



Comparative Analysis of Incidence of Dentinal Defects During Root Canal Preparation with Different Rotary Instruments Using Stereomicroscope

Ali M Abdullah¹, Musab Hameed Saeed², and Biland MS Shukri ¹

¹ College of Dentistry, Mustansiriyah University, Department of Conservative, Iraq

² Department of Pedodontics, Orthodontics and Preventive Dentistry, Collage of Dentistry, Mustansiriyah University, Baghdad, Iraq

³ Conservative Dentistry in the college of dentistry–Ajman University, Ajman, UAE

Correspondence: Ali M Abdullah

Email: ali_mohammed95@uomustansiriyah.edu.iq

Received: 14 November 2023; Accepted: 12 March 2024; Published: 30 June 2024

Abstract

Aim of the study: Study the effect of canal preparation with different Niti rotary systems (Edge x7 file and F-one file) with different tapers (0.04 and 0.06) on the incidence of dentinal defect.

Material and method: 75 straight palatal roots of the maxillary first molar were collected, and the instrumentation was done to 11 mm root length for all samples except the control group; the samples were divided randomly into five groups (n=15 each), Group (A) was a control, Group (B) with Edge x7 taper (0.04), Group (C) with Edge x7 taper (0.06), Group (D) with F-ONE taper (0.04), and Group (E) with F-ONE taper (0.06) Every sample had a horizontal section from the apex at 2 mm, 4.5 mm, and 7 mm, dentinal defect was evaluated with 25x stereomicroscope, the data were statistically evaluated at significance levels of 5% or more using Fisher's exact test.

Results: There is no significant difference between different tapers and between different files; in general, taper 0.04 showed less dentinal defects than taper 0.06, and Edge x7 showed less defect than F-ONE.

Conclusion: F ONE file tapers (0.04 and 0.06) cause slightly more dentinal defect than Edge x7 file tapers (0.04 and 0.06) however, with no significant differences.

Keywords: Edge x7, F-ONE, dentinal defect, stereomicroscope

Correct diagnosis, treatment planning, anatomical assessment, tooth debridement, root canal shape, and three-dimensional obturation are all parts of root canal therapy (Peters et al., 2017), Microcracks and dentinal defects have been connected to chemo-mechanical root canal preparation (Haapasalo et al., 2005; Shemesh, van Soest and Wesselink, 2008). Due to the formation of lateral pressures that strain the canal walls (Versiani, Souza and De-Deus, 2015).

Numerous studies have already linked root canal instrumentation methods to

dentinal microcracks (Shemesh, van Soest and Wesselink, 2008; Bürklein, Tsotsis and Schäfer, 2013). Dentinal microcracks have been proposed as the cause of vertical root fractures, (Miguéns-Vila et al., 2017) which often result in tooth or root extraction (Llena-Puy, Forner-Navarro and Barbero-Navarro, 2001). Dentinal cracks cause biofilm entrapment in these fractured sites along the root surface. Because the biofilm is difficult to remove with an instrument and may be a source of infection, endodontic failure may result from it (Lee et al., 2019).



Dentinal defects may arise to varying degrees as a result of variations in Nickel-titanium (NiTi) instruments (Adorno et al., 2011). According to (Yoldas et al., 2012), various parameters, including geometrical designs, cross-sectional forms, different heat treatments, and the kinematics motion of a particular instrument, may affect the production of dentinal defects in NiTi files (Yoldas, Yilmaz and Atakan, 2012).

The EdgeFile X7 manufacturing method, referred to as Firewire, combines cryogenic applications with heat treatment to create an unusual crystalline structure in the heat-treated Firewire alloy. This matrix lessens the shape memory effect while increasing the file's flexibility and fracture resistance. The file has a triangular cross-section with a changeable helix angle (Gambarini et al., 2019).

The F-One introduces a revolutionary heat treatment known as AF-R wire in a single-file system. Result in more effective cutters with stronger torsional and cyclic fatigue resistance; the F-One file's flat design and S-shaped cross-section provide a number of benefits, like lowering engagement of blades, prolonging fatigue lifespan, and cleaning the prepared area by removing waste from the canal. The tool has a non-cutting tip and two active cutting point (Di Nardo et al., 2020). The current study aimed to evaluate the effect of root canal preparation with two different Niti rotary systems (Edge x7 file and F-one file with different tapers of 0.04 and 0.06) on the incidence of dentinal root canal defect.

Materials and method:

Ethical approval was received from the College of Dentistry institutional ethics committee board at Mustansiriyah University (approval number and date: REC130 on 30/05/2023).

75 extracted human maxillary first molars were collected from patients ranging in age from (20-30) years old. Only straight palatal roots with no evident root caries, no open apices, no restoration, and a fully developed apex with a centrally placed apical foramen were chosen for this study, and diagnostic radiographs were also used to ensure that there was just one straight canal and no evidence of internal resorption (Liu et al., 2013; Karataş et al., 2015). The existence of visible cracks or fractures was examined on all root surfaces using transmitted light and a stereomicroscope (MEIJI Techno, Japan) set at 20X magnification (Karataş et al., 2015). To form root portions 11 mm long from the apex, crowns were decoronated using a diamond disk (Komet, Germany) and water irrigation. The center placements of the foramen and canal patency were verified by inserting a size-15 K-file. (Dentsply Maillefer, Switzerland) (Fisher, Berzins and Bahcall, 2007). To get the working length, insert a file into the canal until the tip becomes visible at the apex, then reduce one mm from this length. Only roots with an initial file size of 20 K-files were included in the study (Bürklein, Tsotsis and Schäfer, 2013).

The canal preparation sequences utilized in this study are completed in compliance with the guidelines provided by the manufacturer. The canals were prepared using a wave one endo motor (Dentsply,

Maillefer, Italy) in the crown-down technique, which has a setting of (speed: 500Rpm and torque: 2.5 N) except Group (A) which is control group that left without preparation, Group (B) prepared with Edge x7 taper 0.04, Group (C) prepared with Edge x7 taper 0.06, Group (D) with AF Fanta taper 0.04, and Group (E) with AF Fanta taper 0.06. Each canal was prepared with three sequence file sizes (25#,30#,35#) and a new file was used for each sample and discarded.

Master apical file matching size 35 was used to instrument all root canals. Following each file size, canal was irrigated with 2 ml of 1% NaOCl irrigation after the file was taken from the canal, recapitulated using a size 15 K file, and then irrigated again with 2 ml of NaOCl. 30-gauge endodontic needle was used at 2mm short from working length (Uzunoglu, Görduysus and Görduysus, 2015). As a last flush, 5 milliliter of distilled water was used to get rid of irrigating solutions and debris. Then the canal was dried with an identical paper point size (Hussien and Al-Gharrawi, 2019).

Gidding lines were drawn horizontally on the roots at four levels: (1.5) mm, (4) mm, (6.5) mm, and (9) mm from the apex. (figure 1) Then, the roots were placed in a mold filled with clear acrylic with the help of a dental surveyor (Hussien and Al-Gharrawi, 2019). After that, the root was sectioned horizontally with a diamond disc (0.4 mm) under cold water to prevent heating and reduce smearing (Guinesi et al., 2014). To extract three sections (apical, middle, and coronal) at (2) mm, (4.5) mm, and (7) mm from the apex, each with a thickness of about 2 mm (Hussien and Al-Gharrawi, 2019; Capar, Ertas and Arslan, 2014; Saieed N A, Al-Zaka, 2015). (figure 2)

Each root segment was inspected with a stereomicroscope (MEIJI Techno, Japan) at 25X magnification; two examiners looked at the samples from the coronal direction (Karataş et al., 2015; Arias et al., 2014; Priya et al., 2014). The quantity and the different types of defects were noted and categorized using the following categorization. (No defect, incomplete crack, craze lines, and complete crack) (Bürklein, Tsotsis and Schäfer, 2013). (figure 3).



Figure 1: Root sample with guiding lines

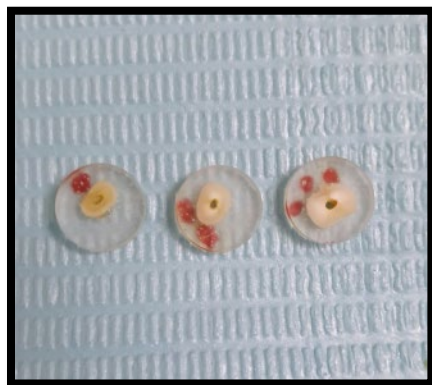


Figure 2 : One dot for apical part, two dot for middle part, and three dot for coronal part

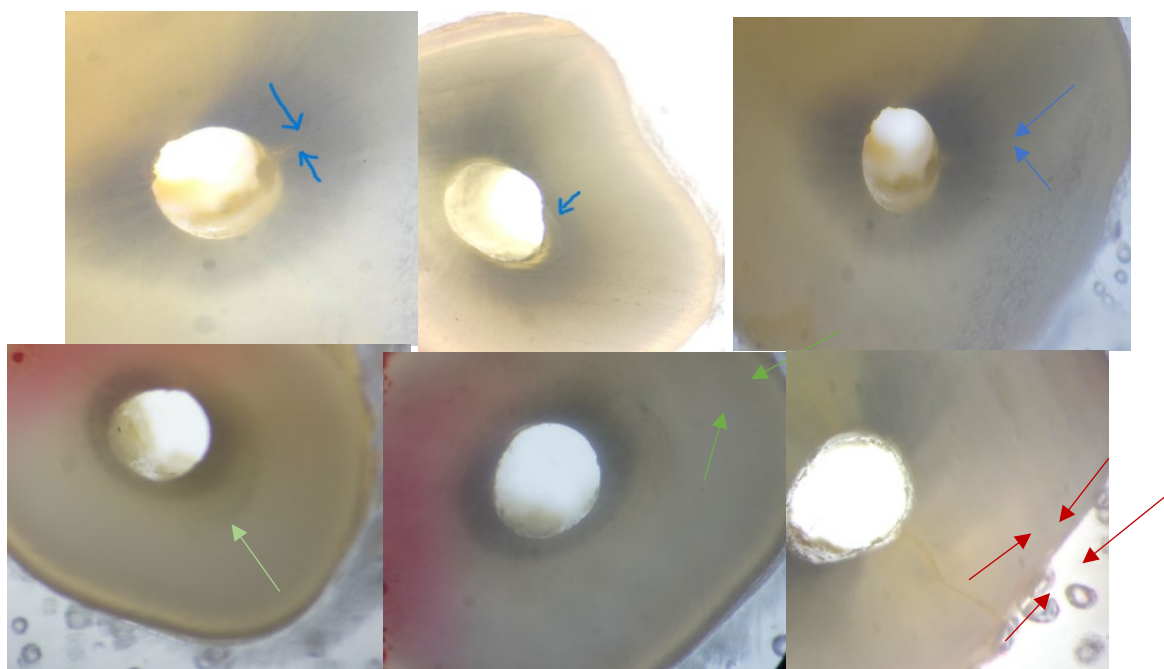


Figure 3: root section with dentinal defect (Blue arrow: incomplete cracks, green arrow: craze line and red arrow: complete cracks

The incidence of defected roots in Edge x7 taper 0.04 was found to be (2/15), followed by AF Fanta taper 0.04 which showed (4/15). Then, Edge x7 taper 0.06 which showed (5/15). The highest number of defected roots showed in AF Fanta taper 0.06 (8/15).

The Statistical Package for Social Science (SPSS version -22, Chicago, Illinois,

USA) was used for data description, analysis, and presentation. This included descriptive and inferential analysis using the Fisher exact test to determine the association of distribution between two qualitative variables when the expected cell counts less than 5 are more than 20%.

Results:

The results revealed that regarding taper of file files, the files with taper 0.04 showed a lower number of dentinal defects than taper 0.06, but with no significant difference (table 1), regarding the type of file used, the Edge x7 showed a lower number of dentinal defect than AF Fanta but with no significant

difference (table 1). Furthermore, whether comparing dentinal defect incidence across groups at the same level or between various levels within the same group, there was no statistically significant difference ($p > 0.05$). (apical, middle, and coronal). Table (2,3,4,5,6,7,8)

Table 1: Fisher's exact test to determine if there was any statistically significant difference between the experimental groups (for Defected roots).

	No defect		Defect		N %	
	N	%	N	%		
A	15	100.00	0	.00	15	100.00
B	13	86.67	2	13.33	15	100.00
C	10	66.67	5	33.33	15	100.00
D	11	73.33	4	26.67	15	100.00
E	7	46.67	8	53.33	15	100.00
Statistics						
B-C (F. E=1.677, p value=0.195)						
D-E (F. E=2.222, p value= 0.136 NS)						
B-D (F. E=0.833, p value=0. 361)						
C-E (F. E=1.222, p value= 0.269 NS)						

Table 2: Association of dentinal defects among groups in apical third.

	Defect				Total	
	Defect		No Defect		N	%
	N	%	N	%		
B	2	13.33	13	86.67	15	100.00
C	3	20.00	12	80.00	15	100.00
D	3	20.00	12	80.00	15	100.00
E	5	33.33	10	66.67	15	100.00
Statistics						
B-C (F. E=0.240, p value=1 NS)						
D-E (F. E=0.682, p value=0.680 NS)						
B-D (F. E= F. E=0.240, p value=1 NS)						
C-E (F. E=0.682, p value=0.680 NS)						

Table 3: Association of dentinal defects among groups in middle third.

	Defect				Total	
	Defect		No Defect			
	N	%	N	%	N	%
B	0	.00	15	100.00	15	100.00
C	1	6.67	14	93.33	15	100.00
D	1	6.67	14	93.33	15	100.00
E	3	20.00	12	80.00	15	100.00
Statistics						
B-C (F. E=1.034, p value= 1 NS)						
D-E (F. E=1.154, p value=0.598 NS)						
B-D (F. E=1.034, p value= 1 NS)						
C-E (F. E=1.154, p value=0.598 NS)						

Table 4: Association of dentinal defects among groups in coronal third.

	Defect				Total	
	Defect		No Defect			
	N	%	N	%	N	%
B	0	.00	15	100.00	15	100
C	1	6.67	14	93.33	15	100
D	0	.00	15	100.00	15	100
E	2	13.33	13	86.67	15	100
Statistics						
B-C (F. E=1.034, p value=1 NS)						
D-E (F. E=2.143, p value=0.483 NS)						
B-D (F. E=---, p value=----)						
C-E (F. E=0.370, p value=1 NS)						

Table 5: Association of dentinal defects among levels in Group B (Edge x7 taper 0.04)

Group B					Fisher exact	P value
	Defect		No Defect			
	N	%	N	%		
Apical Level	2	13.33	13	86.67	2.812	0.316 NS
Middle Level	0	.00	15	100.00		
Coronal Level	0	.00	15	100.00		

Table 6: Association of dentinal defects among levels in Group C (Edge x7 taper 0.06)

Group C					Fisher exact	P value
	Defect		No Defect			

	N	%	N	%		
Apical Level	3	20.00	12	80.00	1.596	0.598 NS
Middle Level	1	6.67	14	93.33		
Coronal Level	1	6.67	14	93.33		

Table 7: Association of dentinal defects among levels in Group D (AF Fanta taper 0.04)

Group D					Fisher exact	P value
	Defect		No Defect			
	N	%	N	%		
Apical Level	3	20.00	12	80.00	3.200	0.310 NS
Middle Level	1	6.67	14	93.33		
Coronal Level	0	.00	15	100.00		

Table 8: Association of dentinal defects among levels in Group E AF Fanta taper (0.06)

Group E					Fisher exact	P value
	Defect		No Defect			
	N	%	N	%		
Apical Level	5	33.33	10	66.67	1.721	0.558 NS
Middle Level	3	20.00	12	80.00		
Coronal Level	2	13.33	13	86.67		

Discussion:

The stress distribution is more regular in a round canal and, because it has a more rounded canal morphology than other teeth, the nearly straight palatal root of a newly extracted human maxillary permanent first molar was chosen for the current investigation (Vertucci, 2006; Khdairah HR, Al-Gharrawi, 2020). Additionally, utilizing only one kind of tooth helps reduce variations, improve parity, and standardize specimens (Kustarci, Altunbas and Akpınar, 2012; Shadan and Biland, 2020; Khdairah and Al-Gharrawi, 2020).

One operator (the researcher) instrumented each canal in order to reduce the variables through the investigation to exclude any personal bias. The defect was revealed by two observers (Hussien and Al-Gharrawi, 2019).

The control group did not develop any dentinal defects, despite the difficulties associated with the root sectioning process. This would suggest that in this research, the root sectioning method did not result in dentinal defects (Hussien and Al-Gharrawi, 2019).

According to the findings of this study, instrumentation with Edge x7 showed the lowest dentinal defect in all parts of the roots as compared to the same taper of AF Fanta file, this might be attributed to the parabolic design (Figure 4), which is responsible for minimizing pressure on the canals' lateral wall (Sobh et al., 2021). Additionally, this file system's cutting efficiency is maximized by the parabolic architecture. This increased cutting effectiveness could reduce the development of dentin cracks (Ozlek and Gunduz et al., 2021). This concurs with a

publication by (Kim et al., 2010) that suggested a connection between the

occurrence of vertical root fractures and the design of NiTi instruments (Kim et al., 2010).

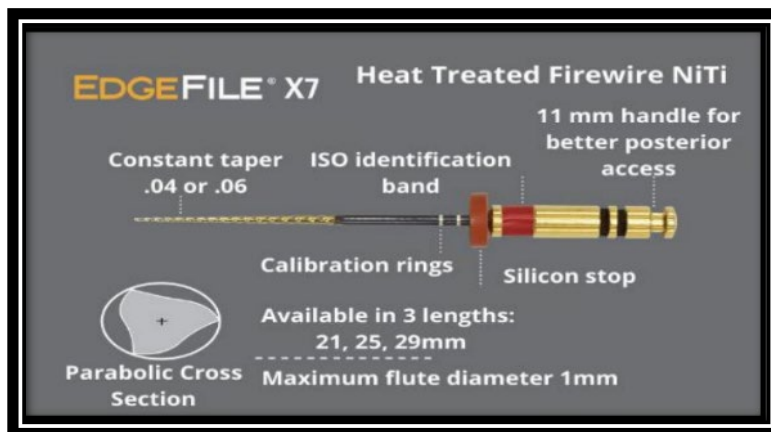


Figure 4: EdgeFile X7 instruments (EdgeEndo, 2018).

While the F-one system's flat shape might lead to an uneven or irregular distribution of pressures on the instrument, leading to reduced cutting efficiency. Additionally, one half of the cross-section has a completely flat design, which might allow more debris to accumulate between the file and canal walls, the surrounding walls may then be cut unevenly (Kaddoura, Ahmad and Al Tayyan, 2021). This result is also supported by (Hamed et al., 2022) that suggested the F-one flat design results in accumulation of debris that lead to affect its cutting efficacy (Hamed et al., 2022). furthermore, F-one file has near- identical helical angles (Martins et al, 2023) which allow debris to accumulate (Koch and Brave, 2002) in opposite to the Edge x7 file which has variable helical angle result in reducing the screwing effect and enhancing the removal of debris (AbdelWahed, 2021).

According to the findings of this study, instrumentation with Edge x7 taper 0.04 and AF. Fanta taper 0.04 showed the lowest

dentinal defect in all parts of roots as compared to taper 0.06 of AF Fanta file and Edge x7 groups.

The files' taper have a positive influence on the development of dentinal cracks, when the taper increases, the stress on the canal wall increases, result in an increase in the number of dentinal defects.³⁵ rotary files with greater tapers have a tendency to put more stress on the radicular dentine, which is one of the causes of root dentin cracking (Kim et al., 2010; Gergi RM, Osta NE, Naaman, 2015). The effect of increasing file taper on dentinal cracks is also supported by (Bhavika et al., 2023) that used files with fixed taper as same as the files used in current study and they conclude the Trunatomy file (26. /0.04) result in less number of cracks than Waldent walflex file (25/0.06) (Bhavika et al., 2023).

The more incidence of dentinal defects discovered at the apical level in all groups, followed by the middle and then the coronal levels, this is in line with what (Bhavika et al.,

2023; 38. Karataş et al., 2016; Nishad and Shivamurthy, 2018; Chole et al., 2019). found in their studies, that cracks may develop as a result of mechanical stress brought on by repetitive instrumentation and the thin, brittle dentin in the apical region's inability to withstand the tension brought on by direct contact with the instrument tip.

Conclusion:

The following conclusions might be drawn based on the results of this in vitro investigation:

1. The dentinal defects were caused by all of the instrumentation systems employed in this investigation.
2. AF Fanta file system taper (0.04 and 0.06) causes more dentinal defects than Edge x7 file system taper (0.04 and 0.06) but with no significant difference.
3. The large taper (0.06) of AF Fanta and Edge x7 systems results in a greater number of dentinal defects than the small taper (0.04) of AF Fanta and Edge x7 systems, but with no significant difference.
4. The apical portion of the instrumented roots showed a high prevalence of dentinal defects.

Supplementary Material

None.

Funding

This research received no external funding.

Data Availability Statement

Data are available from the authors upon reasonable request.

Conflict of interest

The authors reported that they have no conflicts of interest.

Acknowledgments

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad, Iraq, for their support in the present work.

References

1. AbdelWahed, A. (2021) 'Comparative assessment of apically extruded debris using Protaper Next, Hyflex CM and EdgeFile X7 nickel titanium instruments (An in vitro Study)', *Egyptian Dental Journal*, 67(4), pp. 3751-3757. <https://doi.org/10.21608/edj.2021.90728.1751>
2. Adorno, C.G., Yoshioka, T. and Suda, H. (2011) 'Crack initiation on the apical root surface caused by three different nickel-titanium rotary files at different working lengths', *Journal of Endodontics*, 37(4), pp. 522-525. <https://doi.org/10.1016/j.joen.2010.12.002>
3. Arias, A., Lee, Y.H., Peters, C.I., Gluskin, A.H. and Peters, O.A. (2014) 'Comparison of 2 Canal Preparation Techniques in the Induction of Microcracks: A Pilot Study with Cadaver Mandibles', *Journal of Endodontics*, 40(7), pp. 982-985. <https://doi.org/10.1016/j.joen.2013.12.003>
4. Bhavik, A., Pranjely, S., Pratik, S., Sheetal, B., Dimple, J. and Arvind, J. (2023) 'Oval

- Root Canals Prepared with Two Different Endodontic Rotary Files: An In Vitro Study Comparing the Incidence of Dental Defects', *Cureus*, 15(10), p. e47759.
5. Bier, S., Shemesh, H., Tanomaru-Filho, M., Wesselink, R. and Wu, M. (2009) 'The ability of different nickel-titanium rotary instruments to induce dentinal damage during canal preparation', *Journal of Endodontics*, 35(2), pp. 236-238. <https://doi.org/10.1016/j.joen.2008.10.021>
 6. Bürklein, S., Tsotsis, P. and Schäfer, E. (2013) 'Incidence of dentinal defects after root canal preparation: Reciprocating versus rotary instrumentation', *Journal of Endodontics*, 39(4), pp. 501-504. <https://doi.org/10.1016/j.joen.2012.11.045>
 7. Capar, I.D., Ertas, H., Ok, E. and Arslan, H. (2014) 'Comparison of single cone obturation performance of different novel nickel-titanium rotary systems', *Acta Odontologica Scandinavica*, 72(7), pp. 537-542. <https://doi.org/10.3109/00016357.2013.876554>
 8. Chole, D., Kamble, S., Bakle, S., Gandhi, N., Hatte, N. and Bawa, P. (2019) 'Effects of 3 Single-File System (Protaper Universal, Protaper Next, Protaper Gold) on crack formation in dentin after root canal preparation - an in vitro study', *IOSR Journal of Dental and Medical Sciences*, 18(8), pp. 47-50.
 9. Di Nardo, D., Miccoli, G., Mazzoni, A., Seracchiani, M., Gambarini, G. and Testarelli, L. (2020) 'Centering Ability of a New Nickel-Titanium Rotary Instruments with a Peculiar Flat-side Design: An In Vitro Study', *Journal of Contemporary Dental Practice*, 21(1), pp. 539-542. <https://doi.org/10.5005/jp-journals-10024-2829>
 10. Fisher, M.A., Berzins, D.W. and Bahcall, J.K. (2007) 'An in vitro comparison of bond strength of various obturation materials to root canal dentin using a push-out test design', *Journal of Endodontics*, 33(7), pp. 856-858. <https://doi.org/10.1016/j.joen.2007.02.011>
 11. Gambarini, G., Galli, M., Seracchiani, M., et al. (2019) 'In Vivo Evaluation of Operative Torque Generated by Two Nickel-Titanium Rotary Instruments during Root Canal Preparation', *European Journal of Dentistry*, 13(4), pp. 556-562. <https://doi.org/10.1055/s-0039-1698369>
 12. Gergi, R.M., Osta, N.E. and Naaman, A.S. (2015) 'Dentinal crack formation during root canal preparations by the twisted file adaptive, Reciproc and WaveOne instruments', *European Journal of Dentistry*, 9(4), pp. 508-512. <https://doi.org/10.4103/1305-7456.172634>
 13. Guinesi, A.S., Faria, G., Tanomaru-Filho, M. and Bonetti-Filho, I. (2014) 'Influence of Sealer Placement Technique on the Quality of Root Canal Filling by Lateral Compaction or Single Cone', *Brazilian Dental Journal*, 25(2), pp. 117-122. <https://doi.org/10.1590/0103-6440201302370>
 14. Haapasalo, M., Endal, U., Zandi, H. and Coil, J.M. (2005) 'Eradication of endodontic infection by instrumentation and irrigation solutions', *Endodontic Topics*, 10(1), pp. 77-102. <https://doi.org/10.1111/j.1601-1546.2005.00135.x>

15. Hamed, S.A., Shabayek, S. and Hassan, H.Y. (2022) 'Biofilm elimination from infected root canals using four different single files', *BMC Oral Health*, 22(1), p. 660. <https://doi.org/10.1186/s12903-022-02690-5>
16. Hussien, S. and Al-Gharrawi, H.A. (2019) 'Incidence of Dentinal Root Defects Caused by RECIPROC Blue, ProTaper Gold, ProTaper NEXT and RECIPROC Nickel Titanium Rotary Instruments', *The Journal of Contemporary Dental Practice*, 20(3), pp. 291-297. <https://doi.org/10.5005/jp-journals-10024-2512>
17. Karataş, E., Gündüz, H.A., Kırıcı, D.Ö. and Arslan, H. (2016) 'Incidence of dentinal cracks after root canal preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper Universal instruments', *International Endodontic Journal*, 49(9), pp. 905-910. <https://doi.org/10.1111/iej.12541>
18. Khdairah, H.R. and Al-Gharrawi, H.A. (2020) 'The effect of canal preparation using 2shape, protaper gold and protaper next file systems on the fracture resistance of obturated roots', *Journal of International Dental and Medical Research*, 13(1), pp. 42-45.
19. Kim, H.C., Lee, M.H., Yum, J., Versluis, A., Lee, C.J. and Kim, B.M. (2010) 'Potential relationship between design of nickel-titanium rotary instruments and vertical root fracture', *Journal of Endodontics*, 36(7), pp. 1195-1199. <https://doi.org/10.1016/j.joen.2010.02.010>
20. Koch, K. and Brave, D. (2002) 'Real world Endo: Design features of rotary files and how they affect clinical performance', *Oral Health*, 92(3), pp. 39-49.
21. Kustarci, A., Altunbas, D. and Akpınar, K.E. (2012) 'Comparative study of apically extruded debris using one manual and two rotary instrumentation techniques for endodontic', *Journal of Dental Sciences*, 7(1), pp. 1-6. <https://doi.org/10.1016/j.jds.2011.09.011>
22. Lee, O.Y.S., Khan, K., Li, K.Y., Shetty, H., Abiad, R.S., Cheung, G.S.P., et al. (2019) 'Influence of apical preparation size and irrigation technique on root canal debridement: A histological analysis of round and oval root canals', *International Endodontic Journal*, 52(9), pp. 1366-1376. <https://doi.org/10.1111/iej.13127>
23. Liu, R., Kaiwar, A., Shemesh, H., Wesselink, P.R., Hou, B. and Wu, M.K. (2013) 'Incidence of apical root cracks and apical dentinal detachments after canal preparation with hand and rotary files at different instrumentation lengths', *Journal of Endodontics*, 39(1), pp. 129-132. <https://doi.org/10.1016/j.joen.2012.09.019>
24. Llana-Puy, M.C., Forner-Navarro, L. and Barbero-Navarro, I. (2001) 'Vertical root fracture in endodontically treated teeth: A review of 25 cases', *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 92(5), pp. 553-555. <https://doi.org/10.1067/moe.2001.117262>
25. Martins, J., Silva, E., Baruwa, A., PereiradaCosta, R., Fernandes, F. and Versiani, M. (2023) 'Comparative analysis of reciprocating and flat-side heat-treated rotary single-file systems: Design, metallurgical characteristics, and mechanical performance', *International*

- Endodontic Journal*, 56(7), pp. 896-908. <https://doi.org/10.1111/iej.13920>
26. Miguéns-Vila, R., Martín-Biedma, B., Varela-Patiño, P., Ruíz-Piñón, M. and Castelo-Baz, P. (2017) 'Vertical root fracture initiation in curved roots after root canal preparation: A dentinal micro-crack analysis with LED transillumination', *Journal of Clinical and Experimental Dentistry*, 9(10), pp. e1218-e1223. <https://doi.org/10.4317/jced.54227>
 27. Nishad, S.V. and Shivamurthy, G.B. (2018) 'Comparative analysis of apical root crack propagation after root canal preparation at different instrumentation lengths using ProTaper universal, ProTaper next and ProTaper gold rotary files: an in vitro study', *Contemporary Clinical Dentistry*, 9(5), pp. 680-684. https://doi.org/10.4103/ccd.ccd_83017
 28. Ozlek, E. and Gunduz, H. (2021) 'The effect of heat-treated single-file systems on dentinal crack formation', *Nigerian Journal of Clinical Practice*, 24(3), pp. 418-424. https://doi.org/10.4103/njcp.njcp_25020
 29. Peters, O.A., de Azevedo Bahia, M.G. and Pereira, E.S. (2017) 'Contemporary root canal preparation: Innovations in biomechanics', *Dental Clinics of North America*, 61(1), pp. 37-58. <https://doi.org/10.1016/j.cden.2016.08.002>
 30. Priya, N.T., Chandrasekhar, V., Anita, S., Tummala, M., Raj, T.B., Badami, V., Kumar, P. and Soujanya, E. (2014) 'Dentinal microcracks after root canal preparation a comparative evaluation with hand, rotary and reciprocating instrumentation', *Journal of Clinical and Diagnostic Research*, 8(12), pp. ZC70-ZC72. <https://doi.org/10.7860/JCDR/2014/11437.5349>
 31. Kaddoura, R., Ahmad, A. and Al Tayyan, M. (2021) 'Shaping ability of different single-file rotary systems in simulated S-shaped canals by a new investigation approach', *Saudi Endodontic Journal*, 11(2), pp. 173-180. https://doi.org/10.4103/sej.sej_50_20
 32. Saieed, N.A. and Al-Zaka, I.M. (2015) 'The Incidence of dentinal root defects caused by different Nickel Titanium instruments', *Mustansiria Dental Journal*, 12(1), pp. 1-9.
 33. Shadan, S. and Biland, M.S. (2020) 'The Amount of Extruded Debris an In-vitro Comparative Study', *Journal of Oral and Dental Research*, 7(2), pp. 1-3. <https://doi.org/10.12816/0060718>
 34. Shemesh, H., van Soest, G., Wu, M.K. and Wesselink, P.R. (2008) 'Diagnosis of vertical root fractures with optical coherence tomography', *Journal of Endodontics*, 34(6), pp. 739-742. <https://doi.org/10.1016/j.joen.2008.03.013>
 35. Sobh, Y.T., Nour El Deen, M.A. and Hashem, A.A. (2021) 'Effect of Different Contemporary Rotary Nickel Titanium Systems on Root Canal Geometry', *Al-Azhar Dental Journal for Girls*, 8(4), pp. 527-534. <https://doi.org/10.21608/adjg.2021.30708.1266>
 36. Uzunoglu, E., Görduysus, M. and Görduysus, Ö. (2015) 'A comparison of different irrigation systems and gravitational effect on final extrusion of the irrigant', *Journal of Clinical and*

- Experimental Dentistry*, 7(2), pp. e218-e223. <https://doi.org/10.4317/jced.52158>
37. Versiani, M.A., Souza, E. and De-Deus, G. (2015) 'Critical appraisal of studies on dentinal radicular microcracks in endodontics: Methodological issues, contemporary concepts, and future perspectives', *Endodontic Topics*, 33(1), pp. 87-156. <https://doi.org/10.1111/etp.12091>
38. Vertucci, F.J. (2005) 'Root canal morphology and its relationship to endodontic procedures', *Endodontic Topics*, 10(1), pp. 3-29. <https://doi.org/10.1111/j.1601-1546.2005.00129.x>
39. Yoldas, O., Yilmaz, S. and Atakan, G. (2012) 'Dentinal microcrack formation during root canal preparations by different NiTi rotary instruments and the self-adjusting file', *Journal of Endodontics*, 38(2), pp. 232-235. <https://doi.org/10.1016/j.joen.2011.10.011>