

The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer

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ABSTRACT

Objectives: The aim of the study was to evaluate the effect of obturation techniques on the push-out bond strength of a premixed bioceramic (TotalFill BC) root canal sealer to root canal dentin surface.

Methods: The palatal root canal of sixty extracted human maxillary first premolar were prepared with Mtwo rotary system, teeth were divided into two groups; according to the sealer to be obturated with; TotalFill BC sealer and AH Plus sealer. Each group was then divided into three subgroups (n = 10) according to the obturation technique; cold lateral compaction, single cone, and warm vertical compaction. After obturation teeth were stored in an incubator for two weeks. Three slices of 1.5 mm thickness were then obtained from each root. Bond strength of obturation materials to root dentine was measured using push-out test by universal testing machine. Data were analyzed using ANOVA followed by Tukey's test. Mode of failure was determined by optical microscope examination.

Results: Overall, the push-out bond strength of TotalFill BC sealer was significantly higher than that of AH Plus sealer (P < 0.001). The obturation technique had no significant effect on the bond strength of TotalFill. While the bond strength of AH Plus was significantly affected, warm vertical compaction and single cone groups displayed lower bond strength than cold lateral compaction group (P < 0.05). Mixed mode of failure was most predominant in all groups.

Conclusions: TotalFill BC sealer showed a higher push-out bond strength than AH Plus sealer, and the obturation technique significantly affected AH Plus sealer but not the TotalFill.

Clinical Significance: Warm vertical compaction significantly reduced the bond strength of the resin based AH Plus sealer compared to cold lateral compaction, but this was not significant with the bioceramic TotalFill BC sealer. Single cone technique could be used with bioceramic sealer which make the obturation faster and easier.

1. Introduction

Successful root canal therapy depends mainly on controlling pulp space infection, which can be achieved by good cleaning and shaping followed by three-dimensional filling of the root canal space, accessory, and lateral canals [1]. Even though mechanical instrumentation results in a significant reduction in the microbial load, a relatively significant canal surface may remain untouched by cleaning instruments [2]. Hence, obturation of the root canal system plays an important role in prevention of canal reinfection since it reduces coronal leakage, bacterial contamination, provides an apical seal, and entombs the remaining irritants into the canal [3,4].

A calcium silicate bioceramic based sealer TotalFill® BC Sealer (FKG

Dentaire SA, La-Chaux-de-fonds, Switzerland) which is described by the manufacturer as a radiopaque, hydrophilic material, forms hydroxyapatite upon setting and bonds to both root canal dentine surface and to the bioceramic coated gutta-percha points (TotalFill® BC Points). The product is a premixed bioceramic sealer which also produced under the name of Endosequence BC sealer (Brasseler USA, Savannah, GA, USA) or iRoot SP (Innovative Bioceramics, Vancouver, Canada), the three products are similar in their chemical composition which consist of; calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic, and fillers [5]. It is recommended to be used with single cone hydraulic condensation technique since the sealer exhibit zero shrinkage and has some degree of expansion [6]. In addition, the bioceramic coated gutta-percha points chemically bond with the

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bioceramic sealer thus, may guarantee better seal. In clinical practice, bioceramic sealers were given more interest in endodontics, because of the simplicity of their use with single cone technique which may save the clinician and the patient time. Furthermore, both cold lateral compaction and warm vertical compaction were reported in vitro to induce weakening and damage to the root dentine [7–9], single cone or passive compaction technique where accessory gutta-percha cones are passively inserted along the master cone could be a less damaging alternative as this method did not cause any damage to the root dentin of extracted teeth [8]. But, in some cases where the root canal is oval, single cone may not provide enough seal to fill the wider canal space [10], and some clinicians still prefer to use cold lateral compaction technique since it is regarded as the benchmark against which other techniques must be evaluated [11], others prefer to use warm vertical compaction technique because it is supposed to be the best technique that can fill the pulp space in three dimensions [12]. However, some studies reported that the heat produced during this process can affect sealer properties as well as the bond strength of the sealer [13–15].

The adhesion of endodontic sealer to root canal dentine has been reported to be affected by the obturation technique [16–18]. It has been shown that single cone technique had a lower bond strength than cold lateral compaction using epoxy resin sealer [18], but still limited evidence is available regarding the effect of obturation technique on bioceramic sealers. Therefore, the objective of this study was to compare the single cone (SC) technique which is recommended by the manufacturer of TotalFill BC sealer to cold lateral compaction (CLC) technique which is the most commonly used obturation technique and to warm vertical compaction (WVC) technique using two types of sealers TotalFill BC sealer and AH Plus resin-based sealer. The hypothesis is the bond strength of the bioceramic sealer is higher than the resin based sealer despite the obturation technique used.

2. Materials and methods

This study was carried out under the regulations and approval of the deanship of research at corresponding author institution, the project was approved by the research committee and funded as research project number (146/2017).

2.1. Teeth selection and preparation

Sixty intact human maxillary first premolars that were freshly extracted for orthodontic reasons were collected, cleaned and stored in distilled water. The crowns were reduced to achieve a standard length of 20 mm for each tooth (from the upper cusp margin of the crown to the apex) using a diamond disk (SF 913-220, Teka Dental Technology, Milano, Italy) on a straight handpiece. After preparing a straight access cavity, the palatal canal was negotiated establishing a glide path, and working length determination by subtracting 1 mm from the full length, only straight canals were included in the study and the initial size of the canal at the full working length was verified by size 20. The palatal canal of the teeth was prepared with a series of Mtwo rotary system (VDW, Munich, Germany) up to size 50/04 to the full working length, Canals were irrigated with 2 mL of 5.25% NaOCl at each file change, as a final flush 17% EDTA (Prevest Dent Pro, Bari Brahmana, India) was used for one minute to remove the smear layer followed by flushing with 5 mL of normal saline and dried with absorbent paper points (FKG, Dentaire, Switzerland). The teeth were then divided randomly into two groups of 30 each, according to the sealer type (TotalFill, AH plus). Each group was then divided into 3 subgroups (n = 10) according to the obturation technique (Cold lateral compaction (CLC), Warm vertical compaction (WVC) and Single cone (SC)).

2.2. Root canals obturation

2.2.1. Group 1 (TotalFill-CLC)

The canals were obturated with a size 50/04 bioceramic coated GP master cone and TotalFill BC premixed sealer (TotalFill, FKG, Dentaire, Switzerland). The sealer was placed into the coronal one third of the canal with an intracanal tip (FKG, Dentaire, Switzerland). The master cone was coated with a thin layer of sealer and slowly inserted to the working length then cold lateral-compaction was performed using a stainless-steel finger spreader size 30 (Dentsply Tulsa) and fine accessory gutta-percha cones (Diadent, North Fraser Way, Burnaby, BC, Canada) were inserted and condensed laterally to fill the canal space. Finally, cones were seared off at the orifice level and lightly packed vertically with a plugger.

2.2.2. Group 2 (TotalFill-WVC)

A plugger that penetrates 4 mm short of the working length was used for a binding point. After sealer application like in the previous technique, the master cone 50/04 (bioceramic coated GP) was inserted into the canal then the heated plugger inserted into the canal to cut the master cone maintained only the apical gutta-percha (4 mm). Backfill of the canal was done by warm gutta-percha injection using Calamus (Dentsply Tulsa) that was set at 200 °C and the needle placed into the root canal against the apical gutta-percha for 5 s before extruding the gutta-percha. The mass of gutta-percha forced the needle coronally to the canal orifice, then a plugger was used to compact the gutta-percha at the orifice level.

2.2.3. Group 3 (TotalFill -SC)

The canals were obturated with a size 50/04 bioceramic coated TotalFill GP cone and TotalFill BC sealer using a SC according to the manufacturer's recommendation. Sealer was placed into the coronal one third of the canal with an intracanal tip. The master cone was coated with a thin layer of sealer and slowly inserted to the full working length. The cone was seared off at the orifice level and lightly packed vertically with a plugger.

2.2.4. Group 4 (AH Plus-CLC)

The canals were obturated with a size 50/04 GP (Mtwo, VDW, Munich, Germany) master cone and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany), the master cone was coated with a thin layer of sealer then inserted to the full working length, cold lateral-compaction was then performed as in group 1.

2.2.5. Group 5 (AH Plus-WVC)

A plugger that penetrates 4 mm short of the working length was used for a binding point. The master cone 50/04 GP (Mtwo, VDW, Munich, Germany) was coated with AH Plus sealer and inserted into the canal up to the full working length then WVC was performed as in group 2.

2.2.6. Group 6 (AH plus-SC)

The canals were obturated with a size 50/04 GP cone (Mtwo, VDW, Munich, Germany) and AH Plus sealer using SC. the sealer was applied to the canal with finger spreader followed by insertion of the master cone that was coated with the sealer to the full working length. The cone was seared off at the orifice level and lightly compacted with a plugger.

For AH Plus groups, the sealer was mixed according to the manufacturer's instructions, while the TotalFill is a premixed sealer. Overall, patency for the canals were achieved in all the samples before obturation with size 10 file, and after the insertion of the sealer into the canal the Gutta-percha was inserted and moved gently so the sealer puff was noted from the apical foramen. After the obturation the excess sealer in access cavity was removed with cotton pledgets, and the canal entrance was sealed with a quick-setting temporary filling Cavit (3 M

ESPE, 3 M Center, St. Paul, USA). Then the teeth were wrapped with a gauze soaked in normal saline and stored for 2 weeks at 37 °C in 100% humidity in an incubator to allow complete sealer setting.

After 2 weeks, the roots were centrally placed in a cylindrical mold and embedded vertically in Orthodontic resin. The apical 4 mm was first sectioned using a water-cooled diamond wafering blade (Isomet; Buehler Ltd, Lake Bluff, NY, USA) mounted on IsoMet 1000 precisions saw machine (Buehler, Lake Bluff, IL, USA) and discarded, then each root was sectioned horizontally at three levels namely: apical, middle, and coronal to obtain 3 sections 1.5 ± 0.1 mm in thickness. Each slice was marked from the apical surface for ease of placement during push-out test, then the apical and coronal diameter of the canal for each section was measured using a metal caliper (I Wanson Spring Caliper for Metal, Hu-Friedy, Germany) as well as it was used to confirm the section thickness.

2.3. Push-out test

The force required to dislodge the obturation materials from the canal was measured using Universal testing machine (Jinan Testing Equipment IE Corporation, China). A metal base was designed with 3 holes of different diameters as a platform to fix the specimen on it. A specimen holder was designed to hold the section on the metal base, and stainless-steel plungers with 3 different diameters (0.4 mm, 0.5 mm, 0.7 mm) corresponding to the apical, middle, and coronal section respectively were used to apply the force vertically on the obturation materials. Each section was centered over the corresponding hole using 3 × eye loupes and, the plungers mounted on the universal testing machine which is used at a crosshead speed of 0.1 mm/minutes to apply the load over the filling materials in apico-coronal direction (Fig. 1).

The maximum force in Newton (F-max) at which the dislodgement of the filling materials occurred was recorded, and the push-out bond strength in megapascal (MPa) was calculated for each specimen according to the following equation:

$$\text{Push-out bond strength (MPa)} = \text{F-max} / \text{adhesion surface area (mm}^2\text{)}$$

F-max: Maximum force.

Adhesion surface area was calculated according to the following formula:

$$\text{Adhesion surface area} = (D1 + D2/2) \times \mu \times h$$

where D1 = apical diameter, D2 = coronal diameter, $\mu = 3.14$, and h = the section thickness

2.4. Mode of failure evaluation

After completion of the push-out test, the specimens were examined under an optical microscope (Olympus, Tokyo, Japan) at 40 × magnification and the failure modes (adhesive, cohesive, or mixed) that occurred because of displacement of the sealer from the specimens were evaluated. Failure was considered:

- Adhesive: if the sealer was totally separated from dentine (dentine surface without sealer).
- Cohesive if the failure occurred within the sealer (dentine surface

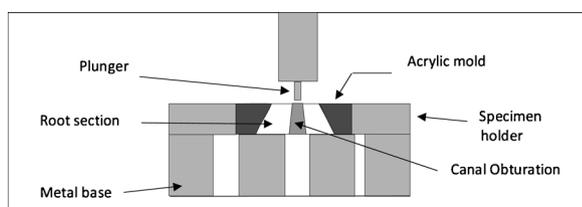


Fig. 1. Illustration for the push-out test.

totally covered by sealer).

- Mixed, when a combination of adhesive and cohesive modes occurred (dentine surface partially covered by the sealer).

2.5. Statistical analysis

Two-way analysis of variance ANOVA was used to determine the statistical and significant effect of the study variables (sealer type, obturation technique) on the push-out test data accordingly. Follow-up comparison was carried out by one-way ANOVA and Tukey pairwise comparison test at 95% confidence intervals.

3. Results

3.1. Bond strength

Indeed, because the three sections were taken from the middle third since the apical third was discarded, the data of the root section were pooled together and analyzed to determine the effect of the obturation technique and the sealer effect and their association together which was the purpose of this study.

For all the groups, the bond strength of the obturation with TotalFill sealer was higher than the bond strength of the obturation with AH Plus sealer in the three obturation techniques as seen in Fig. 2 and presented in Table 1 (total mean; 4.03 ± 1.07 vs. 3.47 ± 1.00 MPa). Overall, the bond strength in CLC was the highest (4.05 ± 0.95 MPa), followed by SC (3.73 ± 1.26 MPa) and then WVC (3.48 ± 0.91 MPa), although the value of the bond strength for the SC-AH (3.26 ± 1.11 MPa) was almost the same for the WVC-AH (3.27 ± 0.87 MPa), and the value of the CLC and SC of the TotalFill was also almost the same mean values (4.21 ± 0.98 MPa, and 4.20 ± 1.24 MPa, respectively).

Two-way analysis of variance (ANOVA) revealed that both variables the sealers and the obturation techniques had highly significant effect on the push-out bond strength from the dentine surface ($P < 0.001$, $P = 0.009$ respectively), but the interaction between the variables (sealer, obturation technique) was not statistically significant ($P = 0.211$) Table 2.

Since the interaction was not statistically significant, the groups within each variable (sealer, obturation technique) could be analyzed first separately, based on the total mean and pooled standard deviation (Table 1) by one way ANOVA followed by Tukey pairwise comparisons.

The analyses for the sealer effect overall the groups showed that the bond in the TotalFill groups significantly higher than the bond in the AH plus groups ($P < 0.001$). For the obturation technique effect, overall the groups showed a significant effect of the obturation technique in the bond strength by One-way ANOVA ($P = 0.013$), the highest bond strength was associated with cold lateral compaction (CLC) technique followed by single cone (SC) technique, and the

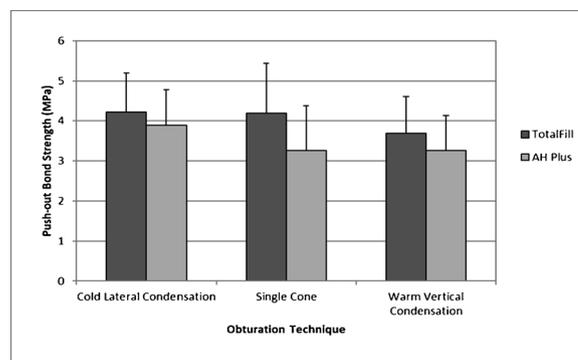


Fig. 2. Mean of the push-out bond strength of the three obturation techniques tested with TotalFill premixed bioceramic sealer or AH Plus resin based sealer (error bar represents SD).

Table 1

Mean \pm SD (MPa) of the push-out bond strength for the three Obturation techniques tested with TotalFill premixed bioceramic sealer or AH Plus resin based sealer with the total means and pooled SD.

Sealer	Obturation Technique			Total Mean ^a
	Cold Lateral compaction	Single Cone	Warm Vertical Compaction	
TotalFill	4.21 \pm 0.98	4.20 \pm 1.24	3.69 \pm 0.92	4.03 \pm 1.07 ^a
AH Plus	3.89 \pm 0.89	3.26 \pm 1.11	3.27 \pm 0.87	3.47 \pm 1.00 ^a
Total Mean^a	4.05 \pm 0.95^b	3.73 \pm 1.26	3.48 \pm 0.91^b	3.75 \pm 1.07

* Total mean values with the same letter indicating statistically significant differences (TotalFill vs. AH Plus and CLC vs. WVC).

^a P < 0.001.

^b P < 0.05.

Table 2

Two-way ANOVA: Push-out bond strength versus Sealer and Obturation technique.

Source	DF	SS	MS	F	P
Sealer	1	14.224	14.2240	13.89	0.000
Obturation	2	9.905	4.9524	4.84	0.009
Interaction	2	3.216	1.6082	1.57	0.211
Error	174	178.125	1.0237		
Total	179	205.470			

weakest was with warm vertical compaction (WVC) technique. Statistically the difference between CLC and WVC was significant (P < 0.05) but between the CLC and SC was not significant neither between SC and WVC (P > 0.05) (Table 1).

For further understanding the effect of the obturation technique in association with the sealer the data were analyzed again for each type of sealer with obturation techniques, and for each type of obturation with the sealers using again one-way ANOVA followed by Tukey test for pairwise comparisons at 95% confidence intervals (significant level 0.05)

In the TotalFill groups the obturation technique had no significant effect on the push-out bond strength (P = 0.096) this was also confirmed by pairwise comparisons that showed no significant differences between the groups (Table 3-A). While in the AH Plus groups the

Table 3

Tukey pairwise comparisons at 95% confidence intervals for the two sealers tested with the three obturation techniques.

A: Comparison between TotalFill groups			
Pairwise Comparisons ^a	CLC-TF	SC-TF	WVC-TF
SC-TF	NS		
WVC-TF	NS		NS
B: Comparison between AH Plus groups			
Pairwise Comparisons ^a	CLC-AH	SC-AH	WVC-AH
SC-AH	S		
WVC-AH	S		NS
C: Comparison between the same obturation technique groups with the two different sealers			
Pairwise Comparison ^a	CLC-TF	SC-TF	WVC-TF
CLC-AH	NS		
SC-AH		S	
WVC-AH			NS

* S: significant; NS: not significant, TF: TotalFill, AH: AH Plus CLC: Cold Lateral Compaction, SC: Single Cone, WVC: Warm Vertical Compaction.

Table 4

Mode of failure, number of specimens and (%), for the two sealers and the three obturation techniques groups.

Group	N	Adhesive(%)	Cohesive (%)	Mixed (%)
CLC TotalFill	30	1(3.3)	6 (20)	23 (76.6)
SC TotalFill	30	4 (13.3)	3 (10)	23 (76.6)
WVC TotalFill	30	0 (0)	13 (43.3)	17 (56.6)
Total	90	5 (5.6)	22 (24.4)	63 (70)
CLC AH plus	30	0 (0)	0 (0)	30 (100)
SC AH plus	30	8 (26.6)	4 (13.3)	18 (60)
WVC AH plus	30	0 (0)	13 (43.3)	17 (56.6)
Total	90	8 (8.9)	17 (18.9)	65 (72.2)

CLC: Cold Lateral Compaction, SC: Single Cone, WVC: Warm Vertical Compaction.

obturation technique had a statistically significant effect on the push-out bond strength (P = 0.019), follow up comparisons showed that the bond strength for the CLC was significantly higher than that of the SC and WVC, while there was no significant difference between the SC and WVC, in fact the means were very closed almost the same 3.26 vs. 3.27 MPa respectively (Table 3-B).

When the same obturation techniques were compared to each other with the two different sealers, the difference was significant only in single cone technique as TotalFill sealer demonstrated significantly higher bond strength than the AH Plus (Table 3-C).

3.2. Mode of failure

The analysis of the failure mode (Table 4) showed that, regardless of the sealer or the obturation technique used, the mixed mode of failure was the most predominant mode followed by cohesive and the least was the adhesive mode.

4. Discussion

Endodontic sealers undergo continuous improvement because they play a critical role in the achievement of a hermetic seal during root canal therapy since it is one of the main goals of endodontic treatment. Lower bond strength of the sealer to the dentine surface of the root canal may have an impact on the clinical behavior of the sealer, since the ability of the sealer to resist disruption of the sealer by micro-mechanical retention or friction is needed during tooth function or during post space preparation [19]. The value of push-out bond strength of the sealer may varies, depend to the type of sealer and to the obturation technique, thus it needs investigation and comparisons to determine the critical bond needed for clinical situation to resist any disruption that may occur during function or post preparation and restoration placement.

TotalFill BC sealer is a premixed bioceramic sealer that is composed of calcium silicate, calcium hydroxide, zirconium oxide, and calcium phosphate. It has excellent properties and it is recommended to be used with single cone technique because it contains nanoparticles that facilitate sealer penetration into the canal irregularities and dentinal tubules, thus may provide a better interface between the canal wall and the sealer [5,20]. In the current study, it has been compared to AH Plus resin based sealer since AH Plus is considered as the benchmark sealer to which most other sealers were compared to [21]. Indeed the push-out bond strength is just one aspect of the obturation quality, but other aspects such as apical leakage, sealing ability, and long-term stability of the bioceramic sealers have been also investigated by other researchers [22–26]. It has been reported that iRoot SP was having stable sealing ability over a 3-month period [27], furthermore in a recent study Endosequence BC sealer showed marked calcium release and strong alkalizing activity higher than other calcium silicate-based materials over a period of 28 days [28].

After obturation, the teeth were wrapped in gauze soaked in normal saline and stored for 2 weeks at 37 °C in 100% humidity in an incubator to allow complete sealer setting. Saline was used to give the humidity to the samples of the two sealers used, although the Totalfill is a bioactive material (calcium silicate based material) so if we used the PBS (phosphate buffer slain) the bond strength may be enhanced even more, matter to be considered in the future research.

Although bond strength testing may not predict the clinical behavior of the materials and the lack of standardization among the previous push-out bond strength studies led to great variability in their results [29], the push-out test still one of the best measure of adhesion currently available [30]. It has been reported that factors such as specimen thickness, plunger diameter, and specimen orientation influence the push-out bond strength value [29,30]. All these factors were considered in our study and it has been designed to ensure that the proper guide lines were followed throughout the preparation of the specimens and the test performance. The plunger were fabricated precisely with the diameter of 0.4, 0.5, 0.7 mm corresponding to the apical diameter of the three sections that were 0.6, 0.7, 0.9 mm apical, middle and coronal sections respectively. The plunger was covering almost most of the Gutta percha and the ratio between the plunger and the diameter of the canal was in accordance with which has been recommended in the literature since the ratio was more than 60% [30].

We should also mentioned that this study is in-vitro study which is different to some extent from the in-vivo where the tooth is seated in its socket with periodontal ligament having the same temperature of the body which may have an influence in the properties of the sealer particularly in the warm vertical compaction technique. Although, a previous study has evaluated the effect of body temperature on the properties of bioceramic sealer and reported no change in the sealer properties [14].

Regardless of the obturation technique used in this study TotalFill BC sealer displayed a higher bond strength to root dentine than AH plus sealer (4.03 ± 1.07 vs. 3.47 ± 1.00 MPa). Our findings are in agreement with previous studies [31,32]. Moreover, DeLong et al. [16] reported that Endosequence BC sealer showed a higher mean bond strength than AH Plus sealer when used with SC technique but in their study, they compared Endosequence BC sealer using SC and WVC technique while AH plus was used with WVC technique only. On the other hand, Gade et al. [17] compared the push-out bond strength of Endosequence, AH Plus and Endomethasone N (Septodont) sealers using CLC and WVC techniques, and reported that AH Plus CLC has a higher bond strength than Endosequence CLC and WVC groups. This difference in results could be attributed to the different methodology since they compared only two techniques without single cone technique which is recommended technique for BC sealer. Also, the incubation period was only for 48 h unlike our study that was for two weeks, since the bond strength of TotalFill BC sealer increase with time as it has been reported by Yap et al. [33].

The higher bond strength of TotalFill BC sealer in our study could be attributed to its bioactivity since bioceramic sealers bond to root dentine by a process known as alkaline etching. This process allows ions exchange where the minerals of bioceramic sealer permeate the dentine [34] and develop a mineral infiltration zone at the dentine- sealer interface which may result in lower gap formation compared to AH Plus sealer [35–37]. Furthermore, Han & Okiji [38] reported that BC sealer forms a tag-like structure inside the dentinal tubules which may be responsible for the sealing ability and dentine bonding of the sealer. Regarding the effect of obturation technique on the bond strength, the highest bond strength was found with CLC regardless of the sealer type the same has been reported by Rached-Junior et al. [18] using epoxy resin based sealers. But in our study, the mean value of the bond strength in the CLC was the same as the SC in TotalFill groups. Our results are in contrast with Gade et al. [17] work since they reported that Endosequence WVC group has higher bond strength than CLC group.

When the bond strength of each obturation technique for the two different sealers was compared, the bond strength of TotalFill SC group (4.20 ± 1.24 MPa) was significantly higher than AH Plus SC group (3.26 ± 1.11 MPa). Up to authors knowledge, no previous study has compared the two sealers using SC technique. This result could be due to the bioactivity of TotalFill BC sealer by forming a chemical bond with root dentine [39], moreover, it is hydrophilic material and has a low contact angle which allowing it to spread easily over the canal walls providing adaptation and a good hermetic seal [40]. Recent SEM based study reported that TotalFill BC sealer showed better adaptability to the canal wall than AH Plus sealer [37], Jeong et al. [20] reported that calcium silicate- based sealers penetrate into the dentinal tubules without applying intracanal compaction pressure that is usually used in obturation techniques. What's more, in the current study we used a bioceramic coated gutta-percha points that bond chemically to the bioceramic sealer and form a mono-block as claimed by the manufacturer, this may improve the bond strength unlike AH Plus sealer that does not chemically bond to the gutta-percha. Based on the authors search in the literature, no previous study has investigated the chemical bonding between the BC sealer and the coated gutta-percha point (GP), but Eltair et al [37] evaluated the adaptation between BC sealer and BC coated points using SEM and reported that there is an interfacial gap between BC sealer and coated GP, more studies are needed to investigate the bonding between the sealer and the coated point and whether it will influence the quality of the root canal obturation.

No significant difference was found between the bond strength of the two sealers when we compared CLC groups. Our results are in agreement with Sagsen et al. [41] and Shokouhinejad et al. [42]. This could be due to technique itself, since with CLC the bond of the obturation materials mainly depend on the compaction of the gutta percha cones to the canal wall and the amount of sealer is minimum comparing to the single cone technique.

When the effect of obturation technique on the bond strength of the sealer itself was evaluated, the bond strength of AH Plus CLC (3.89 ± 0.89 MPa) was significantly higher than both SC (3.26 ± 1.11 MPa) and WVC (3.27 ± 0.87 MPa), the same has been reported by Rached-Junior et al. [18] when they compared CLC, SC, and THT (tagger hybrid technique) techniques. Moreover, Carneiro et al. [43] and Gade et al. [17] reported the same findings when they compared CLC to (THT or WVC) techniques using AH Plus sealer. This could be attributed again to the pressure applied by the spreader over the master cone and accessory cones to compact the gutta perch cons in CLC technique which may create force both in lateral and apical direction that facilitates sealer penetration in canal irregularities unlike single cone technique which probably creates force only in apical direction [18]. On the other hand, the effect of obturation technique on TotalFill BC was not significant, in fact CLC and SC almost have the same mean value this may support the manufacturer recommendation for use of TotalFill BC sealer with SC technique, this could be related to the bioactivity of the TotalFill BC sealer that may provide a good bond to the dentin surface.

The WVC technique demonstrated the weakest bond strength among the three techniques. However, the difference was not significant for TotalFill BC sealer groups. The same has been reported by DeLong et al. [16]. A recent study investigated the effect of heat on the properties of both calcium silicate-based and epoxy resin sealers using Raman spectroscopy, reported that heat application did not seem to affect the chemical composition of the calcium silicate-based sealer, regardless of the temperature or duration [15]. The authors related these findings to the chemical structure of this sealer since hydrated calcium silicate is composed of an inorganic matrix of calcium silicate hydrate enveloping unreacted silicate granules with water-filled microspaces in-between [15,44]. On heat application, water desorption may happen which lead to weight loss and microstructural changes in the cement [15,44]. However, this water loss may be compensated by moisture from the root canal system during the setting reaction [15].

While with AH plus the lower bond strength associated with WVC in our results, could be attributed to the effect of heat on composition and setting time of epoxy resin sealer [13–15]. It has been reported that the heat application during WVC accelerates the setting reaction, so it reduces the setting time [14] which may not allow sealer flowability and penetration into canals irregularities and dentinal tubules. Furthermore, Atmeh et al. [15] reported that the chemical structure of AH Plus was affected when it was subjected to heat. However, the clinical implication of these changes in AH Plus sealer is still unclear. Thus, further studies are needed to evaluate the clinical relevance of such changes [45]. Also, the thermoplastic GP shrinks on cooling and this shrinkage may lead to stress concentration on the sealer, hence affects its bond to the dentine surface. The lower bond strength found in the single cone technique group with AH plus sealer could also be related to the fact that, the volume of the sealer is high relative to the other techniques and in relation to the volume of the GP, which leads to voids formation and reduces the quality of the seal [46]. These findings should be taken into consideration when we use Epoxy resin-based sealers.

Mixed mode of failure was overall the most predominant in both types of sealers (TotalFill 70%, AH plus 72%) followed by cohesive failure (TotalFill 24.4%, AH plus 18.9%) and finally adhesive failure (TotalFill 5.6%, AH plus 8.9%). These results were consistent with other studies that also showed the dominance of mixed or cohesive bond failures [16,42]. However, in Shokouhinejad and co-workers [42] study the cohesive mode of failure was more predominant than the mixed mode, this could be due to different methodology since in their study only lateral condensation technique was used, and two groups either with or without smear layer. In this study however, about 26.6% of the specimens in AH Plus SC group demonstrated an adhesive failure which again indicates the method of obturation could be the reason for these findings.

5. Conclusions

Within the limitation of this *in vitro* study and under its conditions, the following were concluded:

- 1 Overall the push-out bond strength of TotalFill BC sealer was significantly higher than that of AH plus sealer.
- 2 The obturation techniques did not affect significantly the bond strength of TotalFill BC sealer
- 3 In regard to the bond strength; TotalFill BC sealer can be used with single cone coated gutta-percha, since the push-out bond strength of SC technique was equal to the CLC.
- 4 WVC and SC techniques negatively affected the bond strength of AH plus sealer.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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