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Coronal And Apical Leakage Among Five Endodontic Sealers

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Original article

Coronal and apical leakage among five endodontic sealers

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Abstract

Purpose: The aim of this study was to use dye penetration to measure apical and coronal leakage simultaneously in single-canal teeth that had been treated endodontically using a single-cone obturation technique.

Methods: One hundred single-canal, extracted human teeth were cleaned and shaped with ProTaper NEXT rotary files to size-X5 (50/.06), then randomly assigned to five sealer groups for single-cone gutta-percha obturation. The teeth were soaked in 0.6% rhodamine B at 37°C for seven days, then the roots were ground mesiodistally and the maximum apical and coronal dye penetration was measured. Differences in leakage among the sealer groups were examined using the Kruskal-Wallis test. Pairwise comparisons were made using the Mann-Whitney test with Bonferroni correction.

Results: The mean values (mm) of dye penetration for AH Plus, Pulp Canal Sealer, NeoSEALER Flo, EndoSequence BC, and Super-Bond RC Sealer were 0.200, 0.300, 0.675, 0.850, and 0.900 apically, whereas 1.675, 2.075, 4.800, 6.500, and 4.125 coronally. Pairwise comparisons showed significant apical differences between AH Plus/Super-Bond RC Sealer (P = 0.047) and significant coronal differences between AH Plus/NeoSEALER Flo (P = 0.001), AH Plus/EndoSequence BC (P < 0.01), AH Plus/Super-Bond RC Sealer (P < 0.01), Pulp Canal Sealer/NeoSEALER Flo (P = 0.010), Pulp Canal Sealer/EndoSequence BC (P < 0.01), and Pulp Canal Sealer/Super-Bond RC Sealer (P < 0.01).

Conclusion: Coronal leakage was worse than apical leakage for all sealers. AH Plus exhibited the least leakage apically and coronally; Super-Bond RC Sealer showed the most leakage apically, and EndoSequence BC showed the most leakage coronally.

Keywords: endodontic sealers, epoxy resin, methacrylate resin, sealing ability, tricalcium silicate

Introduction

The goal of endodontic obturation is to completely fill the canal system to prevent microbial reinfection after non-surgical root canal treatment (NSRCT) [1,2]. Leakage is the primary cause of NSRCT failure [3,4], in which fluid containing microorganisms seeps between the endodontic sealer and the obturated canal wall, apically or coronally [1,5,6]. The sealer should completely fill any gaps between the gutta-percha points and dentin, as well as the main, lateral, and accessory canals, to prevent ingress of microorganisms that can cause infection [2,7,8].

Endodontic sealers are categorized on the basis of their setting reactions and composition [2]. Epoxy resin-based sealers set through an addition-polymerization reaction [2], and AH Plus (Dentsply Sirona, Charlotte, NC, USA) is often used as the gold standard in this sealer category [9]. Zinc oxide-eugenol sealers form an amorphous gel of zinc eugenolate [2]. Tricalcium silicate-based sealers react with water with concomitant formation of hydroxyapatite at the surface within the canals [2,10]. Methyl methacrylate sealers with tri-*n*-butylborane (MMA-TBB) initiate polymerization at the dentin interface [2,7]. Several studies have evaluated the effectiveness of endodontic sealers for minimizing leakage in either the apical or coronal direction [5,11-13]. Both apical and coronal seals are critical for the clinical success of NSRCT [6,14]. Prevention of apical leakage is important because viable bacteria remaining after chemical-mechanical preparation can cause periapical tissue irritation [6,14]. Prevention of coronal leakage is important because canals may become re-contaminated after loss of coronal sealing or fracture of the remnant tooth [6,14,15]. However, previous findings have suggested that the root canal system is not completely sealed [2,5,8,11-13].

The obturation technique selected can affect the degree of sealing [16,17] and clinical outcomes [18,19]. The obturation techniques commonly employed in North America are cold lateral condensation, carrier-based, warm vertical, and single-cone techniques [20]. The single-cone technique using matched-taper gutta-percha points with NiTi instruments, especially with tricalcium silicate cement sealers, is the simplest and most accepted method [21-23]. Oliver et al. [1] examined apical and coronal leakage simultaneously using the dye penetration technique, but the obturation technique employed was lateral condensation, and not single-cone. The dye penetration test is used most widely for assessing apical and coronal leakage [14], and Schafer and Olthoff [24] have stated that this test provides sufficient data about apical leakage. However, both apical and coronal leakage has not been examined simultaneously after a single-cone obturation technique.

The aim of the present study was to investigate the effectiveness of five sealers for singe-cone obturation: epoxy resin (AH Plus), zinc oxide-eugenol (Pulp Canal Sealer; Kerr, Brea, CA, USA), two tricalcium silicate sealers (EndoSequence BC; Brasseler, Savannah, GA, USA, and NeoSEALER Flo; Avalon Biomed, Houston, TX, USA), and MMA-TBB resin (Super-Bond RC Sealer; Sun Medical, Moriyama, Japan). Apical and coronal leakage was compared simultaneously *in vitro* using the dye penetration technique in single-canal teeth endodontically treated using single-cone obturation with the five endodontic sealers.

Materials and Methods

Materials

The five endodontic sealers used are listed in Table 1 along with their compositions, working time, setting time, and radiopacity [2,9,25-27].

Extracted human teeth

Ethical approval was obtained from the Ethics Committee at the University of New England (IRB: Not Human Subject Research #19.11.12-006) to use one hundred permanent, human, single-rooted maxillary or mandibular premolars and canines. Preoperative digital radiographs were taken (Schick 33 Intraoral sensor, Dentsply Sirona), then a high-speed diamond bur was used to remove the coronal segment at the cemento-enamel junction to standardize the root length to 16 mm using digital calipers.

Root canal preparation

Access to the root pulp canal was gained using a bur, and a 15-mm working length was established (1 mm short of the apical foramen) using a size 10 K file (Dentsply Sirona). Canal patency was verified by extending a #10 K file 1 mm past the anatomical apex. Canals were cleaned and shaped with ProTaper NEXT NiTi rotary files (Dentsply Sirona) successively using the five instruments, X1 to X5 (#50/variable taper, 6% taper with a 3-mm tip), employing a ProMark torque-limited electric motor (Dentsply

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Table 1 Endodontic sealers evaluated

Group	Chemical Matrix	Product Name (Manufacturer, city, country)	Component	Composition	Lot #	Working Time	Setting Time	Radiopacity (mm Al)
1	Epoxy resin	AH Plus (Dentsply Sirona, Charlotte, NC, USA)	Paste A	bisphenol A epoxy resin, zirconia, bisphenol F epoxy resin, calcium tungstate, iron oxide, silica	2008000860	4 h	8.3 h	10.0
			Paste B	*N*,*N*-dibenzyl-5-oxanonadiamin-1,9, amantiameamine, tricyclodecane-diamine, calcium tungstate, zirconia				
2	Zinc oxide-eugenol	Pulp Canal Sealer (Kerr, Brea, CA, USA)	Powder	zinc oxide, precipitated silver, oleo resin, thymol iodide	7756227	7.5 h	26.3 h	8.0
			Liquid	oil of cloves, Canada balsam	7777900			
3	Tricalcium silicate	NeoSEALER Flo (Avalon Biomed, Houston, TX, USA	Single Paste	calcium silicate &calcium aluminate cements, tantalum oxide, organic liquid	2020112401	>1 h †	24 h †	6.0 †
4	Tricalcium silicate	EndoSequence BC (Brasseler, Savannah, GA, USA)	Single Paste	zirconia, calcium silicate cement, calcium phosphate, calcium hydroxide, filler, thickening agents	17003SP	>24 h	2.7 h*	6.7
5	Methacrylate resin	Super-Bond RC Sealer (Sun Medical, Moriyama, Japan)	Powder	zirconia, polymethyl methacrylate (PMMA)	VM1	6 min †	42 min †	4.7 †
			Liquid	methyl methacrylate (MMA), 4-methacryloxyethyl trimellitate anhydride (4-META)	VV2			
			Catalyst	tri-*n*-butylborane (TBB), hexane, ethanol	VV11			

*In a water bath at 37°C; †Manufacturer's data

Sirona). Canals were irrigated with 2 mL of 2.5% sodium hypochlorite (NaOCl) at each instrument change through a 27-G needle (Ultradent Inc., South Jordan, UT, USA). Final irrigation was performed with 5 mL of 17% EDTA for 1 min, followed by 5 mL of 2.5% NaOCl. The canals were dried with ProTaper NEXT absorbent points (Dentsply Sirona).

Inter-group homogeneity of variance in the area of cleaned and shaped canals before root canal filling

All prepared roots were radiographed, and Image J software (National Institute of Health, Bethesda, MD, USA) was used to measure the area in mm^2 shown in each radiograph of a cleaned and shaped canal. The 100 roots were randomly divided into five groups of 20.

Single-cone root canal filling with a gutta-percha point and sealer

Each root was fitted with a ProTaper NEXT variable-taper X5 gutta-percha point (Dentsply Sirona) matched to the last instrument used, size X5. Next, each root was obturated with one of the five following sealers: Pulp Canal Sealer, AH Plus, EndoSequence BC, NeoSEALER Flo, or Super-Bond RC Sealer. The AH Plus and Pulp Canal Sealer were mixed; the tricalcium silicate sealers did not require mixing. In the AH Plus and Pulp Canal Sealer groups, the gutta-percha points were buttered. For EndoSequence BC and NeoSEALER Flo, the dispensing tip of each kit was used to place the sealer into the apical area of the canal. For the Super-Bond RC Sealer groups, the manufacturer's instructions for use were followed: (1) Accel (aromatic sulfinate solution) was applied to the root canal dentin and dried, (2) Green Activator (10:3 citric acid/ ferric chloride solution) was applied to the root canal dentin, water-rinsed and dried, (3) the sealer mixture (three components described in Table 1) was prepared, and (4) the canal was filled with the sealer mixture and a gutta-percha point inserted. For all groups, the gutta-percha point was inserted in the canal to the working length. Excess gutta-percha was cut at the orifice with a heated Calamus Pack heat carrier system (Dentsply Sirona) and vertically condensed with an endodontic plugger. Radiographs were taken mesiobuccally and buccolingually to confirm the fit of the gutta-percha and sealer and completeness of obturation. The obturated teeth were placed in phosphate-buffered saline (PBS) solution (VWR, Radnor, PA, USA) at 37°C for 30 h until all sealers were set.

Dye penetration test

After 30 h, the obturated roots were air-dried and coated with nail polish except for 2 mm around the coronal access and the apex. After the nail polish had dried, the obturated teeth were placed in 0.6% rhodamine B solution (Thermo Fisher Scientific, Ward Hill, MA, USA) at 37°C for seven days, after which they were removed, washed with tap water for 30 s, and air-dried. The roots were ground longitudinally (mesiodistally) with 220, then 800 grit abrasive papers until the gutta-percha and dye were visible both coronally and apically. Images of each root were taken using an ELPH 350 HS digital camera (Canon, Tokyo, Japan), including a millimeter ruler and the number label. Image J software was used to measure the maximum linear dye penetration along the coronal and apical boundaries of the teeth between the filling materials and dentin wall.

Table 2 The area of each cleaned and shaped canal in the five groups

Group	Mean (mm^2)	Standard deviation
AH Plus	18.0	5.7
Pulp Canal Sealer	18.3	5.6
NeoSEALER Flo	18.5	5.7
EndoSequence BC	18.8	5.8
Super-Bond RC Sealer	19.2	5.6
Average	18.6	5.8

Twenty samples in five groups; 100 total. No significant difference among the five groups ($P > 0.05$)

Statistical analysis for inter-group homogeneity of variance in the area of cleaned and shaped canals before root canal filling

Descriptive statistics were computed to measure the area in mm^2 shown in each radiograph of a cleaned and shaped canal. The 100 roots were randomly assigned to five groups of 20. Mean and the standard deviation were calculated for each group. Levene's test was used to determine whether homogeneity of variance among the groups was satisfied.

Statistical analysis for the dye penetration test

Descriptive statistics were computed for dye penetration in the coronal and apical areas of all teeth assigned to the five groups. The Shapiro-Wilk test was conducted to examine data distribution, and this indicated that the data did not exhibit a normal distribution. Therefore, the Kruskal-Wallis test was conducted to examine whether there were significant differences in apical leakage among the sealer groups, as indicated by dye penetration.

Pairwise comparisons were conducted using the Mann-Whitney test with Bonferroni correction to identify which pairs of sealers showed a statistically significant difference.

SPSS (version 27.0, IBM SPSS Inc, Chicago, IL, USA) was used to process and analyze the data. The level of significance was set at $\alpha = 0.05$.

Results

Table 2 displays the mean and standard deviation of the area (mm^2) of each cleaned and shaped canal for the five groups. Levene's test showed no statistical significance ($P > 0.05$); that is, the areas of the cleaned and shaped canals showed equality of variance among the five groups.

Table 3 displays the mean, median, and interquartile values of apical and coronal dye penetration among the five sealer groups. The Shapiro-Wilk test, visual inspection of the histograms, normal Q-Q plots, and box plots showed that the values did not have a normal distribution. Skewness was 2.745 (SE = 0.512), 1.845 (SE = 0.512), 0.634 (SE = 0.512), 0.756 (SE = 0.512), and 1.572 (SE = 0.512) for apical dye penetration, whereas 0.005 (SE = 0.512), 0.678 (SE = 0.512), −0.171 (SE = 0.512), 1.054 (SE = 0.512), and 0.353 (SE = 0.512) for coronal dye penetration in the AH Plus, Pulp Canal Sealer, NeoSEALER Flo, EndoSequence BC, and Super-Bond RC Sealer groups, respectively. The corresponding values for kurtosis

Table 3 The mean, median, and interquartile range of apical and coronal dye penetration among the five sealer groups

Group	Apical			Coronal		
	Mean (mm)	Median (mm)	Interquartile range	Mean (mm)	Median (mm)	Interquartile range
AH Plus	0.200	0.000	0.00	1.675	2.000	1.00
Pulp Canal Sealer	0.300	0.000	0.75	2.075	2.000	1.25
NeoSEALER Flo	0.675	0.000	2.00	4.800	5.000	2.38
EndoSequence BC	0.850	1.000	1.75	6.500	6.000	1.75
Super-Bond RC Sealer	0.900	0.500	1.38	4.125	4.000	2.75

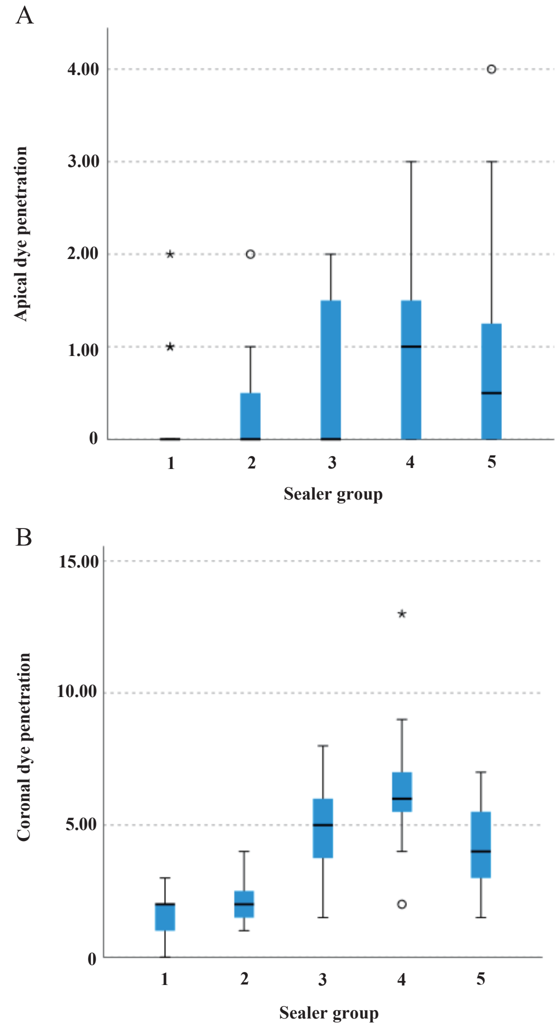

Fig. 1 Box and whisker plot of apical (A) and coronal (B) dye penetration. The plot illustrates a summary of A and B dye penetration based on the median, quartiles, and extreme values. The box represents the inter-quartile range which contains 50% of the values, the whiskers represent the highest and lowest dye penetration values, circles denote outliers, and the bold black line across the box indicates the median dye penetration. (Sealer group: 1. AH Plus, 2. Pulp Canal Sealer, 3. NeoSEALER Flo, 4. EndoSequence BC, and 5. Super-Bond RC Sealer)

were 7.401 (SE = 0.992), 2.861 (SE = 0.992), −1.565 (SE = 0.992), −0.391 (SE = 0.992), and 2.205 (SE = 0.992) for apical dye penetration, whereas −0.859 (SE = 0.992), 0.052 (SE = 0.992), −0.536 (SE = 0.992), 3.793 (SE = 0.992), and −0.610 (SE = 0.992) for coronal dye penetration, respectively. Therefore, the Kruskal-Wallis test (a nonparametric test) was used instead of the ANOVA test (a parametric test).

The Kruskal-Wallis test demonstrated significant differences (Apical: $P = 0.014$ and Coronal: $P < 0.01$). Figure 1 shows box and whisker plots of apical and coronal dye penetrations, respectively. The plots provide a summary of dye penetration based on the median, quartile, and extreme values. The box represents the inter-quartile range containing 50% of the values. The whiskers represent the highest and lowest dye penetration values, the circles denote outliers, and the bold black line across the box indicates the median dye penetration.

Because the Kruskal-Wallis test demonstrated significant differences, the Mann-Whitney test with Bonferroni correction was conducted to identify which pairs of sealers showed statistically significant differences (Table 4). AH Plus and Super-Bond RC Sealer showed a significant difference in apical leakage ($P = 0.047$), and AH Plus and NeoSEALER Flo ($P = 0.001$), AH Plus and EndoSequence BC ($P < 0.01$), AH Plus and Super-Bond RC Sealer ($P < 0.01$), Pulp Canal Sealer, and NeoSEALER Flo ($P = 0.010$), Pulp Canal Sealer and EndoSequence BC ($P < 0.01$), and Pulp Canal Sealer and Super-Bond RC Sealer ($P < 0.01$) showed significant differences in coronal leakage.

Table 4 Pairwise comparisons of sealer groups

Pair	Adjusted significance	
	Apical	Coronal
AH Plus - Pulp Canal Sealer	1.000	1.000
AH Plus - NeoSEALER Flo	0.647	0.001*
AH Plus - EndoSequence BC	0.090	<0.0001*
AH Plus - Super-Bond RC Sealer	0.047*	<0.0001*
Pulp Canal Sealer - NeoSEALER Flo	1.000	0.010*
Pulp Canal Sealer - EndoSequence BC	0.373	<0.0001*
Pulp Canal Sealer - Super-Bond RC Sealer	0.219	<0.0001*
NeoSEALER Flo - EndoSequence BC	1.000	1.000
NeoSEALER Flo - Super-Bond RC Sealer	1.000	0.101
EndoSequence BC - Super-Bond RC Sealer	1.000	0.811

*Statistically significant. The significance level is 0.050. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Discussion

In the present study, dye penetration showed no connection between apical and coronal leakage in any of the samples. AH Plus showed the least leakage at both the coronal and apical ends, and had the lowest apical leakage among the five endodontic sealers studied, in agreement with the apical sealing ability of AH Plus reported by Siqueira et al. [28]. Although AH Plus shrinks during polymerization [25,27,29], thus increasing the risk of leakage [2], in the present study AH Plus showed less leakage than zinc oxide eugenol (ZOE) sealer when single-cone obturation was employed. A previous study using single-cone obturation to compare epoxy resin, glass ionomer, and ZOE sealers indicated that the epoxy resin AH 26 had the lowest apical and coronal leakage [22]. In another study using cold lateral condensation obturation, the apical sealing ability of epoxy resin sealers was also superior to those of the ZOE type [28]. AH Plus is able to penetrate into dentin tubules due to its fine particles and resin composition [30].

EndoSequence BC and NeoSEALER Flo are tricalcium silicate-based sealers, and these demonstrated greater leakage than AH Plus and Pulp Canal Sealers in both the apical and coronal directions. Although in the present study samples were soaked in the dye for seven days rather than ninety days, this result agrees with Dioguardi et al. [31] that the sealing abilities of epoxy resin-based sealer were better than those of tricalcium silicate-based sealer for observation periods longer than ninety days. The setting mechanism of tricalcium silicate-based sealers is water absorption from dentin tubules with concomitant formation of hydroxyapatite at the surface within the canals [10]. In the present study, to avoid errors due to insufficient water absorption until fully set, the obturated teeth were kept in PBS solution at 37°C for 30 h until all the sealers were set. This rigorous experimental process led to results similar to those of Dioguardi et al. [31] for observation periods of up to ninety days. NeoSEALER Flo contains tantalum oxide, while EndoSequence BC contains zirconium oxide for radiopacity. NeoSEALER Flo contains cement phases in addition to tricalcium silicate, which is well known to be bioactive. Pawar et al. [32] reported that EndoSequence BC was superior to AH Plus in terms of dye penetration when the continuous-wave condensation technique was employed. Therefore, in future studies it will be interesting to compare sealing ability among various obturation techniques.

In the present study, Super-Bond RC Sealer had the most apical leakage among the five sealers but less coronal leakage than either of the tricalcium silicate sealers. The apical leakage observed with Super-Bond RC Sealer was significantly greater than those observed for AH Plus and Pulp Canal Sealer. A dye penetration study using Super-Bond RC Sealer emphasized the need to use Accel, which comprises aromatic sulfonate, water, and ethanol [4]. The effect of Accel was expected to weaken the influence of residual NaOCl on the root canal surface, and the effect of Green Activator was expected to remove the smear layer and prevent denaturation of dentin collagen. Although the present protocol used Accel and Green Activator, Super-Bond RC Sealer showed the most leakage apically. The application method and treatment time recommended by the manufacturer might have been insufficient for Accel and Green Activator to be maximally effective on the teeth prepared in this study. Epiphany and EndoREZ [2] are also acrylic resin sealers. In apical leakage studies, Epiphany had lower apical leakage than AH Plus [8,33,34]. In a coronal leakage study, Bodrumlu et al. found there was less leakage with Epiphany than with AH Plus [11]. EndoREZ has demonstrated mixed apical leakage results [8,13,35]. Kumar et al. and Sevimay et al. reported that EndoREZ had more apical leakage than AH Plus [8,35], while Ballullaya et al. found EndoREZ to have less apical leakage than AH Plus [13]. The present study showed that Super-Bond RC Sealer had significantly worse apical and coronal leakage than AH Plus. The difference in the results for these sealers might be due to the difference in their components. Super-Bond RC Sealer is formulated from methyl methacrylate (MMA)-polyMMA/ tri-*n*-butylborane (TBB) initiator and is expected to induce interfacial polymerization of MMA at the dentin interface [36,37]. During the setting of a MMA-TBB resin sealer, the interfacial initiation of the polymerization begins on the dentin side to reduce gap formation between the dentin and resin [7]. An experimental study of leakage from MMA-TBB resin sealer (Endoresin 2) reported a dye penetration of 0.17 mm after 2 days, which was superior the result in a ZOE sealer control group [7]. During the setting of a MMA-TBB resin sealer, the interfacial initiation of polymerization begins on the dentin side to reduce gap formation between the dentin and resin [7]. Endoresin 2 and Super-Bond RC Sealer are in the same sealer category, but Endoresin 2 seals well because its formulation differs from that of Super-Bond RC Sealer in terms of consistency and flow properties.

In this study, coronal leakage was worse than apical leakage for all sealers, similar to a previous study [1], perhaps because of larger angled dentin tubules at the coronal end. Dye penetration testing was used in this study because it is easy to perform [14], even though previous studies have shown some drawbacks [38]. Camps and Pashley [38] found that dye penetration testing did not discriminate differences among sealers. Instead of the dye penetration technique, which requires sample destruction, studies could be conducted using X-ray micro-computed tomography (µCT) to evaluate interface sealing without sample destruction. Such *in vitro* studies are important [3] but do not include clinical factors such as pH, saliva, lateral canals, and variations in obturation technique [3,5]. Therefore, clinical studies to compare endodontic sealers using single-cone obturation are needed.

In this study of dye leakage with five sealers employing the single-cone technique, coronal leakage was worse than apical leakage for all of them. This is the first study to have used the single-cone technique for simultaneous examination of apical and coronal leakage based on dye penetration. AH Plus still remains the gold standard because even with the single-cone technique, it exhibited the least leakage apically and coronally. Super-Bond RC Sealer showed the most apical leakage, and EndoSequence BC had the most coronal leakage.

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Conflict of interest

C Primus is the inventor of NeoSEALER Flo; she did not participate in the data gathering or statistical analysis.

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