lower stress concentrations due to the absence of continuous rotational forces, thereby reducing the risk of crack initiation within root dentin [10].

According to the findings from the study among the rotary file systems used the sample in group B (ProTaper Gold) demonstrated the highest incidence of dentinal microcrack formation, particularly at cervical and middle levels. The cervical third exhibited 70% crack formation, while the middle third showed 60% crack formation. No defects were observed at the apical third. The greater incidence of dentinal defects associated with ProTaper Gold may be related to its progressive taper design and active cutting efficiency[11]. Instruments with larger taper remove greater amounts of dentin during shaping procedures and exert increased lateral stress on canal walls[12]. Continuous rotational motion further contributes to repetitive torsional and compressive forces within dentin, thereby increasing the possibility of crack formation [13].

Although ProTaper Gold is manufactured using heat-treated NiTi alloy that enhances flexibility and cyclic fatigue resistance, the aggressive shaping characteristics of the system may still produce considerable stress within root dentin. Greater dentin engagement, particularly in cervical and middle regions, may explain the higher incidence of cracks observed in the present study[7]. Similar findings have been reported by Bier et al. and Capar et al., who demonstrated increased dentinal crack formation associated with ProTaper systems because of their larger taper and continuous rotational movement [8].

A similar study was conducted by Sarin Koroth et al. (2021), on evaluation of root incidence of cracks associated with ProTaper Gold, WaveOne Gold, and ProTaper Next during cleaning and shaping procedures. The results showed more dentinal defects in ProTaper Gold samples, compared to WaveOne Gold samples, and ProTaper Next samples. The study concluded that all NiTi systems induced dentinal defects irrespective of motion kinematics.

The samples in group C (NeoEndo rotary system) demonstrated moderate dentinal crack formation at all root levels, including the apical third. Crack formation was observed in 50% of cervical sections, 40% of middle sections, and 20% of apical sections. Unlike the other instrumentation systems, detectable defects were noticed even in the apical region. This may indicate greater stress transmission toward the apical portion during canal preparation[9]. The 0.06 taper design and continuous rotational motion may contribute to increased dentin engagement and stress concentration within narrower apical regions [10].

Aacording to the findings, samples in group C (NeoEndo) produced relatively lower crack incidence at cervical and middle thirds compared to group B (ProTaper Gold). This may be attributed to differences in instrument design and cutting efficiency. However, the presence of cracks at all root levels suggests that the system still exerts substantial mechanical stress on root dentin during instrumentation[11]. Previous studies evaluating rotary NiTi systems have similarly reported that instruments with greater taper and active cutting blades may induce higher dentinal stress and contribute to crack formation [12].

According to the findings of the current study, the samples in group D (WaveOne Gold) demonstrated comparatively fewer dentinal microcracks compared to group B (ProTaper Gold) and group C (NeoEndo systems). Crack formation was observed at cervical and middle levels, while no defects were identified at the apical third. The comparatively lower incidence of cracks associated with group D (WaveOne Gold) may be attributed primarily to its reciprocating motion[13]. Reciprocation reduces continuous rotational stress on dentinal walls by alternating clockwise and counterclockwise movements, thereby minimizing torsional stress accumulation within root dentin [14].

The heat-treated Gold wire alloy used in WaveOne Gold files also improves flexibility and allows the instrument to adapt better to canal anatomy with reduced lateral pressure against canal walls [8]. In addition, its parallelogram cross-sectional design decreases the contact area between the instrument and dentin, thereby reducing stress generation during instrumentation [9]. These design characteristics may explain the lower incidence of dentinal defects observed in the present study. Similar findings have been reported in previous studies where reciprocating systems demonstrated fewer dentinal microcracks compared to continuous rotary systems because of improved stress distribution and reduced dentin engagement [15].

In the present study, the cervical third demonstrated the highest incidence of dentinal defects across all groups. This observation may be explained by increased instrumentation forces and greater taper preparation in the coronal portion of the root canal [11]. The middle third demonstrated comparatively lower crack incidence, whereas the apical third showed the least involvement overall. Reduced file engagement and smaller canal diameter at the apical level may contribute to decreased stress generation within apical dentin [12].

Although the differences among groups were statistically non-significant, the results suggest that instrument design, taper, and motion kinematics influence stress distribution within root dentin during biomechanical preparation [13]. Preservation of dentinal integrity remains an important consideration in endodontic treatment because excessive dentin removal and microcrack formation may compromise the long-term survival of endodontically treated teeth [16].

Conclusion

Within the limitations of the present study, all tested file systems produced varying degrees of dentinal microcrack formation. Samples in group B (ProTaper Gold) exhibited the highest incidence of cracks, possibly due to its greater taper and continuous rotational motion. The samples in group C (NeoEndo) demonstrated moderate crack formation at all root levels, including the apical third. The samples from group D (Wave One Gold) and group A (hand K-files) showed comparatively lower incidence of cracks, likely because of reciprocating motion and controlled instrumentation forces, respectively. The results emphasize the importance of instrument design and motion kinematics in preserving root dentin during biomechanical preparation.

References

1. Chandwani N, Ranka A, Jadhav GR, Jagyasi D, Bopche P, Golchha A. Effect of various single file systems on microcrack formation in root canals: Scanning electron microscope study. Dent Res J (Isfahan). 2021 Jul 19;18:52. PMID: 34497687; PMCID: PMC8404562.
2. Rahman H, Chandra A, Khangwal M, Goel A, Shakya VK. Stereomicroscopic Evaluation of Microcrack Formation in Dentin by ProTaper Next, Revo S, and WaveOne Gold File System. Contemp Clin Dent. 2021 Oct-Dec;12(4):439-443. doi: 10.4103/ccd.ccd_760_20. Epub 2021 Dec 21. PMID: 35068846; PMCID: PMC8740783.
3. Ashraf F, Shankarappa P, Misra A, Sawhney A, Sridevi N, Singh A. A Stereomicroscopic Evaluation of Dentinal Cracks at Different Instrumentation Lengths by Using Different Rotary Files (ProTaper Universal, ProTaper Next, and HyFlex CM): An Ex Vivo Study. Scientifica (Cairo). 2016; 2016: 8379865. doi: 10.1155/2016/8379865. Epub 2016 Jun 29. PMID: 27446636; PMCID: PMC 4942666.
4. Abdul-Hamed S, Jehad RH, Abdul-Ameer ZM, Al-Hashemi J. A stereomicroscopic analysis of dentinal micro cracks after root canal preparation using four different rotary instruments. Indian J Forensic Med Toxicol. 2020;14(1):397-402. doi:10.37506/ ijfmt. v14i1.78.

5. Panda A, Shah K, Budakoti V, Dere K, Virda M, Jani J. Evaluation of microcrack formation during root canal preparation using hand, rotary files and self-adjusting file in primary teeth: An in vitro study. J Dent Res Dent Clin Dent Prospects. 2021 Winter;15(1):35-41. doi: 10.34172/joddd.2021.007. Epub 2021 Feb 13. PMID: 33927839; PMCID: PMC8058155.
6. Shahi S, Bahari M, Samiei M, Yavari H, Mohammadzadeh S. Effect of RaCe, ProTaper, and V-Taper rotary systems on dentinal crack formation during endodontic treatment: An *in vitro* study. J Dent Res Dent Clin Dent Prospects. 2021 Fall;15(4):251-255. doi: 10.34172/joddd.2021.041. Epub 2021 Dec 5. PMID: 35070178; PMCID: PMC8760379.
7. Arumugam S, Yew HZ, Baharin SA, Qamaruz Zaman J, Muchtar A, Kanagasingam S. Micro-computed tomography evaluation of dentinal microcracks following canal preparation with thermomechanically heat-treated engine-driven files. Aust Endod J. 2021
8. Mariyam R, Khurana NS, Mann JS, Sidhu HS, A S, Mohan M. Comparative Evaluation of the Incidence of Dentin Microcracks Following Biomechanical Preparation Using Four Different Nickel-Titanium Rotary File Systems: An In Vitro Study. Cureus. 2024 Feb 3;16(2):e53506. doi: 10.7759/cureus. 53506. PMID: 38440012; PMCID: PMC10910425.
9. Gergi RM, Osta NE, Naaman AS. Dentinal crack formation during root canal preparations by the twisted file adaptive, Reciproc and WaveOne instruments. Eur J Dent 2015; 9:508-12. DOI: 10.4103/1305-7456.172634 Dec;47(3):520-530. doi: 10.1111/aej.12516. Epub 2021 May 6. PMID: 33956372; PMCID: PMC9291541.
10. Ustun Y, Aslan T, Sagsen B, Kesim B. The effects of different nickel-titanium instruments on dentinal microcrack formations during root canal preparation. Eur J Dent 2015; 9:41-6.
11. Yanık D, O zel Ş, Dag lı Taşman Co mert F. Brushing motion caused no microcracks: a micro-computed tomography study. Clin Oral Investig. 2025 Mar 10;29(3):173. doi: 10.1007/s00784-025-06253-0. PMID: 40063146; PMCID: PMC11893623.
12. Bilaiya S, Patni PM, Jain P, Raghuwanshi S, Pandey SH, Harinkhere C. Radicular dentinal microcracks during biomechanical root canal preparation using four minimally invasive endodontic files. Med Pharm Rep. 2022 Oct;95(4):455-460. doi: 10.15386/mpr-2455. Epub 2022 Oct 27. PMID: 36506600; PMCID: PMC9694748.
13. Arumugam S, Yew HZ, Baharin SA, Qamaruz Zaman J, Muchtar A, Kanagasingam S. Micro-computed tomography evaluation of dentinal microcracks following canal preparation with thermomechanically heat-treated engine-driven files. Aust Endod J. 2021 Dec;47(3):520-530. doi: 10. 1111/aej.12516. Epub 2021 May 6. PMID: 33956372; PMCID: PMC9291541.
14. Batra R, Dixit A, Tiwari A, Kumar A, Sinha S, Badnaware S, Singh R. Comparative Evaluation of Dentinal Defects After Root Canal Preparation Using Various Nickel Titanium Files: An In Vitro Study. Cureus. 2023 May 10;15(5):e38829. doi: 10.7759/ cureus.38829. PMID: 37303406; PMCID: PMC10252150.
15. Patil MB, Mandroli PS, Jalannavar P, Patil BB. Dentinal Microcracks after Root Canal Preparation in Primary Root: An *In Vitro* Evaluation of ProTaper Gold and Kedo-S Rotary File Systems. Int J Clin Pediatr Dent. 2023 Sep-Oct;16(5):692-697. doi:

10.5005/jp-journals-10005-2677. PMID: 38162241; PMCID: PMC10753097.

16. Cassimiro M, Romeiro K, Gominho L, de Almeida A, Costa L, Albuquerque D. Occurence of dentinal defects after root canal preparation with R-phase, M-Wire and Gold Wire instruments: a micro-CT analysis. BMC Oral Health. 2017 Jun 2;17(1):93. doi: 10.1186/s12903-017-0387-0. PMID: 28577367; PMCID: PMC5457538.