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Original Article

Comparative Evaluation of the Effect of Different Torques on Dentinal Crack Formation after Root Canal Preparation using Heat-treated Rotary Instruments: An *In Vitro* Study

Sneha Chandran[1], Chandini Raveendran[2], Elsy P Simon[3], Rohit Mathew[4], M V Veena[4], Nimmy Kurian[4]

[1]MDS 3rd Year Post Graduate Student, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Mukkam, Kozhikode, India, [2]MDS and Reader, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Mukkam, Kozhikode, India, [3]MDS and Professor and HOD, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Mukkam, Kozhikode, India, [4]MDS and Senior Lecturer, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Mukkam, Kozhikode, India

Abstract

Aim: This study aims to compare and evaluate the formation of dentinal cracks during root canal preparation using a heat-treated rotary system at three different torque settings.

Subjects and Methods: An *in vitro* study was conducted on 32 extracted human premolars, divided into four groups. Group 1 served as a control (no preparation), whereas Groups 2, 3, and 4 underwent canal instrumentation using EdgeEndo heat-treated nickel–titanium rotary files at standard (2.5 N/cm^2), high (3.5 N/cm^2), and low (2.0 N/cm^2) torque settings, respectively. Instrumentation was performed at a constant speed of 350 rpm. Samples were sectioned horizontally at 6 mm and 9 mm from the apex and evaluated under a stereomicroscope at ×40 magnification for the presence of dentinal cracks.

Results: The incidence of dentinal cracks was highest in the high-torque group and lowest in the standard-torque group. The control group showed no cracks. Crack formation was positively correlated with increased torque.

Conclusion: Higher torque during root canal instrumentation using heat-treated rotary files is associated with an increased incidence of dentinal crack formation. Clinicians should consider torque optimization to balance cutting efficiency and preservation of dentinal integrity.

Keywords: Dentinal cracks, Nickel–titanium rotary files, Torque

INTRODUCTION

Root canal therapy (RCT) is a widely performed dental procedure aimed at removing infected pulp tissue, disinfecting the root canal system, and sealing it to prevent reinfection. A critical phase in RCT is biomechanical preparation, which includes cleaning and shaping the canal to facilitate effective disinfection. The introduction of nickel–titanium (NiTi) rotary instruments has revolutionized this step due to their enhanced flexibility, cutting efficiency, and ability to maintain the original canal curvature, especially in anatomically complex or curved canals.[1]

Despite these advantages, rotary instrumentation is associated with mechanical stresses on the root dentin, potentially leading to the formation of dentinal microcracks. These microcracks can act as precursors to vertical root fractures (VRFs), one of the leading causes of failure in endodontically treated teeth.[2,3] The propagation of such cracks under occlusal loading or parafunctional habits may compromise tooth integrity and necessitate extraction.

Among the various factors influencing crack formation – such as instrument design, taper, cross-sectional geometry,

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Corresponding Author: Dr. Sneha Chandran, MDS 3rd Year Post Graduate Student, Department of Conservative Dentistry and Endodontics, KMCT Dental College, Mukkam, Kozhikode, India.

rotational speed, and canal anatomy – torque is one of the most critical yet often overlooked parameters. Torque is defined as the rotational force applied by the endodontic motor to the instrument. When excessive torque is used, the instrument may bind or lock within the canal, transferring concentrated stress to the canal walls, thereby increasing the likelihood of dentinal microcracks.[4]

Some clinicians increase torque settings to improve cutting efficiency or expedite canal preparation, often without fully appreciating the iatrogenic effects of high torque. On the other hand, insufficient torque may reduce shaping efficacy or lead to instrument fracture due to increased torsional fatigue.[5] This necessitates a careful balance between torque and instrument performance to ensure safe and effective canal shaping.

To address these concerns, manufacturers have developed heat-treated NiTi rotary systems, such as the EdgeEndo system. These instruments are made from proprietary alloys (e.g., Fire-Wire™) and undergo annealed heat treatment, which increases flexibility and fatigue resistance while decreasing the stress imparted to dentin during canal shaping.[6] Although such innovations may reduce the risk of mechanical failure or crack formation, limited data exist regarding the optimal torque settings for these systems.

The present study seeks to fill this knowledge gap by investigating the influence of three different torque settings (low, standard, and high) on dentinal crack formation during canal preparation using heat-treated rotary instruments. A better understanding of how torque contributes to dentinal damage will help clinicians optimize treatment protocols and minimize long-term complications such as VRFs. The aim of the study is to compare and evaluate the formation of dentinal cracks during root canal preparation using a heat-treated rotary NiTi system at three different torque settings.

SUBJECTS AND METHODS

Methodology

This was an *in vitro* experimental study conducted to evaluate the effect of different torque settings on dentinal crack formation during root canal preparation using heat-treated rotary NiTi instruments. A total of 32 freshly extracted human maxillary and mandibular premolar teeth with single, straight canals were selected for the study. Teeth were examined under a stereomicroscope at low magnification to exclude any samples with pre-existing cracks, fractures, restorations, root resorption, or calcified canals.

The selected teeth were then stored in distilled water until use to prevent dehydration and maintain dentin properties. To standardize root length, all teeth were decoronated using a diamond disc under water cooling, leaving a uniform root length of 15 mm. A size #10 K-file was introduced into the canal until the tip was visible at the apical foramen. The working length was established by subtracting 1 mm from this length.

Grouping of Samples

The 32 specimens were randomly divided into four experimental groups (n = 8/group):

- Group 1 (Control): No instrumentation. Roots were left unprepared to serve as a baseline for comparison
- Group 2 (Standard Torque): Instrumentation performed at 2.5 N/cm^2 torque
- Group 3 (High Torque): Instrumentation performed at 3.5 N/cm^2 torque
- Group 4 (Low Torque): Instrumentation performed at 2.0 N/cm^2 torque.

Root Canal Instrumentation

Canal instrumentation was carried out using the EdgeEndo rotary file system, which consists of heat-treated NiTi rotary files made from Fire-Wire™ alloy. A torque-controlled endodontic motor was used to ensure precise torque application.

All canals in Groups 2–4 were instrumented to the working length using a 6% tapered rotary file system at a constant speed of 350 revolutions per minute (rpm). Each file was used in a gentle in-and-out pecking motion, and canals were irrigated with 2.5% sodium hypochlorite between each file. A final flush with distilled water was performed to eliminate residual irrigants.

Each rotary file was used for a single canal to avoid instrument fatigue or reuse effects.

Sectioning and Evaluation of Cracks

After instrumentation, all specimens were embedded in acrylic resin blocks to facilitate sectioning. Each root was horizontally sectioned using a diamond disc under water cooling at two levels:

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

A total of 64 sections (two per tooth) were obtained. Each section was examined under a stereomicroscope at ×40 magnification by a blinded examiner. Dentinal cracks were recorded based on the presence of any line extending from the root canal lumen to the outer surface or within the dentin itself. Sections with no visible lines or defects were classified as "no crack." Table 1 shows scoring criteria for determination of dentinal crack formation.

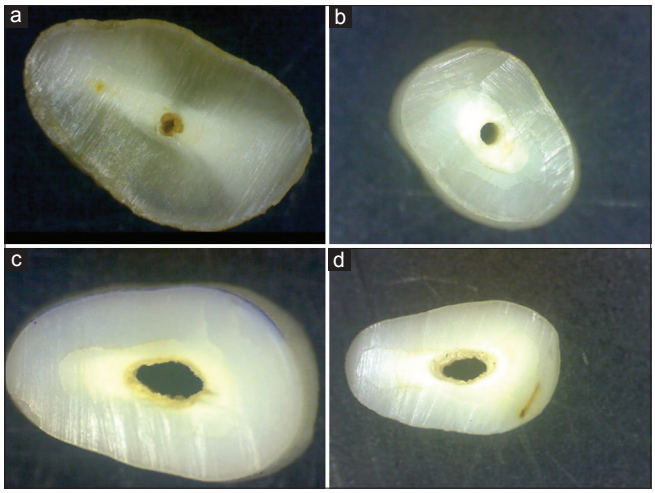

Figure 1: Crack formation in (a) Group 1, (b) Group 2, (c) Group 3, (d) Group 4

Statistical Approach

The frequency of crack formation in each group was recorded and tabulated. Although the initial version of the study did not perform statistical analysis, for publication purposes, it is recommended to use Chi-square or Fisher's exact test to determine the significance of differences among groups ($P < 0.05$ considered statistically significant).

RESULTS

The present *in vitro* study evaluated the incidence of dentinal cracks following root canal instrumentation using heat-treated rotary NiTi files at three different torque settings. Fgure 1 shows crack formation in four experimental groups. A total of 32 premolar teeth were divided into four groups, and two transverse sections were obtained per sample – one at 6 mm and another at 9 mm from the apex – for microscopic evaluation. Table 2 shows distribution of dentinal crack scores among experimental groups at 9 mm. Table 3 distribution of dentinal crack scores among experimental groups at 6 mm.

- Group 1 (Control – No Instrumentation): None of the samples in the control group exhibited dentinal cracks at either the 6 mm or 9 mm levels. This confirmed that the sectioning method and sample handling did not introduce any artifactual damage
- Group 2 (Standard Torque – 2.5 N/cm^2): This group demonstrated the lowest incidence of dentinal cracks among the instrumented groups. A small number of cracks were observed, primarily at the 9 mm level. The findings suggest that this torque setting may be optimal for minimizing dentinal damage while maintaining instrumentation efficiency
- Group 3 (High Torque – 3.5 N/cm^2): The highest number of cracks was recorded in this group. Dentinal defects were evident in both the 6 mm and 9 mm sections, with a notably greater frequency at the coronal level (9 mm). The increased incidence of cracks in this group supports the hypothesis that higher torque generates greater stress on canal walls, predisposing the dentin to microfracture formation
- Group 4 (Low Torque – 2.0 N/cm^2): A moderate number of dentinal cracks were observed in this group, more than in the standard torque group, but fewer than in the high torque group. Cracks were slightly more frequent at the 9 mm level compared to the 6 mm level. This finding suggests that while lower torque may reduce cutting efficiency, it does not eliminate the risk of dentinal damage.

The findings clearly demonstrate that increasing the torque setting during root canal preparation correlates with an increased incidence of dentinal cracks. The standard torque group (2.5 N/cm^2) yielded the most favorable results with minimal crack formation, whereas the high torque group (3.5 N/cm^2) showed the most significant damage to dentin. Although detailed statistical analysis was not originally included, the trend is consistent and clinically relevant, emphasizing the importance of torque optimization during rotary instrumentation.

DISCUSSION

The mechanical preparation of root canals using rotary NiTi instruments is essential for effective RCT, but it also introduces a risk of dentinal microcrack formation – a precursor to VRFs, which are often untreatable and lead to tooth extraction.[3] The present study investigated the influence of different torque settings on dentinal crack formation using heat-treated EdgeEndo rotary files. In the present study, single-rooted premolars were selected due to their straightforward anatomy, which allows for easier handling and standardization. Moreover, their use closely simulates typical clinical scenarios encountered in routine endodontic practice.

The findings demonstrated a positive correlation between increased torque and the incidence of dentinal cracks, with the highest crack formation observed in the high-torque group (3.5 N/cm^2) and the lowest in the standard-torque group (2.5 N/cm^2) among the instrumented groups.

Torque, as the rotational force applied to the file, becomes critical when the file binds within the canal, transferring mechanical energy directly to the canal walls. This energy can create momentary stress concentrations in the dentin, particularly in curved or narrow canals, causing internal

Table 1: Scoring criteria

Score 0	No defect
Score 1	Defects that do not extend from root canal space to outer surface
Score 2	Was defined as line extending from the root canal space all the way to outer surface of root

Table 2: Distribution of dentinal crack scores among experimental groups at 9mm

Defects	Group 1	Group 2	Group 3	Group 4	Chi square	*P*-value
Score 0	100	75	25	50	2.16	0.05
Score 1	0	25	75	50		
Score 2	0	0	0	0		
Total	0	1	3	2		

Table 3: Distribution of dentinal crack scores among experimental groups at 6 mm

Defects	Group 1	Group 2	Group 3	Group 4
Score 0	0	0	25	50
Score 1	0	0	75	50
Score 2	0	0	0	0
Total	0	0	2	0

microstructural damage.[1] Heat-treated files, such as those used in this study, offer increased flexibility, which theoretically reduces such stress. However, the results suggest that instrument flexibility alone does not eliminate the adverse effects of excessive torque.

The current findings are consistent with prior studies. Dane *et al*. demonstrated that higher torque settings significantly increased dentinal crack formation using the ProTaper system, reinforcing the idea that excessive mechanical loading contributes to root dentin damage.[4] Similarly, Saeidi *et al*. showed that lower torque settings (1.5–2 N/cm^2) caused fewer cracks when using the Neoniti rotary system, supporting the need for torque optimization in preserving dentin integrity.[6]

Bier *et al*. assessed the ability of different rotary instruments to induce dentinal damage and emphasized that rotary action and torque contribute to internal root defects, especially when the file engages dentin more aggressively.[2] The high number of cracks observed in the high-torque group in our study can be attributed to this increased engagement and stress transference.

The EdgeEndo files used in this study are manufactured with annealed heat-treated Fire-Wire™ NiTi alloy. These files are designed for improved flexibility and cyclic fatigue resistance. Although this design reduces the likelihood of instrument fracture, it does not completely mitigate the iatrogenic damage to dentin caused by high torque. Therefore, even with advanced metallurgy, torque modulation remains crucial to avoid compromising the structural integrity of the tooth.

The presence of dentinal cracks may not cause immediate clinical symptoms, but can have serious long-term consequences. Under repeated functional loading, cracks can propagate and eventually lead to VRFs. As such, clinicians must aim to optimize torque settings to balance cutting efficiency and safety. The standard torque setting (2.5 N/cm^2), which showed the least crack formation in this study, may offer the best compromise for clinical use.

Limitations and Future Directions

This study is not without limitations. The sectioning technique used – horizontal cuts at 6 mm and 9 mm from the apex – may not detect all cracks, especially those in other planes or longitudinal cracks. Furthermore, stereomicroscopy, though commonly used, lacks the resolution of non-destructive methods such as micro-computed tomography, which could provide 3D crack analysis without altering sample integrity.[7]

The sample size was also limited, and future studies with larger cohorts are necessary to confirm these findings. In addition, investigating the impact of torque across various file designs, cross-sections, and clinical conditions (e.g., curved canals and older dentin) could provide more generalized and applicable insights.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that the torque setting used during root canal preparation has a significant influence on the formation of dentinal cracks, even when using heat-treated NiTi rotary files. The findings demonstrated a clear pattern: as the applied torque increased, so did the incidence of dentinal microcracks.

The control group (no instrumentation) showed no cracks, confirming that the observed damage in experimental groups was a direct result of the biomechanical instrumentation process. Among the instrumented groups, the standard torque setting (2.5 N/cm^2) resulted in the lowest incidence of cracks, suggesting it offers an optimal balance between efficient dentin cutting and preservation of dentinal integrity.

In contrast, the high torque group (3.5 N/cm^2) exhibited the highest number of microcracks, indicating that excessive rotational force can lead to significant internal damage to root dentin, potentially compromising the long-term prognosis of the tooth. Even the low torque group (2.0 N/cm^2), while

better than the high-torque group, still showed a moderate level of microcracks, suggesting that very low torque settings do not completely eliminate the risk of dentinal damage and may potentially reduce shaping efficacy.

These results underscore the importance of careful torque selection during root canal instrumentation, especially when using heat-treated rotary systems. Although heat-treated files, such as those made from Fire-Wire™ NiTi, provide enhanced flexibility and resistance to cyclic fatigue, they do not eliminate the mechanical stresses transferred to dentin under high torque conditions.

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