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Impact of Angle of File Access and Location of Canal Curvature on the Dynamic Cyclic Fatigue of Nickel Titanium Rotary Instruments

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ORIGINAL ARTICLE

Impact of Angle of File Access and Location of Canal Curvature on the Dynamic Cyclic Fatigue of Nickel Titanium Rotary Instruments

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ABSTRACT

Objective: To evaluate the impact of different file access angles and root canal curvature's location on the fatigue failure of One Curve (OC) and E3 Azure (EZ) NiTi files using a dynamic model at simulated body temperature.

Methods: Eighty new instruments with similar tip sizes and taper (#25/0.06) from two NiTi rotary systems, One Curve and E3 Azure, were tested at simulated body temperatures (37°C) using a custom-made dynamic cyclic fatigue device. Instruments were divided into four subgroups according to the location of root canal curvature (a coronal curve 5 mm from the root canal orifice and an apical curve 10 mm from the root canal orifice) and the angle of file access (0° or 30°). Instruments were operated in simulated stainless-steel canals having a 60° curve and a 3 mm radius. A custom-made device produced controlled vertical pecks during file rotation. Time to failure (sec) was registered, and the length of the fragment segments was measured (mm). Data were analysed statistically with One-Way ANOVA and Tukey post hoc tests. The significance level was set at 5%. All separated instruments were examined by scanning electron microscope.

Results: One-way ANOVA ($p<0.05$) found a significant difference among the tested instruments. Post Hoc analysis revealed lower cyclic fatigue resistance when the angle of file access was 30º, and the root canal curvature was located coronally for both files ($p<0.0001$). Three-way ANOVA showed that the angle of file access was the most influential contributor to cyclic fatigue, followed by the location of file curvature and, finally, the file type ($p<0.0001$). The fractographic examination revealed a predominantly ductile fracture mode for all tested instruments. The lengths of all fractured segments showed no significant difference ($p>0.05$), indicating an accurate trajectory during testing.

Conclusion: OC files had superior cyclic fatigue resistance than EZ files; coronal curvatures negatively impacted cyclic fatigue resistance compared to apical curvatures, while the angle of file access presented the highest impact on dynamic cyclic fatigue.

Keywords: Angle of file access, dynamic cyclic fatigue, E3 Azure files, nickel-titanium, One Curve files, root canal curvature

HIGHLIGHTS

- An increased file access angle and coronal curvatures predispose to dynamic cyclic fatigue.
- Providing adequate radicular access by early coronal flaring and considering coronal access modification to avoid fatigue failure of NiTi files is advisable, especially when adopting conservative and ultraconservative access cavity designs.

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INTRODUCTION

Continuous improvements in Nickel-titanium (NiTi) instruments are ongoing to improve clinical efficiency and prevent unexpected separation during use (1, 2). Sattapan et al. (3) described two modes for the failure of NiTi instruments: Torsional and fatigue failures. The former occurs when the stress buildup within the file exceeds its ultimate strength, while the latter is attributed to metal fatigue at maximum flexion (4, 5).

Such incidences may compromise the treatment outcome, especially when adequate disinfection cannot be achieved in infected root canals (6). Several factors predispose to such mishaps, including operator, instrument, and technique-related factors (7). One Curve (OC) (Micro-Mega, Besancon, France) is a conventionally machined NiTi rotary system with a triple-helix cross-section at the tip and an S-shaped cross-section closer to the shank. One Curve undergoes a special heat treatment called C Wire, which gives the file a shape memory effect (8). E3 Azure (EZ) (Pol-dent, Warsaw, Poland) is another machined NiTi rotary system manufactured with HT technology, which is a special heat treatment procedure that, according to the manufacturer, provides the files with both the advantages of the martensite phase, which are more flexibility, ability of pre-bending and greater resistance to fracture, as well as the advantages of the austenite phase which are super elasticity, high cutting ability and resistance to twisting forces at near body temperature during root canal treatment. E3 Azure has an inactive tip, while its cross-section is S-shaped with two cutting edges (9).

The angle, radius, location, and number of canal curvatures are other important anatomic factors influencing instrument fatigue (10). Additionally, the axial inclination of the instrument into the canal through the access opening can produce supplementary curvatures in addition to anatomic ones (11). Multiplanar root canal curves will likely happen with the recently advocated minimally invasive, contracted, or caries-driven access cavity designs (12).

To date, scarce data is available on the interaction of the angle of file access and root canal curvature location on the predicted lifespan of recent heat-treated NiTi instruments. Therefore, this study used a dynamic model at simulated body temperature to assess the impact of the angle of file access and the root canal curvature's location on the fatigue life of OC and EZ NiTi files. The null hypothesis was that there would be no difference in the fatigue failure of OC or EZ NiTi instruments when operated at different angles of file access or locations of root canal curvature.

MATERIALS AND METHODS

The protocol was revised and permitted by the ethics committee at the Faculty of Dentistry, The British University in Egypt (approval number: 21-007 on 23/2/2021), as it does not fall under the umbrella of human subjects. The study was conducted per the Declaration of Helsinki.

Sample Size Calculation

A statistical sample size estimate was implemented based on a previous study (13) using the G-power program. The mean± standard deviation of OC at 0 angle and 35°C was 186±30, while the estimated mean difference of the intervention group is 10.5. Using an alpha-type error of 0.05, a beta power of 0.95, and an N2/N1 ratio of 1. Four groups of 20 files each were finally formed.

Dynamic Cyclic Fatigue Test

Eighty new instruments (#25 tip diameter and 0.06 taper) from two NiTi rotary systems, One Curve (OC) and E3 Azure (EZ), were tested at simulated body temperatures (37°C) using a custom-made device (Fig. 1) previously used by authors for dynamic cyclic fatigue testing (14). Relatively large-tapered instruments (6%) were compared, as the larger the instrument's metal mass, the lower its fatigue resistance due to the buildup of larger magnitudes of internal stresses during operation (15). The instruments were examined under magnification and illumination to verify the absence of any signs of deformation. The selected instruments were divided into four subgroups according to the location of root canal curvature (a coronal curve 5 mm from the root canal orifice and an apical curve 10 mm from the root canal orifice) and the angle of file access (0° or 30°). Instruments were rotated in four simulated stainless steel canals of tip size #25/0.06 taper +0.02 mm offset using a 16:1 reduction handpiece (E-connect Endo motor, Eighteeth, Changzhou, China). The metal block with simulated canals was CNC machined and laser-finished. All files were rotated at the speed of 300 rpm and torque of 2.5 Ncm, following the manufacturers' instructions. The simulated root canals were 16 mm long with a 60° curve and a 3 mm radius (Fig. 2). These parameters were selected to create a challenging clinical simulation for the tested files because increasing the angle of curvature and decreasing the radius of curvature predispose to faster cyclic fatigue of rotary NiTi instruments (16).

The testing device comprised a custom-made linear actuator attached to a custom-made frame holding the handpiece and the artificial canal. The linear actuator was connected to a CNC shield/Arduino Uno complex (Arduino, Irvea, Italy). A custom code written by the Arduino software (version 1.8.13, Arduino, USA) controlled the magnitude of the rotating file's vertical distance and time, 1.5 mm/0.5 s upwards and 1.5 mm/0.5 s downwards. The code allowed repeatable cycles with a 1 second relay. Both the device and the endodontic motor were started simultaneously. The auto-reverse mode of the endodontic motor was turned off. The assembly was placed within a water bath (Fig. 3) with a heat controller to adjust the temperature during testing. The actuator, endodontic motor, and an iPhone camera (12 Pro 14.7.1) started working. A video was captured, and time to fracture (Ttf) was evaluated frame by frame from the beginning of file rotation till breakage using a special video editing program (Adobe Premiere Pro 2020, V14.7.0.23, Adobe Inc., California, USA), recorded and tabulated for all groups. For all instruments, the length of the separated files was measured in mm.

Fractographic Examination

All separated instruments were observed by scanning electron microscope (Thermoscientific Quattro S ThermoFisher Scientific, Waltham, USA) operated at 25 kV and room temperature. The separated pieces were immersed in an ultrasonic bath containing 70% ethyl alcohol for fifteen minutes before analysis. Scanning electron Micrographs were obtained at 200 × and 4000 × magnification to assess the fracture pattern.

Statistical Analysis

Statistical analysis was performed with IBM SPSS 22 (IBM Corporation, Armonk, NY, USA). The mean and standard

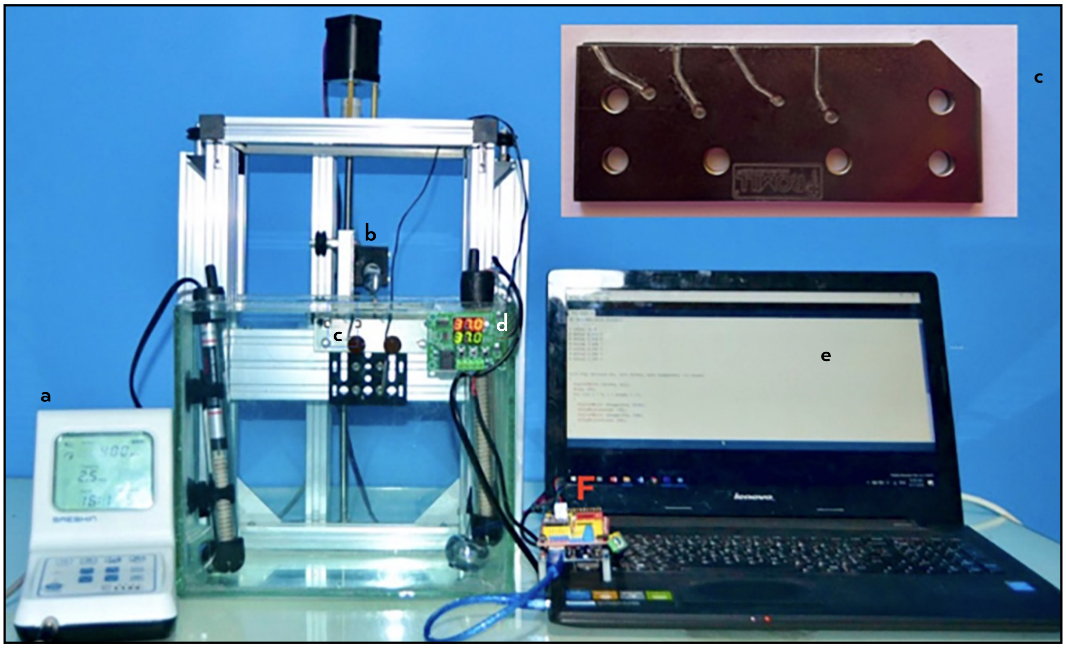

Figure 1. The dynamic cyclic fatigue testing assembly: (a) Endodontic motor, (b) Handpiece with file, (c) Metal block with simulated root canals in water bath, (d) display of water temperature, (e) Screen display of the code responsible for dynamic movement, (f) Arduino/CNC shield complex

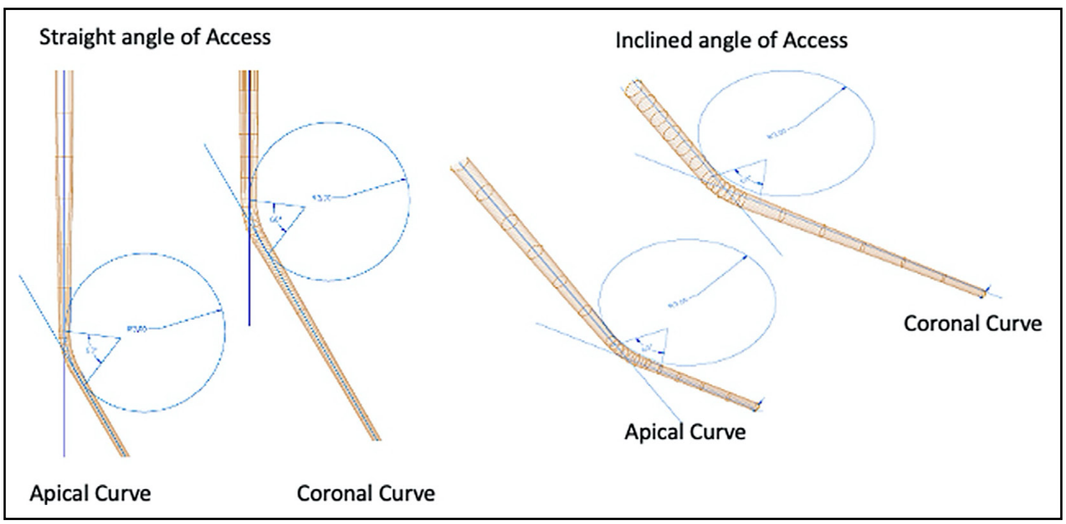

Figure 2. Auto CAD drawings of simulated canals show that they all have the same degree (60) and radius (3 mm) of root canal curvature

deviation were used to describe all quantitative data. Data was explored for normality using the Shapiro-Wilk and Kolmogorov Normality test; the data distribution was normal. All groups were compared using a One-way ANOVA test and Tukey`s Post hoc test for multiple comparisons. The percentage of the total variance for the three parameters (file type, curvature location, and angle of file access) was calculated using the Three-way ANOVA test. Statistical significance was set at $\alpha<0.05$. The lengths of the fractured file segments were compared using the paired t-test.

RESULTS

Table 1 displays the mean TtF SD values after dynamic fatigue testing of the OC and EZ NiTi files. A significant difference between the tested files was found using one-way ANOVA ($p<0.05$). Post hoc analysis showed decreased fatigue resistance when the angle of access was 30°, and the canal curvature was positioned coronally for both files ($p<0.0001$). Three-way ANOVA (Table 2) showed that the angle of file access was the most influential contributor to cyclic fatigue, followed by the location of file curvature and, finally, the file type ($p<0.0001$). The lengths of all fractured segments showed no significant difference ($p>0.05$) among all tested groups, denoting accurate device trajectory (Table 3). SEM of the fractured surface of the separated files (Fig. 4) confirmed a ductile fracture at low magnification (200×), evidenced by the numerous hollows on the surface. At high magnification (4000×), the hollows revealed a characteristic pattern of microvoids for either OC or EZ files.

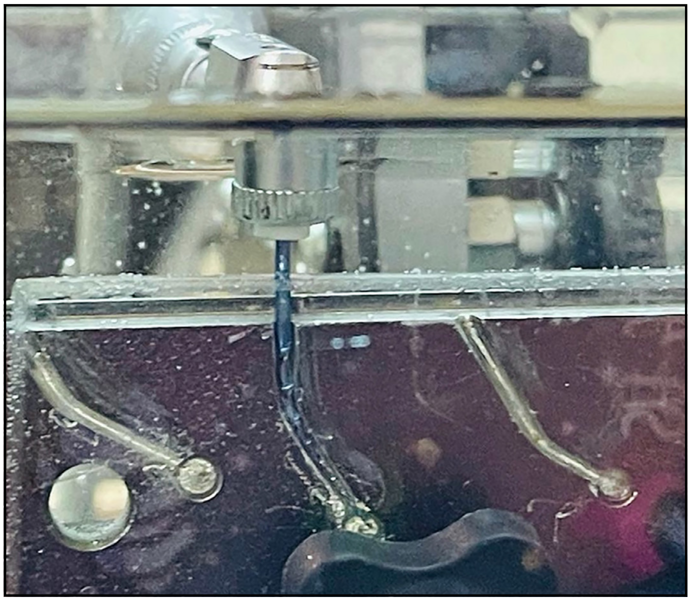

Figure 3. Photograph showing the handpiece with one of the tested files in its corresponding simulated canal

DISCUSSION

This study assessed the impact of the angle of file access, the location of canal curvature, and their interaction on the fatigue failure of OC and EZ rotary NiTi files. Such investigation is important from a clinical standpoint, especially with the increasing trend of adopting lesion-driven or caries-driven access designs in which the angle of file access is not straight.

Our results showed that OC files had superior cyclic fatigue resistance than EZ files, which can be attributed to the enhanced intrinsic chemical and mechanical characteristics of its thermal treatment (17). Our results also showed a decreased fatigue resistance of both tested files when the angle of file access was 30° and the root canal curvature was located coronally. Such a working situation is not uncommon as it subjects the instruments to high levels of environmental stress acting on their active parts, which would eventually overcome the flexural strength of the files, resulting in fatigue failure. This finding agrees with Pedullà et al. (10), who reported that excessively inclined angles of access reduced the fatigue strength of heat-treated files, and Al-Sudani et al. (18), who described a significantly lower fatigue resistance for NiTi instruments operating in double curved-canals versus single curved-ones.

Conversely, our results disagree with LaRosa et al. (13), who reported that a file-inclined insertion angle of 20° did not affect the cyclic fatigue of OC and F6 SkyTaper files (Komet, Brassler GmbH & Co., Lemgo, Germany) at either 20°C or 35°C. This neutral impact on fatigue failure was attributed to the C-wire heat treatment technology for OC. However, our model used a 30° angle of access, representing about a 33% increase in the magnitude of the angle of incidence. Hence, different results were obtained.

The three-way ANOVA revealed that the angle of file access was the most influential factor affecting fatigue failure, followed by the location of root canal curvature and, finally, the file design and thermomechanical history. The lengths of all fractured segments showed no significant differences (p>0.05). This observation agrees with previous static (19, 20) and dynamic tests (14) and confirms an accurate device trajectory during testing.

Recently, the scientific importance of fatigue failure studies has been doubted because of the variable cyclic fatigue testing protocols reported in the endodontic literature, which

TABLE 1. Mean and standard deviation values of time to fracture (Ttf) in seconds for both One Curve and E3Azure files with 0° and 30° insertion angles tested at coronal or apical root canal curvatures

Section	One curve		E3azure		p (One Way ANOVA test)
	0° Mean±SD	30° Mean±SD	0° Mean±SD	30° Mean±SD	
Apical	$743.50^{Aa}\pm54.38$	$368.00^{c}\pm40.86$	$562.90^{b}\pm40.47$	$192.70^{d}\pm35.03$	<0.0001*
Coronal	$506.00^{Ba}\pm44.27$	$202.80^{c}\pm37.95$	$347.90^{b}\pm42.22$	$110.80^{d}\pm36.63$	<0.0001*
p-value Paired t-test	<0.0001*	<0.0001*	<0.0001*	<0.0001*	

*: Significant difference as p<0.05. Means with different superscript letters were significantly different as p<0.05. Means with the same superscript letters were insignificantly different as p>0.05. SD: Standard deviation

TABLE 2. Percentage of total variance

	% of the total variance	p (Three-Way ANOVA)
Effect of angle of file access		
Angle 0° vs Angle 30°	61.86%	<0.0001*
Effect of location of canal curvature		
Apical vs Coronal	18.31%	<0.0001*
Effect of file type		
OC vs EZ	13.74%	<0.0001*

*: Significant difference at p<0.05. OC: One Curve, EZ: E3 Azure

TABLE 3. Comparison between the lengths of the fractured segments of OC and EZ using the Paired t-test

	OC		EZ		Paired differences					p
					MD	SD	SED	95% CI		
	Mean	SD	Mean	SD				L	U	
Apical 0°	3.65	0.42	3.70	0.35	0.05	0.11	0.04	–0.03	0.13	0.222 ns
Apical 30°	14.62	0.85	14.07	0.41	–0.55	0.98	0.31	–1.25	0.15	0.111 ns
Coronal 0°	8.38	0.34	8.56	0.40	0.18	0.27	0.09	–0.02	0.38	0.068 ns
Coronal 30°	15.28	0.36	15.31	0.29	0.03	0.08	0.02	–0.02	0.08	0.239 ns

MD: Mean difference, SED: Standard error difference, CI: Confidence interval, L: Lower arm, U: Upper arm, Ns: Non-significant difference as p>0.05

make comparisons among studies awkward (21, 22). This type of research does not resemble reality because pure rotation inside an artificial canal without any torque on the instrument, such as in cyclic fatigue tests, was unlikely to happen in a clinical scenario. Although these statements are true, cyclic fatigue and torsional resistance tests allow the variables to be isolated and tested individually, increasing the internal validity and reproducibility of the study, which agrees with the basic concepts of the scientific method (14, 23).

Therefore, *in-vitro* studies simulating the clinical applications are justified to evaluate the manufacturers' claims and compare recent productions of NiTi files (14).

The strengths of this study include using a dynamic model with a controlled pecking distance and performing the test in simulated oral temperature. Dynamic models are more clinically relevant and better than static or dynamic models operated by universal testing machines that cannot control the environmental temperature. Previous research has shown that the fatigue strength of rotary NiTi files is adversely affected by raising the temperature from room to body temperature (24–27) because heating transforms the martensitic files, which have superior fatigue-crack growth resistance (19), to more austenite, which has a higher speed of fatigue-crack propagation (23), that is affected by the thermomechanical processing history of the alloys used to manufacture the shaping files, which is often not disclosed by the manufacturers (28, 29).

According to the findings of this study, the null hypothesis has to be disproved. OC files demonstrated superior cyclic fatigue resistance than EZ files, highlighting a better heat treatment technology. Moreover, all the variables tested affected cyclic fatigue but were unequal. The most effective variable was the angle of file access, the location of canal curvature, and the material used to produce the instruments.

Therefore, from the clinical perspective, we advise providing adequate radicular access by early coronal flaring. We also consider coronal access modification with minimally invasive approaches to avoid fatigue failure of NiTi files. Access designs should be executed with a precise balance that provides convenience for safe instrumentation on one side and the other side preserves an adequate amount of tooth structure, which is essential for post-treatment restorability and long-term serviceability of the endodontically treated tooth (30).

CONCLUSION

OC files had superior cyclic fatigue resistance than EZ files; coronal curvatures negatively impacted cyclic fatigue resistance compared to apical curvatures, while the angle of file access presented the highest impact on dynamic cyclic fatigue.

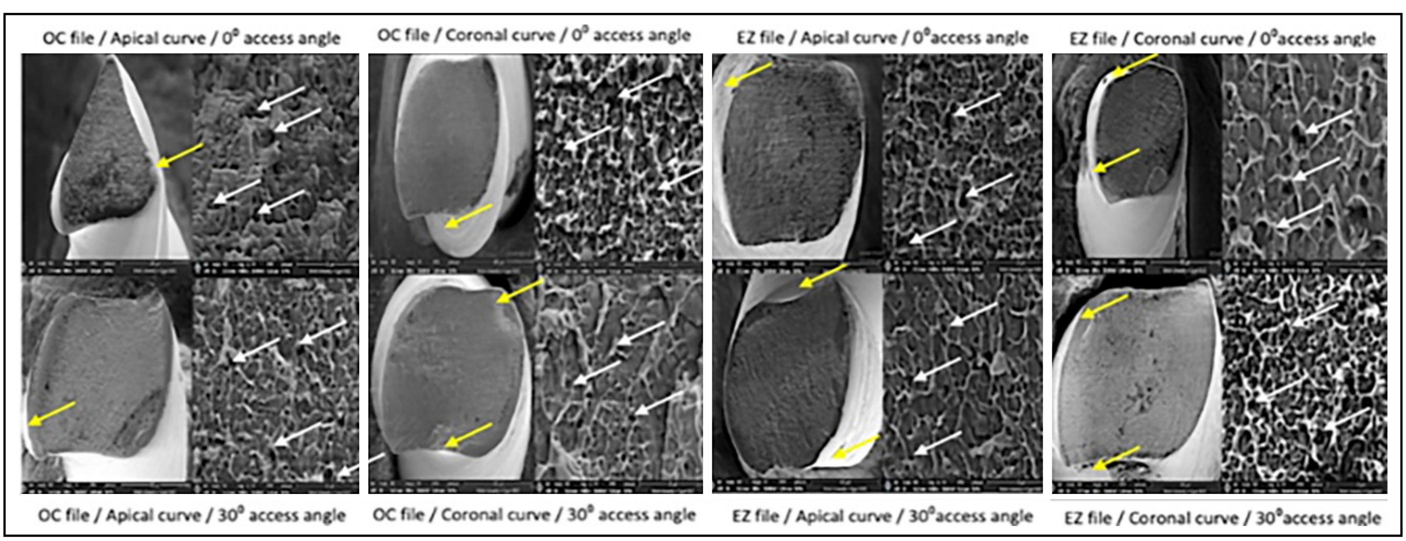

Figure 4. SEM photomicrographs of the fractured surfaces of OC and EZ files after dynamic cyclic fatigue testing showing areas of metal elevation at the file edges (yellow arrows) at low magnification and microstructural voids (white arrows) at high magnification typical of ductile fracture

OC: One Curve, EZ: E3 Azure, SEM: Scanning electron microscope

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: This study was approved by The Faculty of Dentistry, The British University in Egypt Ethics Committee (Date: 23/02/2021, Number: 21-007).

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