Original Research
Endodontic Therapy

Root filling bond strength using reciprocating file-matched single-cones with different sealers

Carla Cristina Camilo ARAÚJO[a]
Manoel BRITO-JÚNIOR[a]
André Luís FARIA-E-SILVA[b]
Rodrigo Dantas PEREIRA[c]
Yara Terezinha SILVA-SOUSA[d]
Antônio Miranda CRUZ-FILHO[c]
Manoel Damião SOUSA-NETO[c]

[a]Universidade Estadual de Montes Claros – Unimontes, Department of Dentistry, State University of Montes Claros, Montes Claros, MG, Brazil.

[b]Universidade Federal de Sergipe – UFS, School of Dentistry, Department of Dentistry, Aracaju, SE, Brazil.

[c]Universidade de São Paulo – USP, School of Dentistry, Department of Restorative Dentistry, Ribeirão Preto, SP, Brazil.

[c]Universidade de Ribeirão Preto – UNAERP, School of Dentistry, Department of Dentistry, Ribeirão Preto, SP, Brazil.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Manoel Brito-Júnior
E-mail: manoelbritojr@gmail.com

DOI: 10.1590/1807-3107BOR-2016.vol30.0053

Submitted: Sep 23, 2015
Accepted for publication: Dec 02, 2015
Last revision: Feb 26, 2016

Abstract: The aim of the present study was to evaluate the bond strength (BS) of root canal fillings to root dentin using the reciprocating file-matched single-cone or lateral compaction techniques with resin-based and calcium-silicate-based sealers. Maxillary canine roots were prepared and filled using one of the following approaches: Reciproc R40 file and R40 single cone, WaveOne Large file and Large single cone, or ProTaper up to F4 file with lateral compaction. The root filling was performed using AH Plus, Epiphany SE or MTA Fillapex (n = 10). Three 1-mm-thick slices were obtained from each third of each root. Two slices were subjected to a push-out test, and the other slices were prepared for scanning electron microscopy (SEM) to examine the dentin-sealer interface. Data (in MPa) from the push-out tests were analyzed using a two-way ANOVA and Tukey's test ($p < 0.05$). Failure modes (adhesive, cohesive or mixed) were evaluated at ×25 magnification. The single-cone techniques resulted in lower BS values than the lateral compaction technique. For lateral compaction, AH Plus and Epiphany SE showed the highest and lowest BS values, respectively. Slight differences were observed between sealers when the single-cone techniques were used. A tendency to reduce the BS toward the apical third was observed. Adhesive failures were predominant for all experimental conditions. A closer adaption of the filling material on the root dentin was observed for the AH Plus and lateral compaction techniques. The Reciproc and WaveOne techniques were associated with lower BS values than the lateral compaction technique. However, the effect of the root canal filling technique appears to be sealer-dependent.

Keywords: Root Canal Filling Materials; Root Canal Obturation; Tensile Strength.

Introduction

The fluid-tight obturation of the root canal system following its chemomechanical debridement is an essential step for successful root canal treatment. For this purpose, an inert core filling material (Gutta-percha, GP) is widely used in conjunction with a root canal sealer (RCS).[1] Because of the GP's lack of adhesiveness, using an RCS is necessary to fill the irregularities between the GP and the root canal walls, thus reducing the interfacial gaps and consequently preventing leakage and contamination of the root canal space.[1,2]

Among the various types of RCS used during the filling procedure, AH Plus (Dentsply De Trey, Konstanz, Germany), an epoxy resin-based sealer, is considered the gold standard due to its low solubility,[3,4] long-term dimensional stability,[4] and suitable sealing and bonding proprieties.[5,6,7,8,9] Methacrylate resin-self-adhesive sealers such as Epiphany SE (Pentron Clinical Technologies, Wallingford, USA) and its successor RealSeal SE (Sybron Endo, Glendora, USA) were developed to improve the root filling bonding to the root dentin.[10] However, controversial results have been reported with respect to the adhesiveness of these sealers.[7,11,12] MTA Fillapex (Angelus, Londrina, Brazil) is a new calcium silicate-based sealer presenting low solubility and disintegration,[13] and good flow[3] and alkaline pH,[14] but it has a reduced bond strength when compared with AH Plus.[15,16]

In addition to RCS, the root filling technique also may affect the quality of the bonding between the filling mass and the root dentin. Currently, lateral compaction remains the most used technique for root canal filling.[17] This filling technique commonly uses .02 taper standard GP cones with the addition of further accessory GP cones in root canals prepared with either stainless steel or rotary nickel-titanium (NiTi) instruments.[17,18,19] Another approach is the single-cone technique, which uses larger master cones that closely match the geometry of the rotary NiTi files used during instrumentation, thereby facilitating the root canal filling in a simple and time-efficient way.[6,17] With the advent of single reciprocating NiTi instrumentation systems, such as Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland), the use of master GP cones with increased taper has been recommended because they match the size and taper of the reciprocating single file used during root canal preparation.[18] Nevertheless, limited information is available on the bond strength to root canal walls created using the matched-taper single cone techniques of reciprocating file systems.

Thus, the aim of the present study was to evaluate the bond strength of root canal filling to root dentin using single cones from the Reciproc and WaveOne systems associated with the AH Plus, Epiphany SE and MTA Fillapex sealers. The lateral compaction technique using .02 taper standard GP cones following canal preparation with rotary NiTi files[19] was used for comparison. The null hypothesis tested was that there is no difference in bond strength values among the root-filling techniques and materials used.

Methodology

Experimental design

This *ex vivo* investigation was performed using a 3 × 3 factorial study design to evaluate the factors "filling technique" in three levels (Reciproc, WaveOne and lateral compaction) and "sealer" in three levels (AH Plus, Epiphany SE and MTA Fillapex). The root third was included in the analysis as a sub-parcel. The bond strength of the root filling to the root dentin from maxillary canines was evaluated using the push-out test. This study was approved by the local Research Ethics Committee (CAAE no. 15278013.0.0000.5146).

Sample selection and preparation

Maxillary human canines stored in a 0.1% thymol solution for up to 6 months were used in this study. Teeth with carious lesions, root fractures and/or cracks (under ×25 magnification) were excluded. Ninety teeth were selected based on radiographs obtained in the mesiodistal and buccolingual directions after considering the similarity between root dimensions, unpronounced flattening, absence of curvature, calcification, resorption and open apex. The teeth were sectioned using a diamond disc (KG Sorensen, Barueri, Brazil) to obtain 15 mm of the remaining root, and the crown was discarded.

Root canal preparation

For the working length determination, a size 15 K-file (Dentsply Maillefer) was inserted into the canal and advanced until the file tip was flush with the apical foramen; 1 mm was subtracted from this measurement. The root canal instrumentation with the Reciproc and WaveOne systems was performed according to the manufacturers' recommendations by using an electric device (VDW Silver, VDW GmbH, Munich, Germany) to produce reciprocating motion. Reciproc R40 and WaveOne Large files were used. The instrumentations were performed with a progressive slight force in the apical direction and an outward circumferential brushing motion in 2–3 mm cycles until the working length was reached.[20] The root canals allocated to

the lateral compaction technique were instrumented using the ProTaper Universal rotary system (Dentsply Maillefer) until the F4 file. The SX file was used to prepare the coronal region, and the other files (S1, S2, F1, F2, F3 and F4) were used sequentially with 2-mm movements toward the apex until the working length was reached. Independent of the system used, the canals were irrigated using a 30-gauge needle (NaviTip, Ultradent Products, South Jordan, USA) with 2 mL of 2.5% sodium hypochlorite (NaOCl) prior to instrumentation, between the files (each cycle for reciprocating file systems) and after instrumentation. Reciprocation or rotary instruments were used to prepare four canals only.[20] Once the instrumentation was completed, the canals were irrigated with 5 mL of 17% ethylenediamine tetraacetic acid (EDTA) for 5 minutes. Next, the root canals were irrigated with 10 mL of distilled water to neutralize the residues of NaOCl and EDTA and dried with absorbent paper cones.

Root filling procedures

The root canal filling was performed using one of the following sealers (n = 10): AH Plus, Epiphany SE or MTA Fillapex. A single gutta-percha cone (Reciproc R40 or WaveOne Large) was used to fill the root canal for the Reciproc and WaveOne systems, whereas the cone was coated with a sealer and inserted into the root canal with circumferential movements until the working length was reached.[18] Next, the excess filling material was removed using a heated instrument. For the lateral compaction technique, the master gutta-percha standardized cone (40.02) (Dentsply Maillefer) was coated with a sealer and inserted into the root canal, which was similar to the procedure used for the single cones. Next, a size 30 finger spreader (Dentsply Maillefer) was used laterally to the master cone, followed by an insertion of accessory F cones (Dentsply Maillefer) until the root canal was filled completely. Because the Epiphany SE is a dual-cured sealer, light-curing (Ultralux, Dabi Atlante, Ribeirão Preto, Brazil) was performed at 5 mm from the specimen for 40 s when this sealer was used. In all techniques, radiographs were obtained to evaluate the quality of the root canal filling with regard to homogeneity and apical extension. All canal preparations and root-filling procedures were completed by the same operator.

Push-out testing

After storage (100% humidity, 37°C) for 24 hours, the roots were sectioned into nine 1-mm thickness slices (Figure 1A) using a precision cutting machine (IsoMet 1000, Buehler, Lake Forest, USA) at 350 rpm under water-cooling conditions. Two slices

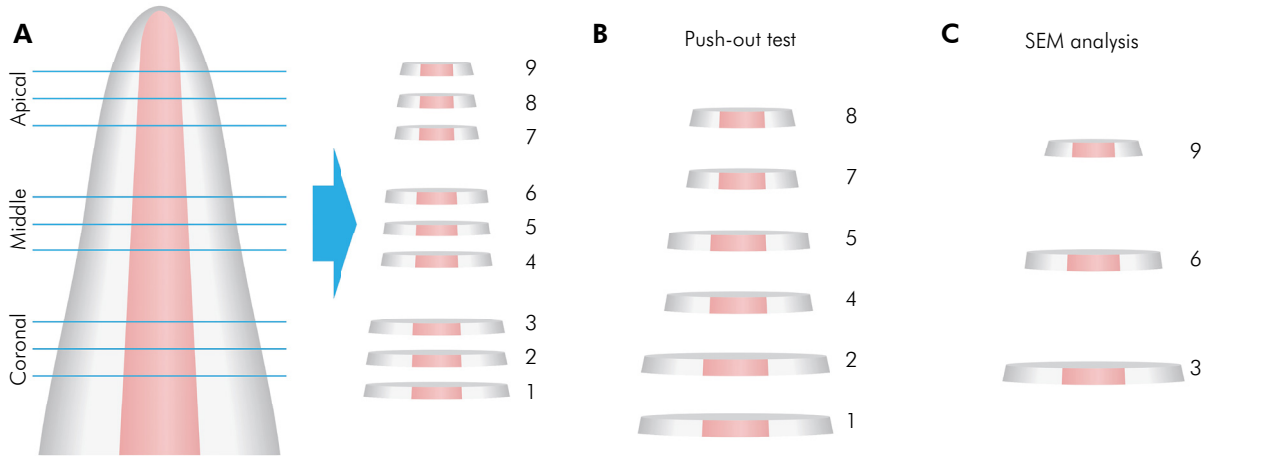


Figure 1. Schematic drawing of the collection and distribution of root slices. (A) Nine 1-mm-thick slices (3 per third) were obtained from each root sample. (B) The first and second slices in each root third were subjected to push-out tests. (C) The other slices in each root third were analyzed by SEM.

from each third were allocated to bond strength testing (Figure 1B). These slices were positioned on a push-out jig in a mechanical testing machine (Model 3344, Instron Engineering Corp., Canton, USA). The load was applied in an apical-coronal direction at a crosshead speed of 0.5 mm/min until the filling material was dislodged. Tips with diameters of 0.6, 0.4 and 0.25 mm were used to apply the load on specimens from the coronal, middle and apical thirds, respectively. The bond strength was converted into megapascals (MPa) by dividing the final load (N) by the bonding area of the filling material (SL) in each slice. SL (mm^2) was calculated using the equation $SL = \pi (R + r) g$, where SL = sealer bonding area; $\pi = 3.14$; R = mean radius of the coronal canal, in mm; r = mean radius of the apical canal, in mm; and g = height relative to the tapered inverted cone, in mm. After the push-out test, the specimens were analyzed by a single calibrated examiner using a stereomicroscope (ISM-PM200S, Insize Co., Ltd., Suzhou, China) at ×25 magnification to evaluate the failure modes (adhesive, cohesive and mixed) according to the displacement of the sealer from the specimen. Thus, adhesive failures were observed when the dentin surface was completely without a sealer, cohesive failures occurred within the filing material when the dentin surface was completely covered by the sealer, and mixed failures occurred when both adhesive and cohesive modes (dentin surface partially covered by the sealer) were verified.[11]

Scanning electron microscopy (SEM) analysis

The third slices obtained from the roots in each third (Figure 1C) were prepared for SEM analysis to qualitatively evaluate the adaptation of the sealer to the root canal dentin and bonding interface that was created. The slices were sequentially polished with SiC abrasive papers from #600 to #1200. The samples were rinsed with distilled water and demineralized with 6 M of HCl for 30 seconds. Deproteinization was performed by immersion in 10% NaOCl for 15 min, followed by dehydration of the samples in an ascending ethanol series (20%, 30%, 40%, 50%, 70%, 90% and 100% for at least 20 min per step) and immersion in hexamethyldisilazane (HMDS) for 10 minutes. After a gold coating process (MED 010, Bal-Tec AG, Balzers, Liechtenstein), each slice was initially visualized under SEM (JSM 5410 JEOL, Tokyo, Japan) at ×100 magnification. Using this first image, 12 evaluation points were determined at four equidistant areas selected along the interface (Figure 2) for analysis using higher magnification (×1,000).

Statistical analysis

A statistical analysis was performed using the SigmaStat v.3.5 statistical software package (Systat Software Inc., Chicago, USA). Data of bond strength were subjected to a two-way ANOVA, and the factors evaluated were "filling technique" and "sealer." To evaluate the effect of the root third on the bond strength, a two-factor split-plot design ANOVA analysis was performed that related the sub-parcel (root third) to "filling technique" and "sealer". All pairwise multiple comparison procedures were performed using Tukey's test. Data of failure modes were subjected to a chi-square test. The significance level was set at $\alpha = 0.05$ for all analyses.

Results

Two-way ANOVA showed a significant effect for "filling technique" ($p < 0.001$), "sealer" ($p < 0.001$) and

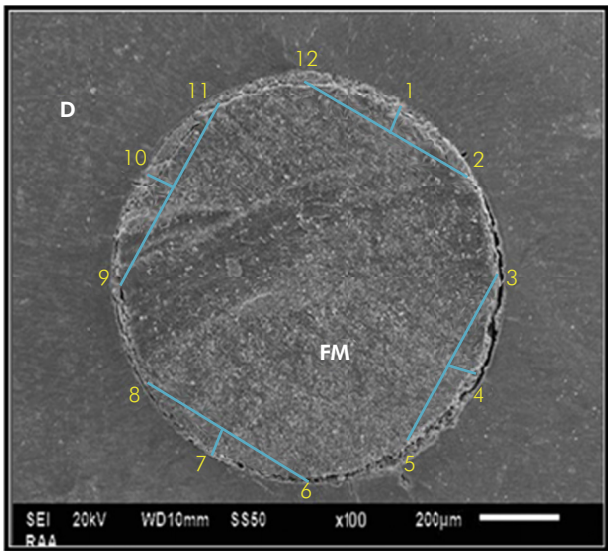


Figure 2. Assessing the presence of gaps on 12 points at the interface between dentin (D) and filling material (FM) using SEM imaging.

their interaction ($p < 0.001$). These results are shown in Table 1. For the lateral compaction technique, AH Plus and Epiphany SE showed the highest and lowest bond strengths, respectively. AH Plus and Epiphany SE showed similar values of bond strength when Reciproc was used, whereas MTA Fillapex presented the lowest values. No difference between sealers was observed when the root canal was filled using the WaveOne single-cone technique. With regard to the use of AH Plus and MTA Fillapex, the lateral compaction technique resulted in the highest values of bond strength, whereas Reciproc and WaveOne showed similar values. For Epiphany SE, Reciproc resulted in a higher bond strength than lateral compaction, whereas no difference was observed between WaveOne and the other filling techniques.

An analysis of the interaction between the filling technique and the root third (Table 2) revealed a significant effect for the "filling technique" ($p < 0.001$), sub-parcel "root third" ($p < 0.001$), and their interaction ($p = 0.012$). When the lateral compaction and WaveOne techniques were used, the apical third presented the lowest values of bond strength, whereas the coronal and middle thirds showed similar values. No difference between root thirds was observed for Reciproc. Independent of the root third, lateral compaction resulted in the highest bond strength. No difference was observed between Reciproc and WaveOne.

An analysis of the interaction between the sealer and root third (Table 3) revealed a significant effect for "sealer" ($p < 0.001$) and sub-parcel "root third" ($p < 0.001$), but not for the interaction between the factors ($p = 0.555$). Independent of the sealer, the apical third showed the lowest values of bond strength, whereas no difference was observed between the coronal and middle thirds. In all root thirds, AH Plus presented the highest values of bond strength, and Epiphany SE had the lowest values.

The results of the failure mode are displayed in Figure 3. A chi-square test showed that all factors significantly affected the failure mode. A predominance of adhesive failures for all experimental conditions was observed, followed by mixed failures. Reciproc showed fewer cohesive failures when compared to the other techniques, while lateral compaction resulted in more adhesive failures. Among the sealers, AH Plus showed the highest number of adhesive failures. Epiphany SE and MTA Fillapex showed similar results for the numbers of adhesive and mixed failures. The highest number of adhesive failures was observed in the apical root third.

Representative SEM micrographs of the gutta-percha/sealer/canal interfaces are shown in Figure 4. The AH Plus sealer showed a homogeneous layer of spherical-shaped fillers. Independent of the filling technique used, AH Plus showed proper adaptation to root dentin (Figures 4A, B, C). More tags were observed when lateral compaction was used, which resulted in the penetration of sealer into dentinal tubules (Figure 4A). The Epiphany SE sealer resulted in a non-homogeneous layer with several voids close to the gutta-percha cone and dentin

Table 1. Means (95%CI) of bond strength in MPa.

Filling Technique	Root canal sealer		
	AH Plus	Epiphany SE	MTA Fillapex
Reciproc	0.77^{Ab} (0.64–0.91)	0.80^{Aa} (0.71–0.89)	0.56^{Bb} (0.48–0.64)
WaveOne	0.67^{Ab} (0.58–0.77)	$0.67A^{ab}$ (0.59–0.76)	0.69^{Ab} (0.59–0.78)
Lateral compaction	2.42^{Aa} (2.13–2.70)	0.62^{Cb} (0.54–0.69)	1.71^{Ba} (1.52–1.90)

MPa: megapascal.
Distinct letters (uppercase for line, lowercase for row) indicate significant differences ($p < 0.05$).

Table 2. Results for filling techniques and root thirds (Means, 95%CI) in MPa.

Filling Technique	Root third		
	Coronal	Middle	Apical
Reciproc	0.73^{Ab} (0.58–0.88)	0.71^{Ab} (0.60–0.81)	0.69^{Ab} (0.63–0.76)
WaveOne	0.78^{Ab} (0.68–0.89)	0.67^{ABb} (0.58–0.76)	0.57^{Bb} (0.51–0.63)
Lateral compaction	1.85^{Aa} (1.46–2.24)	1.71^{Aa} (1.37–2.04)	1.19^{Ba} (0.94–1.43)

MPa: megapascal.
Distinct letters (uppercase for line, lowercase for row) indicate significant differences ($p < 0.05$).

Table 3. Results for root canal sealers and root thirds (Means, 95%CI) in MPa.

Root canal sealer	Root third			Pooled average
	Coronal	Middle	Apical	
AH Plus	1.52 (1.10–1.94)	1.32 (0.96–1.68)	1.01 (0.76–1.27)	1.28[A] (0.93–1.64)
Epiphany SE	0.78 (0.70–0.86)	0.74 (0.65–0.84)	0.56 (0.51–0.62)	0.70[C] (0.61–0.78)
MTA Fillapex	1.06 (0.78–1.34)	1.02 (0.76–1.28)	0.88 (0.76–1.00)	0.99[C] (0.75–1.22)
Pooled average	1.12a (0.81–1.43)	1.03a (0.75–1.30)	0.82b (0.64–1.00)	-

MPa: megapascal.
For pooled averages, distinct letters indicate significant differences ($\alpha = 0.05$).

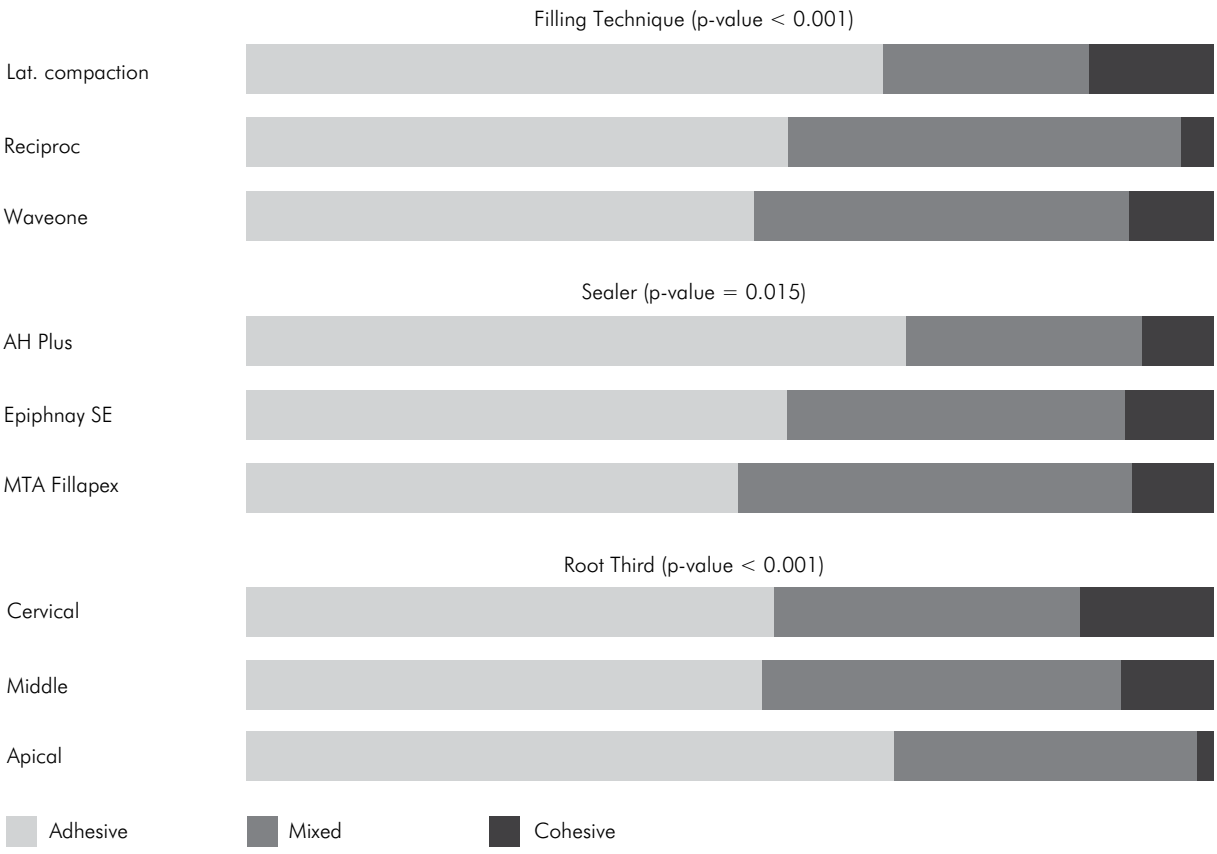
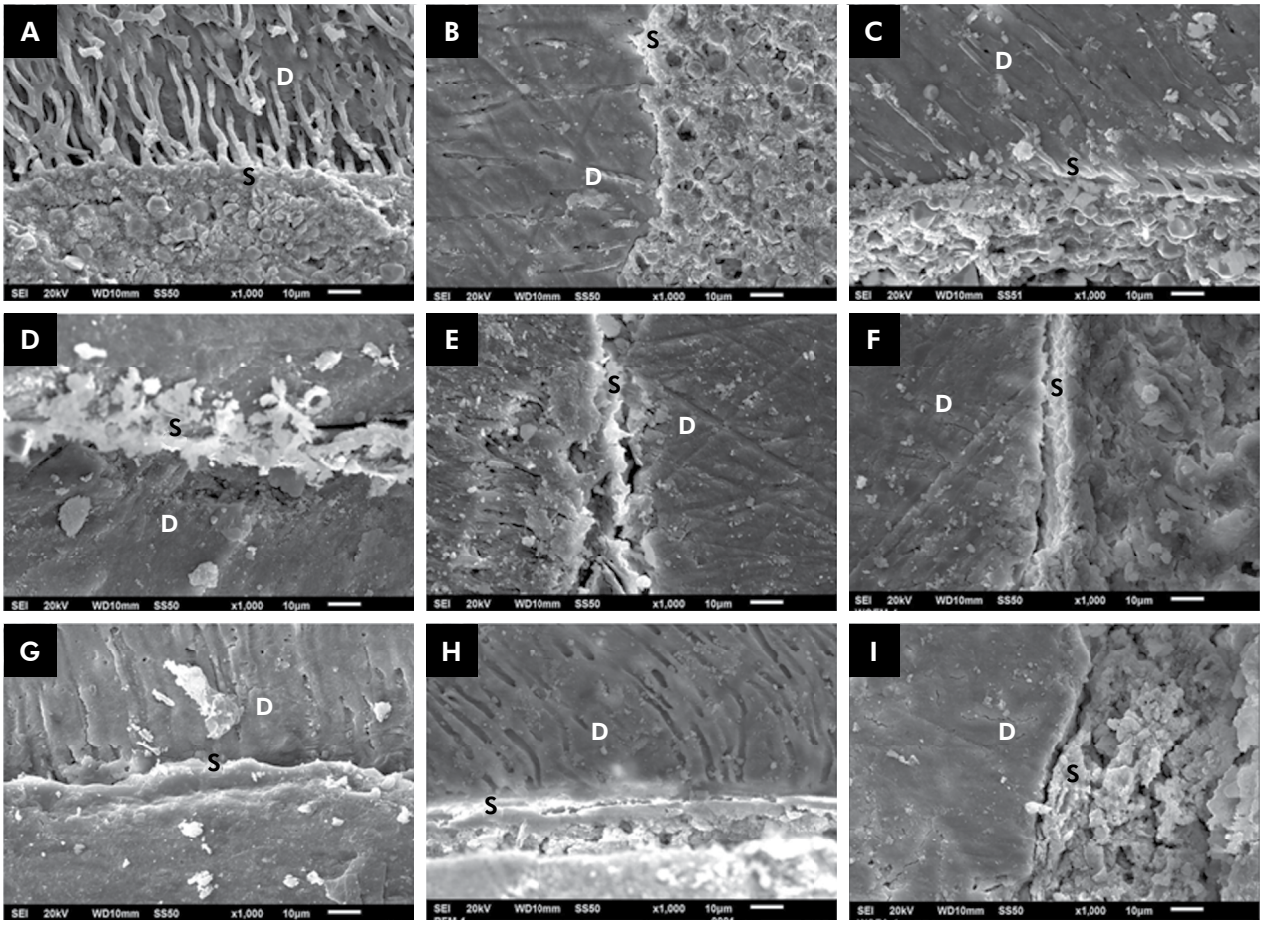


Figure 3. Results for analysis of failure modes. The p-value was obtained from the chi-square test.

when the lateral compaction technique was used (Figure 4D). When this sealer was combined with the Reciproc and WaveOne single-cone techniques, more gaps between the filling material and root canal walls resulted (Figure 4E, F). MTA Fillapex showed satisfactory interfacial adaptation with lateral compaction (Figure 4G). However, gaps in the interfaces with gutta-percha and/or dentin were observed for the Reciproc and WaveOne single-cone techniques (Figure 4H, I). This sealer presented a granular and irregular surface with a wide range of particle sizes.



D: Dentin; S: Sealer.

Figure 4. SEM images showing the bonding interfaces (×1,000) of filling materials with dentin. (A) Interface of AH Plus associated with the lateral compaction technique in the coronal third. Note the presence of several long tags. Root-filling produced in the middle third with AH Plus associated with Reciproc (B) and WaveOne (C), demonstrating a closer adaptation of the filling material to the dentin. Interfaces produced by Epiphany SE associated with lateral compaction (D), Reciproc (E) and WaveOne (F) in the coronal third (middle third at image 4f). Gaps were observed when this sealer was used, independent of the filling technique. Interfaces produced by MTA Fillapex with lateral compaction (G), Reciproc (H) and WaveOne (I) in the coronal, middle and apical thirds, respectively. Note the absence of tags and the presence of gaps that are mainly associated with single-cone techniques.

Discussion

Push-out bond strength evaluations have been extensively used to determine the effectiveness of sealers in retaining the filling materials within the root canal walls.[5,6,7,8,9] In the present study, the bond strength performance of single matched-taper gutta-percha cone techniques of reciprocating NiTi systems with different sealers was evaluated and compared with that of the lateral compaction technique. The results demonstrated that the bond strength of the filling material to the root canal is dependent on both the filling technique and the sealer. The highest bond strength values were observed when the lateral compaction technique was used. However, the filling material retention obtained using this technique was significantly reduced when the Epiphany SE sealer was used. Thus, the null hypothesis was rejected.

The use of single-cone techniques resulted in low bond strength values. Anatomical variations of the root canal often result in an insufficient adaptation of larger master cones to the root canal,[21,22] predominantly in the coronal and middle thirds, which present irregular morphologies.[23] Because the gutta-percha was not compacted against the dentin when using the single-cone techniques (it was only inserted until

the working length), this approach possibly resulted in reduced sustained pressure, which impaired the adaptation of the filling material to the canal walls.[22] The prevalence of adhesive failures observed in the coronal and middle thirds in the specimens filled using the Reciproc and WaveOne single-cone techniques supports this statement. Moreover, SEM analysis revealed various interfacial gaps when these filling techniques were used.

On the other hand, the use of a finger spreader to create space for the insertion of accessory cones might have resulted in significant compaction pressure over the sealer when the lateral compaction technique was used. The application of compaction pressure possibly resulted in better contact between the sealer and dentin.[24] Thus, a higher linear dislocation resistance and a consequent increase in bond strength are expected when lateral compaction is used.

Moreover, a higher compaction pressure during the root-filling procedures favors the reduction of voids in the sealer.[25] Voids can act as flaw-initiating sites during push-out testing, thereby reducing the values of bond strength. Finally, the use of accessory gutta-percha cones filled the irregularities in the root canal,[24] thereby reducing the thickness of the sealer layer and increasing retention.[11] The SEM analysis revealed a more homogeneous mass with few interfacial gaps for the lateral compaction technique, particularly with the AH Plus and MTA Fillapex sealers.

Interestingly, lateral compaction showed a lower bond strength than the Reciproc single-cone technique when the Epiphany SE sealer was used. Root canal sealers commonly exhibit thixotropic behavior, whereas their viscosity is reduced (increasing flow) under increased pressure. A recent study[26] evaluating the rheological properties of root canal sealers demonstrated a reduction in the viscosity of the AH Plus sealer at a constant shear rate with time (thixotropic behavior). Conversely, the Epiphany SE sealer presented an increase in viscosity with time (rheopexic behavior).[26] On the basis of these properties, it may be assumed that, there will be a reduction of the flowing ability of the Epiphany SE when subjected to higher pressure during the lateral compaction technique, which is in contrast to the other sealers evaluated. The findings of the present study confirm this assumption, with Epiphany SE presenting the lowest bond strength when associated with the lateral compaction technique (not significantly different from WaveOne). Despite the significant differences observed between the filling techniques when Epiphany SE was used, all bond strength values were low, and only slight differences were observed.

The bond strengths in the root thirds were also measured in the present study, and their relationships with the sealers and filling techniques were evaluated. The apical third showed the lowest values of bond strength, independent of whichever sealer was used. A reduction in bond strength in the apical region has been described in several studies evaluating bonding procedures on root canal dentin.[9,11] The reduction in the amount and diameter of the dentinal tubules in the more apical portions of the root canals[27] has been shown to be correlated to reduced bond strength values in these areas. Moreover, the limited accessibility of apical areas to the irrigating solutions to deplete the smear layer impairs the penetration of sealers into the dentinal tubules and reduces the contact between the filling material and the root dentin walls.[28,29] This is supported by the prevalence of adhesive failures at the sealer/dentin interface in the apical third for all experimental procedures in this study. An analysis of the root third and filling technique revealed the same tendency of bond strength reduction towards the apical third, except when the Reciproc single-cone technique was employed. Considering that both the Reciproc and WaveOne single-cone techniques produced similar root canal fillings, differences in the amount of the apical debris produced can explain these results.[30]

Although this study demonstrated a better bonding behavior of the lateral compaction technique compared to the single-cone techniques, particularly with the AH Plus and MTA Fillapex sealers, translating the results from laboratory studies to the clinical setting is not always an easy task. Clinical outcomes involve several factors that can overcome the root canal filling retention values obtained in *in vitro* evaluations. It has been claimed

that push-out bond experimental models are limited to only ranking the filling materials/techniques and that they are not guidelines for clinical decision-making.[31] However, push-out tests can contribute to the understanding of the retention characteristics of specific filling materials on root canal dentin, as verified in the present study.

Conclusions

In general, the Reciproc and WaveOne single-cone techniques were associated with lower bond strength values of the filling materials to the root canal dentin than those of the lateral compaction technique. However, the effect of the root canal filling technique appears to be sealer-dependent.

References

1. Ørstavik D. Materials used for root canal obturation: technical, biological and clinical testing. Endod Topics. 2005;12(1):25-38. doi:10.1111/j.1601-1546.2005.00197.x
2. Li GH, Niu LN, Zhang W, Olsen M, De-Deus G, Eid AA, et al. Ability of new obturation materials to improve the seal of the root canal system: a review. Acta Biomater. 2014;10(3):1050-63. doi:10.1016/j.actbio.2013.11.015
3. Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Physical properties of 5 root canal sealers. J Endod. 2013;39(10):1281-6. doi:10.1016/j.joen.2013.06.012
4. Borges RP, Sousa-Neto MD, Versiani MA, Rached-Júnior FA, De-Deus G, Miranda CE, et al. Changes in the surface of four calcium silicate-containing endodontic materials and an epoxy resin-based sealer after a solubility test. Int Endod J. 2012;45(5):419-28. doi:10.1111/j.1365-2591.2011.01992.x
5. Guiotti FA, Kuga MC, Duarte MA, Sant'Anna AJ, Faria G. Effect of calcium hydroxide dressing on push-out bond strength of endodontic sealers to root canal dentin. Braz Oral Res. 2014;28(1):1-6. doi:10.1590/S1806-83242014.50000002
6. Nagas E, Altundasar E, Serper A. The effect of master point taper on bond strength and apical sealing ability of different root canal sealers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107(1):e61-4. doi:10.1016/j.tripleo.2008.09.020
7. Mahdi AA, Bolaños-Carmona V, Gonzalez-Lopez S. Bond strength to root dentin and fluid filtration test of AH Plus/gutta-percha, EndoREZ and RealSeal systems. J Appl Oral Sci. 2013;21(4):369-75. doi:10.1590/1678-775720130114
8. Fisher MA, Berzins DW, Bahcall JK. An in vitro comparison of bond strength of various obturation materials to root canal dentin using a push-out test design. J Endod. 2007;33(7):856-8. doi:10.1016/j.joen.2007.02.011
9. Neelakantan P, Subbarao C, Subbarao CV, De-Deus G, Zehnder M. The impact of root dentine conditioning on sealing ability and push-out bond strength of an epoxy resin root canal sealer. Int Endod J. 2011;44(6):491-8. doi:10.1111/j.1365-2591.2010.01848.x
10. Pameijer CH, Zmener O. Resin materials for root canal obturation. Dent Clin North Am. 2010;54(2):325-44. doi:10.1016/j.cden.2009.12.004
11. Carneiro SM, Sousa-Neto MD, Rached-Júnior FA, Miranda CE, Silva SR, Silva-Sousa YT. Push-out strength of root fillings with or without thermomechanical compaction. Int Endod J. 2012;45(9):821-8. doi:10.1111/j.1365-2591.2012.02039.x
12. Nagas E, Cehreli Z, Uyanik MO, Durmaz V. Bond strength of a calcium silicate-based sealer tested in bulk or with different main core materials. Braz Oral Res. 2014;28(1):1-7. doi:10.1590/1807-3107BOR-2014.vol28.0046
13. Vitti RP, Prati C, Silva EJNL, Sinhoreti MAC, Zanchi CH, Silva MGS, et al. Physical properties of MTA Fillapex sealer. J Endod. 2013;39(7):915-8. doi:10.1016/j.joen.2013.04.015
14. Silva EJ, Rosa TP, Herrera DR, Jacinto RC, Gomes BP, Zaia AA. Evaluation of cytotoxicity and physicochemical properties of calcium silicate-based endodontic sealer MTA Fillapex. J Endod. 2013;39(2):274-7. doi:10.1016/j.joen.2012.06.030
15. Nagas E, Uyanik MO, Eymirli A, Cehreli ZC, Vallittu PK, Lassila LV, et al. Dentin moisture conditions affect the adhesion of root canal sealers. J Endod. 2012;38(2):240-4. doi:10.1016/j.joen.2011.09.027
16. Sagsen B, Ustün Y, Demirbuga S, Pala K. Push-out bond strength of two new calcium silicate-based endodontic sealers to root canal dentine. Int Endod J. 2011;44(12):1088-91. doi:10.1111/j.1365-2591.2011.01925.x
17. Gordon MPJ, Love RM, Chandler NP. An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals. Int Endod J. 2005;38(2):87-96. doi:10.1111/j.1365-2591.2004.00903.x
18. Schäfer E, Köster M, Bürklein S. Percentage of gutta-percha-filled areas in canals instrumented with nickel-titanium systems and obturated with matching single cones. J Endod. 2013;39(7):924-8. doi:10.1016/j.joen.2013.04.001
19. Koçak MM, Darendeliler-Yaman S. Sealing ability of lateral compaction and tapered single cone gutta-percha techniques in root canals prepared with stainless steel and rotary nickel titanium instruments. J Clin Exp Dent. 2012;4(3):e156-9. doi:10.4317/jced.50752.eCollection 2012
20. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J. 2012;45(5):449-61. doi:10.1111/j.1365-2591.2011.01996.x
21. Monticelli F, Sword J, Martin RL, Schuster GS, Weller RN, Ferrari M, et al. Sealing properties of two contemporary

single-cone obturation systems. Int Endod J. 2007;40(5):374-85. doi:10.1111/j.1365-2591.2007.01231.x

22. Robberecht L, Colard T, Claisse-Crinquette A. Qualitative evaluation of two endodontic obturation techniques: tapered single-cone method versus warm vertical condensation and injection system: an in vitro study. J Oral Sci. 2012;54(1):99-104. doi:10.2334/josnusd.54.99
23. Wu MK, Wesselink PR. A primary observation on the preparation and obturation of oval canals. Int Endod J. 2001;34(2):137-41. doi:10.1046/j.1365-2591.2001.00361.x
24. Rossetto DB, Fernandes SL, Cavenago BC, Duarte MA, Ordinola-Zapata R, de Andrade FB. Influence of the method in root canal filling using active lateral compaction techniques. Braz Dent J. 2014;25(4):295-301. doi:10.1590/0103-6440201302224
25. Wu MK, Ozok AR, Wesselink PR. Sealer distribution in root canals obturated by three techniques. Int Endod J. 2000;33(4):340-5. doi:10.1046/j.1365-2591.2000.00309.x
26. Khedmat S, Momen-Heravi F, Pishvaei M. Rheological properties of endodontic sealers: the effect of time, temperature, and composition. Iran Polym J. 2012;21(7):445-50. doi:10.1007/s13726-012-0047-9
27. Mjör IA, Smith MR, Ferrari M, Mannocci F. The structure of dentine in the apical region of human teeth. Int Endod J. 2001;34(5):346-53. doi:10.1046/j.1365-2591.2001.00393.x
28. Prado M, Simão RA, Gomes BP. Effect of different irrigation protocols on resin sealer bond strength to dentin. J Endod. 2013;39(5):689-92. doi:10.1016/j.joen.2012.12.009
29. Tuncel B, Nagas E, Cehreli Z, Uyanik O, Vallittu P, Lassila L. Effect of endodontic chelating solutions on the bond strength of endodontic sealers. Braz Oral Res. 2015;29(1):1-6. doi:10.1590/1807-3107BOR-2015.vol29.0059
30. De-Deus G, Marins J, Silva EJ, Souza E, Belladonna FG, Reis C, et al. Accumulated hard tissue debris produced during reciprocating and rotary nickel-titanium canal preparation. J Endod. 2015;41(5):676-81. doi:10.1016/j.joen.2014.11.028
31. De-Deus G, Souza E, Versiani M. Methodological considerations on push-out tests in Endodontics. Int Endod. J 2015;48(5):501-3. doi:10.1111/iej.12445