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Comparative Evaluation of Apical Microleakage in Root Canals with Separated Rotary Instruments Using Zoe, Calcium Hydroxide, AH Plus and Bioceramic Sealers-An in-Vitro Study

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Abstract

Background and objectives: To evaluate and compare apical microleakage in root canals with intentionally separated rotary instruments, using four different endodontic sealers: Zinc Oxide Eugenol, Sealapex, AH Plus, and Ceraseal.

Materials and methods: In this in vitro investigation, fifty-two extracted single-rooted premolars were disinfected, decoronated, and shaped with ProTaper rotary instruments, deliberately inducing fracture of the F1 file within the middle third. Following successful bypassing of the separated fragment, canals were prepared to size 25 and irrigated sequentially with 5.25% sodium hypochlorite, 17% EDTA, and sterile saline. Specimens were then randomly allocated into four cohorts (n=13) and obturated using a single-cone technique with one of four test sealers. After obturation, samples were sealed, incubated at 37 °C for 48 hours, and subsequently coated with nail varnish—excluding the apical 2 mm—before immersion in 5% methylene blue dye for seven days. Specimens were longitudinally sectioned and examined under 40× stereomicroscopy to quantify dye penetration. Data were subjected to ANOVA and Kruskal–Wallis analyses, with statistical significance determined at $p < 0.05$.

Result: The mean apical dye penetration was highest in the Zinc Oxide Eugenol group, followed by Sealapex, AH Plus, and least in the Ceraseal group. Statistically significant differences ($p < 0.05$) were observed between the groups, with bioceramic sealer Ceraseal showing the most effective apical sealing ability.

Keywords: Apical Microleakage, Separated Rotary Instruments, Single Cone Obturation, Zinc Oxide Eugenol, Sealapex, AH Plus, Ceraseal, Bioceramic Sealer.

Introduction

Endodontic treatment, commonly known as root canal therapy, represents a cornerstone of contemporary conservative dentistry. It is a meticulously designed procedure aimed at preserving the natural dentition by diagnosing, preventing, and managing diseases related to the dental pulp and surrounding periapical tissues. The dental pulp is a specialized connective tissue rich in nerves and blood vessels, vital for the nourishment and sensory function of the tooth. However, exposure to bacterial infection through dental caries, trauma, or iatrogenic insults can lead to irreversible inflammation or necrosis of the pulp tissue. Left untreated, this infection often progresses beyond the apical foramen, resulting in periapical pathosis and bone destruction. The primary objective of endodontic therapy is thus to eradicate infection from the root canal system and to prevent reinfection by establishing a hermetic seal[1.] The success of this treatment directly influences not only the longevity of the tooth but also the overall health and function of the stomatognathic system.

The procedural steps of root canal therapy consist of careful diagnosis, access cavity preparation, thorough chemo-mechanical debridement of the canal system, and subsequent obturation to achieve a fluid-tight seal. In recent decades, advances in dental materials and instrumentation have significantly improved the predictability of these steps. The advent of nickel-titanium (NiTi) rotary instruments revolutionized root canal preparation by offering enhanced flexibility, efficiency, and reduced procedural errors compared to traditional stainless steel files. Alongside this, the evolution of root canal sealers—materials designed to fill the microscopic voids between the gutta-percha core and canal walls—has been integral to achieving optimal obturation quality.[2]

Despite these improvements, root canal therapy is not without its challenges and potential complications. Two of the most critical issues faced by endodontists globally are the separation of rotary instruments within the canal and apical microleakage following obturation. These complications often undermine the treatment outcome and require careful clinical consideration.[3]

Instrument separation is a procedural mishap that occurs when an endodontic file fractures inside the root canal during biomechanical preparation.[4] The introduction of rotary NiTi instruments, while beneficial for enhancing canal shaping, has inadvertently led to an increased incidence of file separation due to their inherent susceptibility to cyclic fatigue and torsional stresses. Cyclic fatigue occurs as the file undergoes repeated tension and compression in curved canals, while torsional stress arises when the file tip binds within the canal but the shank continues to rotate. Instrument separation poses a significant clinical challenge as the retained fragment acts as a physical barrier, obstructing the canal space and interfering with subsequent cleaning and obturation. When the fragment is located in the apical third, retrieval attempts may be more justifiable given the critical importance of sealing the apical constriction. However, separated instruments in the middle third, often more difficult to access and retrieve, can force clinicians to adapt their treatment strategy by bypassing or leaving the fragment in situ. These approaches, while sometimes necessary, raise concerns about the ability to adequately disinfect and obturate the apical segment, thereby jeopardizing the long-term prognosis. [5,6,7]

Apical microleakage refers to the passage of bacteria, fluids, and their byproducts through gaps between the obturation material and the canal walls or through the apical foramen itself. This phenomenon remains the principal cause of endodontic failure, as it facilitates reinfection and persistent inflammation in the periapical tissues. The microanatomy of the root canal system—with its lateral canals, accessory foramina, and dentinal tubules—adds complexity to achieving a hermetic seal. Inadequate sealing allows periapical irritants to persist or recolonize, leading to failure even when other procedural steps are performed meticulously. Numerous clinical investigations have shown that the integrity of the apical seal is paramount in determining treatment success, with a well-sealed canal demonstrating success rates approaching 90 to 97%. Therefore, the obturation materials and techniques selected must be capable of creating a stable, long-lasting seal resistant to mechanical and biological challenges. [8,9]

Gutta-percha, a thermoplastic material derived from the latex of the Palaquium gutta tree, remains the core obturation material in most root canal treatments. However, gutta-percha alone does not adhere to the dentin walls or fill irregularities within the canal, which is why root canal sealers serve as vital adjuncts in the obturation process. Sealers serve multiple critical functions: they fill the microscopic spaces between gutta-percha and canal walls, seal accessory and lateral canals, compensate for dimensional discrepancies caused by gutta-percha shrinkage, and provide antimicrobial effects depending on their formulation. The ideal root canal sealer should exhibit excellent flow and adhesion, dimensional stability, biocompatibility, radiopacity, low solubility, and antibacterial properties. [10,11]

Historically, zinc oxide-eugenol (ZOE)-based sealers were the first to be used extensively in endodontics. Their antibacterial properties and ease of manipulation made them popular in early endodontic practice. Nevertheless, ZOE sealers are associated with various drawbacks, including polymerization shrinkage, high solubility, and potential cytotoxicity. These factors contribute to a loss of sealing integrity over time and increased risk of microleakage. Furthermore, their potential to discolor the tooth structure has also limited their contemporary use. [12]

In response to these shortcomings, calcium hydroxide-based sealers were introduced, with Sealapex being a prominent example. These sealers have demonstrated excellent biocompatibility and the ability to promote healing and hard tissue formation through the release of hydroxyl ions that elevate pH and exert antimicrobial effects. However, calcium hydroxide sealers also exhibit increased solubility compared to resin-based materials, raising concerns about their long-term sealing efficacy in the dynamic oral environment.[13]

Epoxy resin-based sealers, particularly AH Plus, have achieved broad recognition owing to their superior physicochemical properties. These sealers exhibit excellent dimensional stability, low solubility, extended working time, and strong adhesion to both dentin and gutta-percha. Their ability to form a durable, cohesive matrix significantly reduces the potential for microleakage and has established them as the current gold standard among resin-based sealers.[14]

More recently, bioceramic sealers such as Ceraseal have emerged as a new generation of endodontic materials. These premixed, hydrophilic sealers chemically bond to dentin, possess zero shrinkage upon setting, and have the unique ability to stimulate hard tissue formation, aligning with regenerative endodontic principles. Their bioactivity and antimicrobial properties, combined with excellent

sealing potential, make bioceramic sealers particularly attractive for use in compromised canal systems.[15]

The presence of a fractured rotary instrument within the root canal presents a considerable challenge during obturation. The retained fragment occupies canal space and introduces anatomical irregularities that hinder the proper adaptation of gutta-percha and sealer to the canal walls. This irregularity often leads to void formation and potential leakage pathways, particularly in the apical region, which is critical for treatment success. Consequently, clinicians must rely on sealers with excellent flow characteristics, strong adhesion, and dimensional stability to mitigate these obstacles. However, there is limited literature evaluating the performance of various sealers under such compromised clinical conditions. [16]

A substantial portion of existing research on root canal sealers has been conducted under ideal laboratory conditions, often without incorporating the complexity of a retained instrument fragment. As a result, the relevance of these findings to real-world endodontic scenarios—especially those involving separated instruments—remains limited. Although literature discusses the management of separated instruments through retrieval or bypassing techniques, only a few studies have assessed the sealing performance of obturation materials when fragments are retained in the middle third of the canal—one of the most common locations for instrument separation. This lack of data presents a significant challenge for clinicians striving to ensure optimal sealing and clinical success in such compromised cases.[5,6,7]

The current in vitro study was undertaken to simulate a realistic clinical situation by deliberately creating separated rotary instrument fragments in the middle third of the canal, followed by obturation using various categories of sealers. Four types of sealers, each representing a different material class—zinc oxide eugenol-based, calcium hydroxide-based (Sealapex), epoxy resin-based (AH Plus), and bioceramic-based (Ceraseal)—were selected to assess and compare their apical sealing ability under these conditions.

The main aim of this research is to generate comparative data regarding the efficacy of these sealers in scenarios complicated by the presence of a separated instrument. The insights gained are intended to assist practitioners in making informed choices when selecting obturation materials for such cases. Enhanced knowledge of how these sealers behave in the presence of anatomical obstructions may lead to improved clinical strategies, reduced endodontic failure rates, and better overall patient outcomes. Furthermore, this study contributes to the scientific understanding of the interaction between obturation materials and structural challenges within the root canal system.

In summary, root canal therapy remains a cornerstone of restorative dental practice, yet it is not without its complexities. Instrument separation and apical leakage continue to pose significant barriers to long-term success. By exploring the sealing capabilities of different sealer types in the presence of fractured rotary instruments, this study addresses a crucial gap in the literature. The findings aim to offer evidence-based guidance for the selection of sealers in challenging cases, ultimately promoting more reliable and durable endodontic treatments that help preserve the natural dentition

Materials & methods

A total of 52 single-rooted maxillary and mandibular premolars extracted for orthodontic purposes were selected for this study. Radiographs and visual inspection under a stereomicroscope at 10× magnification were used to evaluate and exclude teeth with open apices, cracks, resorptive defects, and canal calcifications. The selected

teeth were immersed in 5.25% sodium hypochlorite (NaOCl) solution for 5 minutes. Subsequently, soft tissue remnants and calculus were mechanically removed, and the specimens were rinsed and stored in normal saline until further use.

All procedures were performed by a single operator to maintain standardization. The teeth were decoronated at the cementoenamel junction using a high-speed diamond disc under water spray coolant to obtain a uniform root length. The working length (WL) was determined by inserting a #15 K-file (Mani, Nakanishi Inc., Tokyo, Japan) into the canal until it was just visible at the apical foramen under 10× magnification. One millimeter was then subtracted from this measurement to establish the WL.

Root canal instrumentation was performed using ProTaper Universal rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) attached to an electronic endodontic handpiece with torque and speed set as per the manufacturer's recommendations. The crown-down technique was employed. The S1 file was used to prepare the coronal portion of the canal, followed by the SX file to further flare the coronal region. The S1 and S2 files were then used sequentially to the full WL. A new set of rotary instruments was used for each group of teeth.

To simulate instrument separation, an F1 rotary file was notched 3 mm from its tip using a high-speed handpiece and intentionally fractured in the middle third of the canal. The separated fragment was left in place, and the canal was bypassed using hand files. Cleaning and shaping were continued up to size #25.

During instrumentation, canals were irrigated with 10 mL of freshly prepared 5.25% NaOCl delivered using 27-gauge disposable plastic syringe needle tips, placed passively into the canal, allowing irrigation up to the apical 3 mm. Following instrumentation, canals were irrigated with 5 mL of 17% EDTA to remove the smear layer, followed by 5 mL of 2.5% NaOCl. A final rinse of 3 mL normal saline was used, and the canals were dried with sterile paper points.

The teeth were then randomly assigned into four groups (n = 13 in each group), including one control and three experimental groups. Root canal obturation in all groups was performed using the single cone obturation technique. Sealers were delivered into the canals using a lentulo spiral. Radiographs were taken after file separation and after obturation for confirmation.

•Group 1 (Control): Obturated with single gutta-percha cone and Zinc Oxide Eugenol (ZOE) sealer

•Group 2: Obturated with single gutta-percha cone and Sealapex (calcium hydroxide-based) sealer

•Group 3: Obturated with single gutta-percha cone and AH Plus (epoxy resin-based) sealer

•Group 4: Obturated with single gutta-percha cone and Ceraseal (bioceramic-based) sealer

In all groups, a #25 2% gutta-percha master cone was coated with the respective sealer and inserted into the canal to the WL. The excess gutta-percha was removed using a heated instrument, and vertical compaction was performed at the canal orifice. The access cavity was sealed with glass ionomer cement (GC Gold Label, GC Corp, Tokyo, Japan).

All specimens were stored in an incubator at 37°C and 100% humidity for 1 week to ensure complete setting of the sealers. Following incubation, the external root surfaces were coated with two layers of different-colored nail varnish, excluding the apical 4 mm to allow dye penetration only through the apical region.

The specimens were then immersed in 5% methylene blue dye solution for 7 days at 37°C. After dye immersion, the samples were rinsed under tap water for

15 minutes and allowed to dry. Each root was sectioned longitudinally in a bucco-lingual direction from coronal to apical using a diamond disc under water coolant.

Evaluation

The samples were longitudinally sectioned in a bucco-lingual direction from the coronal to apical using a high-speed diamond-coated disc. The sections were then examined under a stereomicroscope at 40X magnification. Stereomicroscopic evaluation was conducted. For each sample, dye penetration was measured in millimeters under the stereomicroscope at 40Xmagnification.

Statistical Analysis

Statistical Package for Social Sciences [SPSS] for Windows Version 23.0 was used to perform statistical analysis. One-way ANOVA Test followed by Bonferroni Post Hoc test was used to compare the mean Apical Micro Leakage Length between 4 groups.

Result

Comparison of different endodontic sealers were analysed using one way ANOVA followed by Bonferroni Post Hoc test. A p value <0.05 was considered statistically significant.

Table 1: Showing one-way Anova for comparison of different endodontic sealers

	N	Mean	Std. Deviation	F value	p value
Group 1 (ZOE)	13	3.1979	.35421	129.724	p<0.001*
Group 2(SEALAPEX)	13	2.4209	.25122		
Group 3 (AH PLUS)	13	1.9381	.21994		
Group 4(CERASEAL)	13	1.3224	.12045		

The table presents measurements for four groups with values expressed as mean ± standard deviation. Group 1 (ZOE) has the highest mean at 3.1979 ± 0.35421, followed by Group 2 (SEALAPEX) at 2.4209 ± 0.25122, Group 3 (AH PLUS) at 1.9381 ± 0.21994, and Group 4 (CERASEAL) with the lowest mean at 1.3224 ± 0.12045.

An F-value of 129.724 with a p-value less than 0.000 indicates statistically significant differences between the groups.

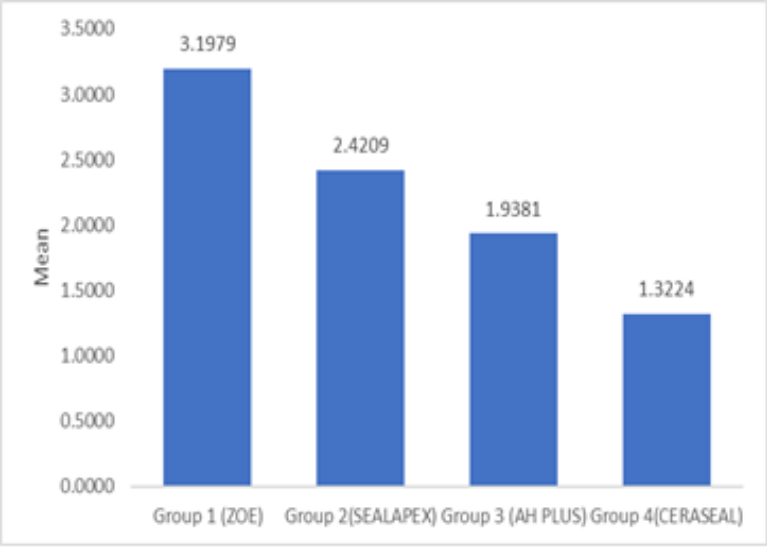

Figure 1: Representing mean of different endodontic sealers

Table 2: Showing multiple comparison in different endodontic sealers

		Mean Difference (I-J)	Std. Error	Sig.	95%Confidence Interval	
					Lower Bound	Upper Bound
Group 1 (ZOE)	Group 2(SEALAPEX)	.77700*	.09834	P<0.001	.5064	1.0476
	Group 3 (AH PLUS)	1.25985*	.09834	P<0.001	.9892	1.5305
	Group 4(CERASEAL)	1.87554*	.09834	P<0.001	1.6049	2.1462
Group 2 (SEALAPEX)	Group 3 (AH PLUS)	.48285*	.09834	P<0.001	.2122	.7535
	Group 4(CERASEAL)	1.09854*	.09834	P<0.001	.8279	1.3692
Group 3 (AH PLUS)	Group 4(CERASEAL)	61569*	.09834	P<0.001	3451	.8863

The pairwise comparisons show significant differences among all groups. Group 1 (ZOE) demonstrated the largest mean differences when compared to Group 2 (0.77700, p = 0.001), Group 3 (1.25985, p = 0.001), and Group 4 (1.87554, p = 0.001). Similarly, Group 2 (SEALAPEX) differed significantly from Group 3 (0.48285, p = 0.001) and Group 4 (1.09854, p = 0.001). Group 3 (AH PLUS) also showed a significant mean difference compared to Group 4 (0.61569, p = 0.001).

Discussion

A hermetic seal throughout the root canal system is a cornerstone of successful endodontic therapy, with the objective of preventing reinfection and promoting periradicular tissue healing. Following thorough biomechanical preparation and disinfection, the quality of obturation, particularly the sealing ability of the filling materials, plays a critical role in long-term prognosis. [17]

A root canal sealer serves as a bonding agent between the root canal walls and the primary root filling material. It fills gaps and seals irregularities in the root canal wall, such as apical ramifications and deltas, along with areas inaccessible to the primary root filling material. [18]

The topic of root canal microleakage is intricate due to the multitude of variables that can impact infiltration. These variables include root filling techniques, the physical and chemical properties of sealers, and the presence or absence of the smear layer. [19]

The smear layer formed during root canal instrumentation serves as a physical barrier, hindering the adaptation and penetration of the sealer into the dentinal tubules. This interference could potentially contribute to an increase in microleakage occurrences. Employing chemically active, adhesive root canal sealers could be pivotal in reducing apical leakage. [20]

In clinical practice, the presence of procedural complications such as separated rotary instruments can pose a significant challenge, especially when they occur in the middle third of the canal. Unlike apical fractures, which may still allow for coronal and middle third debridement, a fractured instrument in the middle third can hinder access to both apical and coronal portions of the canal, thereby potentially affecting cleaning, shaping, and sealing in both directions. [17]

In the present study, an in-vitro comparison of apical microleakage was performed in root canals with a fractured rotary instrument intentionally placed in the middle third of the canal. The canals were obturated using a single-cone technique with four different types of sealers: zinc oxide eugenol (ZOE), calcium hydroxide-based, epoxy resin-based (AH Plus), and bioceramic-based sealers. The middle third was selected for

instrument separation because it represents a clinically relevant zone where instrument fracture frequently occurs due to increased flexural and torsional stresses, especially in curved canals. The obstruction caused by the separated instrument creates a partition within the canal that may impact sealer flow and gutta-percha adaptation, thereby influencing the overall apical seal. [4,21,22,23]

The findings of this study demonstrated that ZOE sealer exhibited the highest level of apical microleakage among the tested groups. This outcome is consistent with previously reported literature, wherein ZOE sealers have shown inferior sealing ability due to their lack of chemical adhesion to dentin and relatively high solubility. The poor performance of ZOE in canals with a fractured file in the middle third can be attributed to its limited flowability and inability to adapt well in anatomically complex or restricted spaces. The physical obstruction posed by the separated instrument may have prevented the sealer from adequately penetrating the apical third, which remained largely inaccessible. Additionally, ZOE's tendency to shrink upon setting may have further exacerbated leakage in these compromised canals. [5,26]

Calcium hydroxide-based sealers demonstrated the next highest microleakage values. While these sealers offer favorable properties such as antimicrobial action, high pH, and the potential to induce apical hard tissue formation, their mechanical characteristics fall short of ideal. In this study, the presence of the separated instrument in the middle third may have acted as a barrier, limiting sealer penetration into the apical region. Calcium hydroxide sealers, being less flowable than bioceramic or resin-based sealers, may have encountered difficulty navigating past the fractured segment to form a homogenous apical seal. Moreover, although some volumetric expansion due to water absorption has been reported with calcium hydroxide sealers, this may not be sufficient to compensate for the voids created by the fractured instrument's obstruction. Consequently, despite their favorable biological properties, calcium hydroxide-based sealers did not perform adequately under the conditions simulated in this study. [23,24,25]

The AH Plus group showed comparatively better sealing ability than the ZOE and calcium hydroxide groups. Epoxy resin-based sealers like AH Plus are known for their excellent physicochemical characteristics, including low solubility, dimensional stability, and effective adhesion to dentinal walls. These properties become particularly advantageous in scenarios where physical continuity within the canal is disrupted, such as the presence of a separated instrument. The superior flow properties of AH Plus may have enabled better penetration past the obstruction, facilitating improved sealing of the apical third. [14,21,26]

Furthermore, AH Plus is capable of forming a strong mechanical interlocking bond with the dentin surface, contributing to its reduced microleakage. Nevertheless, even in the presence of such favorable properties, the overall sealing ability of AH Plus was still inferior to the bioceramic sealer group, underscoring the challenges posed by middle third obstructions. [27,28,29]

The bioceramic sealer group displayed the least apical microleakage among all tested materials. This result reinforces the increasing body of evidence supporting the superior sealing capabilities of bioceramic-based sealers. Their nanometric particle size, hydrophilic nature, and bioactivity allow these materials to penetrate deep into dentinal tubules and to set in the presence of moisture—an attribute particularly relevant in conditions where canal dryness cannot be guaranteed due to anatomical obstructions. The mineral infiltration zone formed by the

sealer's calcium silicate-based composition interacts with dentin to create a bond reinforced by hydroxyapatite formation. In the context of a fractured instrument in the middle third, the bioceramic sealer's capacity to bypass the obstruction and adapt to the apical third is particularly valuable. It is likely that this group benefitted from both enhanced flowability and chemical bonding capabilities, allowing for an effective apical seal despite the segmented canal space. [27,30,38]

Leakage through an obturated canal may occur at several interfaces: between the sealer and dentin, between the sealer and gutta-percha, or within voids in the sealer itself. In this study, the dye penetration method using methylene blue was utilized for microleakage assessment. Although not devoid of limitations, this technique remains a standard in in-vitro studies due to its simplicity, reproducibility, and affordability. The ability of the dye to travel through microscopic pathways allows for a relative comparison of the sealing abilities of different materials, even though it may not perfectly replicate clinical bacterial infiltration. [31,32,33,34]

The influence of the fractured instrument's location is critical to the interpretation of results. While many previous studies focused on instrument separation in the apical third, the middle third represents a unique challenge. It creates a "two-chamber" system—limiting irrigant and sealer access to the apical portion while also potentially affecting coronal compaction. This limitation is significant, as incomplete cleaning and sealing of the apical region are primary contributors to endodontic failure. [36,38,39]

Furthermore, the configuration of the fracture site may influence how obturating materials are compacted and distributed, potentially creating voids or leaving regions unfilled. The effectiveness of the sealer, therefore, becomes paramount in bridging this disrupted canal space and ensuring continuity of the apical seal. [4,17,35]

A point of concern that arises in this context is the role of sealer viscosity and flow dynamics when a physical barrier is present in the canal. The choice of obturation technique plays an equally important role. The single-cone technique, while clinically convenient, may not provide adequate compaction or distribution of sealer when the canal is segmented. Sealer pooling above the obstruction and insufficient apical flow are risks particularly associated with viscous or less flowable sealers like ZOE and calcium hydroxide. In contrast, resin and bioceramic sealers offer improved adaptability due to their thixotropic behavior and better wetting properties, especially under low-stress conditions that mimic passive placement. [38,39,41]

Additionally, the fracture site may introduce stress points within the canal that influence the path of sealer flow. Depending on the morphology and curvature of the canal at the level of instrument separation, the canal space might vary from circular to ovoid to irregular. These variations alter hydraulic dynamics and may lead to void formation if the sealer fails to fill the intricacies effectively. [4,14]

Another critical factor influencing the quality of obturation is the interaction of sealer with intraradicular moisture. In the presence of a fractured file, irrigation and drying become less controlled, and remnants of moisture can either inhibit setting (as with ZOE and resin sealers) or facilitate it (as in bioceramic sealers). This explains why bioceramic sealers may exhibit better performance in these compromised conditions. Moreover, the release of calcium and hydroxide ions by bioceramic sealers promotes a bioactive response, which is likely to induce apatite crystal formation along the

dentin-sealer interface, thereby sealing microgaps that would otherwise serve as leakage pathways. [27,30,42]

From a clinical perspective, the study emphasizes the importance of material selection in cases where a fractured instrument in the middle third cannot be bypassed or removed. When retrieval is not feasible, the priority shifts to maximizing the sealing efficiency of the materials that can work around the obstruction. The clinical success of such cases may depend on choosing sealers that can adapt and set in complex anatomical and moisture-rich environments. As this study suggests, bioceramic sealers, followed by AH Plus, are more suited to such challenges compared to conventional sealers like ZOE and calcium hydroxide.

Several limitations of this study should be acknowledged. Being an in-vitro study, it lacks the physiological complexity of the oral environment, such as blood flow, immune response, and masticatory forces. Moreover, only straight, single-rooted teeth were included, and thus the behavior of obturation materials in curved or multi-rooted teeth with instrument separation may differ. The sample size, though adequate for statistical analysis, may not fully represent the wide range of anatomical variability encountered clinically. Additionally, although the dye penetration method was appropriate for this comparative evaluation, other methods such as bacterial leakage or micro-CT evaluation might offer more comprehensive insights into the sealing efficacy of various materials.[40]

Within the limitations of the current study, it can be concluded that the presence of a separated rotary instrument in the middle third of the canal negatively impacts the sealing ability of root canal filling materials, particularly in their ability to provide an effective apical seal. Among the materials tested, bioceramic sealers showed superior sealing performance, followed by AH Plus, calcium hydroxide-based, and ZOE sealers. These findings suggest that in clinical cases where a fractured instrument remains lodged in the middle third and cannot be retrieved, the choice of a sealer with superior flow, bioactivity, and sealing ability—such as bioceramic sealers—can significantly influence the success of the treatment. Further in-vivo studies and clinical trials are warranted to validate these findings and guide clinical decision-making in the management of complex endodontic cases involving instrument separation.

Conclusion

Within the limitations of this in-vitro study, it can be concluded that the type of endodontic sealer plays a significant role in influencing apical microleakage in root canals with separated rotary instruments, when obturated using the single cone technique.

Among the four sealers evaluated, bioceramic-based Ceraseal exhibited the least apical microleakage, suggesting superior sealing properties, followed by AH Plus, Sealapex, and Zinc Oxide Eugenol (ZOE). The enhanced performance of bioceramic sealers may be attributed to their bioactivity, chemical bonding with dentin, and dimensional stability.

These findings indicate that bioceramic sealers may offer a more favorable outcome in endodontic cases complicated by separated instruments, by providing a more effective apical seal. However, as this was an in-vitro study, further in-vivo and clinical research is warranted to validate these results and assess their long-term clinical relevance.

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