

Comparative Evaluation of Dentinal Crack Propagation after Root Canal Instrumentation Using HyFlex CM, WaveOne Gold and HyFlex EDM Nickel-Titanium File Systems: An In Vitro Stereomicroscopic Study

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Abstract: Background: Contemporary heat-treated nickel–titanium (NiTi) systems offer improved flexibility and fatigue resistance; however, instrumentation-related stresses may induce dentinal defects that can propagate into vertical root fractures. File design, taper, metallurgy, and kinematics may influence crack formation, although evidence remains conflicting. Aim: To compare dentinal crack propagation following root canal instrumentation with HyFlex CM, WaveOne Gold, and HyFlex EDM NiTi systems. Materials and Methods: Thirty-six extracted human single-rooted permanent teeth with mature apices were randomly allocated to three groups (n = 12). Canals were prepared using HyFlex CM (25/06), WaveOne Gold Primary (25/07), or HyFlex EDM OneFile (25/8v). Saline and 3% sodium hypochlorite were used for irrigation. Roots were horizontally sectioned at 3, 6, and 9 mm from the apex and examined under a stereomicroscope (×25). Dentinal defects were recorded at each root level and statistically compared. Results: WaveOne Gold showed the highest incidence of dentinal cracks at all levels. Crack formation was significantly greater with WaveOne Gold than with HyFlex CM (p = 0.003) and HyFlex EDM (p = 0.02), whereas no significant difference was observed between HyFlex CM and HyFlex EDM. Conclusion: WaveOne Gold produced significantly more dentinal crack formation than the HyFlex systems under the conditions of this in vitro study.

Keywords: Dentinal microcracks; HyFlex CM; HyFlex EDM; WaveOne Gold; Stereomicroscopy.

1. Introduction

Successful endodontic therapy depends on effective chemo-mechanical preparation of the root canal system while preserving the structural integrity of the tooth. The principal objectives of canal preparation are to eliminate infected tissue, facilitate irrigation, create adequate space for obturation, and maintain the original canal anatomy. The introduction of nickel–titanium (NiTi) instruments revolutionized endodontic practice because their superior flexibility and super elasticity enable safer preparation of curved canals with less canal transportation than stainless-steel hand instruments. Continued developments in alloy processing, instrument geometry, and manufacturing techniques have led to the introduction of heat-treated and controlled-memory NiTi systems with improved cyclic fatigue resistance and shaping performance¹.

Although contemporary NiTi systems have substantially improved shaping efficiency, concerns remain regarding the stresses generated within root dentin during instrumentation. Mechanical enlargement of the canal inevitably removes dentin and creates tensile and compressive stresses along the canal wall. When these stresses exceed the local strength of dentin, microscopic structural defects may develop in the form of craze lines, incomplete cracks, or complete fractures. These dentinal defects have attracted considerable attention because they have been proposed as possible precursors of vertical root fracture, one of the most catastrophic complications affecting endodontically treated teeth. The relationship between instrumentation-induced dentinal defects and long-term tooth survival therefore continues to be an important area of endodontic research².

The development of dentinal defects is considered multifactorial. Instrument taper, cross-sectional geometry, cutting efficiency, alloy characteristics, canal anatomy, rotational kinematics, irrigation protocols, and operator technique all influence the magnitude and distribution of stresses within radicular dentin. Instruments with larger tapers may remove greater amounts of dentin and generate increased contact forces against canal walls, whereas instruments manufactured from thermomechanically treated alloys generally exhibit lower restoring forces and greater flexibility, potentially reducing stress concentration during canal preparation. Consequently, the selection of an appropriate instrumentation system may have important implications for preserving root integrity¹.

During the past decade, heat-treated NiTi instruments have undergone substantial metallurgical refinement. Controlled Memory (CM) wire technology was developed to reduce the predominance of the austenitic phase at clinical temperatures, thereby producing instruments with greater flexibility and reduced shape-memory behavior. HyFlex CM is one such multiple-file rotary system manufactured from CM wire. Its enhanced flexibility, reduced restoring force, and resistance to cyclic fatigue enable the instrument to conform more closely to canal curvature while minimizing unnecessary dentin removal. These properties have been associated with improved shaping ability and a potentially lower risk of dentinal damage compared with conventional NiTi instruments¹.

Among the recently introduced heat-treated nickel–titanium systems, WaveOne Gold has gained widespread acceptance because of its simplified single-file concept, improved

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flexibility, and enhanced resistance to cyclic fatigue. The instrument is manufactured from Gold-wire NiTi alloy through proprietary post-manufacturing heat treatment, which modifies the transformation temperatures of the alloy and increases the proportion of martensitic phase at clinical temperatures. Compared with the original WaveOne system, WaveOne Gold possesses a parallelogram cross-section with alternating cutting edges that reduces the contact area between the instrument and canal wall while maintaining cutting efficiency.

Furthermore, the reciprocating kinematics employed by the system were developed to decrease torsional stress and instrument separation during canal preparation. Despite these advantages, reciprocating instrumentation repeatedly engages and disengages dentin, generating alternating compressive and tensile stresses that may influence dentinal defect formation, particularly in narrow canals or during preparation with greater taper instruments. Consequently, the effect of reciprocating motion on dentinal crack propagation remains controversial³.

Another important development in NiTi metallurgy is the introduction of HyFlex EDM, which is manufactured using electrical discharge machining (EDM) technology. Unlike conventional grinding, EDM modifies the instrument surface by controlled electrical discharges, producing a hardened surface with increased resistance to cyclic fatigue while preserving the flexibility associated with controlled-memory alloys. The instrument exhibits variable cross-sectional geometry along its working length, including a rectangular cross-section apically, trapezoidal geometry in the middle third, and triangular geometry coronally. This design aims to balance cutting efficiency, flexibility, and resistance to fracture. Because of its enhanced flexibility and reduced restoring force, HyFlex EDM has been reported to preserve canal anatomy effectively while reducing stress transmission to radicular dentin during instrumentation⁴.

Although considerable attention has been directed toward instrumentation-induced dentinal defects, the biological significance of these defects remains uncertain. Early investigations using stereomicroscopy after root sectioning frequently reported a higher incidence of dentinal cracks following root canal preparation. These studies suggested that larger tapers, aggressive cutting efficiency, and certain kinematic motions could increase stress concentration within dentin and initiate crack formation. However, advances in high-resolution micro-computed tomography (micro-CT) and synchrotron radiation-based micro-CT have challenged these observations. By comparing the same specimens before and after instrumentation, several investigators demonstrated that many dentinal defects identified after instrumentation were already present before canal preparation and became visible only after sectioning or image analysis. These findings have generated substantial debate regarding whether instrumentation actually creates new defects or merely propagates pre-existing structural discontinuities⁵.

Despite these controversies, evaluation of dentinal crack propagation continues to be clinically relevant because preservation of radicular dentin is fundamental for the long-

term survival of endodontically treated teeth. Vertical root fracture remains one of the principal causes of extraction of root-filled teeth, and any instrumentation system capable of minimizing unnecessary dentin removal and reducing stress concentration may improve long-term prognosis. Furthermore, improvements in alloy processing, heat treatment, and manufacturing technology have resulted in continuous evolution of NiTi instruments, making comparative evaluation of contemporary systems essential for evidence-based instrument selection¹.

Comparisons among HyFlex CM, WaveOne Gold, and HyFlex EDM are relatively limited, particularly when all three contemporary heat-treated systems are evaluated under identical experimental conditions. These instruments differ substantially in alloy processing, manufacturing method, taper, cross-sectional geometry, and kinematics, all of which may influence stress distribution within radicular dentin. Therefore, direct comparison of these systems may provide valuable information regarding their potential to preserve root integrity during biomechanical preparation.

Accordingly, the present in vitro study was undertaken to compare dentinal crack propagation following root canal instrumentation using HyFlex CM, WaveOne Gold, and HyFlex EDM file systems by stereomicroscopic evaluation of root sections obtained from the coronal, middle, and apical thirds.

2. Materials and Methods

Sample Selection

Thirty-six freshly extracted human permanent single-rooted teeth with fully formed apices were selected for the study. The teeth were obtained following extraction for periodontal or orthodontic reasons and were cleaned of adherent soft tissue and calculus using an ultrasonic scaler. Teeth were examined under magnification to exclude visible cracks or structural defects before inclusion in the study.

Inclusion Criteria

- Human permanent single-rooted teeth
- Fully developed apices
- Single canal
- Intact roots
- No previous endodontic treatment
- No internal or external root resorption
- No visible craze lines or fractures
- Patent root canal

Exclusion Criteria

- Teeth with root caries.
- Teeth with restorations extending into the root
- Teeth with calcified canals
- Teeth with immature apices
- Teeth with multiple canals
- Teeth with severe root curvature ($>25^\circ$)
- Teeth exhibiting pre-existing cracks

Following selection, specimens were stored in 10% buffered formalin. OSHA guidelines were followed during the collection and storage of the samples.

Standardization of Specimens

To minimize variability, all crowns were removed using a diamond disc under copious water irrigation, producing standardized root lengths.

Endodontic access cavities were prepared using Endo Access burs. Canal patency was confirmed using a size 10 K-file.

The working length was established by advancing the file until its tip became visible at the apical foramen and subtracting 1 mm from the measured length.

This protocol standardized canal preparation among all specimens.

Randomization

The thirty-six specimens were randomly assigned into three experimental groups (n = 12) : **Group I** - HyFlex CM (25/.06); **Group II** - WaveOne Gold Primary (25/.07); **Group III** - HyFlex EDM OneFile (25/8v).

Root Canal Instrumentation

Instrumentation was performed by a single experienced operator to eliminate operator-dependent variability.

Each file system was used according to the manufacturer's instructions.

Group I – HyFlex CM

Instrumentation was completed using the HyFlex CM rotary sequence until the master apical preparation reached size 25 with 0.06 taper.

Group II – WaveOne Gold

Instrumentation was performed using the WaveOne Gold Primary instrument (25/.07) in reciprocating motion until the working length was reached.

Group III – HyFlex EDM

Instrumentation was carried out using the HyFlex EDM OneFile system according to the manufacturer's recommended protocol.

Throughout instrumentation, canal patency was maintained using a size 10 K-file.

Irrigation Protocol

After each instrument, canals were irrigated with saline and

3% sodium hypochlorite (NaOCl) delivered using a 27-gauge side-vented irrigation needle positioned as close as possible to the working length without binding. The canals were irrigated throughout instrumentation to remove debris and facilitate disinfection.

Sectioning Procedure

Following completion of canal preparation, the roots were sectioned horizontally at:

- 3 mm from the apex (apical third)
- 6 mm from the apex (middle third)
- 9 mm from the apex (coronal third)

Sectioning was performed using a low-speed diamond disc under continuous water cooling to minimize the introduction of sectioning artifacts.

Each specimen yielded three cross-sectional slices for evaluation.

Stereomicroscopic Evaluation

Each section was examined under a stereomicroscope at $\times 25$ magnification. The images were evaluated for the presence or absence of dentinal defects.

A dentinal crack was defined as any line extending from the root canal lumen toward the external root surface or from the external root surface toward the canal lumen.

The observations were recorded independently for the coronal, middle, and apical thirds.

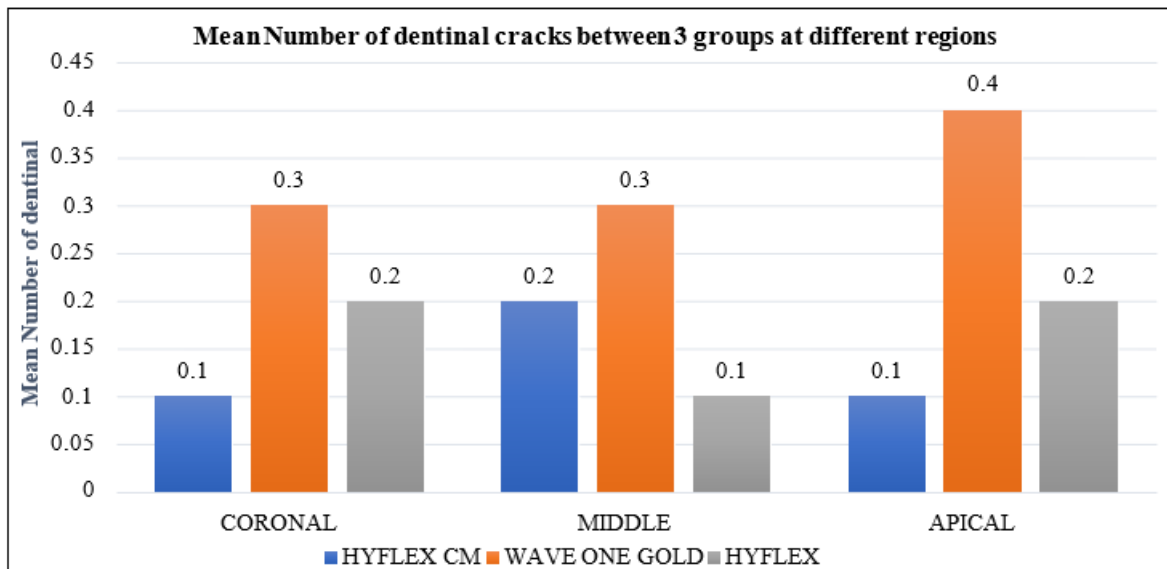
Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using SPSS software (version XX; IBM Corp., Armonk, NY, USA).

Descriptive statistics including mean and standard deviation were calculated. Intergroup comparisons were performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc multiple comparison test.

The level of statistical significance was set at $p < 0.05$.

3. Result



Multiple comparison between groups in Coronal, middle and apical regions demonstrated that Group II showed significantly higher mean number of cracks as compared to Group I & Group III and the mean differences were statistically significant at $p=0.003$ & $p=0.02$ respectively. However, no significant difference was observed in the mean number of cracks between Group I & Group III. This infers that the mean number of dentinal cracks was significantly higher in Group II, followed by Group III and Group I, with no difference between Group I & Group III.

4. Discussion

The primary objective of root canal instrumentation is to achieve effective debridement and shaping of the root canal system while preserving the structural integrity of radicular dentin. The introduction of nickel–titanium (NiTi) instruments has substantially improved the efficiency and predictability of endodontic treatment because of their superior flexibility, cutting efficiency, and ability to maintain the original canal anatomy. However, instrumentation inevitably generates mechanical stresses within dentin, and these stresses have been implicated in the initiation or propagation of dentinal defects. Such defects have attracted considerable attention because they are considered potential precursors of vertical root fractures, one of the most catastrophic complications affecting the long-term prognosis of endodontically treated teeth. Consequently, contemporary endodontic research has focused not only on the shaping ability of NiTi systems but also on their ability to preserve dentinal integrity during canal preparation^{6,7}.

The present study compared dentinal crack propagation following instrumentation with three contemporary heat-treated NiTi systems—HyFlex CM, HyFlex EDM, and WaveOne Gold. The findings demonstrated that WaveOne Gold produced significantly greater dentinal crack propagation than both HyFlex CM and HyFlex EDM, whereas no statistically significant difference was observed between the two HyFlex systems. These results suggest that although all three instruments are manufactured using advanced thermomechanical technologies, differences in alloy characteristics, instrument design, taper, and kinematic

motion significantly influence stress transmission to radicular dentin.

Dentinal crack formation during instrumentation is considered a multifactorial phenomenon. During canal preparation, rotating or reciprocating instruments generate tensile, compressive, radial, and shear stresses at the dentin–instrument interface. The magnitude of these stresses depends on several variables, including canal anatomy, remaining dentin thickness, instrument flexibility, taper, cross-sectional geometry, cutting efficiency, and instrumentation technique. When the generated stresses exceed the tensile strength of dentin, microscopic defects may initiate or pre-existing structural discontinuities may propagate. Peters emphasized that successful biomechanical preparation should balance effective cleaning with maximum preservation of root dentin, thereby minimizing the risk of structural damage during treatment⁶.

Among the three systems evaluated, HyFlex CM demonstrated the lowest incidence of dentinal crack formation, which may be attributed primarily to its controlled-memory (CM) metallurgy. HyFlex CM instruments are manufactured using proprietary thermomechanical processing that modifies the phase transformation behavior of the NiTi alloy, producing an instrument that exists predominantly in the martensitic phase at clinical temperatures.

Compared with conventional superelastic NiTi instruments, CM-wire files exhibit significantly greater flexibility, reduced shape-memory effect, and lower restoring forces^{8,9}. These properties allow the instrument to closely follow the natural canal curvature while exerting lower lateral pressure against canal walls, thereby reducing stress concentration within radicular dentin. Reduced restoring force is particularly advantageous in curved canals because it minimizes the tendency of the instrument to straighten during rotation, a phenomenon that contributes to increased stress generation and unnecessary dentin removal.

Another factor that may explain the favorable performance of HyFlex CM is its multiple-file instrumentation sequence. Progressive enlargement distributes dentin removal over

several instruments rather than concentrating preparation stresses within a single file. This sequential enlargement reduces the mechanical load applied during each stage of preparation and permits more conservative shaping of the canal. Previous studies have consistently reported that CM-wire instruments demonstrate superior cyclic fatigue resistance and flexibility compared with conventional NiTi systems, enabling more centered canal preparation with reduced transportation and lower stress transmission to dentinal walls⁹⁻¹¹. Consequently, the lower incidence of dentinal cracks observed with HyFlex CM in the present study is biologically plausible and consistent with the favorable mechanical behavior reported for controlled-memory instruments. HyFlex EDM demonstrated a similarly low incidence of dentinal defects, with no statistically significant difference compared with HyFlex CM. This finding suggests that both systems effectively preserve radicular dentin despite differences in manufacturing technology. HyFlex EDM represents a further development of controlled-memory metallurgy through the application of Electrical Discharge Machining (EDM), an innovative manufacturing process in which controlled electrical sparks modify the surface characteristics of the instrument instead of conventional grinding. This process creates a hardened surface layer with increased resistance to cyclic fatigue while maintaining the flexibility associated with CM-wire alloys¹². Enhanced fatigue resistance reduces the risk of instrument deformation during canal preparation and may also contribute to more uniform stress distribution within dentin.

The unique design of HyFlex EDM may further explain its favorable performance. Unlike instruments with a uniform cross-section, HyFlex EDM incorporates a variable cross-sectional geometry consisting of rectangular, trapezoidal, and triangular sections along its working length. This design aims to optimize cutting efficiency while preserving flexibility and minimizing unnecessary contact between the instrument and canal wall. Reduced contact decreases frictional resistance and lowers the radial forces transmitted to dentin during instrumentation. Shen and co-workers demonstrated that advances in thermomechanical processing have significantly improved the mechanical behavior of contemporary NiTi instruments by enhancing flexibility and reducing restoring forces, thereby improving their ability to preserve canal anatomy⁸. Likewise, Tanomaru-Filho M et al. reported that heat-treated NiTi alloys exhibit greater cyclic fatigue resistance and flexibility than conventional instruments, characteristics that may reduce dentinal stress during biomechanical preparation¹³.

In contrast, WaveOne Gold exhibited the highest incidence of dentinal crack propagation among the three systems. Although the Gold-wire heat treatment improves the flexibility and mechanical properties of the instrument compared with conventional NiTi instruments, instrument design remains an important determinant of the stresses generated within radicular dentin. The Primary WaveOne Gold instrument has a tip size of 25 with a 0.07 taper, whereas the HyFlex CM instrument used in the present study has a 0.06 taper. A greater instrument taper may result in greater dentin engagement and removal, thereby reducing the remaining dentin thickness and potentially increasing

stress concentration within the root dentin. Finite-element analyses have demonstrated that NiTi instrument geometry and taper influence stress distribution in the apical root dentin, with larger and stiffer instrument designs producing greater stress concentrations¹⁴. Furthermore, studies evaluating dentinal defects have associated more aggressive taper designs and greater dentin removal with increased dentinal damage, particularly in the apical region where the remaining dentin is relatively thin¹⁵.

Another important factor is the reciprocating kinematics of WaveOne Gold. Reciprocation was developed to reduce torsional stress and improve resistance to instrument fracture by alternating clockwise and counterclockwise rotation. While this motion has been shown to improve instrument longevity and maintain canal curvature, its influence on dentinal crack formation remains controversial. Bürklein and Schäfer demonstrated that reciprocating instruments exhibit excellent shaping ability while maintaining the original canal anatomy¹⁶. Conversely, several laboratory studies have suggested that repeated engagement and disengagement of the instrument with canal walls may generate intermittent stress concentrations capable of initiating dentinal defects, particularly when instruments with larger taper are used^{17,18}. Therefore, the greater crack incidence observed with WaveOne Gold in the present investigation is more likely the result of the combined effects of taper, cross-sectional geometry, alloy characteristics, and reciprocating motion rather than kinematics alone.

The findings of the present study are consistent with several investigations demonstrating that thermomechanically treated NiTi instruments preserve radicular dentin more effectively than conventional rotary systems. However, comparison among published studies should be interpreted cautiously because dentinal crack formation is influenced by numerous methodological variables, including tooth type, canal anatomy, root curvature, apical preparation size, irrigation protocols, evaluation methods, and definitions of dentinal defects. Such heterogeneity partly explains the conflicting conclusions reported in the literature and underscores the importance of standardized experimental protocols when comparing different instrumentation systems.

The favorable performance of HyFlex CM observed in the present study is supported by previous investigations evaluating the influence of controlled-memory alloys on root dentin preservation. Shen et al. demonstrated that CM-wire instruments exhibit significantly lower restoring forces than conventional superelastic NiTi files because of their predominantly martensitic microstructure, allowing better adaptation to canal curvature while minimizing lateral pressure against dentinal walls¹⁹. Similarly, Pedulla E et al. reported that improved flexibility associated with thermomechanical treatment decreases the tendency of the instrument to straighten within curved canals, thereby reducing unnecessary dentin removal and stress concentration²⁰. These metallurgical characteristics are particularly advantageous in curved or anatomically complex canals, where excessive restoring forces may contribute to canal transportation and structural damage.

Another explanation for the reduced crack incidence associated with HyFlex CM is its conservative instrumentation philosophy. Unlike single-file systems, HyFlex CM employs a sequential preparation protocol that distributes mechanical stresses over multiple instruments. Progressive enlargement reduces the amount of dentin removed by each instrument and limits localized stress accumulation. Peters and Paqué emphasized that preservation of root dentin should be considered a fundamental objective of modern endodontic instrumentation because excessive dentin removal may adversely affect the long-term fracture resistance of treated teeth ²¹. Therefore, the present findings reinforce the concept that conservative canal enlargement, combined with flexible instrument metallurgy, contributes to better preservation of radicular integrity.

HyFlex EDM demonstrated a comparable incidence of dentinal defects, indicating that the Electrical Discharge Machining (EDM) manufacturing process does not compromise the favorable mechanical behavior associated with controlled-memory alloys. EDM technology produces a hardened surface through electrical spark erosion rather than conventional grinding, creating a unique surface morphology with enhanced wear resistance and exceptional cyclic fatigue resistance. Pirani et al. reported that HyFlex EDM exhibits significantly greater fatigue resistance than many contemporary NiTi systems, largely because of the combined effects of CM metallurgy and EDM surface modification ¹².

Improved fatigue resistance allows the instrument to negotiate curved canals with lower restoring forces and reduced stress transmission to root dentin.

The variable cross-sectional design of HyFlex EDM may have further contributed to its performance. Instrument cross-section directly influences flexibility, cutting efficiency, chip space, torsional resistance, and contact area with dentinal walls. Instruments possessing a smaller core diameter generally exhibit lower stiffness and transmit reduced radial forces to canal walls. Conversely, larger core diameters increase rigidity and may generate greater mechanical stresses during instrumentation. The combination of CM metallurgy, variable cross-sectional geometry, and EDM manufacturing likely explains why HyFlex EDM demonstrated crack propagation comparable to HyFlex CM despite being a single-file system.

In contrast, WaveOne Gold produced significantly more dentinal cracks than both HyFlex systems. Although Gold-wire heat treatment improves flexibility and cyclic fatigue resistance compared with the original WaveOne system, several design characteristics may account for its performance. The Primary WaveOne Gold instrument possesses a greater taper (25/.07), which inevitably removes more dentin than the HyFlex CM finishing instrument (25/.06).

Greater taper has repeatedly been associated with increased stress concentration within radicular dentin, particularly in the apical region where remaining dentinal thickness is minimal ¹⁴. Excessive dentin removal not only weakens root

structure but also increases the likelihood of crack initiation and propagation under functional loading.

Reciprocating motion has also been proposed as a factor influencing dentinal crack formation. The alternating clockwise and counterclockwise movement reduces torsional stress and instrument binding, thereby improving resistance to instrument separation. Plotino et al. concluded that reciprocation represents an important advance in NiTi instrumentation because it enhances cyclic fatigue resistance without compromising shaping ability ²².

However, other investigators have suggested that repeated engagement and disengagement of the cutting blades with dentinal walls may generate intermittent stress concentrations capable of propagating microstructural defects ^{23,24}. Consequently, the influence of reciprocation on dentinal crack formation remains controversial. The present results support the concept that kinematics alone cannot explain crack formation; rather, the observed differences likely result from the interaction between reciprocating motion, greater taper, cross-sectional geometry, cutting efficiency, and alloy properties.

Another noteworthy finding of the present study was the greater frequency of dentinal defects within the apical third. Similar observations have been reported by Adorno et al. and Karataş et al., who demonstrated that crack formation is most prevalent in the apical region following biomechanical preparation ¹⁷. Anatomically, apical dentin is thinner and less capable of dissipating instrumentation-induced stresses than coronal dentin. Furthermore, apical enlargement concentrates mechanical forces within a relatively confined region of the root, making this area particularly susceptible to crack propagation. These findings emphasize the importance of conservative apical enlargement and careful selection of instrument taper, especially in teeth with thin roots or severe canal curvature.

Despite the agreement of the present findings with several sectioning-based studies, it is important to acknowledge that dentinal crack research remains one of the most debated topics in contemporary endodontics. Early stereomicroscopic investigations consistently reported that rotary instrumentation induced dentinal defects. However, the introduction of high-resolution micro-computed tomography (micro-CT) has substantially altered current understanding of this phenomenon. By evaluating the same specimens before and after instrumentation without destructive sectioning, De-Deus and co-workers demonstrated that many defects identified after preparation were already present before instrumentation and became evident only after sectioning ²⁵. These observations suggest that at least some defects previously attributed to instrumentation may actually represent pre-existing structural discontinuities or artifacts produced during specimen sectioning.

5. Conclusion

Within the limitations of this in vitro study, all three thermomechanically treated nickel–titanium instrumentation systems produced dentinal crack propagation following root

canal preparation. However, significant differences were observed among the systems evaluated. HyFlex CM and HyFlex EDM demonstrated a significantly lower incidence of dentinal cracks than WaveOne Gold, whereas no statistically significant difference was found between HyFlex CM and HyFlex EDM. The superior performance of the HyFlex systems may be attributed to their controlled-memory metallurgy, enhanced flexibility, lower restoring forces, and more favorable stress distribution during canal preparation. In contrast, the greater crack propagation observed with WaveOne Gold is likely related to the combined influence of its larger taper, reciprocating kinematics, and instrument design rather than a single design characteristic.

Although these findings suggest that instrument metallurgy and design may influence dentinal crack formation, the clinical significance of such defects remains uncertain because recent nondestructive micro-computed tomography studies have questioned whether all observed cracks are truly instrumentation-induced. Therefore, the results should be interpreted with caution and should not be considered direct evidence of an increased risk of vertical root fracture in clinical practice.

Further well-designed in vivo and micro-computed tomography-based longitudinal studies with larger sample sizes are required to determine whether the differences observed among contemporary nickel-titanium instrumentation systems translate into clinically significant outcomes and influence the long-term survival of endodontically treated teeth.

The selection of nickel-titanium instrumentation systems with improved flexibility and controlled-memory metallurgy may help preserve radicular dentin during root canal preparation. Instruments such as HyFlex CM and HyFlex EDM demonstrated reduced dentinal crack propagation under the conditions of this study, suggesting their potential advantage in maintaining root integrity, particularly in teeth with thin roots or complex canal anatomy. Nevertheless, clinical decision-making should consider the overall shaping ability, disinfection efficacy, and operator experience, as the relationship between dentinal microcracks and long-term clinical outcomes remains inconclusive.

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