RESEARCH PAPER

Antimicrobial Efficacy of Epoxy Resin- And Silicone-Based Root Canal Sealers Against Persistent Clinical Isolates Following Root Canal Disinfection: An Ex Vivo Comparative Study

Naal W[1]*, Sarkis E[2] and Rihawi J[3]

[1]Master's Student, Department of Endodontics, Faculty of Dentistry, University of Aleppo, Aleppo, Syria.
[2]Professor, Faculty of Dentistry, University of Aleppo, Aleppo, Syria. Alternative
[3]Assistant Professor, Faculty of Dentistry, University of Aleppo, Aleppo, Syria.
[1]Email: ward.naal@alepuniv.edu.sy, [2]Email: Sarkiseliz@alepuniv.edu.sy and [3]Email: rihawij@gmail.com
Corresponding author: Ward Naal; Email: ward.naal@alepuniv.edu.sy

Received: 24th April, 2026; Revised: 20th May 2026; Accepted: 30th June, 2026; Available Online: 10th July, 2026

ABSTRACT

Background: Microorganisms persisting within the root canal system may contribute to persistent infection and treatment failure, highlighting the clinical importance of sealer antimicrobial activity. This study aimed to compare the antibacterial and antifungal activity of epoxy resin-based and silicone-based root canal sealers against clinical microbial isolates persisting after root canal disinfection.

Methods: Twenty microbial samples were obtained from root canals of patients diagnosed with asymptomatic periapical lesions. Samples were cultured on Brain Heart Infusion (BHI) agar for bacterial growth and Sabouraud Dextrose Agar for fungal growth. The agar diffusion test (ADT) was used to assess antimicrobial activity under aerobic and fungal growth conditions at 37 °C for 24 hours. The diameters of inhibition zones surrounding each material were measured to evaluate antimicrobial efficacy.

Results: The epoxy resin-based sealer showed significantly greater antibacterial and antifungal activity than the silicone-based sealer. Mean inhibition zones were 30.95 ± 2.56 mm versus 7.80 ± 5.68 mm for bacterial isolates, and 38.70 ± 2.94 mm versus 14.55 ± 3.07 mm for fungal isolates, respectively. These differences were statistically significant ($p < 0.001$).

Conclusions: Within the limitations of this ex vivo study, the epoxy resin-based sealer exhibited significantly greater antibacterial and antifungal activity than the silicone-based sealer against persistent clinical isolates. These findings indicate that sealer composition may influence antimicrobial performance and warrant further clinical investigation.

Keywords: *Root canal sealers, Antimicrobial activity, Epoxy resin-based sealer, Silicone-based sealer, Antibacterial activity, Antifungal activity, Persistent clinical isolates.*

How to cite this article: Naal W, Sarkis E, Rihawi J., Antimicrobial Efficacy of Epoxy Resin- and Silicone-Based Root Canal Sealers Against Persistent Clinical Isolates Following Root Canal Disinfection: An Ex Vivo Comparative Study. Int J Drug Deliv Technol. 2026;16(7): 1046-1052; DOI: 10.25258/ijddt.16.7.111
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

Eradicating microorganisms from the complex root canal anatomy remains a major challenge in clinical endodontics, even with modern instrumentation and irrigation protocols. Because complete disinfection is difficult to achieve, the antimicrobial property of a root canal sealer is a critical factor that directly influences the success of root canal therapy. The primary goal of treatment is to clean, shape, and obturate the canal system to prevent reinfection [1,2]. When microorganisms and their toxins persist within the root canal, they cause pulpal and periapical pathosis, often leading to chronic, asymptomatic periapical lesions [3,4].

These asymptomatic lesions usually harbor complex microbial biofilms that are highly resistant to routine treatments. Fungi, particularly *Candida albicans*, are frequently isolated from such persistent infections. *C. albicans* can easily colonize the dentinal tubules and form a dense extracellular matrix [5]. This biofilm protects the fungi from the host immune system and intracanal medicaments, making it a key factor in endodontic failures [6]. While traditional culture methods detect fungi in 6.3% to 7.5% of primary and secondary infections, molecular techniques show much higher prevalence rates, reaching up to 16% [7].

**Author for Correspondence: Ward Naal*

Consequently, a root canal sealer should not act merely as a physical barrier. It must possess strong, long-lasting antimicrobial activity to eliminate residual pathogens and prevent nutrient leakage to any surviving bacteria or fungi [8].

Although epoxy resin- and silicone-based sealers are widely used, evidence comparing their antimicrobial activity against persistent clinical isolates remains limited. This study therefore evaluated their antibacterial and antifungal efficacy against persistent clinical isolates recovered from asymptomatic periapical lesions after standardized chemomechanical disinfection and intracanal medication, enhancing the clinical relevance of the findings.

MATERIALS AND METHODS

Study Design

This ex vivo experimental study was conducted to evaluate and compare the antimicrobial efficacy of epoxy resin–based and silicone-based root canal sealers against microorganisms isolated from infected root canals. The study assessed the antibacterial activity of the tested sealers under aerobic conditions, as well as their antifungal activity, using standardized experimental procedures.

Sample Collection

Ethical approval and informed consent

The study protocol was approved under the official authorization of the Presidency of the University of Aleppo, Decision No. (3404), and the Directorate of Scientific Research and the Faculty of Dentistry, Decision No. (1862). Written informed consent was obtained from all participants before clinical sample collection, which was performed as part of the approved study procedures.

Twenty microbial samples were collected from the permanent molars of patients diagnosed with asymptomatic periapical lesions at the Dental Clinics of the Faculty of Dentistry, University of Aleppo. Patients with systemic diseases or those who had received antibiotic therapy within the preceding three months were excluded.

Following informed consent, teeth were isolated using a rubber dam. After caries removal and access cavity preparation, the working length was established. Canals were instrumented with stainless steel K-files (sizes #10 to #25, 2% taper) and shaped using UDG Gold nickel-titanium rotary files (sizes #20 and #25, 4% taper). Standard chemical disinfection was performed using 5.25% sodium hypochlorite between file changes, followed by a final rinse with 0.9% sterile saline.

A calcium hydroxide intracanal medicament was then placed in the canals for seven days.

Microbial Sampling

Following removal of the intracanal medicament using H-files and activation of irrigation with 5.25% sodium hypochlorite, the canals were finally rinsed with 5% sodium thiosulfate solution to neutralize any residual sodium hypochlorite, followed by sterile saline (0.9% NaCl) to eliminate any remaining irrigant that might interfere with microbial growth during culturing.

Persistent microbial samples surviving the disinfection protocol were collected using five sterile paper points (size 25/04) inserted to the working length of each canal for one minute to absorb intracanal fluids.

The paper points were immediately transferred into sterile syringes containing 2 mL of sterile physiological saline and labeled according to the sample number. All samples were transported to the Microbiology Laboratory of the Faculty of Dentistry, University of Aleppo within 30 minutes under sterile conditions to prevent contamination.

Preparation of Culture Media

Brain Heart Infusion (BHI) agar was used for bacterial culture, while Sabouraud Dextrose Agar was used for fungal culture. The culture media were prepared according to the manufacturer's instructions by dissolving 50 g of BHI powder in 1000 mL of distilled water and 65 g of Sabouraud Dextrose Agar in 1000 mL of distilled water. The mixtures were heated and stirred until complete dissolution.

The prepared media were sterilized in an autoclave at 121°C for 15 minutes under a pressure of 15 psi. After sterilization, the media were allowed to cool to approximately 40–45°C before being poured into sterile plastic Petri dishes at a volume of 15–20 mL per plate. The plates were left to solidify before use.

Experimental Groups

The agar plates were divided into two experimental groups according to the type of root canal sealer tested:

1. **Group 1:** Epoxy resin-based sealer (ADSEAL; Meta Biomed, Cheongju, Korea)
2. **Group 2:** Silicone-based sealer (Root-Sil; B&E Bio-materials, Gyeonggi-do, Korea)

For each of the 20 clinical microbial isolates, four Petri dishes were prepared: two containing brain heart infusion (BHI) agar for antibacterial testing and two containing Sabouraud dextrose agar (SDA) for antifungal testing. Thus, each sealer was evaluated on one bacterial and one fungal culture plate for each clinical isolate.

Sterile Petri dishes with a diameter of **90 mm** were used. A standardized central well, measuring **6 mm in diameter and 3 mm in depth**, was punched into each agar plate. Each plate contained a single well to prevent potential overlap or interference between inhibition zones and to allow standardized assessment of the antimicrobial activity of each sealer.

Microbial Inoculation and Incubation

A volume of 100 µL of the microbial suspension was inoculated onto the prepared agar plates and evenly spread

using a sterile bent glass rod to ensure uniform distribution across the agar surface.

Freshly mixed root canal sealers were immediately placed into the central wells of the plates. The plates were left at room temperature for approximately 15 minutes to allow initial diffusion of the materials into the agar.

Plates containing only the culture medium, without the addition of any sealer or microbial suspension, were used as a negative control to ensure the absence of contamination during the preparation of the culture media and throughout the incubation period.

Plates designated for bacterial and fungal growth were incubated at 37°C for 24 hours.

After incubation, the plates were removed from the incubator and the diameters of microbial inhibition zones surrounding the wells were measured from the center of the sealer material using a sterile millimeter ruler. The inhibition zone diameters were recorded for all samples (Figure 1 and 2).

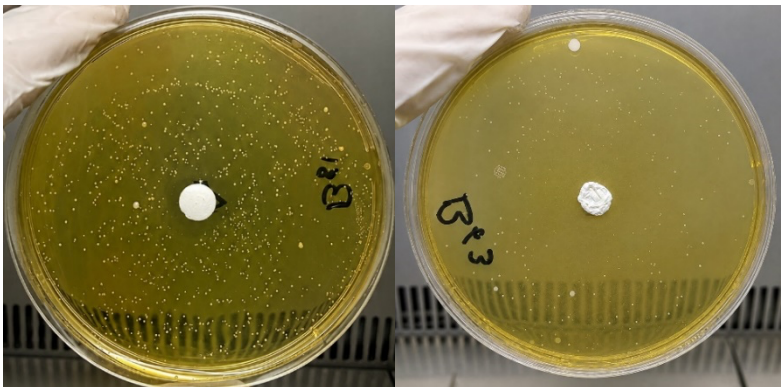

Figure 1: Bacterial colonies on Petri dishes containing the tested root canal sealers after incubation.

A (left): Plate containing the silicone-based sealer; B (right): Plate containing the epoxy resin-based sealer

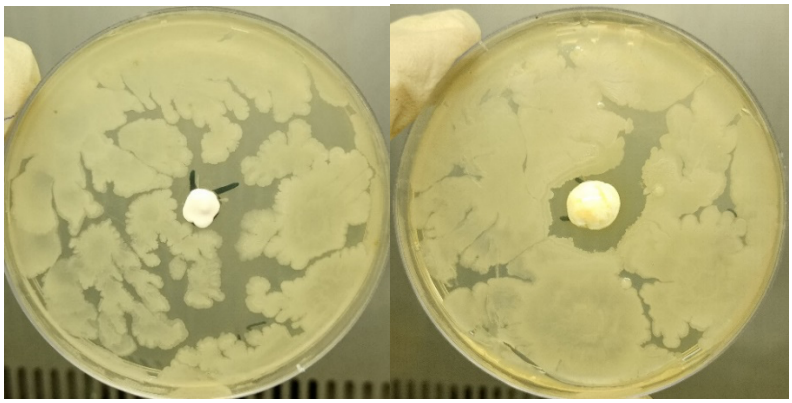

Figure 2: Fungal colonies on Petri dishes containing the tested root canal sealers after incubation.

A (left): Plate containing the silicone-based sealer; B (right): Plate containing the epoxy resin-based sealer.

Statistical Analysis

Data were analyzed using IBM® SPSS® software (version 26.0; IBM Corp., Armonk, NY, USA). The normality of the inhibition zone diameter data was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. For the comparison between the epoxy resin–based sealer (ADSEAL) and the silicone-based sealer (Root-Sil), one-way analysis of variance (ANOVA) was used. Statistical significance was set at $p < 0.05$.

RESULTS

Normality Testing

The normality of the data distribution was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The results indicated that the inhibition zone diameter data for both sealer groups did not significantly deviate from a normal distribution ($p > 0.05$). Therefore, parametric statistical tests were considered appropriate for further analysis.

Antibacterial Activity

The epoxy resin–based sealer (ADSEAL) demonstrated substantially greater antibacterial activity than the silicone-based sealer (Root-Sil). The mean inhibition zone diameter was 30.95 ± 2.56 mm for ADSEAL, compared

with 7.80 ± 5.68 mm for Root-Sil. The corresponding ranges were 27–36 mm and 0–18 mm, respectively.

One-way ANOVA demonstrated a statistically significant difference in the mean inhibition-zone diameters between the two sealer groups (F = 275.908, p < 0.001). ADSEAL produced a significantly larger inhibition zone than Root-Sil, with a mean difference of 23.15 mm. Thus, ADSEAL exhibited significantly greater antibacterial activity than Root-Sil against the aerobic and facultative bacterial isolates. The order of antibacterial effectiveness was therefore: ADSEAL > Root-Sil (Figure 3).

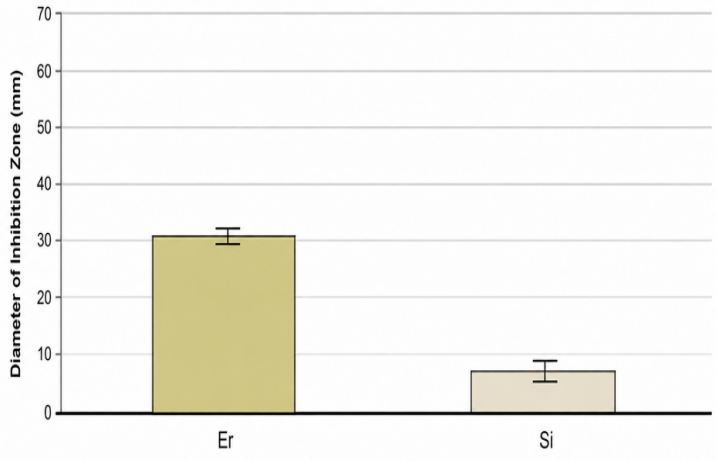

Figure 3: Effectiveness of both root canal sealers against bacteria

Table 1: Antibacterial activity of ADSEAL and Root-Sil

Sealer	N	Mean inhibition zone ± SD (mm)	Mean Difference (mm)	*F*	*p*-Value
ADSEAL	20	30.95 ± 2.56	23.15	275.908	<0.001
Root-Sil	20	7.80 ± 5.68	—	—	—

One-way ANOVA demonstrated a statistically significant difference between the two sealer groups (F = 275.908, p < 0.001).

Antifungal Activity

A marked difference in antifungal activity was also observed between the epoxy resin–based and silicone-based sealers. ADSEAL produced a mean inhibition zone diameter of 38.70 ± 2.94 mm, whereas Root-Sil produced a substantially smaller mean inhibition zone of 14.55 ± 3.07 mm. The observed ranges were 33–44 mm for ADSEAL and 9–20 mm for Root-Sil.

One-way ANOVA demonstrated a statistically significant difference in the mean inhibition-zone diameters between the two sealer groups (**F = 645.788, p < 0.001**). ADSEAL produced a significantly larger inhibition zone than Root-Sil, with a mean difference of **24.15 mm**. Thus, ADSEAL exhibited significantly greater antifungal activity than Root-Sil against the fungal clinical isolates. The order of antifungal effectiveness was therefore: **ADSEAL > Root-Sil** (Figure 4).

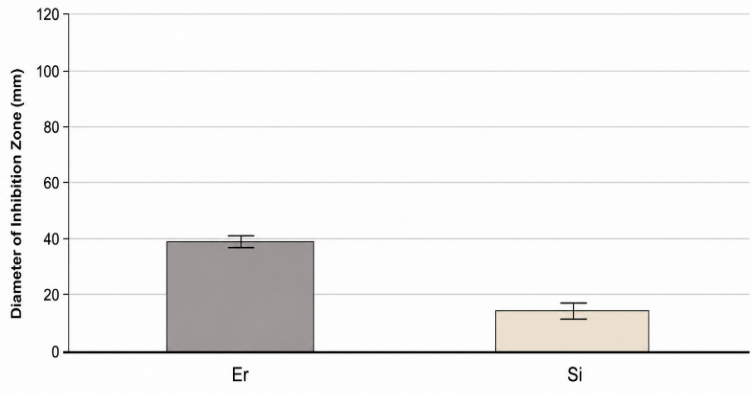

Figure 4: Effectiveness of both root canal sealers against fungi

Table 2: Antifungal activity of ADSEAL and Root-Sil

Sealer	N	Mean inhibition zone ± SD (mm)	Mean Difference (mm)	*F*	*p*-Value
ADSEAL	20	38.70 ± 2.94	24.15	645.788	<0.001
Root-Sil	20	14.55 ± 3.07	—	—	—

One-way ANOVA demonstrated a statistically significant difference between the two sealer groups ($F = 645.788$, $p < 0.001$).

DISCUSSION

This study demonstrated a clear difference in antimicrobial performance between epoxy resin-based sealer (ADSEAL) and silicone-based sealer (Root-Sil), against persistent clinical isolates. ADSEAL showed substantially greater antibacterial and antifungal activity, whereas Root-Sil exhibited consistently limited antimicrobial effects. These findings suggest that sealer composition strongly influences antimicrobial performance, while the use of clinical isolates persisting after chemomechanical disinfection and calcium hydroxide therapy enhances the clinical relevance of the results. In clinical scenarios, residual pathogens within complex anatomical configurations or dentinal tubules often drive secondary endodontic infections and treatment failures [9]. Consequently, utilizing an obturation material with sustained antimicrobial properties is essential to suppress these remaining microorganisms and prevent reinfection [10].

Clinical Relevance and Methodological Variations

Using clinical microbial isolates directly harvested from refractory root canals, rather than standardized laboratory reference strains, provides high clinical relevance to our experimental model. The inhibition zones recorded in this study were likely modulated by the specific nature of these clinical strains and the prior chemomechanical disinfection and intracanal medicaments. These procedural steps naturally reduce the baseline microbial load compared to high-density, standardized laboratory inocula. Consequently, variations in inhibition zone measurements between our findings and previous literature can be largely attributed to these distinct methodological differences.

This approach is critical because, as demonstrated by Lin and Siqueira et al., significant portions of the root canal anatomy remain uninstrumented during mechanical preparation, regardless of the instrumentation system or technique employed [11]. Therefore, root canal obturation must rely on the sustained antimicrobial activity of the sealer to entomb and eliminate these residual pathogens [12]. This is particularly vital against facultative anaerobes and resistant species like Enterococcus faecalis and Candida albicans, which are frequently implicated in persistent periapical lesions and endodontic treatment failures [13–15]. Among these, C. albicans remains the most prevalent fungal pathogen isolated from refractory cases, owing to its ability to survive within uninstrumented canal spaces [14,15].

Methodological Rationale and Experimental Parameters

The agar diffusion test was employed in this study because it remains a standardized, widely accepted method for evaluating the baseline antimicrobial efficacy of endodontic materials [16]. The diameters of the microbial inhibition zones were recorded after 24 hours of incubation, aligning with established protocols [17]. This specific timeframe is critical because most endodontic sealers exert their maximum antimicrobial activity during their setting phase within the first 24 hours, followed by a marked decline at 48 and 72 hours as the material stabilizes and diffusion rates diminish [18].

Calcium hydroxide was used as an intracanal medicament prior to the sampling stage because it is one of the most widely used intracanal medications. Calcium hydroxide has been extensively used in dentistry since the 1920s and is currently considered the most widely used intracanal medicament worldwide[19]. It exhibits strong antimicrobial activity primarily because of its high pH, and it can disrupt protein integrity through the release of hydroxyl ions. Consequently, calcium hydroxide can effectively eliminate most of the predominant pathogens encountered in endodontic treatment when used as an intracanal medicament [20].

A 5.25% sodium hypochlorite solution was used as the irrigant because it is one of the most commonly employed irrigation solutions in endodontic treatment [21]. In addition to its antimicrobial activity, sodium hypochlorite facilitates the dissolution of vital and necrotic pulp tissues, enhances the lubricity of instruments along the root canal walls, and assists in the removal of dentinal debris from the root canal system [22].

Comparative Antimicrobial Activity and Literature-Based Interpretation of Epoxy Resin- and Silicone-Based Root Canal Sealers

In the present study, the epoxy resin-based sealer ADSEAL (Meta Biomed) demonstrated greater antimicrobial activity than the silicone-based sealer Root-Sil, indicating a more favorable antimicrobial profile under the conditions of the present study. This finding may be attributed, at least in part, to the antimicrobial effects of its principal constituents and the by-products generated during the setting reaction. ADSEAL is a two-component sealer consisting of a base and a catalyst, with the base composed primarily of bisphenol A diglycidyl ether [23], a compound reported to possess mutagenic properties [24]. During the setting reaction, small amounts of formaldehyde may be released. Formaldehyde can interact

with bacterial proteins, DNA, and RNA, thereby exerting detrimental effects on Enterococcus faecalis [25].

One study demonstrated strong antibacterial activity of an epoxy resin-based sealer, accompanied by a marked reduction in bacterial cell proliferation [26]. Similarly, Saleh et al. reported that the epoxy resin-based sealer was capable of eliminating all bacterial species present within dentinal tubules [27].

In contrast, the relatively weak antimicrobial and antifungal activity observed for the silicone-based sealer (Root-Sil) in the present study is broadly consistent with previous findings. Saleh et al. [27] reported limited antibacterial activity of a silicone-based sealer, whereas Huang et al. [28] detected no antibacterial or antifungal activity against *Candida albicans* when the material was evaluated using either the agar diffusion or direct contact test. Likewise, Slutzky-Goldberg et al. [29] found no antibacterial activity of the silicone-based sealer when several root canal sealers were tested against bacterial species.

Furthermore, the present findings are in agreement with a previous comparative study demonstrating greater antibacterial activity of an epoxy resin-based sealer than that of a silicone-based sealer [30]. Consistent with these observations, Raju et al. [31] reported that the silicone-based sealer produced no inhibition zones when assessed using the agar diffusion method. Similarly, Özcan et al. [32] found no antifungal activity for the silicone-based sealer using the direct contact test, with assessments performed at 24, 48, and 72 hours.

CONCLUSION

Within the limitations of this study, the epoxy resin-based sealer (ADSEAL) demonstrated significantly greater antibacterial and antifungal activity than the silicone-based sealer (Root-Sil) against bacterial and fungal isolates that survived standard chemomechanical preparation and intracanal medicaments. In contrast, Root-Sil exhibited limited antimicrobial activity against both bacterial and fungal isolates. These findings indicate that the chemical composition of root canal sealers may substantially influence their antimicrobial performance, with ADSEAL showing a more favorable antimicrobial profile under the conditions of the present study. Further well-designed clinical studies are warranted to determine whether these in vitro findings translate into clinically relevant antimicrobial effects in the complex endodontic environment.

ACKNOWLEDGEMENTS

Nil.

SOURCE OF SUPPORT

Nil.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Fadhil NH, Ali AH, AL-HASHIMI RA, Al-Qathi OS, Foschi F. Assessment of treatment quality risk factors influencing the radiographic detection of apical periodontitis in root-filled teeth: a retrospective CBCT analysis. European endodontic journal. 2024;9(3):252.
2. Pandey P, Aggarwal H, Tikku A, Singh A, Bains R, Mishra S. Comparative evaluation of sealing ability of gutta percha and resilon as root canal filling materials-a systematic review. Journal of Oral Biology and Craniofacial Research. 2020;10(2):220-6.
3. Alves M, Grenho L, Lopes C, Borges J, Vaz F, Vaz I, et al. Antibacterial effect and biocompatibility of a novel nanostructured ZnO-coated gutta-percha cone for improved endodontic treatment. Materials Science and Engineering: C. 2018;92:840-8.
4. Long J, Kreft J-U, Camilleri J. Antimicrobial and ultrastructural properties of root canal filling materials exposed to bacterial challenge. Journal of Dentistry. 2020;93:103283.
5. Karamifar K, Tondari A, Saghiri MA. Endodontic periapical lesion: an overview on the etiology, diagnosis and current treatment modalities. European endodontic journal. 2020;5(2):54.
6. Gomes C, Fidel S, Fidel R, de Moura Sarquis MI. Isolation and taxonomy of filamentous fungi in endodontic infections. Journal of endodontics. 2010;36(4):626-9.
7. Alberti A, Corbella S, Taschieri S, Francetti L, Fakhruddin KS, Samaranayake LP. Fungal species in endodontic infections: A systematic review and meta-analysis. PLoS One. 2021;16(7):e0255003.
8. Kapralos V, Koutroulis A, Ørstavik D, Sunde PT, Rukke HV. Antibacterial activity of endodontic sealers against planktonic bacteria and bacteria in biofilms. Journal of endodontics. 2018;44(1):149-54.
9. Anumula L, Kumar S, Kumar VS, Sekhar C, Krishna M, Pathapati RM, et al. An assessment of antibacterial activity of four endodontic sealers on Enterococcus faecalis by a direct contact test: an in vitro study. International Scholarly Research Notices. 2012;2012(1):989781.
10. Dagna A, Colombo M, Poggio C, Russo G, Pellegrini M, Pietrocola G, et al. In vitro antibacterial activity of different bioceramic root canal sealers. Ceramics. 2022;5(4):901-7.
11. Lin LM, Pascon EA, Skribner J, Gängler P, Langeland K. Clinical, radiographic, and histologic study of endodontic treatment failures. Oral surgery, oral medicine, oral pathology. 1991;71(5):603-11.

12. Peters L, Wesselink P, Moorer W. The fate and the role of bacteria left in root dentinal tubules. International endodontic journal. 1995;28(2):95-9.

13. Yasuda Y, Kamaguchi A, Saito T. In vitro evaluation of the antimicrobial activity of a new resin-based endodontic sealer against endodontic pathogens. Journal of oral science. 2008;50(3):309-13.

14. Fujii R, Saito Y, Tokura Y, Nakagawa KI, Okuda K, Ishihara K. Characterization of bacterial flora in persistent apical periodontitis lesions. Oral microbiology and immunology. 2009;24(6):502-5.

15. Waltimo T, Siren E, Torkko H, Olsen I, Haapasalo M. Fungi in therapy-resistant apical periodontitis. International Endodontic Journal. 1997;30(2):96-101.

16. Vibha H, Rathod R. Assessment of antimicrobial efficacy of bioceramic sealer, Epiphany self-etch sealer, and AH Plus sealer against Enterococcus faecalis: an in vitro study. Endodontology. 2017;29(2):151-5.

17. Castillo-Villagomez P, Madla-Cruz E, Lopez-Martinez F, Rodriguez-Delgado I, Flores-Treviño JJ, Malagon-Santiago GI, et al. Antimicrobial effectiveness of root canal sealers against Enterococcus faecalis. Biomaterial Investigations in Dentistry. 2022;9(1):47-51.

18. Pallavi P, Bansal A, Kukreja N, Kaur N, Chhabra S, Ahuja J. Comparative evaluation of antimicrobial efficacy of different endodontic sealers against Enterococcus Faecalis: An in-vitro study. International Journal of Health Sciences. 2022(I):9838-45.

19. Tang G, Samaranayake LP, Yip HK. Molecular evaluation of residual endodontic micro-organisms after instrumentation, irrigation and medication with either calcium hydroxide or Septomixine. Oral Dis. 2004;10(6):389-397. doi:10.1111/j.1601-0825.2004.01015.x.

20. Delgado RJR, Gasparoto TH, Sipert CR, Pinheiro CR, de Moraes IG, Garcia RB, et al. Antimicrobial activity of calcium hydroxide and chlorhexidine on intratubular Candida albicans. Int J Oral Sci. 2013;5(1):32-36. doi:10.1038/ijos.2013.12.

21. Torabinejad M, Fouad AF, Walton RE. Endodontics: Principles and Practice. 5th ed. St. Louis, MO: Elsevier Saunders; 2014. p. 278, 322-323.

22. Iandolo A, Amato M, Dagna A, Poggio C, Abdellatif D, Franco V, et al. Intracanal heating of sodium hypochlorite: scanning electron microscope evaluation of root canal walls. J Conserv Dent. 2018;21(5):569-573. doi:10.4103/JCD.JCD_245_18.

23. Komabayashi T, Colmenar D, Cvach N, Bhat A, Primus C, Imai Y. Comprehensive review of current endodontic sealers. Dent Mater J. 2020;39(5):703-720. doi:10.4012/dmj.2019-288.

24. Heil J, Reifferscheid G, Waldmann P, Leyhausen G, Geurtsen W. Genotoxicity of dental materials. Mutat Res. 1996;368(3-4):181-194. doi:10.1016/S0165-1218(96)90060-9.

25. Shin JH, Lee DY, Lee SH. Comparison of antimicrobial activity of traditional and new developed root sealers against pathogens related root canal. J Dent Sci. 2018;13(1):54-59. doi:10.1016/j.jds.2017.10.007.

26. Willershausen I, Callaway A, Briseño B, Willershausen B. In vitro analysis of the cytotoxicity and the antimicrobial effect of four endodontic sealers. Head Face Med. 2011;7:15. doi:10.1186/1746-160X-7-15.

27. Saleh IM, Ruyter IE, Haapasalo M, Ørstavik D. Survival of Enterococcus faecalis in infected dentinal tubules after root canal filling with different root canal sealers in vitro. Int Endod J. 2004;37(3):193-198. doi:10.1111/j.0143-2885.2004.00785.x.

28. Huang Y, Li X, Mandal P, Wu Y, Liu L, Gui H, Liu J. The in vitro antimicrobial activities of four endodontic sealers. BMC Oral Health. 2019;19(1):118. doi:10.1186/s12903-019-0817-2.

29. Slutzky-Goldberg I, Slutzky H, Solomonov M, Moshonov J, Weiss EI, Matalon S. Antibacterial properties of four endodontic sealers. J Endod. 2008;34(6):735-738. doi:10.1016/j.joen.2008.03.012.

30. Shakya VK, Gupta P, Tikku AP, Pathak AK, Chandra A, Yadav RK, et al. An in vitro evaluation of antimicrobial efficacy and flow characteristics for AH Plus, MTA Fillapex, CRCS and GuttaFlow 2 root canal sealers. J Clin Diagn Res. 2016;10(8):ZC104-ZC108. doi:10.7860/JCDR/2016/20885.8351.

31. Raju A, Jindal N, Aggarwal R, Kaur A, Choudhary M. Comparing and evaluating the antimicrobial efficacy of endodontic root canal sealers against Enterococcus faecalis, Staphylococcus aureus, and Candida albicans at 24, 48, and 72 h: an in vitro study. Indian J Dent Sci. 2023;15(3):125-129. doi:10.4103/ijds.ijds_124_22.

32. Özcan E, Yula E, Arslanoğlu Z, İnci M. Antifungal activity of several root canal sealers against Candida albicans. Acta Odontol Scand. 2013;71(6):1481-1485. doi:10.3109/00016357.2013.771405.