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COMPARATIVE EVALUATION OF THE INTERFACIAL ADHESION ABILITY OF SINGLE VERSUS LATERAL COMPACTION OBTURATION TECHNIQUES USING DIFFERENT SEALER TYPES. AN IN-VITRO STUDY

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ABSTRACT

Introduction: The goal of this research was to compare the adhesion ability of an epoxy resin-based and two bio-ceramic sealers, used with gutta percha in the single cone (SC) versus the lateral compaction (LC) obturation techniques.

Materials and Methods: Ninety sound, mature, single-canaled human mandibular premolars were employed. Canals were cleaned and shaped, then randomly divided into two groups (n= 45), according to the obturation technique used. Each group was further subdivided into three subgroups (n=15), depending on the sealer type (AH-Plus, Endoseal MTA, and TotalFill BC). To get coronal and apical sections, the roots were sectioned horizontally. For evaluation of the gap percentage and measurement of the bond strength, the SEM and the push-out test were used respectively. The data was statistically examined at the 0.05 significance level.

Results: The LC obturation technique showed higher statistically significant push-out bond strength values than the SC technique with all sealers, except Endoseal MTA that showed higher values in the SC technique. All sealers demonstrated a significantly stronger push-out bond strength apically than coronally. At the sealer/dentin interface, there were almost no significant differences in gap% values between both techniques. However, at the sealer/gutta percha interface, the LC technique showed more significant gap% values than the SC technique.

Conclusions: AH-Plus and TotalFill BC revealed better adhesion to dentine in the LC compared to the SC obturation technique. Endoseal MTA showed better adhesion to dentine in the SC technique. No correlation existed between gap presence, and the bond strength of the tested sealers.

KEYWORDS: Bioceramic sealer, Gap percentage, Lateral compaction, Push-out bond strength, Single cone.

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INTRODUCTION

A successful root canal therapy requires a three-dimensional obturation of thoroughly cleansed root canal systems. The filling materials' tight adherence and adaptability to dentinal walls remove the intracanal gaps, preventing bacterial colonization or root canal reinfection.[1] In a cold lateral compaction (LC) approach, obturation of the root canal was traditionally accomplished by inserting a gutta-percha core and cementing auxiliaries by a zinc-oxide eugenol (ZnO/E) root-canal sealer.[2] Although some studies proved acceptable outcomes using this technique, still, clinicians suffered from prolonged time and big effort spent on it.

Nowadays, there is a trend towards an effective and simple single-visit endodontics, that saves more time for preparation and obturation techniques. As a result, a variety of sealer types and obturation strategies have been proposed to improve obturation quality and efficacy. Gutta-percha cones matching both, the taper and size of motor-driven master files were introduced for the re-use of single-cone (SC) obturation technique. This technique decreases extra effort and time required for patients and dentists for the LC technique. However, as compared to the LC approach, its adhesion to radicular dentin is questioned, particularly when utilizing standard ZnO/E sealers, [3] which lack the dentin bonding capacity and the ability to deposit mineralized tissue. As a result, sealers that aid in the implementation of the "monoblock concept" for bonding to the core material and the dentinal wall, as well as an enhancement in bond strength and adaptation of the SC obturation technique, are in high demand. [4]

Hence, sealers based on glass-ionomer (GI), silicone, epoxy, or methacrylate resins, or bio-ceramics, have been proposed. The modified epoxy resin-based sealer AH-Plus, which demonstrated excellent sealing ability to dentin, decreased solubility in tissue fluids, and slight cytotoxic reactions, quickly became the gold standard for use with gutta percha in both the SC and LC obturation techniques.[5] However, AH-Plus sealers lack bioactivity with surrounding tissues.[6] To overcome this deficiency, bio-ceramics (BC) were introduced in the 1970s, to biomedicine, to be used for the manufacturing root canal sealers. [7]

Bio-ceramics exhibit unusual bioactivity in the presence of moisture, forming a link with dentin by mineral infiltration into the inter-tubular dentin. Following denaturation of collagen fibers with a strong alkaline sealer, the formation of a mineral-infiltration-zone of hydroxyapatite occurs. [6,8]

They promote the development and regeneration of new lasting mineralized tissues due to their favorable physicochemical features.[9,10] Even when accidentally extruded peri-apically during root-canal filling, bio-ceramic-based sealers promote bone regeneration. [11]

TotalFill BC and Endoseal MTA (Mineral Trioxide Aggregate) are hydrophilic, premixed bio-ceramic root canal sealers. These sealers were proposed to flow into canal ramifications and dentinal tubules due to the small particles, strengthening a good chemical attachment to dentin, resulting in root reinforcement and higher fracture resistance. [8–10,12,13]

Measuring the adhesion ability of the recently introduced endodontic sealers for different obturation techniques is quite important for the clinician to select a high quality obturation strategy. Current research concentrates on evaluating the validity of the SC obturation techique with the appropriate sealer type, that improves the adhesion abilty to both dentine and gutta percha core material. Up to our knowledge, the adhesion ability of TotalFill BC, Endoseal MTA bio-ceramic sealers and AH Plus epoxy resin sealer has not been compared in both the SC and LC obturation techniques so far. As a result, the goal of the current study was to test and compare the adhesion ability of these sealers in terms of push-out bond strength and dentine / core interfacial intimacy (adaptation) in both the SC and

LC obturation techniques. The null hypothesis was that there was no difference between both obturation techniques, and the tested sealers utilized.

MATERIALS AND METHODS

The Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 criteria were used to write the paper for this laboratory investigation (Figure.1). [14] The Research Ethics Committee (REC) at the Faculty of Dentistry, Suez Canal University (no.452/2021) waived the clearance of the current study because it was conducted on extracted unidentified human teeth. As a result, ethical considerations for patients or experimental animals were not applied.

Sample size calculation

The push-out bond strength and adaptation of two different obturation procedures (SC and LC) on human teeth were studied and compared in in vitro, using different root-canal sealers (TotalFill® BC, Endoseal MTA, and AH Plus). A total sample size of 90 samples was required to detect an effect size of 0.40, a power (1-β) of 85 percent, a partial eta-squared of 0.06, and $p \leq 0.05$ significance level. Forty-five samples were used for each obturation technique (Groups 1 and 2), and 15 samples were used for each sealer type in each subgroup (A, B, and C). The sample size was calculated using the G*Power software (G Power; Franz Faul, University of Kiel, Germany).[15]

Sample selection and preparation

Ninety human mandibular premolar teeth were used, all of which were newly extracted, sound, mature, single-rooted, and single-canaled. To rule out any teeth with internal resorption, calcifications, past root canal therapy, or aberrant canal anatomy, pre-operative radiographs were done for all teeth in the buccolingual and mesiodistal directions. The selected teeth were cleansed, disinfected (immersed in 2.5 percent of sodium hypochlorite solution (NaOCl) for two hours, rinsed, and finally kept in saline solution until use.

Samples randomization (blind allocation) and grouping

Teeth were randomly divided into two groups equally (n= 45) according to the obturation technique utilized(Group.1: SC or Group.2: LC). Following that, roots in each group were randomly subdivided into three subgroups equally (n=15) according on the sealer used with gutta percha for obturation (subgroups 1.1 and 2.1: AH-Plus, subgroups 1.2 and 2.2: Endoseal MTA and subgroups 1.3 and 2.3: TotalFill BC). Blind allocation and randomization were done by the second author R.M.A (allocator). Every single root was placed in a numbered opaque envelope, and each sealer was masked with a numbered opaque cover. Randomization was done for grouping using Microsoft excel.

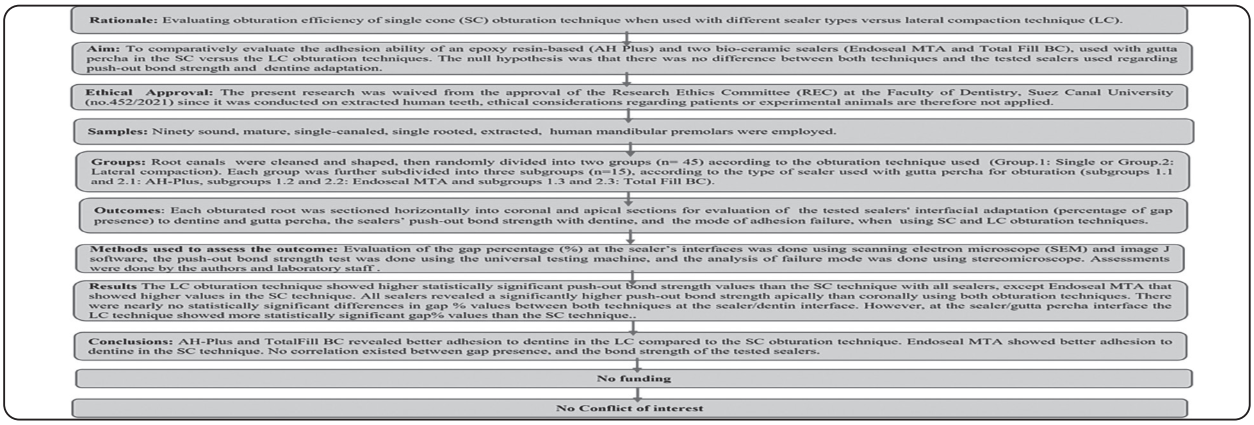

Fig. (1) PRILE 2021 flowchart for the present study.

The first author (D.A.M) completed the canal preparation and obturation procedures for standardization. To avoid dehydration, moist gauze was utilized to hold the roots during the preparation. The crowns of the selected teeth were horizontally cut using a diamond-disk installed on a slow-speed hand piece in conjunction with saline coolant. To facilitate a straight line access, teeth were sectioned at right angles to their long axis, yielding standardized 15 mm long roots. [11]

First, a K-file #15 (Mani Inc., Japan) was used to ensure canal patency and standardization for the working length (WL), which was set at 0.5 mm short of the root apex. All the canals were then instrumented with a ProTaper Next rotary instruments (Dentsply Maillefer, USA) until file X4 (tip size # 40, with 6% taper) was achieved using an endodontic motor (X-Smart, Dentsply Maillefer, USA) set at a speed of 300 rpm, as directed by the manufacturer. After each use, patency of the file was re-checked and the canals were irrigated with 2 mL of 2.5 percent sodium hypochlorite (NaOCl, DEXA company for chemicals, Egypt) (total 10 mL/canal) using 30-gauge needles (NaviTip; Ultradent, South Jordan, UT) inserted at 1mm short of the WL. For smear layer removal, a final rinse with 5 mL saline 9%, then 5 mL EDTA 17% (Prevest Denpro Limited Company, India) for 1 min was applied respectively. This step was followed by canal irrigation with 10mL saline 9% solution to remove EDTA remnants which may affect both, the properties of the sealer as well as the quality of obturation. [3,16,17]

The root canals were softly dried out before obturation with a dental endo-aspirator tip (Cerkamed, Poland) and a matching #40 tip size, as well as 6% taper absorbent paper points (Dentsply Maillefer, USA). [18,19] The allocator prepared the three tested sealers (Table 1) corresponding to the manufacturer's directions, and obturation was done in each group as follows:

Group 1 (SC obturation technique): The master gutta-percha cone (tip size # 40, taper 6%) (Dentsply Maillefer, USA) was confirmed to the working length (using visual and radiological means). Before dipping the master cone into the matching sealer for canal obturation. The premixed sealers were injected in the middle third of the root canals (by compressing the plunger of the premixed syringe), while the lentulo-spiral (Dentsply Maillefer, Switzerland) was used to insert the resin sealer inside the corresponding canals. The master cone was then pressed inside the canal to the full WL with the help of a tweezer.

TABLE (1): The details of the tested sealers in the current study (trade name, chemical composition, and manufacturers).

Sealer	Type of Sealer	Chemical Composition	Manufacturer (Batch no)
1-AH-Plus®	Resin-based (Epoxy)	Two pasts: A) Epoxide paste composed of: Di-epoxide, Zirconium- oxide (radio-opacifier), Calcium tungstate, Iron oxide and, Dyes. B) Amine paste composed of: N,N'-dibenzyl-5-,1-Adamantan amine, Oxa-nonandiamine-1,9, Zirconium oxide (radio-opacifier), TCD-Di-amine, Silicon oil, Calcium tungstate and, Aerosil.	Dentsply, Konstanz, Germany (1705000906)
2-Endoseal MTA	Bio-ceramic (Hydraulic calcium silicate)	Ready to use syringe composed of: Calcium silicate, Calcium sulfate, Calcium aluminates, Zirconium oxide (radio-opacifier), Bismuth oxide, Hydoxypropyl methylcellulose-HPMC (thickening agent) and, N-methyl-2-pyrolidone, NMP (solvent).	Maruchi, Wonju, Korea (CI 171027A)
3-TotalFill BC	Bio-ceramic (Hydraulic calcium silicate)	Premixed syringe composed of: Calcium silicate, Zirconium oxide (radio-opacifier), Calcium phosphate, monobasic Calcium hydroxide, thickening agents and, fillers.	FKG Dentair SA, Switzerland. (160045P)

Group 2 (LC technique): The working length of the master gutta percha cone (size #40 taper 0.02) was confirmed. The tested sealers and master cone were introduced to their corresponding canals as described previously. Gutta percha was compacted laterally using a #25 spreader (that should be pre-fitted to extend deeply into the canal with an apical resistance at 2mm short of the working length after master cone insertion), producing a space for the insertion of its corresponding size additional gutta percha until the root canal was filled to the orifice.

Excess gutta percha was eliminated with a heated endodontic Plugger (Dentsply Maillefer, Switzerland) in both groups, and the roots were sealed coronally with a glass ionomer filling material (Medifil, Promedica Dental Material GmbH, Germany). The obturated roots were put in storage inside an incubator at 37°C and 100% humidity for one week, to allow for thorough setting of the tested sealer before sectioning. [20]

Sectioning of samples

Each root was implanted in chemically cured acrylic resin. The samples were sectioned at right angles to the root long axis using an IsoMet 4000 micro-saw (Buehler, USA) with a diamond disc of 0.6 mm thickness mounted on it. To obtain coronal and apical 1mm thick slices, roots were sectioned at ten- and two-mm distances from the root apex. [20,21] To avoid frictional heat, sectioning was done with ample water cooling.

Each subgroup received thirty slices (15 coronal and 15 apical). The coronal and apical slices were examined by Field Emission scanning electron microscopic (FE-SEM) imaging (Model Quanta 250 Field Emission Gun (FEG), FEI company, Netherlands) to evaluate the sealer adaptation in terms of gap % presence at the sealer's interfaces. The entire root canal area was scanned at magnifications ranging from X 100 to X 1500 with accelerating voltage 30 K.V.

Calculation of the gap %

For each scanned image, the scale measurements and color threshold were adjusted to determine the entire canal perimeter and gaps. Then, the root canal area was identified, and the current gap area at the sealer-dentine and sealer-gutta percha core interface was quantified using ImageJ software program (Image J 1.52d, National Institutes of Health, USA). [22] The percentage of the gap was computed, and data was gathered (Figure. 2).

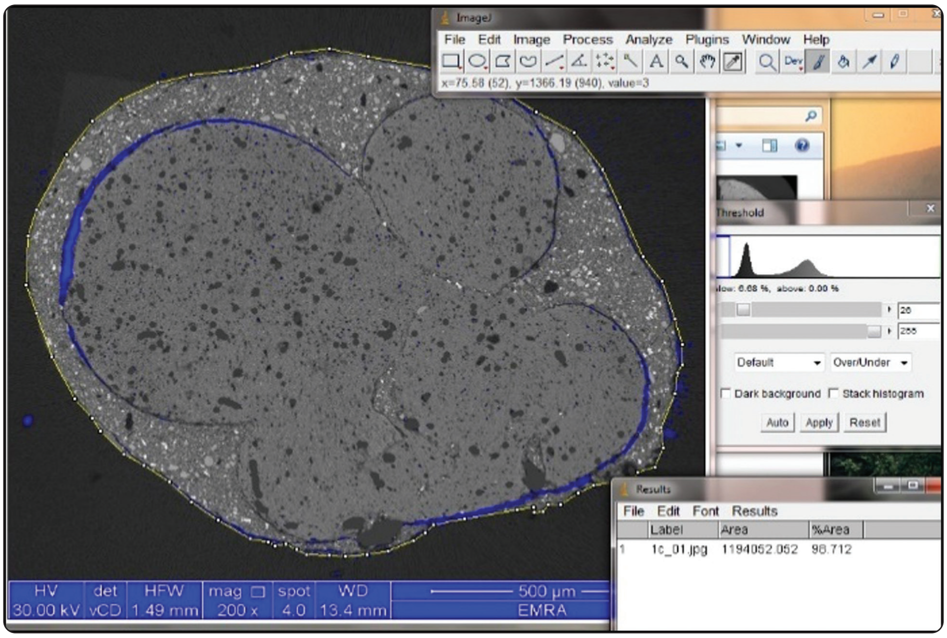

Fig. (2)

Representative image (screen shot from desktop) showing area selection and gap area percentage analysis by image J software in the coronal section of a root obturated with Endoseal MTA sealer in lateral compaction technique.

Push out bond strength evaluation

After SEM examination, the slices were analyzed with a Stereomicroscope (Nikon MA100, Japan) to to ensure that filling material was free of dentinal fissures or artifacts. The same slices (n=90 for each group) were utilized for the push-out bond strength test on a universal testing device (Instron universal testing machine type 3345 England) because no special preparation (metallization) for the samples was done in the FE-SEM evaluation.

To prevent any interfering constrictions, the slices were placed on the mechanical testing machine with the cylindrical stainless-steel plungers (0.5- and 0.9-mm diameters for the apical and coronal slices respectively) pointing to the canal obturation in an apical-coronal path. [20, 23] The tests were carried out with a 500N load cell and a 0.5mm/min crosshead speed till the obturating material was displaced. The highest load (N) was recorded, and the filling area in mm^2 under load (Area = 2 r π h; r = radius of root canal in mm, π = 3.14, h = sample thickness in millimeters) was computed. [24] The test data was gathered and analyzed according to this equation:

$$\text{Push-out bond strength in MPa} = \frac{\text{Maximum load in N}}{\text{Filling Area in mm}^2}$$

The tooth sections obtained after finishing the push-out test were observed using a stereomicroscope (Nikon MA100, Japan). The failure mode was also determined (adhesive failure that found at the sealer/dentin or sealer/core interfaces, cohesive failure that found within the sealer or core, or mixed that combine both adhesive and cohesive failures).

Statistical analyses

The data was statistically analyzed using the SPSS version (20) software program for Windows (SPSS, Chicago, IL, USA). To check the data distribution (normality), the Kolmogorov–Smirnov and Shapiro–Wilk tests were used, and the findings were presented as means and standard deviations. As the push-out bond strength test data had a normal distribution, so analysis was done using parametric independent t-test, one way ANOVA with Tukey post hoc test and paired sample t-test.

However, the gap % data was statistically examined with the Mann-Whitney U, Kruskal-Wallis, and Wilcoxon Signed Ranks tests respectively because they were not normally distributed. The association between total gap percentage and push-out bond strength values was determined using Pearson correlation analysis, which was statistically significant at ($p \leq 0.05$).

RESULTS

Push out bond strength

For AH Plus and TotalFill sealers, the LC obturation approach demonstrated higher statistically significant bond strength values than the SC technique. However, when compared to the LC obturation approach, Endoseal MTA demonstrated significantly greater bond strength for SC at both levels (Figure 3).

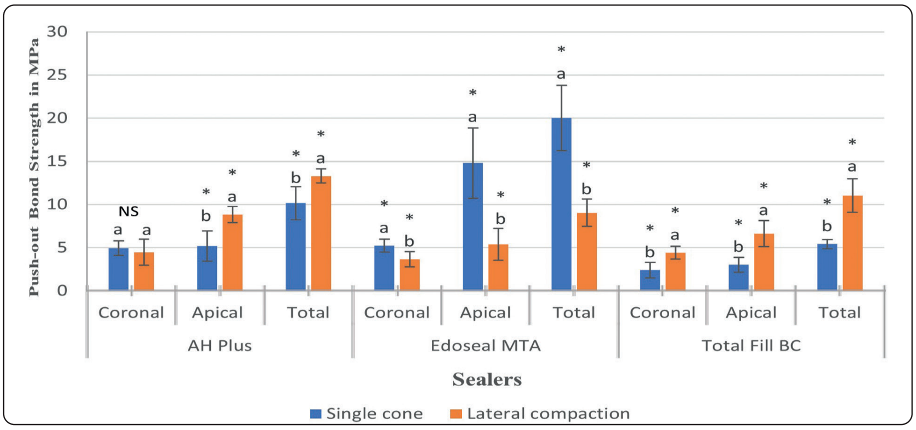

Fig. (3):

Bar chart showing mean ± SD values for the push-out bond strength for the SC and LC obturation techniques using different sealers at different tooth levels. Different lowercases with * mean: statistically significant ($p \leq 0.05$), NS: statistically insignificant using independent t-test.

For the SC and LC procedures, the Endoseal MTA and AH Plus sealers demonstrated the greatest statistically significant total bond strength records. The strongest statistically significant bond strength for the SC obturation was found apically in the Endoseal MTA sealer. The AH Plus sealer, on the other hand, had the highest statistically significant bond strength values apically for the LC obturation technique, whereas Endoseal MTA and TotalFill BC sealers revealed no statistical significance at both levels. For all obturation groups and sealer subgroups, the apical bond strength was much higher than the coronal bond strength (Table 2).

Gap percentage (%)

There were statistically insignificant differences for all sealers subgroups between SC and LC techniques at the sealer/dentin interface. While for the SC technique, AH Plus sealer showed statistically significant lower sealer-dentin gap % values than for the LC technique only at apical level. On the other hand, at the interface of the sealer with gutta percha, and the overall gap percentages, the LC technique showed more statistically significant gap % values than for the SC technique. However, the TotalFill BC sealer at the coronal level showed more statistically significant gap % values for the SC technique (Figures 4,5).

TABLE (2): Comparison between the mean ± standard deviation (SD) values of push out bond strength for three tested sealers subgroups using two obturation techniques at the coronal and apical root levels.

Obturation technique groups	Sealer subgroups / Root level	Subgroup 1 (AH Plus) Mean ± SD	Subgroup 2 (Endoseal MTA) Mean ± SD	Subgroup 3 (TotalFill BC) Mean ± SD	p- values
Group 1	Coronal	$4.96 \pm .83^{Aa}$	$5.22 \pm .73^{Ba}$	2.39 ± 0.90^{Ab}	≥ 0.001***
SC	Apical	5.19 ± 1.73^{Ab}	14.81 ± 4.08^{Aa}	3.02 ± 0.85^{Ab}	≥ 0.001***
‡ p-values		0.654 (NS)	≥ 0.001***	0.167(NS)	
Total SC		10.15 ± 1.91^{b}	20.03 ± 3.79^{a}	5.41 ± 0.53^{c}	≥ 0.001***
Group 2	Coronal	4.46 ± 1.52^{Ba}	3.65 ± 0.90^{Aa}	4.42 ± 0.76^{Ba}	0.126 (NS)
LC	Apical	$8.83 \pm 0.92^{A\ a}$	5.39 ± 1.83^{Ab}	6.62 ± 1.50^{Ab}	0.01**
‡ p-values		≥ 0.001***	0.14 (NS)	≥ 0.001***	
Total LC		13.29 ± 0.82^{a}	9.04 ± 1.59^{c}	11.04 ± 1.93^{b}	≥ 0.001***

Different upper-case letters (capital letters "A, B ") within the same column and different lower cases (small letters "a, b") within the same raw mean that they are statistically significant different at p ≤ 0.05 using ‡paired sample t- test and one way ANOVA with Tukey post hoc tests respectively. NS = statistically insignificant (p ≥ 0.05). *** mean highly significant at ≤ 0.001.

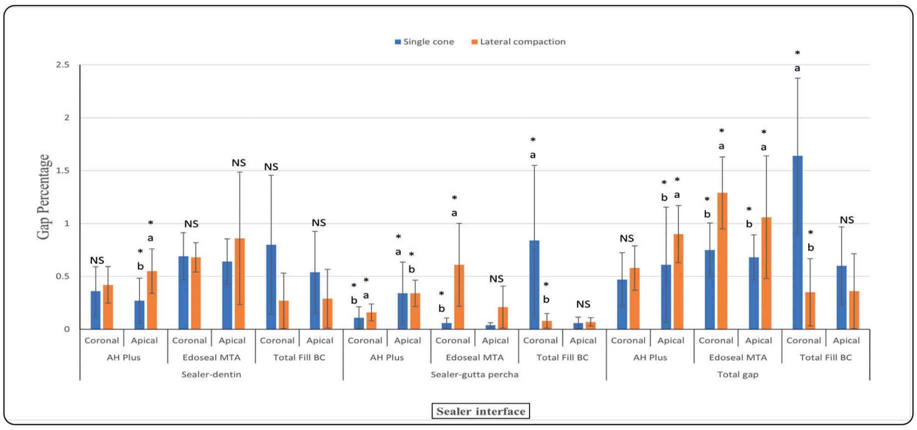

Fig. (4):

Bar chart showing comparison between gap percentage mean± SD values for SC and LC obturation techniques at different sealer interfaces. Different letters and * mean statistically significant differences (p ≤ 0.05) within each sealer and tooth level. NS: statistically insignificant using Mann-Whitney U test.

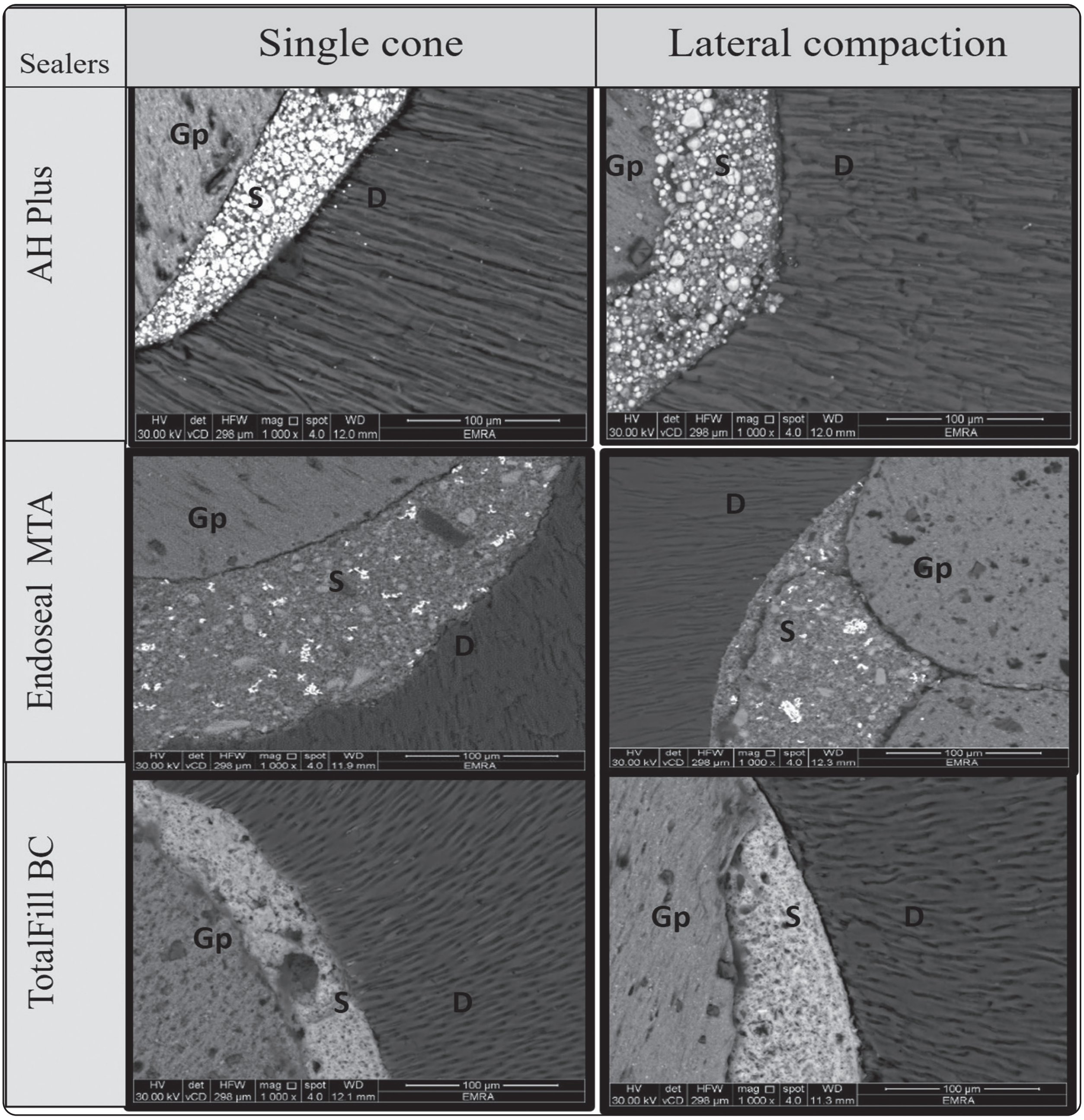

Fig. (5): Representative SEM photomicrographs showing interfacial adaptation of three tested sealers (S) with dentin (D) and gutta percha (GP) using the single cone (SC) and lateral compaction (LC) obturation techniques.

TotalFill BC and Endoseal MTA sealers had the lowest and greatest statistically significant gap percent values, respectively, using the LC method. The maximum statistically significant gap percent value for the SC obturation approach was observed at the coronal level with TotalFill BC. While the lowest statistically significant gap percent values were observed with AH Plus and Endoseal MTA.

Insignificant differences were detected between the coronal and apical levels for the SC obturation technique, with the exception of TotalFill BC at the sealer-gutta percha interface, where the coronal gap percent values were substantially larger than those at the apical level. AH Plus, on the other hand, revealed considerably higher gap percent values apically than coronally at all interfaces when using the LC approach. At the sealer-gutta percha interface, however, Endoseal MTA only showed significantly smaller gap percent values apically than coronally (Table.3).

Correlation between the sealer’s adaptation and bond strength

In the tested sealers (AH Plus, Endoseal MTA, and TotalFill BC), both obturation procedures (SC and LC) exhibited an insignificant association (R= 0.089, p-value=0.815) between the total gap percentage and the push-out bond strength mean values.

TABLE (3): Comparing mean ± standard deviation (SD) values of the gap percentages in each sealer subgroup at coronal and apical levels using single cone (SC) and lateral compaction (LC) obturation techniques.

Sealers’ subgroups			AH Plus	Endoseal MTA	Total Fill BC	p-values
Sealer interface	Groups	Root sections	Mean ± SD	Mean ± SD	Mean ± SD	
Sealer-dentin	SC	Coronal	0.36±0.23^{Aa}	0.69±0.22^{Aa}	0.80±0.66^{Aa}	0.058 NS
		Apical	0.27±0.21^{Ab}	0.64±0.22^{Aa}	0.54±0.39^{Aa}	0.003**
		‡p-value	0.11 NS	0.638 NS	0.233 NS	
	LC	Coronal	0.42±0.17^{Bb}	0.68±014^{Aa}	0.27±0.26^{Ab}	≥ 0.001***
		Apical	0.55±0.21^{Aa}	0.86±0.63^{Aa}	0.29±0.28^{Ab}	0.009**
		‡p-value	0.041*	0.256 NS	0.798 NS	
Sealer-gutta percha	SC	Coronal	0.11±0.10^{Ab}	0.06±0.05^{Ab}	0.84±0.71^{Aa}	0.004**
		Apical	0.34±0.29^{Aa}	0.04±0.02^{Aab}	0.06±0.05^{Bb}	0.017*
		‡p-value	0.12 NS	0.124 NS	0.002*	
	LC	Coronal	0.16±0.08 ^{Bab}	0.61±0.39^{Aa}	0.08±0.07^{Ab}	≥ 0.001***
		Apical	0.34±0.12^{Aa}	0.21±0.20^{Bb}	0.07±0.04^{Ab}	≥ 0.001***
		‡p-value	0.001*	0.027 *	0.478 NS	
Total gap	SC	Coronal	0.47±0.25^{Ab}	0.75±0.26^{Aab}	1.64±0.73^{Aa}	0.032*
		Apical	0.61±0.55^{Aa}	0.68±0.21^{Aa}	0.60±0.37^{Aa}	0.2 (NS)
		‡p-value	0.995 NS	0.460 NS	0.088 NS	
	LC	Coronal	0.58±0.21^{Bb}	1.29±0.34^{Aa}	0.35±0.32^{Ab}	≥ 0.001***
		Apical	0.90±0.27^{Aa}	1.06±0.58^{Aa}	0.36±0.35^{Ab}	≥ 0.001***
		‡p-value	0.001*	0.173 NS	1.000 NS	

Different upper-case letters (capital letters “A, B “) within the same column and different lower cases (small letters “a, b”) within the same raw mean that they are statistically significantly different at p ≤ 0.05 using ‡Wilcoxon Signed Ranks and Kruskal-Wallis Tests, respectively. NS = statistically insignificant (p ≥ 0.05). *, **, *** mean significant at ≤ 0.05, ≤ 0.01, ≤ 0.001 respectively

Mode of failure

Observational analysis of failure mode revealed that mixed failure was the most common form, then the adhesive failure, particularly among the sealer and gutta percha.

DISCUSSION

The presence of a gap in the obturation system is thought to be a gateway for bacterial re-entry and colonization inside the root canals. According to studies, the gap percentage should be as low as 1% to prevent microorganisms or their secretions from penetrating.[25] Accordingly, the use of endodontic sealers is especially mandatory in cold obturation techniques, as the gutta percha can't fill all the irregularities at the root canal walls. For elimination of any potential gaps, the sealer should ideally create a perfect adhesion between gutta percha and the dentinal walls, besides bonding the core materials together. [26,27]

The physio-chemical qualities of the sealers, dentin penetrability, obturation technique, and removal of the smear layer, are all factors that influence the sealers' adhesion to root dentine. [28] Our goal was to see how the obturation technique affected the adhesion of different types of sealers to dentine.

The SC obturation technique was initially developed in the 1960s. One master cone of ISO standardized taper 0.02 was used with zinc oxide sealer to obturate the whole root canal space, without insertion of accessory cones. Nowadays, tapered gutta percha, matching the geometrical power driven master apical file was reused in this technique to overcome the lack of adaptation and low push-out bond strength values associated with taper 0.02 filling points. [2,3]

More recently, bio-ceramic-based (BC)sealers were introduced to enhance the obturation quality, especially in the SC technique.[9] These BC sealers have shown favorable biocompatibility and bioactive properties. [7,11,29] Premixed injectable calcium silicate BC sealers were manufactured to facilitate its hydraulic compaction inside the canals. With this premixed sealer, the master cone could be employed as a delivery technique, allowing its flow into root canal abnormalities and auxiliary canals by hydraulic action. The setting of these sealers depends mainly on the moisture available in the root canal by hydration reaction. [30,31] Additionally, BC sealers revealed a slight volumetric expansion during setting, that was suggested to increase the bonding to dentin. [32]

Brasseler USA introduced the premixed EndoSequence BC sealer in 2008. FKG Dentaire, Switzerland, has recently released a Totalfill BC sealer that is similar to this sort of sealer. [32] Endoseal MTA is a premixed calcium silicate sealer containing alumina silicate, which when hydrated produces a pozzolanic reaction. It was thought that this process might increase its adherence to dentine. [33,34]

Because of its exceptional qualities, the AH Plus sealer was selected in the present study as a control to be compared with the other evaluated BC-based sealers [35] (Endoseal MTA and TotalFill BC). The LC obturation technique was chosen as a standard also, because it is simple to use and does not require any specific tools or advanced training, as do other techniques. [27,36]

Multiple methods were proposed for assessment of the obturation efficiency of an endodontic filling material. Leakage tests using radioisotopes, India ink, methylene blue, bacterial or fluid transport, were previously utilized to evaluate the sealing ability. None of these approaches, however, are totally trustworthy for determining the seal of obturated root canals.[37,38]

Other commonly used endodontic approaches for evaluation of the sealer adhesion ability, are the measurement of the sealer-dentine tensile and shear bond strengths. The push-out bond strength test was shown to be the most accurate and repeatable method for determining adhesion strength. As a result, it might be used as a substitute for testing the sealing ability.[39–41]

Additional information about the sealer penetration into dentine, gap presence and failure modes in the obturation system are also important. Accordingly, multiple imaging tools like the laboratory micro CT, stereomicroscope, confocal laser microscope and scanning electron microscope (SEM) were used in different research. [29,39,42]

Confocal laser microscopic analysis needs mixing sealers with organic dyes (such as rhodamine B) to detect their fluorescence indirectly. The rhodamine B dye, on the other hand, has been shown to impact the accuracy of sealer detection in the dentine and obturation system, making it an ineffective approach.[43] Furthermore, the penetrability of sealers into the dentinal tubules was not regarded as a sign of improved interfacial adaptability. [44]

According to Tuncer et al., a universal push-out testing machine and a scanning electron microscope were employed in the current investigation to compare the SC against the LC obturation strategies employing the studied sealers.[20] The tests were performed on each tooth sample at the coronal and apical levels due to the importance of the seal at both levels in the outcome of endodontic treatment. [45]

In contrast to traditional SEMs, the current study used a field emission gun SEM, which has the advantage of skipping sample treatment or manipulation stage (dehydration, conductive gold coating, and high vacuum) before analysis. Consequently, allowing sample hydration during the analysis, to avoid processing artifacts (gaps and cracks) which may be associated with specimens' preparation. [42] Because the same root samples were used for both tests, [46] it was feasible to link the data obtained from SEM (gap percentage evaluation) and the universal testing machine (push-out bond strength).

However, only a small piece of the root dentine is visible due to the SEM evaluation's ability to detect the sealer at the specimen's surface. Similarly, cutting the specimen could affect the outcome because the sealer may be rinsed out of the dentine.

The null hypothesis was rejected in this study. The AH Plus and Total fill BC sealers demonstrated considerably greater LC push-out bond strength records than the SC obturation approach. During LC procedures, forces are created in both, the lateral and the apical directions, which might increase the packing of sealer toward dentinal wall, and thus enhancing the bonding to dentin. Furthermore, the higher total volume of gutta percha in the LC techniques compared to the SC techniques may enhance the filling system's frictional resistance, according to previous studies. [3,11,22] On the other hand, Pawar et al. [21] observed that the Endosequence BC sealer utilizing C point with the SC obturation technique had a stronger push-out bond strength than the AH Plus with gutta percha in the LC obturation technique.

When the LC technique was employed at both the coronal and apical levels in this investigation, the AH Plus sealer demonstrated stronger bond strength than both BC-based sealers. In agreement with Silva et al, [47] who did a meta-analysis and found that the epoxy resin sealer had greater push-out bond strength values than the premixed BC sealers. The development of covalent bonds among the epoxide rings and the amino groups in the bare collagen network of dentin, with exceptional adhesion capabilities, was attributed to the superior push-out bond strength in previous studies.[48–50] Furthermore, the moderate acidity of AH Plus may result in dentine self-etching as the sealer is introduced into the dentinal tubules by LC pressures, improving interfacial bonding. [28,51,52]

Moreover, being chemically cured, AH Plus compensates for the polymerization shrinkage without the development of polymerization stresses. AH Plus also shows pseudoplasticity of liquids, exhibiting a thixotropic behavior of decreased viscosity associated with an increased shear rate during compaction. [53]

In the current study, AH Plus revealed greater total push-out bond strength records with the SC obturation procedure than TotalFill BC. While, two weeks after obturation, Yap et al. [17] found similar bond strength values for TotalFill BC and AH Plus sealers. Furthermore, this result contradicted Al-Hiyasat et al., [54] who discovered that TotalFill BC had greater binding strength values than AH Plus. Different sample selection (palatal roots of maxillary first premolars), increased storage period (which may allow higher incorporation of calcium phosphates reacting with calcium hydroxide of dentin upon hydration), and a slice thickness of 1.5 mm could all be contributing to the discrepancies.

With the SC obturation approach, Endoseal MTA showed the highest significant bond strength values. At both levels, their bond strength values for the SC approach were much higher than LC obturation technique.

The good bonding ability of Endoseal MTA might be due to the Pozzolanic reaction produced. It resulted in more cementitious particles along the dentinal walls, making it more suitable for the SC obturation technique. However, these cementitious particles in Endoseal MTA might challenge the cold LC obturation technique. [55,56] As a result, the LC procedures in this investigation produced a greater total gap and lower bond strength values than the SC techniques.

Tanita et al [33] found that Endoseal MTA had a stronger bond strength than iRoot SP® when employing the SC obturation procedure. They attributed this to the Pozzolanic reaction, which occurs when alumina silicate reacts with water, resulting in a slow decrease in calcium hydroxide. This improves the SC technique's binding strength by making the sealer's mechanical qualities more stable. [33,34,57]

Endoseal MTA also has a smaller particle size (1.5 m) than TotallFill BC, which permits the sealers to flow inside the root canal dentinal tubules, ramifications, and abnormalities. Especially since the particles are even more tiny than dentinal tubules.[34,46] Furthermore, having the longest setting time (about 1223 minutes) among the tested sealers may allow for better polymerization, resulting in enhanced bond strength for the SC compaction technique as compared to the LC compaction approach. That is because the setting is being interrupted by the action of spreader during the LC technique, which unfortunately decreases their bond strength, and increases gaping within the sealer. [58]

It's also worth noting that Endoseal MTA expands much more than AH-Plus sealer, which could contribute to better push-out bond strength when employed as a bulk in the SC obturation approach. However, as this expansion had no effect with its thin film thickness on the LC technique, an obvious lack of significant differences between Endoseal MTA and Total Fill BC were noticed. [13]

In contrary, Celik et al [50] and Silva et al [59] found lower push-out bond strength records for Endoseal MTA sealer than AH Plus. This could be because they evaluated the sealers' bond strength for cavities only generated and filled in root slices, rather than after obturating the entire canal with a gutta percha, as was done in the current investigation. [50,59]

The greater bond strength values at the apical level for all sealers and obturation procedures might be attributed to the resistance form imparted by the uniform rounded apical preparation, with a rounded cross section of the gutta-percha. Furthermore, the stronger phase, gutta percha, had a higher mass in comparison to the sealer in a specific canal cross section diameter, pushing the sealer deeper into the dentin, producing a stronger connection. [22,49]

These findings were consistent with those of Sagsen et al. [60], but they contrasted with those of Araujo et al., [3] who reported a decrease in bond strength values apically for both the SC and LC procedures. This contradiction may be related to different storage time of 24 hours following obturation. [3,60]

The stereomicroscopic observational sample analysis performed after the push-out test found that the adhesive type of failure among the dentine /sealer interface was less than the mixed type, according Nagas et al. [61]. This result may reflect the good physiochemical properties, good interfacial intimacy (gaps were almost less than 1%), and high bonding ability of the assessed sealers, making them more resistant to dislodgment from the dentine interface. [13,33,58,61]

Regarding the data from SEM evaluating the gap percent for all of the sealers studied at their dentin interface, there were no statistically significant variations between the SC and LC techniques (except for AH Plus that revealed more gap percent in LC apically). This was in accordance with Eltair *et al,* [22] while contradicting Moinzadeh *et al* [62] in their micro computed tomography study. The latter found that the SC obturation technique with Smartpaste Bio sealer revealed a significant lower void percentage than with the LC obturation technique. [22,62]

On the other hand, among all sealers at their interface with gutta percha, and the total gap % values, higher statistically significant gap % values for the LC technique compared to the SC technique were recorded. This may be related to the increased non-homogenous sealer thickness, entrapping more voids during obturation with the LC technique. [28,55]

Using the SC technique, the existence of insignificant differences in gap % values between the coronal and apical sections for all tested sealers at all interfaces were in accordance with Eltair *et al*. [22] While, Polineni *et al*. [63] using C points for SC obturation with Endosequence BC sealer and Alhadad *et al* [28] noticed better sealer adaptation at the coronal level compared to apical halves. This contradiction may be attributed to the different instrumentation used, and evaluation methods applied for gap detection (maximum gap width) [63] and conofocal laser scanning microscopy. [28]

Similarly, the tested bioceramic sealers exhibited no significant differences between both levels when using the LC approach, which is consistent with Almqayyad et al [64] and, Eltair et al .[22] These results may possibly be ascribed to the use of BC sealers in conjunction with the capillary tip introducing system, as well as the bioceramic sealers' delayed setting time, which aids in uniform flow and penetration of their small particle size throughout the canal.

On the contrary, the AH Plus sealer for the LC had a higher statistically significant gap percent at the apical level compared to the coronal approach at all interfaces, which is consistent with earlier investigations. [55,64] These results might be attributed to the increased liability of imparting voids apically in the cold LC technique together with the decreased apical smear layer removal capability resulting in non-homogenous sealer layers along the root canal wall.[65] El-Asfouri [56] showed a better apical adaptation of AH Plus for the LC technique, which was attributed to the premolars' root's cross-sectional character.

TotalFill BC had the largest statistically significant gap percent values when using the SC obturation approach, especially at the coronal level. This contradicted the findings of Polineni et al.,[63] who observed that utilizing the SC obturation procedure, epoxy resin sealer (MM-Seal) demonstrated non-significant marginal adaptation with BC sealer (Endosequence BC). Also, Hegde et al [66] found less gapping for the assessed BC sealers (TotalFill BC and Endoseal MTA) than for AH Plus resin sealer in their study.

While, the similar low gap % values for AH Plus and Endoseal MTA were in agreement with Kim et al. [29] who used micro-CT scans for evaluation of the sealer adaptation in extracted human root canals. On the contrary to this, Ibrahim [67] and Hedge et al [66] declared significantly less marginal gapping for Endoseal MTA compared to the examined epoxy resin sealer, regardless of the irrigation protocol used. The authors attributed this to the material's self-adhesive properties, as well as its proclivity for forming a chemical bond with dentin via the creation of hydroxyapatite layers and its fast flow rate.

The lack of correlation between gap percent and bond strength in this study might be owing to the tested sealers' low gap mean values (within 1%), which had a negligible impact on bond strength values. This underlines that sealer adherence to dentin is a complex process involving multiple parameters, including the dentin and /or gutta percha surface energies, the sealer's wettability, in addition to the cleanliness of the dentin surface. [1,20] Accordingly, more investigations are needed to correlate further factors like the effect of time on sealer setting and strength. [17]

Although the current in vitro study replicated clinical root canal therapy processes, it has a flaw in that it does not directly correspond with endodontic treatment outcomes. Still, none of the laboratory tests can be considered as a completely reliable interpreter of the clinical performance of root canal sealers. [40,47] The real oral environmental conditions might differ and affect the physical properties of the sealers over time. So, more extended-time clinical trials on root canal filling with BC sealers, particularly for the SC approach, are needed.

CONCLUSION

Within the constraints of the current investigation, the following conclusions can be drawn:

1. Both AH-Plus and TotalFill BC revealed better adhesion to dentine in the LC compared to the SC obturation technique.
2. Endoseal MTA showed better adhesion to dentine in the SC technique.
3. There is no link between gapping and the adhesion strength of the sealers tested.

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I affirm that I have no financial affiliation or involvement with any commercial organization with direct financial interest in the subject or materials discussed in this manuscript, nor have any such arrangements existed in the past three years. Any other potential conflict of interest is disclosed.

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