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Effect of Different Kinematics of Contemporary Motor-Driven File Systems on Root Dentin Cracks: An In-Vitro Study

Youssef A Algarni[1*], Nuha S Alghamdi[2]

[*1]Assistant Professor and Chairman, Department of Restorative Dental Sciences, King Khalid University College of Dentistry, Abha, Kingdom of Saudi Arabia.

[2]Assistant Professor, Department of Restorative Dental Sciences, King Khalid University College of Dentistry, Abha, Kingdom of Saudi Arabia.

***Corresponding Author:**

Youssef A Algarni,

Assistant Professor and Chairman, Department of Restorative Dental Sciences, King Khalid University College of Dentistry, Abha, Kingdom of Saudi Arabia.

Email ID: yalgarni@kku.edu.sa

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ABSTRACT

Objective: To evaluate and compare the root dentin crack formation after root canal preparation with different rotary instruments.

Materials and Methods: Root canals of 60 freshly extracted single-rooted premolars were prepared and randomly assigned into six groups (n=10 teeth). The root canals were instrumented with "ProTaper Next," Vortex blue, Twisted File System, Reciproc, Reciproc blue and Twisted File Adaptive motor-driven file systems having different instrumentation kinematics. Root canals of another 10 premolars were left with no preparation for the control purpose. Horizontal, 3 mm thick, slices were obtained from the apical, middle and cervical thirds of each root. The cut slices were then inspected using the digital microscope to confirm the absence or the presence of root cracks.

Results: All test subgroups showed root cracks with varied incidences. Instrumentation with "ProTaper Next," system, vortex blue and TF system with continuous motion.

showed higher incidences of cervical root cracks in comparison to the control and other study groups.

Conclusion: Although dentin cracking is possible in premolar roots prepared with motor- driven file systems, higher incidences of cervical root cracks are expected with canals instrumented with file systems in continuous rotation motion.

Keywords: *Continuous motion, Cracks, Kinematics, Reciprocal motion, Root.*

1. INTRODUCTION

Vertical Root Fracture (VRF) is a crucial clinical problem that may compromise the long-term success of endodontic treatment. The formation of dentinal cracks during the root canal preparation may propagate and result in VRF.[1] The varying taper of files and their composition all have a direct effect on root dentin during root canal shaping.[2, 3] The dentin defects following root canal preparation with rotary instruments varies and mainly depend on the extent of dentin removal from the root canal and degree of canal enlargement.[4]Extending the root canal preparation introduces a risk for VRFs due to greater mechanical stress.[5]

NiTi rotary endodontic instruments are commonly employed with two distinct motion techniques, continuous full rotating motion and the reciprocating motion. A third type has been introduced which is a combination of continuous rotary and reciprocating motion. Stresses such as torsion and flexion are generated with continuous rotating NiTi instruments, potentially resulting to instrument separation. To circumvent this disadvantage, the reciprocating movement was introduced.[6] This technique was a combination of counterclockwise (cutting action) and clockwise (instrument release) motions to reduce stress on the instrument. Reciprocating movement decreases the risks that are related to continuous rotation motion and claims to mimic manual movement. However, literature reports that reciprocating systems with small and equal Clockwise (CW)/Counterclockwise (CCM) angles exhibit reduced cutting efficiency. This may induce more stress because of the pressure hence making the progression into the canal more tedious.[6,7]

Current researches and reviews have eloquently deliberated on the effect of dynamics and design characteristics on the performance of the NiTi rotary file systems. The newly introduced NiTi system such as Reciproc and Reciproc blue (VDW, Munich, Germany) makes it possible to complete the shaping of root canals with one instrument. The flexibility of these instruments has been increased by subjecting the M-wire NiTi alloy to the special thermal process.[8]

A new generation of NiTi rotary instrumentation systems has been marketedrecently which is utilized in both reciprocating and continuous rotation modes. The Twisted File Adaptive (TFA) (Sybron-Endo, CA, USA) is shaped by transforming the NiTi wire from the austenitic crystalline structure to the super-elastic R-phase structure through a heating and cooling process.[9] During root canal preparation, the TFA instrument can switch between continuous rotation and reciprocation modes depending on the pressure exerted on the file. The angles for clockwise and counterclockwise rotation can vary from 0° to 600°, adjusting to a range of 370° to 50°. [10]

The objective of this study was to compare and evaluate the frequency of dentinal cracks during root canal shaping with different kinematics.

2. MATERIALS AND METHODS

An observational in vitro study was conducted at King Khalid University College of Dentistry, located in Abha, Kingdom of Saudi Arabia, over the course of two years: 2018-2019. Due to limited resources and time constraints, a convenience sampling approach was used in this study. The single-rooted mandibular premolars were selected from the department of oral and maxillofacial surgery, which were readily available and accessible during the study period.

Seventy recently extracted single-rooted mandibular premolars were collected from 18-30y old patients undergoing orthodontic treatment. The teeth were ultrasonically cleaned to remove any hard or soft tissue deposits before being disinfected in 0.1% thymol solution for seven days. Next, teeth were stored wet in a refrigerator at 4ºC (FLOCCHETTI, Frigoriferi Scientifici, Luzzara, Italy) for one month. To fulfill the selection criteria, each tooth was visually examined and radiographed for further evaluation. Teeth with more than one root canal, internal or external resorption, immature root apices, root caries, root cracks, root fractures and previously treated root canals were excluded. Additionally, all radiographs were traced to help determine the root canal curvature in each tooth using a measuring ruler and protractor (Fig.1). Teeth with root canal curvature exceeding 10º were also excluded.[10]

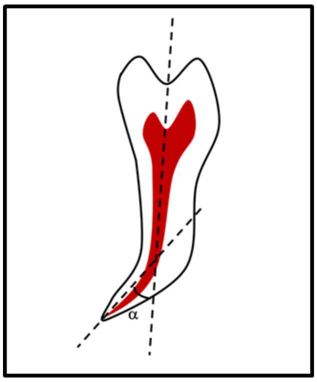

FIG. 1: Schematic representation of a root canal curvature measurement technique.

The selected teeth were decoronated to standardize the root length to 13mm using a precision saw machine (Isomet, Lake Bluff, IL, USA) under water cooling. The external surfaces of each root were then observed using a digital microscope (Hirox RH 2000, Tokyo, Japan) at X15 original magnification to assure that no detects or cracks were induced in response to the cutting procedure. The cut roots were then coated with a layer of low-viscosity silicone impression material (Imprint, 3M ESPE, St. Paul, MN, USA) to simulate the periodontal ligament before their mounting into self-cured acrylic blocks (Hygenic, Coltene/Whaledent AG. Alstatten, Switzerland). The mounted roots were randomly divided into six test groups (n=10) based on the root canal preparation systems utilized. Another 10 teeth were left with no root canal preparation to serve as the control. The patency of root canals of all roots was checked using #10 k-files and the root canal preparation was accomplished in each of the test groups following the manufacturer's instructions of the nominated system. The classification of study groups in addition to the criteria and manufactures of the utilized root canal preparation systems are shown in Table 1.

Table 1: Classification of study groups

Group	File system/ Manufacturer	Alloy	Kinematics	Torque/ rotation speed	Size of apical preparation
Control	No preparation	-	-	-	No preparation
G1	"ProTaper Next" *DentsplyMaillefer, Ballaigues, Switzerland*	M-wire	Continuous Motion	As per manufacture recommendation	# X4
G2	Vortex Blue *Dentsply Tulsa Dental specialty*	M-wire with blue treatment	Continuous Motion	As per manufacture recommendation	# 40/06
G3	Twisted file TF *SybronEndo, Orange, CA*	R-Phase	Continuous Motion	As per manufacture recommendation	# ML2
G4	Reciproc *VDW, Munich, Germany*	M-wire	Reciprocal Motion	As per manufacture recommendation	# R40
G5	Reciproc Blue *VDW, Munich, Germany*	M-wire with blue treatment	Reciprocal Motion	As per manufacture recommendation	# R40
G6	Twisted file adaptive TF *SybronEndo, Orange, CA*	R-Phase	Continuous and Reciprocal Motions	As per manufacture recommendation	# ML2

Next, the horizontal 3mm thick slices were obtained from each root. Standard cuts were made using isomet precision saw at 3mm, 6mm, and 9mm from the apex and the cut surfaces of each slice werethen smoothed up using serial grit polishing (AutoMet 30, Buehler, lake Bluff, IL), washed with 95% ethanol (Merck KGaA, Darmstadt, Germany) and air-dried for crack detection using the digital microscope at X25. The presence or absence of dentinal cracks was inspected at either face of the cut slices. The collected data were then analyzed using Kruskal-Wallis test and *post hoc* Dunn's test for evaluation of the significance of differences detected between study subgroups.

3. RESULTS

The results of the Kruskal-Wallis test show a significant difference among the test groups. The crack incidence was more with rotary files used in continuous rotation motion than reciprocating motion with highest incidence seen in pro-taper next file system followed by vortex blue and Twisted file.

The comparative difference between the groups at different section is shown in Table 2,3,4 and 5.

The table 2 presents a comparison of rotary preparation techniques in three different sections of the root canal: the apical, middle, and coronal thirds. In the apical third, there were no significant differences between the groups, as indicated by a p-value of 0.19600, which is greater than 0.05. This suggests that the different rotary techniques did not produce varying outcomes in this section. In contrast, in the middle third, significant differences were observed among the groups, with a p-value of 0.000004*, well below the 0.05 threshold for statistical significance. This indicates that the rotary preparation techniques had a varying impact in the middle third of the canal. Similarly, in the coronal third, the differences between the groups were also significant, with a p-value of 0.004216*, indicating that the techniques produced different results in this section as well. Overall, while the techniques did not show significant differences in the apical third, they did in the middle and coronal thirds, highlighting the varying effectiveness of the techniques depending on the section of the root canal being treated.

The table 3 presents the results of Dunn's post-hoc test comparing the mean rank differences (MRD) between the control group and the six experimental rotary preparation techniques (G1-G6) in the apical third of the root canal. The MRD values indicate small differences in the ranks between the groups, and the p-values are consistently greater than 0.05 (e.g., control vs. G1: p = 0.103, G1 vs. G2: p = 0.9458), suggesting that none of the differences neither between the control and experimental groups, nor between the experimental groups themselves, are statistically significant. These results indicate that there are no significant differences in the effectiveness of the rotary preparation techniques in the apical third of the root canal.

The table 4 shows that the control group significantly differs from several experimental groups (Gp1, Gp2, and Gp3) in the middle third of the root canal. Gp1 (ProTaper Next) also differs significantly from most other groups, while Gp2 (Vortex Blue) only differs from the control and Gp1. Gp3 (TF) shows significant differences with the control and Gp1, but not with Gp2, Gp4, or Gp5. Gp4 (Reciproc) and Gp5 (Reciproc Blue) differ significantly from the control but not from other experimental groups.

The table 5 presents the results of Dunn's post-hoc test comparing the mean rank differences (MRD) between the control group and six experimental rotary preparation techniques (G1-G6) in the coronal third of the root canal. The control group shows significant differences with G1 (ProTaper Next), G2 (Vortex Blue), and G3 (TF), with p-values of 0.00299, 0.0020, and 0.0276, respectively, indicating that these groups differ significantly from the control. However, there are no significant differences between the control and G4, G5, or G6. Gp1 (ProTaper Next) differs significantly from G4, G5, and G6, while Gp2 (Vortex Blue) shows significant differences with the control, G4, G5, and G6. Gp3 (TF) differs significantly only from the control group, while Gp4 (Reciproc) and Gp5 (Reciproc Blue) both show significant differences with the control and G1, G2, but not with other groups. Overall, the results suggest that while some experimental groups differ significantly from the control in the coronal third, others show fewer significant differences.

Fig 2shows graphical representation of frequency of dentinal fractures between various groups

Group 1 "ProTaper Next," shows maximum number of failures n=18 followed by Group 2 (Vortex blue (n =13) while as group 3 (TF) showed 12 failures

Group 4 (Reciproc) and Group 5 (Reciproc blue) showed less failures n=4 while least number of failures were produced by group 6 (TF Adaptive) n=1.

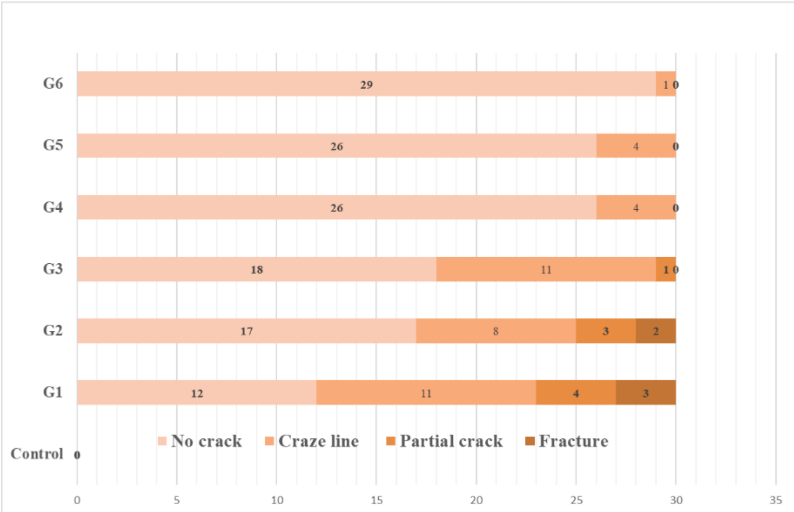

Fig. 2: Graphical representation of the frequency distribution of the outcome of biomechanical root canal preparation

Table 2: Comparative differences in median values between the different rotary preparation techniques at three different sections (apical, middle, coronal) and the significance of differences using one-way ANOVA (Kruskal Wallis) rank test.

Section area	Group	N	Median	IQR	Minimum	Maximum	MRS	H Statistic	P value
Apical third (n=10)	Control	10	0.00	0.00	0.00	0.00	32.5	8.6215	0.19600
	G1	10	0.00	0.00	0.00	2.00	39.7		
	G2	10	0.00	0.00	0.00	1.00	39.4		

	G3	10	0.00	0.00	0.00	1.00	39.4		
	G4	10	0.00	0.00	0.00	0.00	32.5		
	G5	10	0.00	0.00	0.00	0.00	32.5		
	G6	10	0.00	0.00	0.00	0.00	32.5		
Middle third (n=10)	Control	10	0.00	0.00	0.00	0.00	23.5	35.0563	0.000004*
	G1	10	1.00	1.00	1.00	3.00	60.15		
	G2	10	0.50	1.00	0.00	2.00	41.15		
	G3	10	0.50	1.00	0.00	1.00	40.00		
	G4	10	0.00	0.00	0.00	1.00	30.1		
	G5	10	0.00	0.00	0.00	1.00	30.1		
	G6	10	0.00	0.00	0.00	0.00	23.5		
Coronal third (n=10)	Control	10	0.00	0.00	0.00	0.00	24.5	18.9692	0.004216*
	G1	10	1.00	2.00	0.00	3.00	46.6		
	G2	10	0.50	2.00	0.00	3.00	47.5		
	G3	10	0.50	1.00	0.00	2.00	40.9		
	G4	10	0.00	0.00	0.00	1.00	30.7		
	G5	10	0.00	0.00	0.00	1.00	30.7		
	G6	10	0.00	0.00	0.00	1.00	27.6		

* = significant difference.

Table 3: Post Hoc (Dunn's) Test (multiple group comparison) for the mean rank differences (MRD) of the apical third between control and experimental Rotary preparations.

Group		**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
Control	**MRD**	-7.2	-6.9	-6.9	0	0	0
	p-value	0.103	0.1182	0.1182	1	1	1
G1	**MRD**		0.3	0.3	7.2	7.2	7.2
	p-value		0.9458	0.9458	0.103	0.103	0.103
G2	**MRD**	0.3		0	6.9	6.9	6.9
	p-value	0.9458		1	0.1182	0.1182	0.1182
G3	**MRD**	0.3	0		6.9	6.9	6.9
	p-value	0.9458	1		0.1182	0.1182	0.1182
G4	**MRD**	7.2	6.9	6.9		0	0
	p-value	0.103	0.1182	0.1182		1	1
G5	**MRD**	7.2	6.9	6.9	0		0
	p-value	0.103	0.1182	0.1182	1		1

Table 4: Post Hoc (Dunn's) Test (multiple group comparison) for the mean rank differences (MRD) of the middle third between control and experimental Rotary preparations.

Group		Gp1 (ProTaper Next)	Gp2 (Vortex Blue)	Gp3 (TF)	Gp4 (Reciproc)	Gp5 (Reciproc Blue)	Gp6 (TF Adaptive)
Control	MRD	-36.65	17.65	-16.5	-6.6	-6.6	0
	p-value	0.0000	0.01983	0.02942	0.3837	0.3837	1
G1	MRD		19	20.15	30.05	30.05	36.65
	p-value		0.01215	0.007823	0.0000	0.0000	0.0000
G2	MRD	19.0		1.15	11.05	11.05	17.65
	p-value	0.01215		0.8794	0.1447	0.1447	0.01983
G3	MRD	20.15	1.15		9.9	9.9	16.5
	p-value	0.007823	0.8794		0.1913	0.1913	0.02942
G4	MRD	30.05	11.05	9.9		0	6.6
	p-value	0.0000	0.1447	0.1913		1	0.3837
G5	MRD	30.05	11.05	9.9	0		6.6
	p-value	0.0000	0.1447	0.1913	1		0.3837

Table 5: Post Hoc (Dunn's) Test (multiple group comparison) for the mean rank differences (MRD) of the coronal third between control and experimental Rotary preparations

Group		G1	G2	G3	G4	Gp5	G6
Control	MRD	-22.1	-23.0	-16.4	-6.2	-6.2	-3.1
	p-value	0.00299	0.0020	0.0276	0.405	0.405	0.6772
G1	MRD		-0.9	5.7	15.9	15.9	19
	p-value		0.9038	0.444	0.0327	0.0327	0.0107
G2	MRD	-0.9		6.6	16.8	16.8	19.9
	p-value	0.9038		0.3754	0.02406	0.02406	0.0075
G3	MRD	5.7	6.6		10.2	10.2	13.3
	p-value	0.444	0.3754		0.1707	0.1707	0.0740
G4	MRD	15.9	16.8	10.2		0	3.1
	p-value	0.0327	0.02406	0.1707		1	0.6772
G5	MRD	15.9	16.8	10.2	0		3.1
	p-value	0.0327	0.02406	0.1707	1		0.6772

4. DISCUSSION

With the introduction of rotary instrumentation in root canal shaping, there have been several concerns regarding their safety and efficacy. Dentinal crack formation is one of them because of its serious implication in the long-time success in root canal treatment. Research has established that multiple factors, especially instrumentation techniques and methods of obturation, can cause defects in the root dentin during root canal treatment.[11] The correlation between root canal preparation and dentinal crack formation has been reported in many studies. [11-14]

During root canal preparation, stress concentrations in the dentin are created momentarily by the contact between the canal walls and the instruments during motion which may lead todentinal defects initiating cracks leading to VRF. Formation of cracks is related to instrument features such as taper, flute form, pitch design, cross-sectional geometry and tipdesign. [15]

There have been several methods for the detection of dentin cracks. Sectioning of the specimens at apical, middle and coronal levels followed by their stereomicroscopic evaluation is one of the most prevailing approaches.[16]

In this study, the cracks were found mostly in the cervical and mid-root regions as compared to the apical region. This could be explained due to the occurrence of maximum functional strain distribution at the coronal and mid-root surfaces.[17,18] The taper of the instruments is the maximum at these levels. In this study, reciprocating motion file systems showed fewer cracks than the continuous rotation file system. The reason may be due to the mimicking of hand instrumentation by the reciprocating motion. This has also been attributed to the reciprocating movement of the rotary file that might lower the torsional and flexural stresses, reduce canal transportation and the cross-sectional design of the instrument. Moreover, it has been reported that reciprocating motion has better resistance to cyclic fatigue.[19]

TFA produced the least dentin defects. The lowest incidence may be due to the new adaptive reciprocating motion. This file uses continuous rotation when it is subjected to a minimum load and uses the reciprocal motion when it is subjected to a higher load.[20] The adaptive motion combined with the high flexibility and the multi-file system seems to lower torsional forces resulting in fewer dentin defects. [21, 22]

In this study "ProTaper Next," even though having M-Wire technology showed more cracks. This may be because it has been reported that the "ProTaper Next," file system uses an offset mass of rotation that generate same chanical wave of motion which is analogous to the oscillation noted along with a sinusoidal wave. This action results in a bigger envelope of motion when compared to a similarly sized file having a symmetrical mass and axis of rotation.[23]Vortex blue showed the less number of cracks than "ProTaper Next," in a continuous rotation motion. The possible reason could be attributed to the heat treatment of these NiTi files resulting in instruments being more flexibleand fatigue resistant.[24]

Regardless of statistical significance, Twisted File systems showed dentinal cracks similar to those of Vortex Blue. This may be because of its taper of 0.08 and the triangular cross-section. The continuous rotary motion also causes high tension over the root canal walls.[25]

In 2020, Vieira MLO, et al. used scanning electron microscopy (SEM) and micro-computed tomography (micro-CT) investigations to assess the morphologic alterations on the apical foramen and the development of dentinal microcracks following foraminal expansion in straight and curved root canals. According to the study's findings, using Reciproc Blue to prepare straight and moderately curved root canals, irrespective of working length, had no effect on the development of dentinal microcracks or apical foramen deformations. [26]

Versiani MA, et al. carried out a study in 2022 to talk about the scientific turning points that resulted in the current comprehension of the root dentinal microcrack phenomenon. This study was based on the interaction between a close-to-mouth experimental model and the use of micro-computed tomography (micro-CT) as an analytical tool. According to the study's findings, dentinal microcracks in extracted teeth are a non-natural phenomenon that is only seen in a lab setting and results from storage and dehydration. [27]

In 2024, Wang Z. et al. used micro-computed tomography (micro-CT) analysis to compare the differences between four types of mechanical Ni-Ti files: T-Flex, Reciproc Blue (RB), ProTaper Gold (PTG), and ProTaper Universal (PTU) in dentinal microcrack generation following root canal preparation in vitro. According to the study's findings, straight root canals in premolars did not develop new dentinal microcracks when root canals were prepared utilizing Ni-Ti files, such as T-Flex, Reciproc Blue (RB), ProTaper Gold (PTG), and ProTaper Universal (PTU) systems. [28]

In 2021, Miguéns-Vila R. used micro-computed tomographic analysis to assess the impact of reciprocating (WaveOne Gold [WOG, Dentsply Maillefer]) and rotary (ProTaper Next [PTN; Dentsply Maillefer, Ballaigues, Switzerland] and ProTaper Gold [PTG, Dentsply Maillefer]) systems on the development of dentinal microcracks following the preparation of curved root canals. According to the study's findings, new dentinal microcracks were not created by root canal instrumentation using PTN, PTG, and WOG methods. [29]

In 2021, Martins JCLGD, et al. used micro-computed tomographic (micro-CT) analysis to assess the development of microcracks in the roots of extracted teeth following the shaping of straight and curved root canals using hand, rotary, and reciprocating files. According to the study's findings, when assessed using micro-CT, straight and curved root canals prepared with the ProTaper Universal for Hand Use, HyFlex EDM, and Reciproc Blue devices did not result in microcracks in extracted teeth. [30]

Future perspectives: The study on "Effect of Different Kinematics of Contemporary Motor-Driven File Systems on Root Dentin Cracks" opens up opportunities for optimizing kinematic parameters like speed and motion type to reduce dentin cracks. Future research could focus on linking specific kinematic settings to better clinical outcomes, such as fewer fractures and improved root canal treatment success. This could lead to advancements in file design, personalized treatment plans, and the integration of real-time imaging technologies. Ultimately, these improvements could refine endodontic practices, ensuring safer, more effective treatments while reducing the risk of dentin damage.

5. CONCLUSION

Considering the limitations of this study, there was a significant difference in the formation of dentinal cracks was observed between the groups. The TFA system and the Reciproc Blue and Reciprocsystem caused fewer dentin cracks. "ProTaper Next," TF, Vortex blue file system produced more dentinal cracks irrespective of their motions. It can be concluded from this study that TFA which combines rotary and reciprocating motion shows better performance with regards to dentin crack formation. Further studies may be required to assess the advantage of the combination of continuous motion and reciprocating root canal instrumentation systems concerning its impact on the dynamics of root canal preparation.

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Author contributions

Conceptualization: Youssef Algarni.

Data curation: Youssef Algarni, Nuha Alghamdi.

Investigation: Youssef Algarni.

Methodology: Youssef Algarni, Nuha Alghamdi.

Supervision: Youssef Algarni, Nuha Alghamdi.

Validation: Youssef Algarni.

Visualization: Nuha Alghamdi.

Writing – original draft: Youssef Algarni, Nuha Alghamdi.

Writing – review & editing: Youssef Algarni, Nuha Alghamdi.

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