Apical Leakage of Bioceramic versus Epoxy Resin–Based Sealers in Single-Cone Obturation: A Systematic Review and Meta-Analysis

Vikri Sandya Dhika[1], Veriantara Satya Dhika[2]

[1] *Department of Conservative Dentistry, Guntur Hospital, Indonesia*
[2] *Master of Hospital Administration Program, Universitas Esa Unggul, Indonesia*

Citation: Dhika, V. S., & Dhika, V. S. 2026. Apical Leakage of Bioceramic versus Epoxy Resin–Based Sealers in Single-Cone Obturation: A Systematic Review and Meta-Analysis. *Medicinus*, 15(3), 93–103.
Keywords: Apical leakage; bioceramic sealer; epoxy resin sealer; single-cone obturation
Correspondance: Vikri Sandya Dhika
E-mail: vikrisandya@gmail.com
Online First: 20 July 2026

Abstract

Background:
Bioceramic sealers paired with the single-cone obturation technique represent an evolving clinical paradigm, yet no systematic review has exclusively evaluated their apical sealing performance against epoxy resin–based sealers within this specific technique. This study aimed to systematically compare the in vitro apical leakage of bioceramic versus epoxy resin–based sealers used with single-cone obturation in extracted human teeth.

Methods:
A systematic search of PubMed, Embase, and Scopus was conducted from inception to 1 April 2026, following PRISMA 2020 guidelines. Only English-language publications were included. In vitro and ex vivo studies comparing apical leakage between bioceramic and epoxy resin sealers with at least one single-cone obturation group were included. Risk of bias was assessed using the QUIN tool. Standardized mean differences were pooled using a random-effects model for studies reporting comparable continuous leakage data.

Result:
Eight studies met the inclusion criteria. Five were rated as low risk of bias and three as medium risk. Meta-analysis of four studies with continuous leakage data (n = 77 per group) yielded a pooled SMD of −1.75 (95% CI: −3.92 to 0.42), favoring bioceramic sealers, though heterogeneity was considerable (I^2 = 88.1%). Narrative synthesis of the remaining four studies showed directionally consistent trends supporting bioceramic sealers across bacterial leakage and nanoleakage methodologies.

Conclusions:
Bioceramic sealers demonstrated a trend toward less apical leakage than epoxy resin–based sealers with single-cone obturation; however, evidence certainty remains low due to high heterogeneity and limited study numbers. Standardized multicenter in vitro studies and long-term clinical trials are warranted.

Introduction

Root canal obturation aims to achieve a three-dimensional hermetic seal that prevents reinfection of the root canal system by eliminating communication between the periapical tissues and the oral cavity.[1,2] The quality of this seal is a critical determinant of endodontic treatment success, with incomplete obturation identified as a leading cause of treatment failure. Root canal sealers play an essential role in this process by filling the interface between the core material and the dentinal wall, compensating for the inherent inability

of gutta-percha to bond to root canal dentin.[2]

Epoxy resin–based sealers, most notably AH Plus (Dentsply Sirona), have long been regarded as a clinical benchmark due to their favorable physicochemical properties, dimensional stability, and well-documented bonding to root dentin through covalent interaction with exposed collagen.[3] However, these sealers set through a polymerization reaction that can result in slight shrinkage, and their performance is potentially compromised in the presence of residual moisture.[4–6]

In recent years, bioceramic-based sealers have emerged as a promising alternative. These calcium silicate–based materials, including EndoSequence BC Sealer, TotalFill BC Sealer, CeraSeal, BioRoot RCS, and Endoseal MTA, are hydrophilic and require moisture to initiate their setting reaction, theoretically converting a clinical limitation into an advantage.[7,8] Their slight setting expansion, bioactivity through hydroxyapatite formation, high alkaline pH conferring antimicrobial properties, and excellent flow characteristics have generated considerable interest. Manufacturers recommend the use of these sealers with the single-cone obturation technique.[9]

The single-cone technique has gained renewed clinical relevance alongside bioceramic sealers, shifting the traditional obturation philosophy from maximizing gutta-percha volume to relying on a bioactive sealer to achieve the apical seal.[10] However, the evidence regarding whether bioceramic sealers truly provide superior apical sealing compared to epoxy resin–based sealers when used in this specific technique remains inconsistent. Individual in vitro studies have reported conflicting findings depending on the sealer brand, leakage assessment method, canal morphology, and observation period.

A previous systematic review and meta-analysis by Rekha et al. (2023) compared the sealing ability of bioceramic versus epoxy resin sealers across all obturation techniques, finding no significant overall difference.[11] However, that review pooled studies using lateral condensation, continuous wave compaction, and single-cone obturation together, potentially masking technique-specific effects. Other systematic reviews by Elmsmari et al. (2025) and Dewi et al. (2025) focused on clinical and radiographic outcomes of randomized controlled trials rather than laboratory-based leakage outcomes.[12,13] To date, no systematic review has specifically isolated the single-cone obturation technique to evaluate whether bioceramic sealers offer a measurable advantage in apical leakage over epoxy resin–based sealers in controlled laboratory settings. Therefore, the aim of this systematic review and meta-analysis is to critically appraise and synthesize the available in vitro and ex vivo evidence comparing apical leakage between bioceramic and epoxy resin–based root canal sealers when used exclusively with the single-cone obturation technique.

Method

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (PROSPERO: CRD420261368916).[14] We did not receive any financial assistance to conduct this study.

The eligibility criteria were established a priori according to the PICO framework. Studies were considered eligible if they employed an in vitro or ex vivo laboratory design, used extracted human permanent teeth with fully formed apices, and included at least one experimental group obturated using the single-cone technique with a bioceramic-based sealer. Eligible bioceramic sealers included calcium silicate–based materials such as EndoSequence BC Sealer, TotalFill BC Sealer, CeraSeal, BioRoot RCS, Endoseal MTA, Bio-C Sealer, Cerafill RCS, or equivalent products. To be included, studies were also required to contain a comparator group using an epoxy resin–based sealer, such as AH Plus, AH Plus Jet, ADSeal, or an equivalent material, applied with the single-cone technique or reported in a way that allowed extraction of single-cone

subgroup data. In addition, studies had to report a quantitative outcome related to apical leakage or microleakage using a validated laboratory method, including dye penetration, bacterial leakage, fluid filtration, glucose penetration, or micro-computed tomography analysis of apical voids or gaps. Studies were excluded if they were conducted on bovine, artificial, acrylic, or simulated teeth; if they used obturation techniques other than single-cone without reporting separate extractable data for the single-cone subgroup; if they did not include both a bioceramic and an epoxy resin–based sealer group; if they evaluated outcomes unrelated to apical leakage, such as push-out bond strength, solubility, or biocompatibility alone; if they were reviews, case reports, editorials, opinion articles, or conference abstracts without full text; or if they were not published in English.

A comprehensive electronic search was conducted in PubMed/MEDLINE, Embase via Ovid, and Scopus from database inception to 1 April 2026. No restrictions on publication date or language were applied during the initial database search, although studies published in languages other than English were excluded during the screening process. The search strategy combined controlled vocabulary, where applicable, with free-text terms related to bioceramic sealers, epoxy resin–based sealers, single-cone obturation, and apical leakage outcomes. The PubMed strategy was developed using Boolean operators and was subsequently adapted to match the indexing terms and syntax of Embase and Scopus. In addition to the electronic search, the reference lists of all included studies and relevant systematic reviews were manually screened to identify any additional eligible articles. Grey literature was not searched.

All identified records were exported to reference management software, and duplicate entries were removed before screening. Two reviewers independently assessed titles and abstracts for potential eligibility. Full texts of potentially relevant studies were then retrieved and independently evaluated by the same reviewers against the predefined inclusion and exclusion criteria. Any disagreements arising during title and abstract screening or full-text assessment were resolved through discussion, and where necessary, a third reviewer was consulted to reach consensus. The entire study selection process was documented using a PRISMA 2020 flow diagram, which recorded the number of records identified, screened, excluded, and ultimately included, together with reasons for exclusion at the full-text stage.

Data extraction was carried out independently by two reviewers using a standardized and pilot-tested data extraction form. The extracted data included study characteristics such as first author, year of publication, and country, as well as methodological and experimental details including sample size per group, tooth type, root canal preparation system, final apical size, type of bioceramic sealer, type of epoxy resin–based sealer, and the type of gutta-percha cone used, whether conventional or bioceramic-coated. Information related to the leakage assessment method, observation period, outcome measurements, and principal findings was also collected. Quantitative results were extracted as means and standard deviations whenever available, while medians and interquartile ranges were recorded when these were the only reported summary measures. In cases where data were missing, incomplete, or unclear, the corresponding authors were contacted by email on up to two occasions. Any discrepancies between the two reviewers during data extraction were resolved by discussion and consensus.

The methodological quality of the included studies was assessed using the QUIN tool, a quality assessment instrument specifically developed for in vitro studies in dentistry. This tool was selected because it is more appropriate for laboratory-based research than risk-of-bias tools designed for randomized clinical trials or observational clinical studies. The QUIN tool evaluates whether studies clearly report their aims, sample size calculation, sampling technique, comparison groups, methodological details, operator

information, randomization procedures, outcome measurement methods, blinding of outcome assessors, statistical analyses, presentation of results, and whether the conclusions are supported by the findings. Each domain is scored as adequately specified, inadequately specified, or not specified, corresponding to scores of 2, 1, and 0, respectively. The overall score is then converted into a percentage and used to classify studies as having low, moderate, or high risk of bias. Two reviewers independently performed the quality assessment, and any disagreements were settled through discussion.

Results

Study selection

Figure 1 shows the study selection process: 631 records were identified through database searching, including PubMed (n = 231), EMBASE (n = 204), and Scopus (n = 196). After removal of 22 duplicate records, 609 records remained for screening. Of these, 577 were excluded, leaving 32 reports sought for retrieval; all 32 were successfully retrieved and assessed for eligibility. During full-text review, 24 reports were excluded for the following reasons: literature review, narrative review, or existing systematic review (n = 3); devious teeth (n = 5); multi-rooted teeth where canals were not isolated or sectioned into single-canal segments (n = 7); and study evaluators' root-end filling materials (n = 9). Ultimately, 8 studies were included in the review.[15–22]

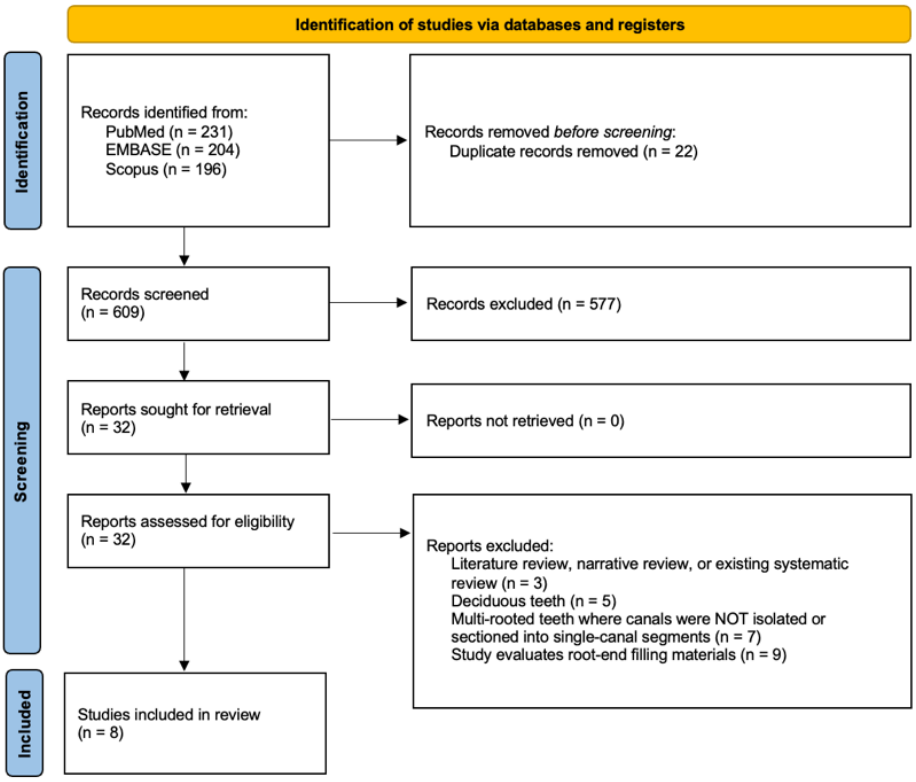

Figure 1. PRISMA 2020 flow diagram.

Study Characteristics

The eight included studies were published between 2018 and 2025 and originated from six countries (India, Iran, Egypt, Thailand, Czech Republic, and Saudi Arabia). The demographic characteristics of included literature is presented in table 1. Sample sizes per group ranged from 5 to 30 teeth. Five studies employed dye-penetration techniques, two used bacterial-leakage models with dual-chamber assemblies, and one assessed

nanoleakage via silver-nitrate tracer penetration under scanning electron microscopy. Bioceramic sealers tested included EndoSequence BC, CeraSeal, BioRoot RCS, TotalFill BC, Well Root ST, Sure-Seal Root BC, TotalFill BC HiFlow, and MTA Fillapex, while the epoxy resin–based comparators were AH Plus, AH-Plus, and AdSeal. All four meta-analysed studies used single-cone obturation in both experimental and control arms, thereby eliminating obturation technique as a confounder. Risk-of-bias assessment using the modified QUIN tool classified five studies as low risk and three as medium risk (Table 2).

Among the bacterial-leakage studies, Tour Savadkouhi et al. (2020) reported that Well Root ST exhibited the lowest leakage rate (33.3%) compared with AH-Plus (40%), AdSeal (53.3%), and MTA Fillapex (66.6%) over 90 days, although only the difference between Well Root ST and MTA Fillapex reached statistical significance (P = 0.02).[21] Yanpiset et al. (2018) found no significant difference among four cone–sealer combinations (TotalFill BC and AH Plus with conventional and bioceramic-coated gutta-percha) over 60 days (P = 0.216), with micro-CT confirming minimal voids (<1%) in all groups. AlEraky et al. (2023)[15] similarly found no significant difference among MTA Fillapex, CeraSeal, and AH Plus (P = 0.061). In the nanoleakage domain, Medhat et al. (2022) demonstrated that Sure-Seal Root BC sealer had significantly lower silver-nitrate penetration than AH Plus (P < 0.001), and that the final irrigant protocol influenced the post-obturation seal of both sealers. Medhat et al. (2022)[17] reported no difference in spectrophotometric dye extraction between TotalFill BC HiFlow and AH Plus (P = 0.299).

Table 1. Characteristics of included studies

Study	Country	Tooth type	n/grp	BC sealer	Epoxy sealer	Technique (BC / Epoxy)	Leakage method	BC leakage (mean ± SD)	Epoxy leakage (mean ± SD)	P	Outcome
Kaul et al. 2021	India	Mand 3rd molar roots	25	EndoSequence BC	AH Plus	SC / SC	Dye (MB)	0.89 ± 0.30 mm	1.73 ± 0.27 mm	0.662	NS
Nimiya et al. 2025	India	Mand premolars	17	CeraSeal	AH Plus	SC / SC	Dye (MB)	1.31 ± 0.35 mm	1.65 ± 0.55 mm	0.193	NS
Somolová et al. 2025	Czech Rep.	Single-root teeth	30	BioRoot RCS	AdSeal	SC / WVC	Dye (CD)	0.14 ± 0.34 mm	0.66 ± 0.92 mm	0.003*	BC sig. better
Mezaal et al. 2022	Iraq	Max palatal root	15	TotalFill BC HiFlow	AH Plus	SC / SC	Dye extraction	0.080 OD	0.077 OD	0.299	NS
AlEraky et al. 2023	Saudi Arabia	Mand premolars	10	MTA Fillapex; CeraSeal	AH Plus	SC / LC	Bacterial (E. faecalis)	MF: 30%CE: 80%	50% leaked	0.061	NS
Tour Savadkouhi et al. 2020	Iran	Max central incisors	15	Well Root ST	AH-Plus	LC / LC	Bacterial (saliva)	33.3% leaked85.6 ± 2.1 d	40% leaked81.6 ± 3.1 d	NS†	NS
Medhat et al. 2022	Egypt	Mand premolars	5	Sure-Seal Root BC	AH Plus	SC / SC	Nanoleakage ($AgNO_3$)	1.40 ± 0.33 mm	2.37 ± 0.15 mm	<0.001*	BC sig. better
Yanpiset et al. 2018	Thailand	Max molar DB roots	20	TotalFill BC Sealer	AH Plus	SC / SC	Bacterial (E. faecalis)	BCC/BCS: 25% leaked	GP/AH: 20% leaked	0.216	NS

Table 2. QUIN Risk of Bias

Study ID	Total (/24)	% Score	Risk Level
Kaul 2021	15	62.5	Medium
Nimiya 2025	21	87.5	Low
Somolova 2025	22	91.7	Low
Mezaal 2022	16	66.7	Medium
Al-Eraky 2023	19	79.2	Low
Tour Savadkouhi 2020	17	70.8	Low
Medhat 2022	20	83.3	Low
Yanpiset 2018	19	79.2	Low

Meta-analysis

The meta-analysis included four studies comparing bioceramic and epoxy resin sealers using single-cone obturation, with 77 samples in each group (Figure 2). Study-specific standardized mean differences (SMDs) were -2.90 for Kaul 2021, -3.42 for Medhat 2022, -0.72 for Nimiya 2025, and -0.74 for Somolová 2025. The pooled random-effects model (REML + HKSJ) showed an overall SMD of -1.75 with a 95% confidence interval of -3.92 to 0.42. Heterogeneity was substantial, with I^2 = 88.1%, τ^2 = 1.5041, and p <

0.0001. Leave-one-out analysis produced pooled SMDs ranging from -0.82 to -2.18, with I² values from 61.8% to 91.0%.

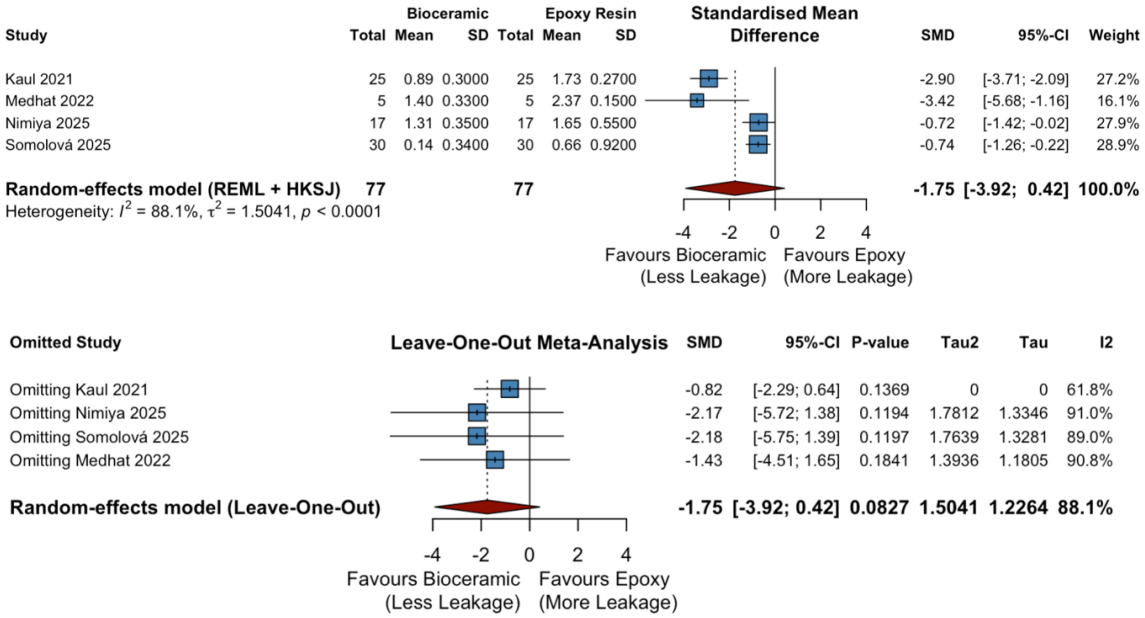

Figure 2. Meta-analysis for dye/nanoleakage data (mm) comparing bioceramic vs epoxy resin with single-cone.

Discussion

The present analysis showed a pooled standardized mean difference of -1.75 (95% CI: -3.92 to 0.42) with high heterogeneity (I² = 88.1%), while the individual study effects consistently favored bioceramic sealers, with SMDs ranging from -0.72 to -3.42. This trend is biologically plausible because the sealer-dentin interface is strongly influenced by dentinal moisture, tubular anatomy, and the presence of accessory spaces that cannot be instrumented completely. Calcium silicate–based sealers are hydrophilic and may perform well in this environment by flowing into dentinal irregularities and supporting interfacial mineral deposition, which can improve adaptation and reduce nanoleakage at the canal wall.[23,24]

A further explanation may relate to the interaction of calcium silicate–based sealers with dentin. Bioceramic materials have been reported to form an interfacial mineralized layer and tag-like structures within dentinal tubules, which may improve sealing at the dentin–sealer interface.[25] This behavior is especially relevant in endodontics because complete mechanical debridement of the root canal system is not possible; therefore, long-term success depends not only on canal shaping and irrigation, but also on the obturation material's ability to entomb residual microorganisms and reduce reinfection.[24] In contrast, although epoxy resin sealers have traditionally shown good dimensional stability and adhesion, their performance may be more technique-sensitive in the presence of residual moisture, which is difficult to eliminate completely under clinical conditions.[23–25]

Studies that support the present finding have reported better penetration or adaptation for bioceramic materials than for epoxy resin sealers. Almasri et al., 2024[26] found that AH Plus Bioceramic and Sure-Seal showed significantly higher dentinal tubular penetration ratios than AH Plus in the apical, middle, and coronal thirds, and also higher total penetration values, supporting the concept that bioceramic sealers may achieve closer interaction with dentinal tubules. Likewise, a 2021 study on Bio-C Sealer reported greater tubule penetration than AH Plus in all three root thirds, and a 2024 in vitro comparison concluded that BIO-C ION+ showed

maximum dentinal tubule penetration whereas AH Plus showed higher push-out bond strength, suggesting that bioceramic materials may have an advantage specifically for interfacial penetration rather than for every mechanical property.[27]

However, opposed findings also exist and help explain the substantial heterogeneity in the current meta-analysis. Reynolds et al., 2020[28] found no statistically significant difference in dentinal tubule penetration between bioceramic sealers and a resin-based sealer across the tested sections, and a 2024 systematic review and meta-analysis including 54 in vitro studies concluded that bioceramic and AH Plus sealers showed no statistical difference in dentinal tubule penetration in the coronal, middle, or apical thirds.[29] Similarly, a systematic review focused on sealing ability reported no significant difference in microleakage outcomes between bioceramic and epoxy resin sealers overall.

Limitations

Several limitations should be acknowledged. First, the meta-analysis was restricted to four studies with a combined sample of 154 teeth, which limits statistical power and precludes meaningful assessment of publication bias. Second, the high heterogeneity (I^2 = 88.1%) indicates that the pooled estimate should be interpreted as an average effect across materially different study designs rather than a single true effect. Third, four of the eight studies could not be included in the quantitative synthesis because of incompatible outcome measures (bacterial leakage, nanoleakage, or spectrophotometric optical density), reducing the comprehensiveness of the meta-analytic conclusions. Fourth, all included studies were *in vitro* investigations, and the translation of bench-top leakage findings to clinical periapical outcomes remains uncertain. The short observation periods of the dye-penetration studies (48–72 hours) may not capture long-term degradation phenomena such as sealer dissolution or hydrolytic breakdown. Finally, none of the included studies reported operator blinding during outcome assessment, introducing potential detection bias.

Conclusion

Within the constraints of the available *in vitro* evidence, bioceramic root canal sealers demonstrated a non-significant trend toward less apical leakage than epoxy resin–based sealers when used with single-cone obturation (pooled SMD: −1.75; 95% CI: −3.92 to 0.42). This finding is derived from only four studies with considerable heterogeneity, and the overall certainty of evidence is low. The qualitative synthesis of the remaining four studies provided directionally consistent, though not uniformly significant, support for the sealing superiority of bioceramic sealers across bacterial-leakage and nanoleakage methodologies. Well-designed, multi-centre *in vitro* studies with standardised protocols and, ultimately, long-term clinical trials evaluating periapical healing outcomes are necessary to establish definitive recommendations for sealer selection in contemporary single-cone obturation.

Acknowledgement

None.

References

1. Gasner NS, Brizuela M. Endodontic Materials Used To Fill Root Canals. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026 [cited 2026 Apr 8]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK587367/ PubMed PMID: 36508541.
2. Zhekov K, Stefanova V. Clinical and Radiographic Outcomes of Root Canal Obturation with Hydraulic Condensation and Tricalcium Silicate Bioceramic Sealer: A 12-Month Observational Study on Periapical Healing. J Funct Biomater. 2025 Nov 5;16(11):412. doi:10.3390/jfb16110412 PubMed PMID: 41295067; PubMed Central PMCID: PMC12653093.
3. Moghadam AA, Aminsobhani M, Afzali Z, Sarraf P. Physical properties comparison of four bioceramic vs. epoxy resin-based root canal sealers: an in vitro study. BMC Oral Health. 2026 Jan 7;26(1):364. doi:10.1186/s12903-025-07623-6 PubMed PMID: 41501783; PubMed Central PMCID: PMC12930880.
4. Błaszczyk-Pośpiech A, Struzik N, Szymonowicz M, Sareło P, Wiśniewska-Wrona M, Wiśniewska K, et al. Endodontic Sealers and Innovations to Enhance Their Properties: A Current Review. Materials (Basel). 2025 Sep 11;18(18):4259. doi:10.3390/ma18184259 PubMed PMID: 41010104; PubMed Central PMCID: PMC12471766.
5. Ivanova S, Tomova Z, Vlahova A, Stoeva IL, Vasileva E, Uzunova Y, et al. Contemporary Use of Polymers in Dentistry: A Narrative Review. Polymers. 2026 Jan 2;18(1):138. doi:10.3390/polym18010138
6. Sfeir G, Zogheib C, Patel S, Giraud T, Nagendrababu V, Bukiet F. Calcium Silicate-Based Root Canal Sealers: A Narrative Review and Clinical Perspectives. Materials (Basel). 2021 Jul 15;14(14):3965. doi:10.3390/ma14143965 PubMed PMID: 34300886; PubMed Central PMCID: PMC8306764.
7. Lim M, Jung C, Shin DH, Cho YB, Song M. Calcium silicate-based root canal sealers: a literature review. Restor Dent Endod. 2020 Aug;45(3):e35. doi:10.5395/rde.2020.45.e35 PubMed PMID: 32839716; PubMed Central PMCID: PMC7431927.
8. Prasad Kumara PAAS, Cooper PR, Cathro P, Gould M, Dias G, Ratnayake J. Bioceramics in Endodontics: Limitations and Future Innovations—A Review. Dentistry Journal. 2025 Apr 1;13(4):157. doi:10.3390/dj13040157
9. Al-Askary RA, Al-Ashou WMO, Al-Jubori SH. In Vitro Apatite-Forming Ability of Different Root Canal Sealers (A Comparative Study). J Int Soc Prev Community Dent. 2025;15(2):173–83. doi:10.4103/jispcd.jispcd_12_25 PubMed PMID: 40433434; PubMed Central PMCID: PMC12105809.
10. Zhang Q, Meng X, Zhan J, Huo L, Lei Y. Sealing ability of the single-cone obturation technique with bioceramic sealer iRoot SP in oval root canals: an in vitro study. BMC Oral

Health. 2025 Aug 23;25(1):1364. doi:10.1186/s12903-025-06713-9 PubMed PMID: 40849477; PubMed Central PMCID: PMC12374461.

11. Rekha R, Kavitha R, Venkitachalam R, Prabath SV, Deepthy S, Krishnan V. Comparison of the sealing ability of bioceramic sealer against epoxy resin based sealer: A systematic review & meta-analysis. J Oral Biol Craniofac Res. 2023;13(1):28–35. doi:10.1016/j.jobcr.2022.10.006 PubMed PMID: 36345495; PubMed Central PMCID: PMC9636474.
12. Dewi A, Soonthornpusit A, Jittarat W. Comparative Micro-CT Analysis of Bioceramic Sealer Activation Techniques in Distal Root Canals of Mandibular Molars. The Journal of Contemporary Dental Practice. 2025 Aug 20;26(6):533–9. doi:10.5005/jp-journals-10024-3893
13. Elmsmari F, Elsayed Y, Aboubakr A, Kaafarani M, Nour O, Pawar AM. Clinical and radiographic success of single-cone bioceramic obturation versus traditional techniques: a systematic review and meta-analysis of randomized controlled trials. J Oral Biol Craniofac Res. 2025;15(6):1422–32. doi:10.1016/j.jobcr.2025.08.031 PubMed PMID: 40948576; PubMed Central PMCID: PMC12424407.
14. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021 Mar 29;372:n71. doi:10.1136/bmj.n71 PubMed PMID: 33782057; PubMed Central PMCID: PMC8005924.
15. AlEraky DM, Rahoma AM, Abuohashish HM, AlQasser A, AlHamali A, AlHussain HM, et al. Assessment of Bacterial Sealing Ability of Two Different Bio-Ceramic Sealers in Single-Rooted Teeth Using Single Cone Obturation Technique: An In Vitro Study. Applied Sciences. 2023 Feb 24;13(5):2906. doi:10.3390/app13052906
16. Kaul S, Kumar A, Badiyani BK, Sukhtankar L, Madhumitha M, Kumar A. Comparison of Sealing Ability of Bioceramic Sealer, AH Plus, and GuttaFlow in Conservatively Prepared Curved Root Canals Obturated with Single-Cone Technique: An In vitro Study. Journal of Pharmacy and Bioallied Sciences. 2021 Jun;13(Suppl 1):S857–60. doi:10.4103/jpbs.jpbs_52_21
17. Medhat A, Ghoneim A, Nabil Roshdy N. The Effect of Final Irrigation Protocols on the Apical Sealing Ability of Epoxy Resin-based and Bioceramic-based Root Canal Sealers. Open Access Maced J Med Sci. 2022 Dec 17;10(D):458–64. doi:10.3889/oamjms.2022.10864
18. Nimiya V, Chernad V, Thankachan RP, Samuel A, Ranjith K, David EC. In vitro study comparing sealing ability of resin-based and bioceramic sealers using single-cone obturation technique. Bioinformation. 2025;21(10):3436.

19. Sahib Mezaal Z, Abdulkareem S, G. Shareef L. In vitro apical microleakage evaluation for different endodontic sealers by spectrophotometric analysis: an observational study. F1000Res. 2022 Nov 28;11:1396. doi:10.12688/f1000research.127911.1
20. Somolová L, Morozova Y, Voborná I, Rosa M, Novotná B, Holík P, et al. Comparison of Apical Microleakage in Bioceramic and Resin-Based Endodontic Sealers with Conventional and Bioceramic Surface-Impregnated Gutta-Percha Points. Ceramics. 2025 May 26;8(2):65. doi:10.3390/ceramics8020065
21. Tour Savadkouhi S, Roghanizad N, Aghabeigi M, Sangchouli S, Khajavi F, Khalilak Z. Assessment the bacterial leakage of four endodontic root canal sealers using fresh human saliva, an ex vivo study. Iranian Endodontic Journal. 2020 May 17;15(2):106–10. doi:10.22037/iej.v15i2.28089
22. Yanpiset K, Banomyong D, Chotvorrarak K, Srisatjaluk RL. Bacterial leakage and micro-computed tomography evaluation in round-shaped canals obturated with bioceramic cone and sealer using matched single cone technique. Restor Dent Endod. 2018;43(3):e30. doi:10.5395/rde.2018.43.e30
23. Camilleri J, Atmeh A, Li X, Meschi N. Present status and future directions: Hydraulic materials for endodontic use. Int Endod J. 2022 May;55 Suppl 3(Suppl 3):710–77. doi:10.1111/iej.13709 PubMed PMID: 35167119; PubMed Central PMCID: PMC9314068.
24. Hristov K, Bogovska-Gigova R. A Micro-Computed Tomography Analysis of Void Formation in Apical Plugs Created with Calcium Silicate-Based Materials Using Various Application Techniques in 3D-Printed Simulated Immature Teeth. Dentistry Journal. 2025 Aug 25;13(9):385. doi:10.3390/dj13090385
25. Ashkar I, Sanz JL, Forner L, Melo M. Calcium Silicate-Based Sealer Dentinal Tubule Penetration-A Systematic Review of In Vitro Studies. Materials (Basel). 2023 Mar 29;16(7):2734. doi:10.3390/ma16072734 PubMed PMID: 37049028; PubMed Central PMCID: PMC10096084.
26. Almasri A, Abduljalil M, Aksoy U. Efficacy of Different Irrigation Activation Techniques on Dentinal Tubule Penetration of the Novel AH-Plus Bioceramic Sealer. Applied Sciences. 2024 Jan 14;14(2):701. doi:10.3390/app14020701
27. Verma A, Arora A, Taneja S. Comparative evaluation of dentinal tubule penetration and push-out bond strength of new injectable hydraulic calcium disilicate based root canal sealer: A single blinded in vitro study. Journal of Oral Biology and Craniofacial Research. 2024 Mar;14(2):143–51. doi:10.1016/j.jobcr.2024.01.009
28. Reynolds JZ, Augsburger RA, Svoboda KKH, Jalali P. Comparing dentinal tubule penetration of conventional and “HiFlow” bioceramic sealers with resin-based sealer: An in

vitro study. Aust Endod J. 2020 Dec;46(3):387–93. doi:10.1111/aej.12425 PubMed PMID: 32741025.

29. Malik B, Chowdhary D, Taneja S. Comparative Evaluation of Dentinal Tubule Penetration, Void Formation, and Push-Out Bond Strength of Premixed Injectable Bioceramic Sealers and AH Plus. Cureus. 2026 Feb;18(2):e102804. doi:10.7759/cureus.102804 PubMed PMID: 41788106; PubMed Central PMCID: PMC12957894.

Author's Statement

The authors declared that all the images and figures in this manuscript is/are author's own work and/or has obtained necessary permission to re-use the content from the authors and publisher of respective materials.

(Vikri Sandya Dhika)