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EVALUATION OF ADAPTABILITY AND PUSH-OUT BOND STRENGTH OF A NOVEL BIO-CERAMIC SEALER USING TWO DIFFERENT OBTURATION TECHNIQUES. (IN VITRO STUDY)

Marwa Mamdouh Zaki Ibrahim[*], Mohamed Mokhtar Nagy[**] *and* Sara Hossam Fahmy[***]

ABSTRACT

Introduction: Obturation with a fluid tight seal has a direct impact on the success of root canal treatment; therefore, sealer bonding and adaptability are critical parameters.

Aim: This in-vitro study compared two different root canal sealers with two different obturation techniques in terms of adaptability and push-out bond strength.

Materials and methods: Forty extracted single rooted lower premolars were prepared. The samples were divided into two groups (n=20). Group I was obturated with well-Root ST sealer and group II was obturated with ADSEAL sealer. Each group was subdivided into two subgroups (n=10). Subgroup A was obturated with single cone technique and subgroup B was obturated with cold lateral compaction technique. Each subgroup was divided into two subdivisions (n=5). Subdivision 1 for adaptability evaluation and subdivision 2 for push-out bond strength evaluation. Specimens were then sectioned horizontally. Adaptability was evaluated using scanning electron microscope and push-out bond strength was assessed using universal testing machine.

Results: Well-Root ST showed higher push-out bond strength and better adaptability than ADSEAL. Cold lateral compaction technique showed higher push-out bond strength than single cone technique, while no significant difference was found between the two techniques regarding adaptability. Middle and apical sections showed higher push-out bond strength and better adaptability than coronal sections.

Conclusion: Within the limitation of this study, bio-ceramic sealers are promising root canal sealers. Cold lateral compaction technique improves the push-out bond strength of the root canal sealer; however, technique of obturation showed no significant effect on adaptability.

KEYWORDS: Bio-ceramic, Push-out, Adaptability.

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[*] B.D.S., Faculty of Dentistry, Ain Shams University
[**] Professor of Endodontics, Endodontic Department, Faculty of Dentistry, Ain Shams University
[***] Lecturer in Endodontics, Endodontic Department, Faculty of Dentistry, Ain Shams University

INTRODUCTION

The aim of root canal treatment is to eliminate infection within the root canal system and to prevent recontamination. Infection can be eliminated by chemo-mechanical preparation, but it is extremely difficult to be eliminated completely from the complex root canal system. Therefore, obturation is necessary to overcome this limitation of chemo-mechanical preparation and to prevent recontamination by achieving a fluid-tight seal.

Adhesion is critical for achieving a fluid-tight seal, which reduces microleakage and has a direct impact on the success of root canal treatment; push-out bond strength and adaptation of the sealer are important parameters to assess adhesion to root canal dentine.

MTA is a calcium silicate cement that has been proved to have excellent sealing ability[1]. As a result, there is a strong interest in developing calcium silicate-based sealers for root canal obturation. Calcium silicate-based endodontic sealers seem to be the most promising in their sealing ability, and there are currently several commercially available products based on calcium silicate. Well-Root ST canal sealer is one of the commercially available calcium silicate-based sealers. The available information in the literature about Well-Root ST and its use in conjunction with single cone technique regarding the adaptability and bond strength is limited.

Aim of the study

The aim of the present study was to compare a novel bio-ceramic endodontic sealer (Well-Root ST) with a resin-based sealer (ADSEAL) in terms of adaptability and push-out bond strength using two different obturation techniques, single cone technique (SC) and cold lateral compaction technique (CLC).

MATERIALS AND METHODS

I. Materials

A. Well-Root ST sealer

The material is supplied in a premixed syringe with intra-canal tip and the sealer is directly applied into the canal. The material is chemically composed of calcium silicate, zirconium oxide, filler, and thickening agents.[2–4]

B. ADSEAL sealer

The material is supplied in a dual syringe, the plunger is pressed to extrude two equal portions of the material on a paper pad, then the material is mixed by a spatula till the mix becomes homogenous. The dual syringes contain a base and a catalyst, the base chemically composed of epoxy oligomer resin, ethylene glycol salicylate, calcium phosphate, bismuth sub-carbonate, zirconium oxide and the catalyst composed of poly aminobenzoate, triethanolamine, calcium phosphate, bismuth sub-carbonate, zirconium oxide, calcium oxide.[5]

II. Methods

A. Sample selection

Forty human extracted single-rooted mandibular premolars were used with a single canal and a single apical foramen devoid of root defects, fractures, with mature apices and with no internal or external resorption or calcification , then the teeth were rinsed thoroughly under water and stored in distilled water until use.

B. Sample classification

Forty teeth were divided into two groups according to the type of sealer used; Group I, Well-Root ST, (n=20) and Group II, ADSEAL, (n=20).

Each group was further subdivided into two subgroups according to the technique of obturation; Subgroup A, single cone technique (SC), (n=10) and Subgroup B, cold lateral compaction technique (CLC), (n=10).

Each subgroup was sub divided according to the evaluation parameter into two subdivisions; subdivision 1, adaptability evaluation, (n=5) and subdivision 2, push-out bond strength evaluation, (n=5).

C. Sample preparation

Each tooth was de-coronated at the cemento-enamel junction (CEJ) using a diamond-coated disc under water coolant, adjusting the roots to a length of 15 mm. The working length was adjusted to be 14 mm. Root canals were instrumented using a crown down technique by M3 Pro Gold rotary files (*) up to the master apical file size 40/0.04. The files were used in small pecking motion, at speed 350 rpm and torque 1.5 N.cm, following the manufacturer's instructions.

Recapitulation was performed between each file size and the next using a k-file size 15 (**) and in conjunction with irrigation by 1 ml of 2.5% sodium hypochlorite (NaOCl) (***) using a 31G side-perforated needle at 1 mm shorter than the working length.[6]

Before obturation, 5 ml of 17% ethylene diamine tetra acetic acid (EDTA) (****) was used, followed by final flushing with 5 ml of saline.

D. Sample obturation

Gutta percha cone (*****) was selected to be the same size and taper as the last endodontic file used for root canal enlargement (40/0.04),[7–9] then it was checked inside the canal to confirm that it reached the full working length and to check the presence of tug back.

For Group I, the canals were dried using one paper point of the same size of the master apical file. The canal was considered not to be over dried when 3-4 mm from the tip of the paper point is wet.[10] The Sealer was injected into the canal by placing the tip of the syringe to the end of the coronal third of the canal.

For Group II, the canals were dried using paper points of the same size of the master apical file until the last paper point came out dry. The sealer was mixed according to the manufacturer's instructions on paper pad, then it was inserted into the canal by coating the master gutta-percha cone.

For Subgroup A, SC technique was used by placing the master cone into the root canal to the full working length. Then excess gutta-percha was removed by a heated instrument at the level of the canal orifice.

For Subgroup B, CLC technique was used by placing the master cone into the root canal to the full working length. Then lateral compaction was performed using a spreader of size 30 and auxillaries gutta-percha cones of size 25 and taper 0.02 till filling the canal and excess gutta-percha was removed by heated instrument at the level of canal orifice.

After obturation all samples were radiographed at both mesio-distal and bucco-lingual directions to ensure the quality of obturation, and then all specimens were wrapped in gauze soaked in normal saline and stored in incubator at 37°C for two weeks.

From each tooth 3 Slices of 2 mm thickness were sectioned perpendicularly to tooth long axis at three different levels: apical (3 mm from apex), middle (8 mm from apex) and coronal (13 mm from apex) using a diamond-coated disc under water coolant. The thickness of each slice was measured using a digital caliper. The apical surface of each section was marked using an indelible marker.

E. Evaluation methods

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* United Dental,Shangahai, China

** MANI Inc., Japan

*** Calix, DHARMA, USA

**** Calix, DHARMA, USA

***** MetaBiomed, South Korea

1. Adaptability evaluation

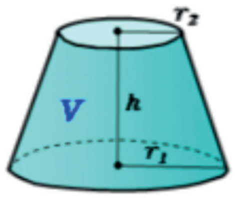
The samples were mounted on aluminum stubs, then placed in a vacuum chamber and viewed under scanning electron microscope.(*) Gaps at sealer and root dentin interface were evaluated under 1000× magnification, three representative areas from each sample were focused and photomicrographs were taken then dentin-sealer interfacial gaps were recorded in micrometers (μm). Overall average gaps at this interface were calculated for each sample and were tabulated to be used for statistical analysis.

2. Push-out bond strength evaluation

Bond strength was evaluated using universal testing machine (**), the filling material was loaded with flat tip cylindrical stainless-steel plungers of diameter 0.8, 0.6 and 0.4 mm for coronal, middle and apical slices respectively and at a speed of 1 mm/min until debonding occured. Plungers were positioned to cover almost the entire root filling without touching canal walls, and the load was applied in an apical-coronal direction, and the maximum load needed to dislodge the filling material was recorded in Newtons (N).

After the push out test was performed, photomicrographs were captured for both sides (coronal and apical) of each slice at a magnification of 4x using a digital video camera (***), mounted on a stereo microscope (****). Images were then transferred to the computer system for analysis. Canal dimensions were measured; one measurement for the circular canal and two measurements for the oval one, the linear measurements were carried out using image analysis software (*****). The collected data were recorded, tabulated to be used for statistical analysis.

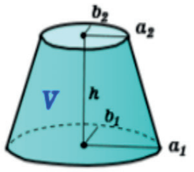
The area of the bonded surface was calculated, for the canals with round cross section using the formula of lateral surface area of circular truncated cone presented in **Figure 1** was used, while for the canals with oval cross section, the formula of lateral surface area of elliptic truncated cone presented in **Figure 2** was used.[11] Then the bond strength was calculated in mega pascals (MPa) by dividing the load by the area of the bonded surface area



$$\pi(r_1 + r_2)^2 \times \sqrt{(r_1 - r_2)^2 + h^2}$$

Fig. (1): Circular truncated cone lateral area.

Where π =3.14, r1 is the canal diameter at the coronal side in mm, r2 is the canal diameter at the apical side in mm and h is the thickness of the specimen in mm.



$$\left(2a_1\sqrt{b_1^2 + (\frac{ha_1}{a_1 - a_2})^2} - 2a_2\sqrt{\frac{b_1^2 a_2^2}{a_1^2} + \left(\frac{ha_2}{a_1 - a_2}\right)^2}\right)E\left(\sqrt{\frac{1 - {b_1^2}/{a_1^2}}{1 + {b_1^2(a_1 - a_2)^2}/{h^2 a_1^2}}}\right)$$

Fig. (2): Elliptical truncated cone lateral area.

Where a1 is the major semi-axis of coronal side in mm, b1 is the minor semi-axis of the coronal side, a2 is the major semi-axis of the apical side in mm, b2 is the minor semi-axis of the apical side, h is the thickness of the specimen in mm and E(k) is the 2nd complete elliptic integral.

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* FEIQuanta FEG-250 SEM instrument, USA

** Lloyd LR 5K: Lloyd instruments ltd, Fareham, UK

*** Canon EOS 650D, Japan

**** LG-PS2, Olympus, Japan

***** Image J, 1.41a, NIH, USA

F. Statistical analysis

Categorical data were presented as frequency and percentage values and were analyzed using chi-square test followed by pairwise comparisons utilizing multiple z-tests with Bonferroni correction. Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. Data showed parametric distribution, so they were analyzed using one-way ANOVA followed by Tukey's post hoc test for independent samples and repeated measures ANOVA followed by Bonferroni post hoc test for paired samples. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows (*).

RESULTS

I. Adaptability

A. Effect of sealer

Mean and standard deviation (SD) values of interfacial gaps (μm) for different sealers were presented in **Table 1**.

TABLE (1): Mean and standard deviation (SD) values of interfacial gaps (μm) for different sealers

Interfacial gaps (μm) (mean ± SD)		**p-value**
Well-Root ST	**ADSEAL**	
3.98±1.77	5.86±1.50	**0.002***

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

ADSEAL (5.86±1.50) had a significantly higher value than Well-Root ST (3.98±1.77) (p=0.002).

B. Effect of obturation technique

Mean and standard deviation (SD) values of interfacial gaps (μm) for different obturation techniques were presented in **Table 2**.

TABLE (2): Mean and standard deviation (SD) values of interfacial gaps (μm) for different obturation techniques

Interfacial gaps (µm) (mean ± SD)		**p-value**
SC	**CLC**	
5.40±2.19	4.44±1.41	**0.128ns**

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

SC (5.40±2.19) had a higher value than CLC (4.44±1.41) yet the difference was not statistically significant (p=0.128).

C. Effect of root section

Mean and standard deviation (SD) values of interfacial gaps (μm) for different root sections were presented in **Table 3**.

TABLE (3): Mean and standard deviation (SD) values of interfacial gaps (μm) for different root sections

Interfacial gaps (μm) (mean ± SD)			**p-value**
Coronal	**Middle**	**Apical**	
6.20±2.23^{A}	4.39±1.40^{B}	4.18±1.27^{B}	**0.001***

Different superscript letters indicate a statistically significant difference within the same horizontal row

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

There was a significant difference between values measured at different sections (p=0.001). The highest value was measured at the coronal section (6.20±2.23), followed by the middle section (4.39±1.40), while the lowest value was found at the apical section (4.18±1.27). Post hoc pairwise comparisons showed value measured at the coronal section to be significantly higher than the values measured at other sections (p<0.001).

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* R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

II. Push-out bond strength (MPa)

A. Effect of sealer

Mean and standard deviation (SD) values of push-out bond strength (MPa) for different sealers were presented in **Table 4.**

TABLE (4): Mean and standard deviation (SD) values of push-out bond strength (MPa) for different sealers

Push-out bond strength (MPa) (mean ± SD)		**p-value**
Well-Root ST	**ADSEAL**	
5.86±2.67	2.64±1.35	**<0.001***

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

Well-Root ST (5.86±2.67) had a significantly higher value than ADSEAL (2.64±1.35) (p<0.001).

B. Effect of obturation technique

Mean and standard deviation (SD) values of push-out bond strength (MPa) for different obturation techniques were presented in **Table 5**.

TABLE (5): Mean and standard deviation (SD) values of push-out bond strength (MPa) for different obturation techniques

Push-out bond strength (MPa) (mean ± SD)		**p-value**
SC	**CLC**	
2.77±1.70	5.73±2.63	**<0.001***

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

CLC (5.73±2.63) had a significantly higher value than SC (2.77±1.70) (p<0.001).

C. Effect of root section

Mean and standard deviation (SD) values of push-out bond strength (MPa) for different root sections were presented in **Table 6**.

TABLE (6): Mean and standard deviation (SD) values of push-out bond strength (MPa) for different root sections

Push-out bond strength (MPa) (mean ± SD)			**p-value**
Coronal	**Middle**	**Apical**	
3.05±3.16^{B}	4.58±2.39^{A}	5.13±1.93^{A}	**<0.001***

Different superscript letters indicate a statistically significant difference within the same horizontal row

; significant (p ≤ 0.05) ns; non-significant (p>0.05)

There was a significant difference between values measured at different sections (p<0.001). The highest value was measured at the apical section (5.13±1.93), followed by the middle section (4.58±2.39), while the lowest value was found at the coronal section (3.05±3.16). Post hoc pairwise comparisons showed value measured at the coronal section to be significantly lower than values measured at other sections (p<0.001).

DISCUSSION

In endodontics, a proper seal of the canal is a key step in successful root canal therapy since studies showed that it is correlated with decreased microleakage.[12,13]Additionally, when preparation of a post-space is required, maintaining the integrity of the root canal filling material's seal is critical[14] because the root canal filling material may get dislodged during mechanical preparation of the post-space, causing voids in the obturation and compromising the seal's quality.[15–18] Gutta percha can't bind to the dentinal walls of the root canal; therefore, using root canal sealer in conjunction with gutta percha is the most common and most accepted obturation technique to fill the canals.[19]

ADSEAL was used because it is an epoxy resin-based sealer, which is considered the gold standard material that is utilized as a comparative material in studies, and it was found to have strong retention to root dentin and greater push-out bond strength values when compared to other endodontic sealers.[13,20–30]

Well-Root ST sealer is a commercially available calcium silicate-based sealer which is a premixed type that uses moisture in dentinal tubules to initiate and complete its setting reactions.[2,3] The manufacturer claims that Well-Root ST performs successfully as a root canal filler, and it has become widely used in clinical practice. However, the available information in the literature regarding its adaptability and bond strength is limited.

The SC technique does not require a long learning curve and is simple enough for even inexperienced clinicians to perform.[31,32]

In many studies, bio-ceramic sealers are suggested to be used with single cone obturation technique[31,33] because these materials do not shrink and have long-term dimensional stability.[8,32,34] Studies have also shown that bio-ceramic sealers with single cone technique have comparable or superior outcomes when compared to conventional obturation materials and techniques.[33–39]

The preliminary retrospective clinical studies of using the single cone technique with bio-ceramic sealer reported a high success rate of 90.9% [31,40]; however, long-term randomized clinical trials are required to reveal its long-term efficacy.

The CLC technique was used because it is considered the gold standard technique that is used for comparison in many studies for evaluation of obturation systems.

Good adaptability of the sealers to dentinal walls is required because the formation of gaps between the root canal wall and the root filling material leads to reinfection of the root canal system and results in endodontic failure.[41]

The push-out bond strength test is important to assess the adhesion of the root filling material to the root canal. According to Üreyen Kaya et al.[42] and Drummond et al.,[43] the push-out test has been suggested to be a better evaluation method for the bond strength than the conventional shear test because fracture occurs parallel to the dentine–bonding interface in the push-out test, which makes it a true shear test for parallel-sided samples. Additionally, according to Yap et al.,[44] push-out bond strength is a better way to measure adhesion of the sealer to the dentin because force distribution is in a more homogenous way, making the results more reproducible with less variability. According to Teixeira et al.,[45] the push-out bond strength test allows accurate standardization of the specimens compared with the shear test.

The purpose of this study was to compare Well-Root ST, the calcium silicate-based sealer, and ADSEAL, the epoxy resin-based sealer, in terms of adaptability and push-out bond strength, with two techniques: the single cone obturation technique and the cold lateral compaction technique.

Human extracted single-rooted mandibular premolars were used. Only teeth with straight roots were selected to allow positioning of the specimens in a vertical alignment during push-out bond testing. Teeth were de-coronated at CEJ, producing roots of 15 mm to eliminate any variables in access preparation.

All samples were mechanically instrumented by rotary files up to size 40 with a continuous taper of 0.4. Although some studies used a diamond or carbide bur in preparing a simulation of a root canal to standardize the diameter of the filling material[12,46–49], the current study was intended to provide information in a clinically oriented setup; therefore, root canals were mechanically prepared in a manner that is commonly used by clinicians and in accordance with other studies.[6,50,51] Recapitulation was performed between each file change using a k-file of size 15, in conjunction with 1 mL of 2.5% sodium hypochlorite irrigation, using a side-perforated needle to avoid debris accumulation.

5 ml of 17% EDTA was used to remove the smear

layer as most studies recommended the removal of the smear layer as it may harbor bacteria and found that removing the smear layer has a positive effect on root canal sealing because it allows the sealer and gutta percha to better adapt to the canal walls and penetrate the dentinal tubules.[52–54] The final flush used was 5 ml of saline to neutralize the effect of the irrigation solutions,[55,56] as some studies stated that EDTA has a negative effect on the bond strength of calcium silicate-based sealers.[57,58]

Canals were blot dried using paper points of the same size as the master apical file. For ADSEAL, drying was achieved by several paper points until the last paper point came out dry; however, for Well-Root ST, the canals were dried using one paper point to leave the canals slightly moist, which is essential for the setting of the sealer.[59–61]

The obturation was performed using both the sealer and gutta-percha core material, to best mimic the clinical situation. In contrast to some studies, the canals were filled with sealer only without using a core material[12,13,56,62], and the purpose of that was to better assess the sealer-dentin link itself without the effect of the link between the sealer and gutta-percha, which can compromise the results; however, this methodology seems to be far off from clinical practice and it excludes the effect of the sealer bond to gutta-percha on the bond strength.

The sealers were prepared according to the manufacturer’s instructions.

ADSEAL was mixed and applied inside the canal by coating the master gutta-percha cone with sealer, then inserting it to the full working length. Well-Root ST, on the other hand, is a premixed calcium silicate sealer that does not need to be mixed before use; it is injected directly into the canal. This injectable delivery method can be superior as it allows a greater volume of sealer to be delivered and dispersed more evenly in the root canal.[7,8,63]

After obturation, all specimens were wrapped in gauze soaked in normal saline to provide humidity essential for the setting of the calcium silicate based-sealer and stored in an incubator at 37 °C to mimic the clinical situation for 2 weeks to allow sufficient time for hydration and setting of the sealer.[2]

After the incubation period, from each root, one section from each third (coronal, middle, and apical) was sectioned, because several studies suggested that the bond strength varies in different regions of the canal dentin.[64–66] The thickness of the slices used was 2 mm to avoid dislodgement of the filling material while slicing, as reported by Gesi et al.[67], and also in accordance with Barbizam et al.[68]

Roots were sectioned perpendicular to the long axis of the root, causing specimens to be positioned in a vertical alignment during push-out bond testing. However, as stated by Pane et al.[69], the deviation of alignment could easily occur during the sectioning procedures, but the minor deviations from vertical alignment up to 10° appear to have little non-significant effect on the outcome of the push-out strength test.

Sealers adaptability was assessed in the literature by different techniques including stereomicroscopy, dye penetration, fluid filtration, electrochemical techniques and radiographs. SEM was used to evaluate the adaptability because it enables investigation of the root canal sealer adaptation to the radicular dentinal walls on the different levels of sectioning in a more accurate way than other techniques.[70,71]

The plungers used in the push out bond strength evaluation had a diameter of 0.8 mm, 0.6 mm, and 0.4 mm for the coronal, middle, and apical sections, respectively, because it is recommended that the plunger size be slightly smaller than the canal diameter to minimize interfacial sliding friction; however, it should not be so small that it punctures the filling material.[72] Pane et al.[69] stated that the bond strength was unaffected when the plunger size was in the 70-90% range. The plunger size was fabricated accurately to be within this range.

During push-out bond strength testing, the force was applied from the apical side of the dentin slice, so that the slight change in the canal shape would not cause any wedging of the material and the result should be accurate.

Within the limitations of this study, Well-Root ST showed significantly better adaptability and higher push-out bond strength than ADSEAL. The superior result of the calcium silicate-based sealer is probably due to its mechanism of bonding. As reported by studies, the strong alkaline effect of the sealer causes denaturation of the collagen fibers, thus allowing the infiltration of the mineral content of the sealer into the inter-tubular dentin, producing a mineral infiltration zone.[73,74] This, along with the hydration reaction of calcium silicate sealer, produces calcium hydroxide that reacts with phosphate, producing hydroxy apatite along the mineral infiltration zone that develops a chemical bond between calcium silicate-based materials and dentinal walls.[33,75]

Furthermore, as reported in many studies,[37,76] their excellent flowability is relative to epoxy resin-based sealers, which causes good dentinal wall distribution and deeper penetration of the sealer into the dentinal tubules for micromechanical interlocking.[65,77] A study showed that Well-Root ST has flowability that meets the ISO 6876:2012 standard, and it is higher than AH plus the epoxy resin-based sealer.[4]

Moreover, calcium silicate-based sealers were shown to be dimensionally stable with a slight expansion that leads to the formation of fewer gaps between the sealer and the root canal wall. In contrast, epoxy resin sealers undergo shrinkage that leads to disintegration of adaptation and de-bonding from the root canal wall.[76]

Additionally, calcium silicate-based sealers are hydrophilic and have a low contact angle, which enables the sealer to spread easily over the dentinal wall and penetrate into the tubules and irregularities of radicular dentine.[75]

The results of the current study are in agreement with other studies that stated that calcium silicate-based sealers had better adaptability and higher push-out bond strength than epoxy resin-based sealers.[59,65,70,78–80]

However, some studies showed that epoxy resin-based sealers are superior to bio-ceramic sealers in marginal adaptation[81,82] or push-out bond strength[12,23,48,55] and other studies found no difference between them.[19,27,46,77,83,84] The differences between these studies and the other previous studies may be related to the differences in methodology.

Regarding the effect of the obturation technique on adaptability, the CLC technique showed better adaptability than the SC technique, but the difference was not statistically significant. The non-significant difference in the technique effect on the adaptability of Well-Root ST can be justified by the high flow and dimensional stability of the calcium silicate-based sealer.[76] These results are in agreement with Eltair et al.[70], who stated that the single cone technique with bio-ceramic sealer showed similar results to CLC. Furthermore, other studies[84–86] found no difference between the SC technique and other techniques. However, Alsabawi et al.[71] showed that CLC had significantly better adaptation than SC. The non-significant difference in the technique effect on the adaptability of ADSEAL is probably because the evaluation was performed after two weeks, which may not be enough time for the shrinkage of the sealer to be significant, as some studies[76,87] have shown that epoxy resin sealers showed shrinkage after 30 days, and this result is in accordance with another study[88] that showed no statistically significant difference between the two techniques with an epoxy resin-based sealer.

The CLC technique showed significantly higher push-out bond strength than the SC technique. This result is probably because the SC technique resulted in an increase in the volume of sealer in irregular or oval canals, especially in the coronal and middle thirds. In contrast, applying accessory cones in the CLC technique results in reducing the sealer thickness,[56,89] that was in accordance with Mokhtari et al.[56] However, Nagas et al.[90] showed that the bond strength is higher with the SC technique than with the CLC technique. This discrepancy might be explained by differences in methodologies between the studies.

There was generally better adaptability and higher bond strengths in the middle and apical thirds than in the coronal third, and there was no significant difference between the middle and apical specimens. The higher values in the middle and apical specimens could be related to the higher lateral condensation forces for the CLC groups or as a result of the anatomical variations of dentine structure in these parts of the roots, where low densities of dentinal tubules are present. These results were in agreement with previous studies.[27,91,92]

CONCLUSION

Based on the present results, within the limitations of this in-vitro study, it can be concluded that:

1. The calcium silicate-based sealer is superior to the epoxy resin-based sealer in terms of push-out bond strength and adaptability.
2. The cold lateral compaction technique is superior to the single cone technique in terms of push-out bond strength.
3. Both cold lateral compaction technique and single cone technique showed similar results in terms of adaptability.
4. Adaptability and push-out bond strength are better in the middle and apical thirds of the root than in the coronal third, with no difference between the middle and apical thirds.

Future recommendations

1. Further studies assessing the long-term adaptability of the tested sealers with the SC technique are needed since the results of this study showed no significant difference between the two tested techniques.
2. Further studies assessing the solubility of Well-Root ST are needed as it is an important parameter in the long-term sealing ability.
3. Further studies assessing the biological properties of Well-Root ST are needed to better understand the effect of this sealer on periapical inflammation and healing.

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