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Comparative Apical Sealing Performance of Bioceramic and Resin-Based Sealers: A Fluid Filtration Analysis

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Abstract

Introduction: Achieving a three-dimensional seal in the apical, lateral, and coronal regions of the root canal is a key objective in endodontic treatment. This study aimed to compare the apical sealing ability of NeoSealer Flo, MTA-Fillapex, and AH-26 over different time intervals using the fluid filtration method. **Materials and Methods**: In this *in vitro* study, 58 single-rooted premolars (n=18 per group; 2 positive and 2 negative controls) were selected and prepared using the ProTaper system up to file F3. Canals were obturated with the single-cone technique using one of the three tested sealers. Apical microleakage was measured at 24 hours, 1 week, and 4 weeks using the fluid filtration method. Data were analyzed using one-way ANOVA, repeated measures ANOVA, ANCOVA, and Tukey's HSD post hoc test (P<0.05). **Results**: The results indicated that sealer type, time, and their interaction had a statistically significant effect on apical microleakage (P<0.001). NeoSealer Flo showed the lowest and AH-26 the highest leakage values across all time intervals. In all three groups, microleakage decreased over time. This reduction was statistically significant from 24 hours to 1 week in the NeoSealer Flo and MTA-Fillapex groups (P<0.001), and from 1 week to 4 weeks in the AH-26 group (P<0.05). **Conclusion**: Within the limitations of this study, NeoSealer Flo demonstrated superior apical sealing ability at all time points. Under single-cone obturation conditions, bioceramic sealers such as NeoSealer Flo may provide more predictable long-term apical sealing compared to resin-based alternatives.

Keywords: Apical Sealing Ability; AH-26; Canals Sealer; Dental Leakage; MTA-Fillapex

Introduction

The primary objective of root canal obturation is to establish a three-dimensional seal in the apical, lateral, and coronal regions of the canal, thereby preventing the penetration of microorganisms and contributing to the maintenance of periapical tissue health [1]. Such a seal is not only effective in minimizing the likelihood of microleakage, but also plays a crucial role in the success of root canal treatment [2].

Since gutta-percha cannot adhere to the dentinal walls by itself, the use of sealers is necessary to prevent apical microleakage [3]. Root canal sealers act as lubricants during obturation, sealing the space between dentinal walls and the core material, and filling accessory canals, voids, and irregularities in the root canal system [4, 5].

Endodontic sealers should possess characteristics such as biocompatibility, dimensional stability, low solubility in tissue fluids, antibacterial properties, radiopacity, and the ability to provide an effective seal. However, no sealer has yet met all the ideal criteria. Moreover, differences in the chemical composition of sealers affect their behavior, including adhesion to dentin walls and their ability to create an effective seal [6]. Accordingly, various formulations have been developed, including MTA-based, zinc oxide-eugenol, calcium hydroxide, epoxy resin, and bioceramic sealers [7]. In this study, three sealers with different formulations were selected to allow for effective comparison among the main groups and to evaluate their apical microleakage under the same conditions.

NeoSealer Flo (Avalon Biomed, Houston, TX, USA) is a bioceramic, resin-free, calcium silicate-based sealer, available in a

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premixed form, which can set effectively in the presence of moisture. According to the manufacturer's report, this sealer exhibits dimensional stability with shrinkage of less than 1% and expansion of less than 0.1% [8]. Given the limited number of studies evaluating the apical sealing ability of this sealer, further investigation of its performance under standard conditions remains necessary [9, 10].

MTA-Fillapex (Angelus, Londrina, Brazil) is an MTA-based sealer containing salicylate resin, natural resin, bismuth oxide, silica, and approximately 40% MTA [9]. Due to the beneficial biological and mineral properties of MTA in endodontic treatment, MTA-based sealers such as MTA-Fillapex have been extensively studied. These evaluations have been conducted using different obturation techniques, various leakage assessment methods, and under diverse laboratory conditions. However, contrary to expectations, some of these studies have reported contradictory results or weak performance for this sealer, highlighting the importance of re-evaluating its performance under standardized conditions [4, 5, 11-13].

AH-26 (Dentsply De Trey, Konstanz, Germany) is one of the oldest epoxy resin-based sealers. Due to its stable physicochemical properties and extensive use in previous studies, it has been used as a reference sealer in many investigations. Its ability to create effective apical sealing, especially when used with the lateral condensation technique, has been demonstrated in numerous studies [11, 14-16].

In recent years, with the increasing use of nickel-titanium rotary files, the single-cone obturation technique has gained popularity [17]. The ease of implementation and reduced chairside time are among the advantages of this method compared to lateral and vertical compaction techniques. However, in canals with more complex anatomy, such as oval or ribbon-shaped canals, this method may result in voids within the sealer or between the gutta-percha and the canal wall. This issue can compromise the quality of the seal and increase the risk of bacterial penetration and treatment failure [18].

Various methods have been introduced to evaluate microleakage, including dye penetration, bacterial leakage, and fluid filtration. Among these, the fluid filtration technique is considered non-destructive, allowing longitudinal assessment of the same specimens [9]. Moreover, the ability to record volumetric data and adjust system sensitivity makes it a practical and efficient method in laboratory studies [19].

Several studies have examined sealer microleakage [5, 13, 20, 21]. However, comparisons using the single-cone technique *via* fluid filtration remain limited. This *in vitro* study was conducted to compare the sealing ability of NeoSealer Flo, MTA-Fillapex, and AH-26 at 24 h, 1 week, and 4 weeks using the fluid-filtration technique. Null hypothesis: there is no difference in apical microleakage among the three sealers or across time points.

Materials and Methods

Considering three equal groups, a type I error of 0.01 and a type II error of 0.10 were assumed. The expected group means were μ_1=0.04, μ_2=0.60, and μ_3=0.71, with a common variance of 0.21, based on previously published data [5, 9, 13, 22]. The overall mean of these three groups was 0.45. Under these assumptions, the required sample size was estimated to be 15 teeth per group (total=45). To account for a possible 20% dropout, 54 teeth were finally included in the study.

$$\Delta = \frac{1}{\sigma^2}\sum_{i=1}^{k}(\mu - \bar{\mu})^2$$

$$n = (\lambda_{g,\alpha,1-\beta})/\Delta$$

This laboratory-based *in vitro* study was conducted on fifty-eight extracted human single-rooted premolars collected from the Oral Surgery Department of Isfahan Dental School. The study protocol was approved by the Research Ethics Committee of Isfahan University of Medical Sciences under the code IR.MUI.DHMT.REC.1403.160.

The inclusion criteria comprised single-canal teeth with a minimum root length of 15 mm, extracted within the previous month, and presenting no root curvature greater than 10 °. Teeth were excluded if they exhibited caries, internal or external root resorption, open apices, cracks or fractures, or any morphological variations of the canal, as confirmed by periapical radiographs taken in both buccal and proximal views.

Soft tissue remnants and calculus were removed using ultrasonic tips. All teeth were stored in a 0.1% thymol solution at room temperature until use. Crowns were sectioned at the cementoenamel junction using a low-speed diamond disc (Isomet, Buehler, USA) under water cooling to obtain standardized 15-mm root segments. Canal patency was confirmed using a size 10 K-file (Mani, Tochigi, Japan). Working length was established 0.5 mm short of the apical foramen.

Root canals were prepared using ProTaper rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland). Apical preparation was completed up to size F3. Canals were irrigated with 5 mL of 2.5% sodium hypochlorite (Pakshoma, Tehran, Iran) between each instrument. After instrumentation, smear layer was removed using 3 mL of 17% EDTA (Nik Darman Asia, Tehran, Iran) for 1 min, followed by a final rinse with 3 mL of 2.5% NaOCl [23].

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A final irrigation with 20 mL of normal saline was performed [24]. All irrigations were delivered using a 30-gauge side-vented needle. Canals were then dried with F3-sized paper points (Diadent, Almere, Netherlands).

Four samples were randomly selected as control groups (2 positive, 2 negative). The remaining 54 samples were randomly divided into three experimental groups (n=18 per group), according to the sealer used:

Group 1: NeoSealer Flo (Avalon Biomed, TX, USA)

Group 2: MTA-Fillapex (Angelus, Londrina, Brazil)

Group 3: AH-26 (Dentsply DeTrey, Konstanz, Germany)

All samples were obturated using the single-cone technique with F3 gutta-percha cones (Dentplus, Seoul, South Korea).

For NeoSealer Flo, the premixed syringe delivery tip was introduced into the canal without exceeding the middle third, and sealer was delivered while gradually withdrawing the tip under continuous pressure, as recommended by the manufacturer [10].

For the MTA-Fillapex and AH-26 groups, the sealers were prepared according to the manufacturer's instructions on a glass slab using a stainless-steel spatula. The tip of the F3 gutta-percha cone was coated with the sealer and then slowly inserted to working length.

Excess gutta-percha was seared at the orifice using a hot plugger, coronal sealer remnants were removed, and the coronal cavity was sealed using temporary Cavit (3M ESPE, Seefeld, Germany).

Post-obturation radiographs were taken in buccolingual and mesiodistal directions to confirm obturation quality; poorly filled samples were replaced.

Positive control samples were filled with gutta-percha only, without sealer. Negative controls were also obturated without sealer, and all external surfaces, including the apical foramen, were sealed with two layers of nail varnish. In the experimental and positive control groups, all root surfaces except for the apical 1 mm were coated with two layers of nail varnish.

All specimens were stored in an incubator at 37 ˚C and 100% humidity for proper sealer setting.

Apical microleakage was evaluated using the fluid filtration method, first introduced by Wu *et al.* [25]. All specimens were connected to the fluid filtration apparatus. The system consisted of a graduated micropipette (0.1 mL volume, 1 µL accuracy, and 0.5 mm^2 cross-sectional area) containing a small air bubble and positioned between the specimen and a reservoir of double-distilled water. A simulated pulpal pressure of 40 kPa (300 mmHg) was applied to the entire system using 99.98% pure nitrogen gas, which directed the fluid flow from the reservoir toward the tooth and displaced the air bubble inside the micropipette. The bubble diameter was adjusted to match the internal diameter of the micropipette, ensuring its movement served as a precise indicator of fluid transport. Bubble displacement was recorded after 10 min and documented using a digital camera. The gas pressure was regulated with a manometer and maintained constant throughout the experiment [26].

Microleakage was recorded at three time intervals: 24 h, 1 week, and 4 weeks after obturation. Data were analyzed using one-way ANOVA, repeated measures ANOVA, ANCOVA, and Tukey's HSD post hoc test. A P-value<0.05 was considered statistically significant.

Results

A total of 58 extracted single-rooted premolars were collected. Four specimens were assigned as positive and negative controls. Another four specimens were excluded due to abnormal fluid-bubble displacement, defined as inconsistent or non-interpretable bubble movement with clear deviation from the expected linear pattern. These cases included two teeth from the NeoSealer Flo group and one tooth each from the MTA-Fillapex and AH-26 groups. The final experimental sample consisted of 50 teeth (NeoSealer Flo: n=16; MTA-Fillapex: n=17; AH-26: n=17).

Positive and negative samples were used to validate the system. Fluid displacement in the positive and negative control groups was 50–80 µL/min, measured within 30 sec (notable) and 0–0.05 µL/min over 10 min (minimal), respectively, which confirmed the sensitivity of the fluid filtration device.

Repeated measures ANOVA revealed significant main effects of both Sealer and *Time*, as well as a significant Sealer×Time interaction (all P<0.001). Post-hoc simple-effects tests, adjusted for multiple comparisons, indicated that apical microleakage decreased significantly over time in both NeoSealer Flo and MTA-Fillapex (P<0.001), and also decreased in AH-26 (P=0.006). The mean±SD values (µL/min) for each group at all-time points are presented in Table 1 and Fig. 1.

At the 24-h interval, NeoSealer Flo exhibited significantly lower microleakage than both AH-26 (P<0.001) and MTA-Fillapex (P<0.05). The difference between MTA-Fillapex and AH-26 was also statistically significant (P<0.001). At 1 week and 4 weeks, NeoSealer Flo consistently demonstrated superior sealing ability compared to both MTA-Fillapex and AH-26 (P<0.001 for both comparisons). MTA-Fillapex also showed significantly lower leakage than AH-26 at both time points (P<0.001). The pairwise comparisons between sealers at each time point are shown in Table 2 and Fig. 2.

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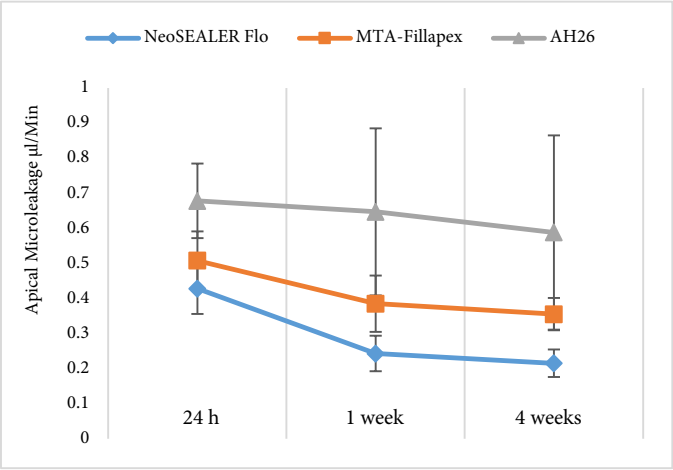

Figure 1. Comparison of mean apical microleakage at three time intervals (24 hours, 1 week, and 4 weeks) in µL/minute

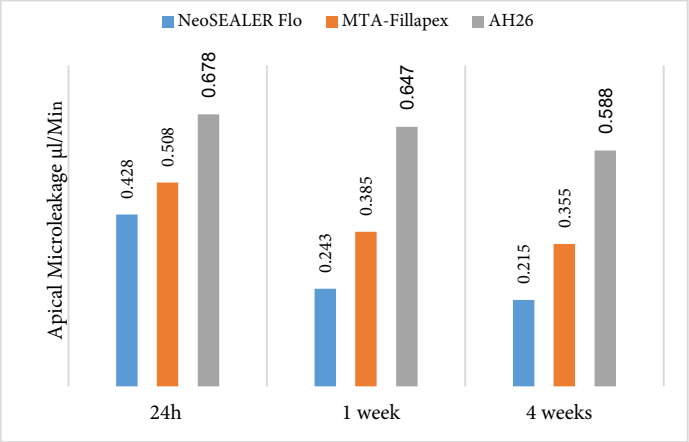

Figure 2. Comparison of mean apical microleakage between sealers at each time interval in µL/minute

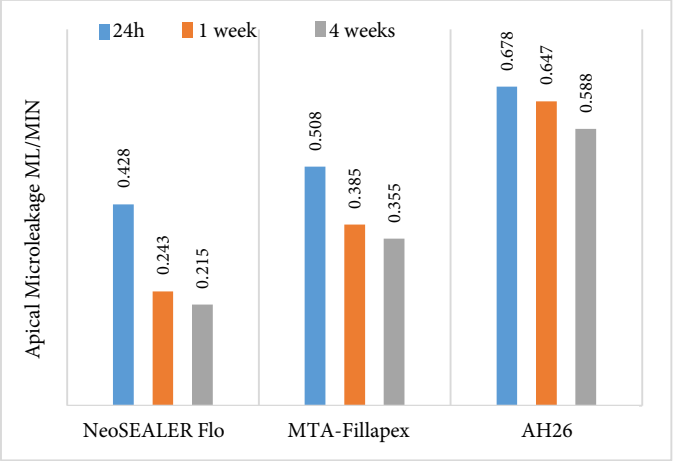

Figure 3. Comparison of mean apical microleakage between time intervals for each sealer in µL/minute

Within-group comparisons over time showed that both NeoSealer Flo and MTA-Fillapex exhibited significant reductions in apical microleakage from 24 h to 1 week and from 24 h to 4 weeks (P<0.001). However, the difference between 1 week and 4 weeks was not statistically significant (P>0.05). In contrast, AH-26 showed a significant reduction from 24 h to 4 weeks and from 1 week to 4 weeks, while the decrease from 24 h to 1 week was not statistically significant. Comparisons between time intervals for each sealer are presented in Table 3 and Fig. 3.

Discussion

The primary objective of endodontic treatment is to thoroughly clean, shape, and achieve a three-dimensional seal of the root canal system to eliminate infection and prevent reinfection [27]. One of the major causes of endodontic failure is apical microleakage occurring at the interface between the sealer and either the dentinal wall or the core filling material [28]. This study aimed to compare the apical microleakage of NeoSealer Flo, MTA-Fillapex, and AH-26 using the single-cone technique and the fluid filtration method at intervals of 24 h, 1 week, and 4 weeks.

Among various techniques available for assessing apical microleakage, we used the fluid filtration technique as a quantitative and reproducible method. This technique enables accurate measurement of microleakage over different time intervals without causing any structural damage to the specimens, thereby allowing longitudinal evaluation of each sample throughout the study period [13, 22].

Given the objectives of this study and the need for an accurate evaluation of sealer performance, the single-cone technique was employed. This method relies more heavily on the sealing capability of the sealer itself and creates a more challenging condition for assessing apical sealing effectiveness [29]. The use of gutta-percha cones matching the size of the final preparation file reduces the thickness of the sealer layer and increases the proportion of gutta-percha within the filled canal space. Some studies have associated the reduced sealer volume with decreased microleakage and improved filling stability [30]. In the present *in vitro* study, this system was selected to standardize all specimens and allow for evaluation of the sealers' performance under controlled conditions, eliminating potential confounding variables associated with obturation techniques.

All procedures in this study were performed by a single operator to eliminate potential errors related to inter-operator variability.

According to the results, NeoSealer Flo exhibited the lowest apical microleakage among the tested sealers across all three time intervals, and the differences were statistically significant

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compared to MTA-Fillapex and AH-26 (P<0.001). In contrast, AH-26 showed the highest microleakage values at all time points.

Studies have demonstrated that calcium silicate-based sealers, when used with the single-cone technique, are capable of creating an effective apical seal and contributing to favorable treatment outcomes [18]. It appears that the structural characteristics of NeoSealer Flo played a decisive role in its favorable performance in the present study. The findings of the present study are consistent with those reported by Li *et al.* [9]. In their investigation, which employed the fluid filtration method and the single-cone technique, NeoSealer Flo exhibited significantly lower apical microleakage than MTA-Fillapex at both 1 and 42 days. Their analysis revealed the presence of extensive calcium carbonate deposits within the structure of NeoSealer Flo. These deposits were found to form a protective layer that limited ion diffusion from the sealer mass and mitigated structural degradation, factors that may enhance its apical sealing capacity. However, our results differ from those of Vo *et al.* [10] who evaluated apical microleakage of several sealers, including NeoSealer Flo and AH-Plus, using the dye penetration method in combination with the single-cone technique. Contrary to our observations, they reported higher microleakage for NeoSealer Flo compared to AH-Plus. This discrepancy may be attributed to differences in microleakage assessment methods, as well as variations in the sealers used. Therefore, such divergent findings should be interpreted in light of differences in study design.

Table 1. Comparison mean (SD) of apical microleakage at three time intervals (24 h, 1 week, and 4 weeks) in µL/min

Time / Sealer	24 h	1 week	4 weeks	Time *P*-value	Intervention *P*-value	Interaction *P*-value
NeoSealer Flo	0.43 (0.07)	0.24 (0.05)	0.22 (0.04)	<0.001	<0.001	<0.001
MTA-Fillapex	0.51 (0.08)	0.39 (0.08)	0.36 (0.05)	<0.001		
AH-26	0.68 (0.11)	0.65 (0.24)	0.59 (0.28)	<0.006		
ANOVA	*P*<0.001 F=34.23	*P*<0.001 F=68.88	*P*<0.001 F=70.87			

Table 2. Pairwise comparison of mean apical microleakage between sealers at each time interval in µL/min

Time	Sealers comparison	Mean Difference (I-J)	*P*-value
24 hour	NeoSealer Flo *vs* AH-26	-0.25	< 0.001
	NeoSealer Flo *vs* MTA-Fillapex	-0.08	0.032
	MTA-Fillapex *vs* AH-26	-0.17	< 0.001
1 week	NeoSealer Flo *vs* AH-26	-0.95	< 0.001
	NeoSealer Flo *vs* MTA-Fillapex	-0.46	< 0.001
	MTA-Fillapex *vs* AH-26	-0.50	< 0.001
4 weeks	NeoSealer Flo *vs* AH-26	-0.96	< 0.001
	NeoSealer Flo *vs* MTA-Fillapex	-0.51	< 0.001
	MTA-Fillapex *vs* AH-26	-0.45	< 0.001

Table 3. Pairwise comparison of mean apical microleakage between time intervals for each sealer in µL/min

Sealer	Time comparison	Mean Difference (I-J)	*P*-value
NeoSealer Flo	24h *vs* 1 week	+0.57	< 0.001
	24h *vs* 4 weeks	+0.69	< 0.001
	1week *vs* 4 weeks	+0.12	0.231
AH-26	24h *vs* 1 week	+0.08	0.297
	24h *vs* 4 weeks	+0.19	0.024
	1week *vs* 4 weeks	+0.11	0.025
MTA-Fillapex	24h *vs* 1 week	+0.29	< 0.001
	24h *vs* 4 weeks	+0.35	< 0.001
	1week *vs* 4 weeks	+0.07	0.604

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Despite the favorable characteristics of MTA-Fillapex, such as acceptable radiopacity, ease of handling, and satisfactory biocompatibility the presence of resinous components in its formulation may negatively affect its bonding ability to dentin and overall sealing performance [5, 31]. Incomplete polymerization, polymerization shrinkage, and lower hydroxyapatite precipitation have been suggested as potential reasons for its greater apical microleakage compared to bioceramic alternatives [32]. Some studies have attributed the potential improvement in this sealer's performance over time to the formation of hydration products. However, due to its predominantly resinous nature and limited calcium ion release, this mechanism alone may not sufficiently compensate for its structural shortcomings [13]. Accordingly, the higher microleakage values observed for MTA-Fillapex in the present study, relative to NeoSealer Flo, are consistent with the existing literature and are scientifically defensible.

Evidence suggests that the use of resin-based sealers with the single-cone technique may result in increased void formation in the apical region compared to lateral condensation, thereby reducing the sealing efficacy relative to bioceramic sealers [33]. The poor performance of AH-26 observed in the present study, characterized by the highest levels of apical microleakage, can be interpreted within this context.

The comparative analysis between MTA-Fillapex and AH-26 in the present study demonstrated that MTA-Fillapex exhibited significantly lower apical microleakage than AH-26 at all evaluated time points (P<0.001).

These findings are partially consistent with those reported by Asawaworarit *et al.* [13] who employed the fluid filtration method and similar time intervals of 24 h, 1 week, and 4 weeks. In their study, MTA-Fillapex showed better sealing ability than AH-Plus on the first and twenty-eighth days; however, at the one-week interval, AH-Plus exhibited lower microleakage. The authors attributed these temporal differences to the combined chemical properties of the sealers. The calcium silicate-based composition and the ability to set in moist environments may allow MTA-Fillapex to form calcium carbonate deposits and hydration products over time, thereby improving apical sealing. Additionally, its hygroscopic nature and potential for slight expansion upon setting were reported as contributing factors to enhanced sealing over time.

Altan *et al.* [5] using the fluid filtration method with lateral condensation, found lower microleakage for MTA-Fillapex than AH-Plus at 24 h, but the trend reversed at 180 days. The authors attributed this change to the high proportion of salicylate resin in the composition of MTA-Fillapex and its prolonged setting time. Given that the obturation technique can influence the distribution and adaptation of the sealer to canal walls, the difference in obturation methods between that study and the present one may have contributed to the conflicting results.

In contrast, several studies have reported inferior performance of MTA-Fillapex compared to resin-based sealers. In a study by Jafari *et al.* [14] which utilized the bacterial leakage method alongside lateral compaction, AH-26 demonstrated lower apical microleakage than MTA-Fillapex. Similarly, Sönmez *et al.* [34] reported greater dye penetration in canals obturated with MTA-Fillapex than those sealed with AH-Plus using the same compaction technique. Remy *et al.* [35] employing scanning electron microscopy (SEM) analysis, observed poorer marginal adaptation of MTA-Fillapex in comparison to AH-Plus. The authors attributed this to the low adhesive strength of apatite-like structures formed at the sealer interface when immersed in phosphate-buffered saline (PBS), a solution that simulates body fluids. These discrepancies in results can be partially explained by differences in obturation technique, leakage evaluation method, and chemical composition of the sealers.

In the subsequent comparative analysis, both NeoSealer Flo and MTA-Fillapex exhibited a statistically significant reduction in apical microleakage from 24 h to 1 week and 4 weeks. However, the difference between the 1-week and 4-week intervals was not statistically significant in either group. In contrast, AH-26 demonstrated a significant decrease in microleakage between 24 h and 4 weeks, as well as between 1 week and 4 weeks, while the reduction between 24 h and 1 week was not statistically significant.

The findings of the present study were consistent with the majority of previous reports [5, 11, 13], while only a limited number of studies have reported increased microleakage over time. For instance, in the study by Shourgashti *et al.* [22] employing the fluid filtration method and lateral condensation technique, AH-26 showed increased leakage after one month. The authors attributed this phenomenon to the volumetric shrinkage of the sealer following an initial expansion phase during setting, which may disrupt the bond between the sealer and dentin and result in gap formation at the interface. Similarly, Razavian *et al.* [15] using a bacterial leakage model, observed increased microleakage of MTA-Fillapex over time. Variations in obturation technique, leakage assessment methods, and storage conditions may account for such discrepancies in the reported outcomes.

Further investigations are recommended to validate these findings under clinical conditions and to explore the sealing behavior of different sealers in teeth with more complex anatomies. The use of advanced imaging techniques, such as micro-computed tomography, and larger sample sizes may enhance the generalizability and translational value of future studies.

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Conclusion

Within the limitations of this *in vitro* study, NeoSealer Flo demonstrated superior apical sealing ability compared to MTA-Fillapex and AH-26 across all evaluated time intervals. It consistently exhibited the lowest microleakage values, followed by MTA-Fillapex, while AH-26 showed the highest levels of apical microleakage. These findings suggest that, when used with the single-cone technique, bioceramic sealers such as NeoSealer Flo may provide more effective and stable apical sealing over time than resin-based alternatives. Clinical studies are required to confirm these results.

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Conflict of interest
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Authors' contributions
Conceptualization: RH; Methodology: MR/NSE; Formal Analysis and Investigation: MR/MJT; Writing-Original Draft Preparation: MR; Writing-Review and Editing: RH/NSE; Supervision: RH/NSE. All authors read and approved the final manuscript.

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