THE EFFECT OF TWO DIFFERENT OBTURATION TECHNIQUES USING A NEWLY INTRODUCED BIO-CERAMIC SEALER ON THE RADICULAR FRACTURE RESISTANCE AND DENTINAL TUBULES PENETRATION DEPTH (AN IN-VITRO STUDY)

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Abstract

Objective: The study's aim was to assess the tubular penetration depth and fracture resistance of resin-based AH Plus sealer and bio ceramic-based NeoSealer Flo using scanning electron microscopy (SEM) by various obturation techniques.

Material and Methods: 100 recently extracted single-canaled human maxillary upper central incisors were utilized. Samples were prepared and obturated using different obturation techniques and various sealers. For tubular penetration test, a diamond bur with water coolant was used to make root slices with a thickness of 2 mm at 2 to 3, 5 to 6, and 8 to 9 mm from the root tip. Sealer penetration was then assessed by scanning electron microscope at a magnification of 2000x. For fracture resistance test, a universal testing machine was utilized to record the utmost forces responsible for fracture in Newton (N). One way ANOVA test was used to compare results of various groups and sections. Tukey's Post Hoc test was then used for multiple comparisons, with a significance level (P-value) was set as of P-value < 0.05.

Results: AH Plus /WVC group showed the highest tubular penetration depth with statistically significant difference followed by AH Plus/ CLC then NeoSEALER Flo/CLC group. NeoSEALER Flo/WVC group showed the lowest penetration, favoring the cervical section over the apical in all groups. The greatest levels of fracture resistance were recorded within the negative control group with a statistically significant difference. The NeoSEALER/CLC group had greater fracture resistance than the NeoSEALER/WVC group. In comparison to the other groups, the positive control group showed the worst results among all groups.

Conclusions: This study concluded that the type of sealer had a remarkable effect on tubular penetration depth. According to this study, AH Plus sealer has higher tubular penetration than NeoSEALER Flo. Concerning the obturation technique used, it had minimal effect compared to type of sealer. However, the usage of bio-ceramic sealer with lateral compaction increases the fracture resistance of endodontically treated teeth over the resin-based sealers.

Keywords: Bio-ceramic sealer, Fracture resistance, Resin-based sealer, Tubular penetration.

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1. INTRODUCTION

Root canal treatment (RCT) has always been a controversial dilemma since it includes a series of techniques and procedures including access cavity preparation, removal of inflamed pulp, mechanical instrumentation, obturation of the canal, and finally the coronal restoration of the tooth to entomb the bacteria preventing reinfection and damage of the periodontal tissue; hence facilitating tissue repair (1).

The most important steps in achieving long-term progress in endodontic treatment are adequate root canal disinfection and obturation. Through years, pitfalls with a single technique have often led to the invention of brand-new strategies of obturation, along with the perception that none of the obturation methods may satisfy all clinical cases. It's mandatory for prosperous endodontic obturation, to pick out a root-canal filling material with the potential to attain a hermetic three-dimensional filling within root-canal area. Due to the development of periapical lesions under these conditions, fluid leakage and bacterial percolation are likely to occur, endangering the lifetime of the endodontic therapy (2,3).

Unfortunately, the obturation materials utilized today cannot completely fill the root canal hence gaps eventually form between the root-filling material and at the dentine-material interface. The lateral compaction technique is very effective in confining the obturation inside the root canal system, but several reports suggested that this technique causes voids and spaces due to inhomogeneous distribution of sealer within the obturation (4).

At present, the key norms of the materials available to saturate root canals in the market are gutta-percha along with a sealer. A root canal sealer's compulsory function is to patch up any imperfections in the canal system and gaps between gutta percha in addition to dentinal tubules penetration to entomb the bacteria potentially surviving inside them where this significantly has high impact on endodontic treatment success (5). Therefore, the sealer penetration depth and percentage, combined with antimicrobial properties, have implications for succeeded endodontic treatment. Also, the sealer penetration improves the retention of obturation with the canal walls as it acts as mechanical lock inside the dentinal tubules.

Mechanical preparation and gutta-percha insertion result in increased stresses, so teeth that were endodontically treated are regarded weaker and more likely to fracture than healthy teeth (6). As a result, the roots will be less able to sustain stresses and more susceptible to fracture.

Endodontic sealers made of bio-ceramic materials have recently entered clinical dental practice. These materials are distinguished by their biocompatibility, antibacterial activity, high pH during setting, and chemical attachment to dentine via the development of hydroxyapatite in the area of contact between the sealer and dentine. It might penetrate the dentinal tubules because of its nanoparticles and set with shrinkage (3).

Gutta percha cones and bio-ceramic-based sealers have been shown to strengthen root canal-treated teeth in the same way that untreated teeth do. On the contrary, epoxy resin- and zinc oxide-based sealers did not show the ability to considerably strengthen roots that had undergone endodontic treatment (6).

Utilizing a variety of obturation procedures, the current study's goal is to assess the tubular penetration depth and fracture resistance of a new bio-ceramic-based sealer (NeoSEALER Flo) including lateral and vertical compaction in mature single-canaled maxillary central incisor teeth using scanning electron microscope (SEM).

2. MATERIALS AND METHODS

Sample size calculation:

The sample size was calculated based on Turkyilmaz and Erdemir (2020) (1) previous study. This study discovered that the responses of each subject group were regularly distributed, with a standard deviation of 17. If the true difference between the experimental and control means is 17, the study required at least 17 teeth in each group to reject the null hypothesis that the population means of the experimental and control groups are identical with probability (power) 0.8. The probability of a Type I error in this null hypothesis test is 0.05. The sample size was increased to 20 teeth in each group to account for a 20% drop out.

Specimen preparation:

The research Ethics committee of the Faculty of Dentistry approved the study, (REC: 11-2021) and the study was conducted following the principles of declaration of Helsinki. 100 freshly extracted human single-canaled maxillary central incisors were gathered from the Faculty of Dentistry's Oral Surgery and outpatient’s clinic extracted due to periodontal causes, and were free of cavities, root resorption, and fractures. For surface disinfection, each tooth was submerged in 5.25% sodium hypochlorite (NaOCl) (Clorox; Clorox Inc., Oakland, CA, USA) for two hours. A diamond-coated disc was used to decoronate each sample at the cemento-enamel junction while being kept under enough coolant.

In 90 samples, working length was determined by introducing#10 K-file (MANI, Inc., Japan) into the root canal until it become visible through the apical foramen. During instrumentation, 1 mm was then subtracted from this length while 10 samples were left decoronated only without any instrumentation to be used as a negative control group for the fracture resistance test.

Using an E-connect Pro Endomotor (Changzhou Eighteeth Medical Technology Co., Ltd, China), ProTaper Next rotary files (Dentsply Sirona, Ballaigues, Switzerland) were utilized to instrument canals in a crown-down manner, resulting in a final size of X4 (40/0.06). To irrigate the canals, 2.5 ml of sodium hypochlorite (NaOCl) 2.6% (Clorox; Clorox Inc, Oakland, CA, USA) was used between each file alongside a final flush using 5 ml of NaOCl 2.6 % and ultrasonic activation (IRR20-21, Satelec, Acteon, France) for 30 sec. Then 5 ml of EDTA 17% (META BIOMED Co., Chungbuk, Korea) was used then a final flush with 5 ml NaCl 0.9% was done. All specimens were kept at 37°C and 100% humidity for 24 hours in an incubator before root canal obturation to mimic physiological temperature.

Root Canal Filling using NeoSEALER Flo and AH plus Sealers: **(Table 1).**

Table (1): Sealers; types, manufacturers and composition.

Materials	Manufacturer	Composition	Batch	Form
Neo SEALER Flo	Avalon Biomed, Texas, USA	Thickening agent, calcium silicates, zirconium oxide	LOT 2021062802	Premixed (Flex Flo Tips to minimize product waste by 81 %.)
AH Plus Sealer	(Dentsply Sirona, Ballaigues, Switzerland)	Paste A: A 10%–25% zirconium dioxide, NS calcium tungstate, NS iron oxide pigments and 25%–50% bisphenol and silica. Paste B: zirconium oxide, 2.5%–10% N, n-dibenzyl-5-oxanonandiamin-1, silicone oil and silica.	LOT 2202000224	Paste to paste system

All roots had been dried using matching sterile paper points (META BIOMED Co., Chungbuk, Korea). According to the manufacturer instructions, all sealers were prepared.

For the Lateral compaction technique, a master cone (size 40/0.06) (META BIOMED Co., Chungbuk, Korea) was inserted to full WL and Tug-back was inspected. A sealer was spread on the master cone and introduced inside the canal until reaching the full WL then lateral compaction technique was carried out using suitable sized finger spreader (MANI, Inc, Japan) and auxiliary cones (META BIOMED Co., Chungbuk, Korea) of the same size of the spreader. This process has to be redone until no more than 2 mm of spreader could be progressed into the canal.

For groups with warm vertical compaction technique, the continuous-wave technique was utilized. The master cone (size 40/0.06) and sealer were placed to fit the apical preparation then Tug-back was also checked. A heated plugger was used at 230°C then applied inside the root canal to down pack the master cone 5 mm of gutta-percha apically by the obturation device (EQ-V, META BIOMED Co., Chungbuk, Korea), followed by compaction with a pre-fitted cold plugger. A second coat of sealant was used, and incremental backfilling with a thermoplasticized gutta-percha Obtura III tool (EQ-V, META BIOMED Co., Chungbuk, Korea) was carried out before compaction with a plugger. Confirmation for the quality of obturation was performed using a preapical radiograph before undergoing the examination using scanning electron microscope and fracture resistance test.

A. Tubular Penetration depth:

After final obturation, the samples were stored for one week at 37 °C, 100% relative humidity to allow setting of the sealer. All samples were encased in resin blocks and sectioned transversely at 2, 5, and 8 mm from the root apex while being kept in sufficiently chilled water. Sections were prepared at a thickness of 200 microns for each tooth; After that, specimens were put on glass slides and investigated with a scanning electron microscope (Quanta FEG 250, Netherlands) and photographed at 2000x magnification then measured at 3 different levels (coronal, middle, apical) to investigate the sealer's maximum depth of penetration, then statistical analysis was done.

❖Grouping

Each group was divided into two subgroups:

Group (A1): 20 teeth were obturated using NeoSEALER Flo.

- 10 teeth by NeoSEALER Flo, obturated by cold lateral compaction technique (NL).
- 10 teeth by NeoSEALER Flo, obturated by warm vertical compaction technique (NV).

Group (A2): 20 teeth were obturated using AH Plus Sealer.

- 10 teeth by AH Plus Sealer, obturated by cold lateral compaction technique (AL).
- 10 teeth by AH Plus Sealer, obturated by warm vertical compaction technique (AV).

B. Fracture Resistance:

5 mm of the apical part of all roots were covered with a wax material of 0.2-0.3 mm thickness for periodontal membrane simulation, which was calibrated digitally to ensure its uniform thickness. A 15 mm height and 20 mm in diameter of acrylic resin cylinders were used to vertically fix the samples covering 4 mm of the root length. After acrylic resin polymerization, specimens were separated from the resin cylinders followed by wax removal. Application of a thin coat of addition silicone rubber base impression material (Ultradent Products, Inc, UT, and USA) was utilized for periodontal tissue simulation then returned back into the acrylic cylinders.

A universal testing machine (Instron Corp., MA, and USA) was utilized for fracture resistance testing. Acrylic resin blocks were positioned on the lower plate of the instrument while the upper plate involves a spherical steel tip of 2 mm in diameter that was used for compressing the canal center parallel to vertical loading application equal to (1 mm/min) till fracture occurred. The utmost force exerted for fracturing each root was pointed out in Newton (N) (6).

❖Grouping

Each group was divided into two subgroups:

Group (B1): 20 teeth were obturated using NeoSEALER Flo.

- 10 teeth by NeoSEALER Flo, obturated by cold lateral compaction technique (NL).
- 10 teeth by NeoSEALER Flo, obturated by warm vertical compaction technique (NV).

Group (B2): 20 teeth were obturated using AH Plus Sealer.

- 10 teeth by AH Plus Sealer, obturated by cold lateral compaction technique (AL).
- 10 teeth by AH Plus Sealer, obturated by warm vertical compaction technique (AV).

Group (B3): +Ve Control Group:

- 10 teeth were decoronated and prepared mechanically without obturation.

Group (B4): -Ve Control Group:

- 10 teeth were decoronated only.

STATISTICAL ANALYSIS:

SPSS 20® (Statistical Package for Scientific Studies, IBM Co., New York, USA), GraphPad Prism®, and Microsoft Excel 2016 were used for the statistical analysis. Shapiro Wilk and Kolmogorov Normality test was carried out to explore the normality of all the quantitative data and provided as means and standard deviation (SD) values. While One Way ANOVA test was used to compare between various groups and sections, followed by Tukey`s Post Hoc test for multiple comparisons.

3. RESULTS

I. Tubular penetration depth: (Figures 3, 4, 5, 6)

Mean and standard deviation of tubular depth penetration at all sections of all groups were presented in Table (2) and Figure (1).

The One-Way ANOVA test was used to compare several groups, which revealed a significant difference between them in all sections as P<0.05, accompanied by the Tukey's Post Hoc test for numerous comparisons, which indicated that:

- In cervical section: NV group (9.72 ± 8.27) was significantly the lowest, group AV (27.73 ± 17.76) was significantly the highest, while AL group (23.48 ± 12.42) and NL group (24.44 ± 13.5) revealed insignificant difference with all other groups.
- In middle section: NV group (6.94 ± 3.88) was significantly the lowest, group AV (23.88 ± 11.61) and AL group (21.80 ± 10.76) were significantly the highest, while NL group (16.30 ± 7.27) revealed insignificant difference with all other groups.
- In apical section: NV group (4.68 ± 2.20) was significantly the lowest, then NL group (12.84 ± 6.51) and AV group (13.02 ± 4.32) with no statistically significant difference between them, while AL group (19.71 ± 10.22) was significantly the highest.
- In overall section: NV group (7.11 ± 4.78) was significantly the lowest, group AV (21.54 ± 11.23) and AL group (21.66 ± 11.13) were significantly the highest, while NL group (17.86 ± 9.09) revealed insignificant difference with all other groups.

Table (2): Mean and standard deviation of tubular penetration depth at all sections of all groups and comparison between different groups using One Way ANOVA test

Section	Gr A1				Gr A2				P value
	NL		NV		AL		AV		
	M	SD	M	SD	M	SD	M	SD	
Cervical	24.44 ^{ab}	13.5	9.72 ^{b}	8.27	23.48 ^{ab}	12.42	27.73 ^{a}	17.76	0.02*
Middle	16.30 ^{ab}	7.27	6.94 ^{b}	3.88	21.80 ^{a}	10.76	23.88 ^{a}	11.61	0.0007*
Apical	12.84 ^{b}	6.51	4.68 ^{c}	2.2	19.71 ^{a}	10.22	13.02 ^{b}	4.32	<0.0001*
Overall	17.86 ^{ab}	9.09	7.11 ^{b}	4.78	21.66 ^{a}	11.13	21.54 ^{a}	11.23	0.004*

M: Mean SD: standard deviation
Ns: non-significant difference as P>0.05 *Significant difference as P<0.05
Means with the same superscript letters per row were insignificantly different as P>0.05.
Means with different superscript letters per row were significantly different as P<0.05.

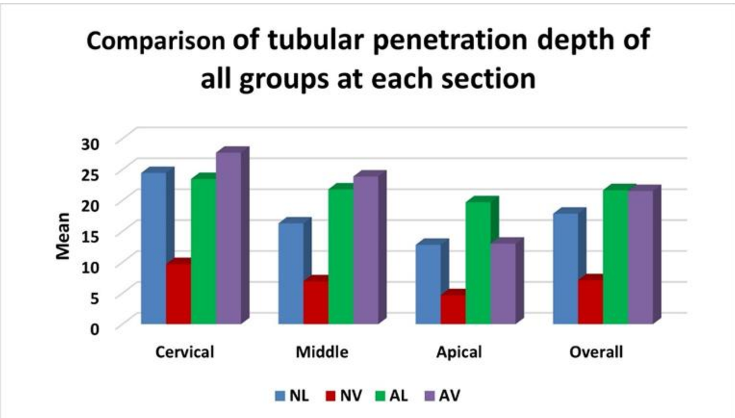

Figure (1): Bar chart showing tubular penetration depth of all groups at each section.

II. Fracture resistance:

Mean and standard deviation of fracture resistance in all groups were presented in Table (3) and Figure (2).

Comparison between different groups was performed by using One Way ANOVA test which revealed significant difference between them as P<0.0001, followed by Tukey`s Post Hoc test for multiple comparisons which revealed that:

The negative control group showed the highest fracture resistance (901.27 ± 543.36) while the positive control group showed the lowest statistically significant fracture resistance (73.63 ± 20.71), followed by AV group (170.69 ± 104.76) and AL group (288.51 ± 201.25), then NV group (339.65 ± 148.46) and NL group (550.35 ± 188.45). There was a statistically significant difference between the negative control group and all groups while there was no statistically significant difference between positive control group and each of AV group and AL group. While there was a statistically significant difference between NL group and all other groups.

Table (3): Mean and standard deviation of fracture resistance in all groups and comparison between different sections using One Way ANOVA test

Fracture resistance		M	SD	P value
Gr B1	NV	339.65 [b]	148.46	<0.0001*
	NL	550.35 [c]	188.45	
Gr B2	AV	170.69 [ab]	104.76	
	AL	288.51 [ab]	201.25	
Gr B3	+Ve C	73.63 [a]	20.71	
Gr B4	-Ve C	901.27 [d]	543.67	

M: Mean SD: standard deviation

Ns: non-significant difference as P>0.05 *Significant difference as P<0.05

Means with the same superscript letters per row were insignificantly different as P>0.05.

Means with different superscript letters per row were significantly different as P<0.05.

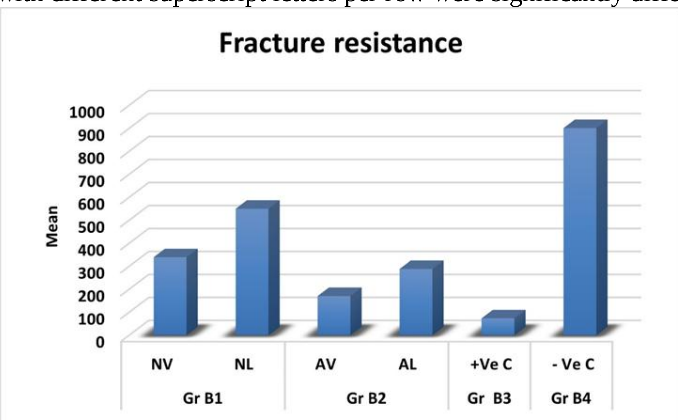

Figure (2): Bar chart showing mean of fracture resistance in all groups.

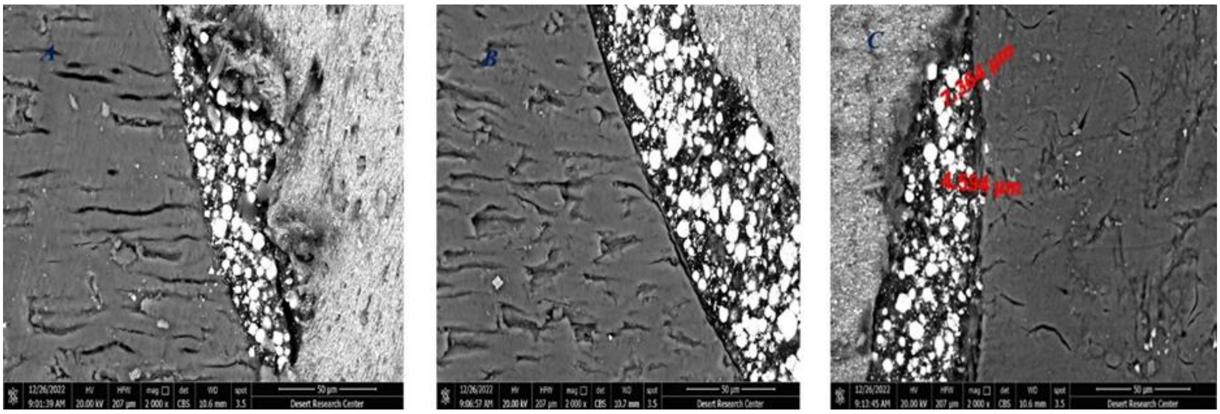

Figure (3): SEM 2000x magnification, showing the dentinal tubules penetration of AH Plus/ CLC (µm)

A) Coronal section. B) Middle section. C) Apical section

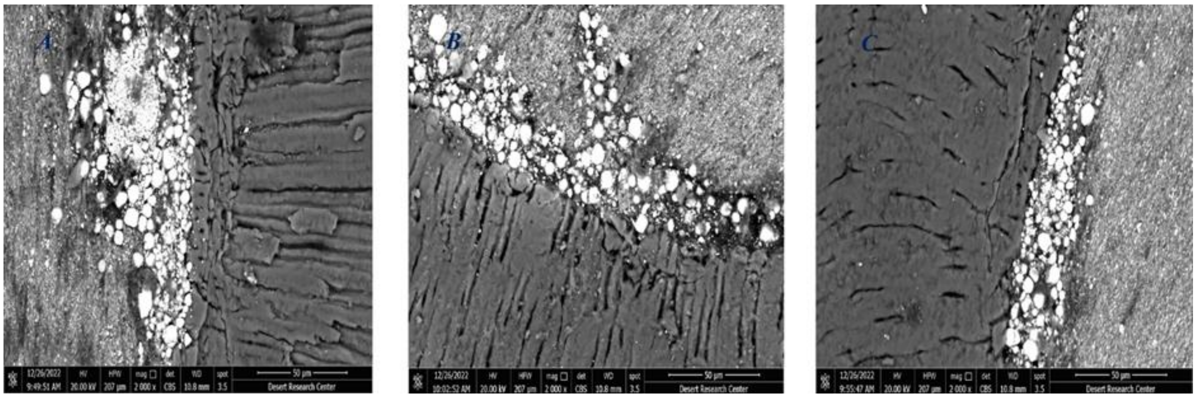

Figure (4): SEM 2000x magnification, showing the dentinal tubules penetration of AH Plus/ WVC (µm)
A) Coronal section. B) Middle section. C) Apical section

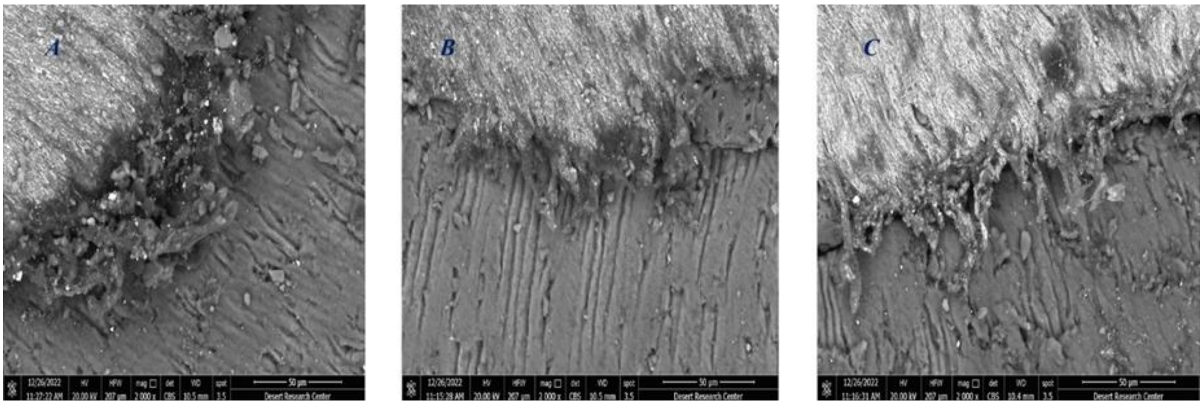

Figure (5): SEM 2000x magnification, showing the dentinal tubules penetration of NeoSealer Flo/ CLC (µm)
A) Coronal section. B) Middle section. C) Apical section

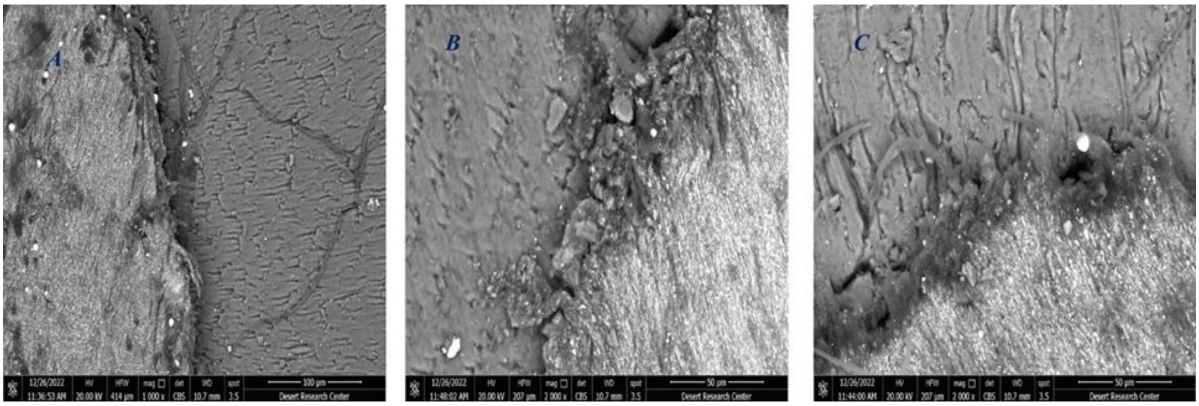

Figure (6): SEM 2000x magnification, showing the dentinal tubules penetration of NeoSealer Flo/ WVC (µm)
A) Coronal section. B) Middle section. C) Apical section

4. DISCUSSION

Microorganisms are the main challenge for successful root canal treatment. Due to the root canal's challenging anatomy, bacteria can remain hidden inside the dentinal tubules and the lateral canals, which contribute to treatment failure. The preceding fact made clear how important it is to create a suitable hermetic seal between the core material and the canal wall. Furthermore, creating a 3D-tight seal throughout the root canal region is essential for obturation. In order to attain this condition various obturation techniques have been developed such as lateral compaction, warm vertical compaction and single cone technique (2).
The current study aimed to determine the tubular penetration depth and the fracture resistance of a new bio-ceramic sealer (NeoSEALER Flo) and resin sealer (AH plus) with different obturation techniques in mature upper central incisors.
The choice of the sealer has paramount significance in the success or failure of the obturation procedure (3). Endodontic sealers of various forms, including as resin-based sealers and bio-ceramic sealers, have been provided in the market. is widely regarded as the market's gold standard resin-based sealer, since it has proper bond strength, high flow, good sealing abilities, convenient film thickness and cost-effectiveness (4). That's why it was used in this current study as a control group to compare it with a bio-ceramic based sealer (7). In the past 30 years, bio-ceramic based sealers have been launched in the dental field. They are composed of glass ceramics, zirconia, alumina, bioactive glass, calcium phosphates and hydroxyapatite. They are distinguishable by having bio inert and bioactive characteristics, which enhance the growth of the surrounding tissues without affecting them negatively (5). A unique bio-ceramic based sealer has been introduced to the market under the name of NeoSEALER Flo which has been chosen to be examined in this study. Likewise, Ha et al. have tested various bio-ceramic based sealers such as (Endoseal MTA, MTA Fillapex, and EndoSequence BC sealer) as they showed bioactive characteristics and superior calcium ion release and high dimensional stability (8).
The momentous in vitro investigation was carried out on mature, maxillary central incisors, aiming for standardization and to control the confounding variables resulting from different root canal anatomy as well as to have an accurate assessment for the tubular penetration depth of the sealer (2). Whereas multi-rooted teeth have more complex anatomy. On the other hand, another in vitro trial selected a third molar to be examined (9).
In the current study, samples were prepared by putting the teeth in 5.25% sodium hypochlorite (NaOCl) for two hours to sterilize the surface before being placed in distilled water followed by decoronation at the cemento-enamel junction to be standardized at 15 mm (10). A diamond disc mounted in a straight hand piece was used to decoronate all of the teeth at the level of the cemento-enamel junction after thoroughly cleaning them with pumice and storing them in distilled water during the duration of the study (11).
Regarding the irrigation protocol, 2.6% sodium hypochlorite was selected since it is capable of disintegrating the organic part, which was also done in previous trials (1, 3, 8). A final flush with17% EDTA was carried out, whereas it acts as chelating agent removing the inorganic part of the pulp. Smear layer removal will allow enhanced tubular sealer penetration throughout the dentinal tubules. After cleaning and shaping, all the canals had been dried using paper points to avoid the presence of moisture as it affects the penetration depth of resin-based sealers (12).
Various obturation techniques have been used to fulfill the 3D obturation concept. Warm vertical compaction (WVC) and lateral compaction (LC) were chosen as the obturation procedures in this investigation. Lateral compaction technique (LC) was chosen because of its simplicity, it doesn't require costly equipment and it is considered the most frequently used technique (13). However, Farias et al. claimed that LC does not efficiently seal the canal wall due to absence of heat and it doesn't allow equal distribution of the sealer, which permits the presence of voids (14).
The warm vertical compaction (WVC) technique was selected as it allows surpassing gutta percha adaptation in the complex canal anatomy. Thus, it prevents the presence of voids in the obturation. Also, WVC allows for faster packing, which reduces the time of the procedure (15). Similar studies have compared the obturation quality of the aforementioned techniques and other techniques such as the single cone technique (16, 17).
As well as warm vertical compaction technique was superior, more effective and professional to other techniques as single cone, providing more homogeneity and three-dimensional compaction (3, 18)

The ability to penetrate the dentinal tubules is essential to ensure successful obturation. Due to the antimicrobial property, they can be suitable for eliminating or entombing bacteria that remained in the dentinal tubules and challenge areas (lateral canals and the isthmus) (1). Sealer penetration depends on several factors as the sealer's contact angle, the diameter and quantity of dentinal tubules, and the obturation method utilized. Temperature, setting time, and particle size are all factors that influence sealer flow (19). It is noteworthy that proper sealer penetration in the dentinal tubules reduces the incidence of micro leakage, which prevents future reinfection. In addition, it allows mechanical interlocking of the obturating material (10).

Several types of microscopes can be proposed to evaluate tubular penetration depth like the use of transmission electron microscopy (TEM), scanning electron microscopy (SEM), optical microscopy, confocal laser microscopy (CLSM) and stereomicroscopy (20).

In the current study, a scanning electron microscope (SEM) was utilized to examine tubular penetration of the specimens which was in agreement with Reska et al. study which used SEM to measure the tubular penetration of the sealer. They justified its use as simple, cost-effective and a time-saver (21). However, another study claimed that SEM pictures require specific processing procedures, which may result in image artifacts. Because it gives images with minimal artifacts, scientists utilized a confocal laser scanning microscope (CLSM) to appraise the tubular penetration. Additionally, CLSM permits the user to make a histo-tomographic image from the dentin sample without the need for sample preparation and it gives extensive data about the depth of sealer penetration at low magnification powers (50X - 100X) using fluorescence dye (10).

In accordance, another study explained that SEM can't show accurate imaging for tubular penetration of the sealer considering the configuration of dentinal tubules (22, 23). On the contrary, Ozbay & Erdemir et al. reported that SEM is able to display the smear layer on the canal wall at high magnification power, thereby, showing the details of the dentinal tubules. However, they pointed out that using SEM can cause observer bias as the imaging process depends on the operator. (24)

The results of this study, NeoSEALER Flo's vertical compaction technique had the lowest tubular penetration. It didn't show any significant difference with lateral compaction technique in overall section or when compared with AH plus groups. A possible explanation may be due to the effect of the heat used. In fact, the setting of bio-ceramic sealer depends on water absorption from the dentinal tubule, so when heat is applied it leads to water evaporation, which extends the setting time (25). Although a previous study found that bio-ceramic sealers had superior penetration depth in comparison to AH plus (26). This result can be clarified as the sealer can penetrate the dentinal tubule more deeply the smaller the sealer's particle size is, where Total Fill BC sealer has particle size less than 0.2 µm whereas AH plus has a particle size of 8 µm (27).

Moreover, the AH plus group had a greater penetration depth in this trial in overall sections. However, DaSilva's study (28) showed no appreciable difference in penetration depth between AH plus and another bio-ceramic sealer, which was inconsistent with the current results. In contrast to earlier finding, Zordan-Bronzel et al. (29) stated that AH plus had lower flowability than another bio-ceramic sealer (Bio-C), which can be due to the satisfactory formed cross bonds in resin-based materials.

Regarding the obturation technique, the present results identified that the lateral compaction technique led to greater penetration depth in comparison to vertical compaction technique using the bio-ceramic sealer. This result may be explained by the fact that the heat used with warm vertical compaction technique seems to accelerate the setting time of the bio-ceramic sealer, hence it reduces its film thickness and the tubular penetration depth is reduced (30). However, this result contradicts with another study which showed no statistically significant difference in penetration depth of bio-ceramic sealer with both obturation techniques (31).

On the other hand, the present finding seems to be consistent with other researches that found no difference in tubular penetration depth with AH plus and previously mentioned obturation techniques (32). Whilst, another study found that AH plus showed better results with warm vertical compaction technique (30, 33).

When comparing tubular penetration depth in each section, the best penetration depth was in the cervical section in all groups. This likely presented due to a corresponding rise in the diameter and quantity of dentinal tubules in the root's cervical part. However, the least tubular penetration was in the apical section when compared with other sections. This result may be attributed to the fact that smaller tubules were found near the apex and also the complex anatomy at the apex makes it difficult for the sealer to penetrate (34).

Furthermore, the fracture resistance of the teeth was also investigated in this trial, since there is a notable impact of endodontic treatment on the fracture resistance. Mechanical preparation of the root canal results in loss in the radicular dentin, which in turn elevates the stresses on the tooth structure and raises the possibility of fracture. Also, the friction between the rotary file and the canal wall can cause cracks (35). Dehydration is attributed to a lower fracture resistance of the tooth. A study showed that dehydration can induce stresses up to 20 times simulating hard food mastication. The radicular dentin may not withstand these stresses, causing dentin defects (36).

Our findings identified that -Ve control group (decoronated teeth without mechanical preparation and obturation) showed the greatest fracture resistance with statistically significant difference compared to the other groups. This is due to the preservation of the radicular dentin. On the other hand, +Ve control group (decoronated teeth with mechanical preparation, but without obturation) demonstrated the lowest fracture resistance. From these results, it can be speculated that radicular dentin loss during canal shaping may have a negative impact on the tooth's fracture resistance. Additionally, the sealer and the obturating material strengthen the tooth structure by restoring the lost dentin and thus enhance its fracture resistance. Similarly, Ulusoy et al. (37) found that non-obturated group was the lowest among the other groups.

Moreover, lateral compaction technique with NeoSEALER Flo sealer was the second highest in fracture resistance. Our statistical analysis highlighted a notably appreciable difference in fracture resistance between the group that used NeoSEALER Flo sealer with lateral compaction technique and other groups, which is consistent with a previous Patil study (38). They justified it due to the biocompatibility and sealing ability exhibited by the bio-ceramic sealers; where bio-ceramic sealer builds a chemical link with the dentin by releasing hydroxyapatite on setting. NeoSEALER Flo is hydrophilic with a small contact angle with the canal surface, which allows superior spread of the sealer on the canal wall (38, 39).

Within the NeoSEALER Flo sealer group, the results of this study were in favor of using this sealer with lateral compaction technique, as it provides exceeding fracture resistance when compared to warm vertical compaction technique. However, Almohaimede study (6) clarified that the wedging action accompanied with the lateral compaction technique can increase stresses on the canal wall, which increase the liability for fracture.

There was no statistically significant difference in the fracture resistance between; AH plus sealer groups and NeoSEALER Flo with warm vertical compaction. The present findings seem to be consistent with Ibrahim Ersoy’s research (40). Although a statistically significant difference was noticed between AH plus sealer group, NeoSEALER Flo accompanied by lateral compaction technique and -Ve control group.

Furthermore, AH plus showed the lowest results in comparison to the -Ve control group and NeoSEALER Flo sealer group except with +Ve control group. It may be due to the sufficient remaining dentin thickness for the -Ve control group and the superior properties gained by the NeoSEALER Flo sealer. Inversely, an in vitro study found opposite results and relate this to the AH plus characteristics as it can penetrate the micro-irregularities. Additionally, AH Plus forms a covalent bond between the epoxy ring and the amino group in the collagen of the dentin (41).

One of the limitations of this study was that it only assessed the fracture resistance of vertical forces on the tooth structure; however, teeth are subjected to continuous loading in different directions in the oral cavity. Therefore, it is suggested to test the endodontically treated teeth under cyclic loading. A further limitation is that the study was done on extracted teeth, where clinical trials would need to be executed in order to know the efficacy of the tested sealers in the actual conditions. Additionally, scanning electron microscopy was used over more accurate microscopic evaluation techniques to measure tubular penetration depth

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