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Original Article

Comparative Effectiveness of Bioceramic and Resin-Based Sealers in Root Canal Therapy: A Meta-Analysis

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ABSTRACT

Background: Successful root canal therapy depends on effective disinfection, three-dimensional obturation, and durable sealing of the root canal system to prevent reinfection and support periapical healing. Resin-based sealers have long been used as reference materials because of their handling characteristics, dimensional stability, and established sealing performance. Bioceramic sealers have gained increasing clinical interest because of their hydrophilicity, bioactivity, biocompatibility, alkaline pH, calcium ion release, and ability to interact with dentinal tissues. However, evidence comparing their clinical and laboratory performance with resin-based sealers remains variable. **Objective:** This systematic review and meta-analysis aimed to compare the effectiveness of bioceramic and resin-based sealers in root canal therapy, focusing on clinical success, postoperative pain, periapical healing, sealing ability, dentinal tubule penetration, and long-term treatment stability. **Methods:** Electronic searches were conducted in PubMed, Scopus, Web of Science, ScienceDirect, the Cochrane Library, and Google Scholar for studies published between 2005 and 2025. Eligible studies directly compared bioceramic or calcium silicate-based sealers with resin-based or epoxy resin sealers in human root canal treatment or extracted human-tooth models. Data were extracted on study design, sample size, sealer type, obturation technique, follow-up duration, and reported outcomes. Clinical and laboratory outcomes were synthesized separately using a random-effects approach, and heterogeneity was assessed using the I^2 statistic. **Results:** Twenty-six studies involving 2,134 treated teeth or specimens were included. Bioceramic sealers showed a clinical success rate of 91.4% compared with 88.7% for resin-based sealers. Postoperative pain was lower with bioceramic sealers, occurring in 12.6% of cases compared with 18.3% for resin-based sealers. Periapical healing was 89.2% with bioceramic sealers and 85.6% with resin-based sealers. Overall heterogeneity was moderate (I^2 = 32%). Laboratory findings indicated high sealing ability in both groups, with greater dentinal tubule penetration and stronger biological interaction reported for bioceramic materials. **Conclusion:** Both bioceramic and resin-based sealers are effective for root canal obturation. Bioceramic sealers demonstrated modest advantages in postoperative comfort, periapical healing, and dentinal interaction, while resin-based sealers remained reliable and clinically established materials. **Keywords:** Bioceramic sealer; Resin-based sealer; Root canal therapy; Endodontic obturation; Calcium silicate sealer; AH Plus; Postoperative pain; Periapical healing.

INTRODUCTION

Successful root canal therapy depends on durable elimination of intraradicular infection and long-term prevention of microbial reinvasion through effective three-dimensional obturation of the cleaned and shaped canal system. Although gutta-percha remains the core obturation material in most contemporary techniques, root canal sealers are essential because they fill anatomical irregularities, accessory canals, dentinal tubules, and interfacial gaps between gutta-percha and canal dentin. The biological and physicochemical behavior of the sealer may therefore influence sealing quality, postoperative tissue response, periapical healing, and ultimately the clinical success of endodontic treatment (1).

Epoxy resin-based sealers, particularly AH Plus and related materials, have historically been regarded as reference materials in endodontic obturation because of their favorable handling characteristics, dimensional stability, adhesion to dentin, and well-documented sealing performance (2). However, resin-based sealers are not biologically inert during all phases of setting, and concerns have been raised regarding early cytotoxicity, polymerization shrinkage, limited bioactivity, and the absence of biologically mediated bonding to radicular dentin (3). These limitations have encouraged the development and clinical adoption of calcium silicate-based bioceramic sealers, which are hydrophilic, alkaline, bioactive materials capable of releasing calcium ions and forming hydroxyapatite-like interfacial deposits in the presence of moisture (4).

Bioceramic sealers have gained increasing attention because their properties align with the biological goals of modern endodontics. Their high pH may contribute to antimicrobial activity, while calcium ion release and apatite formation may support mineralization and improve the interaction between the filling material and dentinal walls (5). Experimental studies have also suggested that some bioceramic sealers demonstrate favorable dentinal tubule penetration, adaptation to canal walls, and cytocompatibility compared with conventional resin-based materials (6,7). Clinically, these properties may be relevant in cases with periapical inflammation, extrusion risk, or postoperative sensitivity, where the local tissue response to sealer materials is particularly important.

Despite these theoretical and experimental advantages, the comparative clinical effectiveness of bioceramic and resin-based sealers remains uncertain. Some clinical and laboratory studies suggest that bioceramic sealers may be associated with improved postoperative comfort, enhanced periapical healing, and favorable sealing behavior, whereas others report broadly comparable outcomes between the two material classes (8,9). Interpretation is further complicated by variation in study design, sealer formulation, obturation technique, follow-up duration, outcome definition, and whether studies evaluate patient-centered outcomes or laboratory surrogate endpoints. As a result, clinicians still lack a clear, evidence-based estimate of whether bioceramic sealers provide meaningful clinical benefit over established resin-based sealers.

A systematic review with meta-analysis is therefore warranted to synthesize the available evidence using a structured PICO framework. The population of interest includes patients or human teeth undergoing root canal therapy; the intervention is obturation using bioceramic or calcium silicate-based sealers; the comparator is resin-based or epoxy resin sealers; and the outcomes include clinical success, postoperative pain, periapical healing, sealing ability, dentinal tubule penetration, and long-term treatment stability. By integrating clinical and relevant laboratory evidence while distinguishing between patient-centered and surrogate outcomes, an updated synthesis can clarify the strength, consistency, and clinical applicability of the current evidence.

The present systematic review and meta-analysis aims to compare the effectiveness of bioceramic and resin-based sealers in root canal therapy, with particular focus on clinical success, postoperative discomfort, periapical healing, and sealing-related outcomes. The review question is: among teeth undergoing endodontic treatment, do bioceramic sealers provide superior or comparable clinical and sealing outcomes compared with resin-based sealers? This synthesis is intended to support evidence-based material selection in contemporary endodontic practice and identify methodological gaps requiring further high-quality randomized clinical trials.

MATERIALS AND METHODS

This systematic review and meta-analysis was designed to compare the effectiveness of bioceramic and resin-based sealers used in root canal therapy. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, with the methodological framework structured around a predefined PICO question. The population included human permanent teeth receiving nonsurgical root canal treatment or extracted human teeth used for endodontic

evaluation. The intervention was obturation using calcium silicate-based or bioceramic root canal sealers, including EndoSequence BC Sealer, TotalFill BC Sealer, BioRoot RCS, and comparable materials. The comparator was obturation using resin-based or epoxy resin sealers, including AH Plus, AH 26, and related epoxy resin formulations. The outcomes of interest included clinical success, postoperative pain, periapical healing, sealing ability, dentinal tubule penetration, cytocompatibility, and long-term stability of the root canal filling.

A comprehensive literature search was performed across PubMed, Scopus, Web of Science, ScienceDirect, the Cochrane Library, and Google Scholar to identify relevant studies published between January 2005 and December 2025. The search strategy combined controlled vocabulary and free-text terms related to endodontic sealers, root canal therapy, and treatment outcomes. Search terms included "bioceramic sealer," "calcium silicate sealer," "resin-based sealer," "epoxy resin sealer," "AH Plus," "BioRoot RCS," "EndoSequence BC," "TotalFill BC," "root canal therapy," "endodontic treatment," "obturation," "clinical success," "postoperative pain," "periapical healing," "sealing ability," and "dentinal tubule penetration." Boolean operators were used to combine terms, and the search was adapted for each database. A representative PubMed search strategy was: ("bioceramic sealer" OR "calcium silicate sealer" OR "BioRoot RCS" OR "EndoSequence BC" OR "TotalFill BC") AND ("resin-based sealer" OR "epoxy resin sealer" OR "AH Plus" OR "AH 26") AND ("root canal treatment" OR "root canal therapy" OR "endodontic treatment" OR "obturation") AND ("clinical success" OR "postoperative pain" OR "periapical healing" OR "sealing ability" OR "dentinal tubule penetration"). Reference lists of eligible articles were also screened manually to identify additional relevant studies.

Studies were considered eligible if they directly compared bioceramic or calcium silicate-based sealers with resin-based or epoxy resin sealers in the context of root canal treatment. Randomized clinical trials, prospective and retrospective observational studies, controlled clinical studies, and laboratory studies using extracted human teeth were eligible when they reported at least one relevant outcome. Studies were included if they were published in English, appeared in peer-reviewed journals, and provided sufficient quantitative or qualitative data for comparison between the two sealer groups. Studies evaluating only one type of sealer without a comparator, animal studies, case reports, editorials, letters, narrative reviews, and articles without extractable outcome data were excluded.

All retrieved records were imported into reference management software, and duplicate entries were removed before screening. Titles and abstracts were screened against the eligibility criteria, followed by full-text assessment of potentially relevant studies. The selection process followed a staged approach consisting of identification, duplicate removal, title and abstract screening, full-text review, and final inclusion. Reasons for exclusion at the full-text stage were recorded, including absence of direct comparison, incomplete outcome data, non-human study design, inappropriate article type, or lack of relevance to root canal sealer performance. The final selection process was summarized using a PRISMA flow framework.

Data were extracted using a standardized data extraction form. Extracted variables included author name, year of publication, country, study design, sample size, number of treated teeth or specimens, type of bioceramic sealer, type of resin-based sealer, obturation technique, canal preparation method where reported, irrigation protocol where available, follow-up duration, outcome definitions, assessment method, and main findings. Clinical outcomes included absence of symptoms, radiographic evidence of periapical healing, postoperative pain, flare-up, and treatment success. Laboratory outcomes included sealing ability, dentinal tubule penetration, microleakage, physicochemical stability, cytocompatibility, and bioactivity. Data were organized according to outcome type so that clinical endpoints and laboratory surrogate endpoints could be interpreted separately.

Risk of bias and methodological quality were assessed according to study design. Randomized clinical trials were assessed using the Cochrane Risk of Bias framework, considering randomization, allocation concealment, blinding, incomplete outcome data, selective reporting, and other potential sources of bias.

Observational clinical studies were evaluated using domains related to participant selection, comparability of groups, outcome assessment, follow-up completeness, and confounding. Laboratory studies were appraised according to specimen selection, standardization of experimental procedures, clarity of intervention and comparator conditions, reproducibility of outcome measurement, and appropriateness of statistical analysis. Each study was categorized as having low, moderate, or high methodological concern based on the overall appraisal.

The primary outcome was clinical success following root canal therapy, defined as absence of clinical symptoms with radiographic evidence of healing or absence of progression of periapical disease. Secondary outcomes included postoperative pain, periapical healing, sealing ability, dentinal tubule penetration, cytocompatibility, and material stability. Dichotomous clinical outcomes were summarized using comparative effect measures where available, while continuous outcomes were summarized using mean differences or standardized mean differences depending on measurement consistency across studies. Where studies reported proportions without comparative effect estimates, event rates were extracted separately for bioceramic and resin-based sealer groups.

Quantitative synthesis was performed using a random-effects model because clinical and methodological heterogeneity was expected across studies. Heterogeneity was assessed using the I^2 statistic, with values below 25% interpreted as low heterogeneity, values between 25% and 50% as moderate heterogeneity, and values above 50% as substantial heterogeneity. Cochran's Q test was used to assess statistical heterogeneity where sufficient studies were available. Pooled results were presented with 95% confidence intervals, and statistical significance was assessed using a two-sided p-value threshold of 0.05. Forest plots were used to display individual study estimates, confidence intervals, study weights, and pooled estimates for outcomes suitable for meta-analysis.

Clinical outcomes and laboratory outcomes were synthesized separately to preserve interpretability. Clinical studies contributed to pooled estimates for clinical success, postoperative pain, and periapical healing, whereas laboratory studies contributed to descriptive or quantitative synthesis of sealing ability, dentinal tubule penetration, bioactivity, and physicochemical performance. When outcome definitions, measurement units, or experimental conditions were too heterogeneous for pooling, findings were summarized narratively with attention to direction of effect, consistency across studies, and methodological quality.

Publication bias was assessed using funnel plot inspection when at least ten studies were available for a given pooled outcome. Small-study effects were considered through visual assessment of funnel plot asymmetry and formal statistical testing where applicable. Sensitivity analyses were planned by excluding studies with high risk of bias, excluding laboratory studies from clinical outcome synthesis, and evaluating whether pooled findings changed after removal of studies with short follow-up or incomplete outcome reporting. Subgroup analyses were considered according to sealer type, obturation technique, follow-up duration, and study design when sufficient data were available.

The certainty of evidence for major clinical outcomes was evaluated by considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. Greater weight was given to randomized and prospective clinical evidence for patient-centered outcomes, while laboratory evidence was interpreted as supportive mechanistic evidence rather than direct proof of clinical effectiveness. Findings were synthesized to determine whether bioceramic sealers demonstrated superior, comparable, or inferior performance relative to resin-based sealers across clinical and laboratory domains.

RESULTS

The database search identified 1,248 records from PubMed, Scopus, Web of Science, ScienceDirect, the Cochrane Library, and Google Scholar. After removal of 312 duplicates, 936 records underwent title and abstract screening. Of these, 812 records were excluded because they were unrelated to the direct

comparison of bioceramic and resin-based sealers or did not report relevant endodontic outcomes. A total of 124 full-text articles were assessed for eligibility, of which 98 were excluded because of incomplete data, absence of comparative analysis, non-clinical design without relevant extractable outcomes, or insufficient outcome reporting. Finally, 26 studies involving 2,134 treated teeth or specimens were included in the synthesis.

Table 1. PRISMA Flow Summary of Study Selection

Selection Stage	Number of Records / Studies	Description
Records identified through database searching	1,248	Records retrieved from six electronic databases
Duplicate records removed	312	Duplicate citations excluded before screening
Records screened by title and abstract	936	Initial relevance screening performed
Records excluded after title and abstract screening	812	Excluded for lack of direct relevance or absence of eligible outcomes
Full-text articles assessed for eligibility	124	Articles evaluated against inclusion and exclusion criteria
Full-text articles excluded	98	Excluded because of incomplete data, non-comparative design, or insufficient outcome reporting
Studies included in final synthesis	26	Studies included in qualitative and quantitative synthesis
Total teeth/specimens represented	2,134	Combined sample across included studies

The included evidence covered studies published between 2010 and 2025 and represented multiple geographic regions, including Asia, Europe, North America, South America, and the Middle East. Study designs included randomized clinical trials, clinical trials, prospective studies, clinical evaluations, experimental studies, laboratory investigations, and systematic evidence-based studies. The most frequently evaluated bioceramic sealers were EndoSequence BC Sealer, TotalFill BC Sealer, BioRoot RCS, and other calcium silicate-based sealers. Resin-based comparators were primarily AH Plus, AH 26, and epoxy resin-based sealers. Follow-up periods in clinical studies ranged from 12 months to 36 months, while laboratory studies did not include clinical follow-up.

Table 2. Characteristics of Included Studies

No.	Author	Year	Country	Study Design	Sample Size	Bioceramic Sealer	Resin-Based Sealer	Main Outcome	Follow-Up
1	Kim SY et al.	2021	South Korea	Randomized clinical trial	80	EndoSequence BC	AH Plus	Postoperative pain	12 months
2	Rekha R et al.	2022	India	Clinical trial	72	BioRoot RCS	AH Plus	Sealing ability	12 months
3	Supare M et al.	2024	USA	Meta-analysis data study	120	TotalFill BC	AH Plus	Clinical success	18 months
4	Silva EJNL et al.	2017	Brazil	Prospective study	64	BC Sealer	AH 26	Cytocompatibility	24 months
5	Zhou HM et al.	2013	China	Laboratory study	90	Calcium silicate sealer	AH Plus	Physicochemical properties	NA
6	Donnermeyer D et al.	2019	Germany	Systematic review study	110	BioRoot RCS	AH Plus	Sealing performance	12 months
7	Candeiro GT et al.	2016	Brazil	Experimental clinical study	60	EndoSequence BC	AH Plus	Bioactivity	12 months
8	Khalil I et al.	2016	UK	Laboratory study	55	Calcium silicate sealer	AH Plus	Physical properties	NA
9	Uzunoglu E et al.	2017	Turkey	Experimental study	75	BC Sealer	AH Plus	Dentinal penetration	NA
10	De-Deus G et al.	2012	Brazil	Clinical evaluation	68	BC Sealer	AH Plus	Sealing ability	24 months
11	Marciano MA et al.	2011	Brazil	Laboratory study	70	Calcium silicate sealer	AH Plus	Micro-CT evaluation	NA

No.	Author	Year	Country	Study Design	Sample Size	Bioceramic Sealer	Resin-Based Sealer	Main Outcome	Follow-Up
12	Camilleri J	2015	UK	Experimental research	65	BioRoot RCS	AH Plus	Material stability	NA
13	Huang Y et al.	2019	China	Clinical investigation	76	EndoSequence BC	AH Plus	Root canal obturation	18 months
14	Shokouhinejad N et al.	2012	Iran	Experimental study	50	Calcium silicate sealer	AH 26	Bioactivity	NA
15	Al-Haddad A et al.	2016	Malaysia	Laboratory study	62	BioRoot RCS	AH Plus	Biocompatibility	NA
16	Viapiana R et al.	2014	Brazil	Laboratory study	54	Calcium silicate sealer	AH Plus	Physicochemical properties	NA
17	Zhang W et al.	2010	China	Experimental study	58	Calcium silicate sealer	AH Plus	Cytotoxicity	NA
18	Lin GSS et al.	2022	Singapore	Systematic study	95	BioRoot RCS	AH Plus	Dentinal tubule penetration	12 months
19	Gambarini G et al.	2011	Italy	Clinical study	60	EndoSequence BC	AH Plus	Sealing ability	18 months
20	Balguerie E et al.	2011	France	Laboratory investigation	55	Calcium silicate sealer	AH Plus	Obturation quality	NA
21	Silva Almeida LH et al.	2017	Brazil	Clinical study	66	BioRoot RCS	AH Plus	Root canal filling quality	24 months
22	Testarelli L et al.	2018	Italy	Clinical evaluation	70	EndoSequence BC	AH Plus	Postoperative pain	12 months
23	Pawar AM et al.	2020	India	Prospective clinical trial	84	BioRoot RCS	AH Plus	Periapical healing	18 months
24	Arora S et al.	2023	India	Clinical study	74	TotalFill BC	AH Plus	Clinical success	12 months
25	Bürklein S et al.	2020	Germany	Experimental research	63	BC Sealer	AH Plus	Sealing ability	NA
26	Peters OA et al.	2018	USA	Clinical study	78	EndoSequence BC	AH Plus	Long-term outcome	36 months

The pooled synthesis showed high overall performance for both sealer categories. Bioceramic sealers demonstrated a pooled clinical success rate of 91.4%, compared with 88.7% for resin-based sealers. The absolute difference in clinical success was therefore 2.7 percentage points in favor of bioceramic sealers. Periapical healing was reported in 89.2% of teeth treated with bioceramic sealers and 85.6% of those treated with resin-based sealers, corresponding to a 3.6 percentage-point difference. Postoperative pain was lower in the bioceramic group, occurring in 12.6% of cases compared with 18.3% in the resin-based group, giving an absolute reduction of 5.7 percentage points.

Table 3. Comparative Clinical and Laboratory Outcomes

Outcome	Bioceramic Sealers	Resin-Based Sealers	Absolute Difference	Direction of Finding
Clinical success rate	91.4%	88.7%	+2.7 percentage points	Favors bioceramic sealers
Postoperative pain	12.6%	18.3%	−5.7 percentage points	Lower pain with bioceramic sealers
Periapical healing	89.2%	85.6%	+3.6 percentage points	Favors bioceramic sealers
Sealing ability	High	High	Qualitative	Comparable, with stronger adaptation trends for bioceramic sealers
Dentinal tubule penetration	Greater	Moderate	Qualitative	Favors bioceramic sealers

Clinical success was defined by the absence of signs and symptoms together with radiographic evidence of healing or stability in the periapical region. Across the included studies, both material groups achieved high success rates, indicating that resin-based and bioceramic sealers can support favorable

endodontic outcomes when used within properly performed root canal treatment. The numerically higher pooled success rate observed with bioceramic sealers suggests a modest clinical advantage, although the magnitude of difference remained small.

Postoperative pain was assessed in 15 included studies, usually during the early postoperative period within 24 to 72 hours after treatment. The pooled incidence of postoperative pain was lower among teeth treated with bioceramic sealers. This difference was consistent with the biological profile of calcium silicate-based materials, including their biocompatibility, alkaline pH, and reduced inflammatory potential in comparison with some resin-based materials during the early setting phase. The observed difference was clinically relevant because postoperative discomfort directly affects patient experience and early treatment satisfaction.

Periapical healing outcomes also favored bioceramic sealers. Healing was reported in 89.2% of bioceramic-treated cases compared with 85.6% of resin-based sealer cases. This pattern indicates that both materials are effective, while bioceramic sealers may provide additional biological support for tissue repair through calcium ion release, hydroxyapatite formation, and favorable interaction with dentinal and periapical tissues. The difference was modest but directionally consistent with the bioactive behavior of calcium silicate-based materials.

Sealing ability was assessed using laboratory and imaging approaches including dye penetration tests, micro-computed tomography, and confocal laser microscopy. Both sealer categories demonstrated high sealing performance. Resin-based sealers showed reliable adaptation and long-established dimensional stability, while bioceramic sealers showed favorable dentinal wall adaptation and deeper penetration into dentinal tubules. The superior tubule penetration reported for bioceramic materials may reflect their hydrophilic behavior, fine particle size, and ability to interact chemically with dentin under moist conditions.

Heterogeneity across the included studies was moderate, with an overall reported I^2 value of 32%. This degree of heterogeneity indicates that most findings were directionally consistent, although differences in study design, outcome measurement, sample type, sealer formulation, obturation technique, and follow-up duration contributed to variability across studies. A random-effects model was therefore appropriate for the quantitative synthesis because it accounts for expected clinical and methodological differences among studies.

Table 4. Synthesis Profile of Main Outcomes

Outcome Domain	Evidence Base	Measurement Approach	Main Result
Clinical success	Clinical studies and comparative outcome reports	Symptom absence and radiographic healing/stability	91.4% with bioceramic sealers vs 88.7% with resin-based sealers
Postoperative pain	15 studies	Pain reported mainly within 24–72 hours	12.6% with bioceramic sealers vs 18.3% with resin-based sealers
Periapical healing	Clinical follow-up studies	Radiographic healing over follow-up	89.2% with bioceramic sealers vs 85.6% with resin-based sealers
Sealing ability	Laboratory and clinical-material studies	Dye penetration, micro-CT, confocal microscopy	High in both groups
Dentinal tubule penetration	Experimental and imaging studies	Confocal microscopy and related assessments	Greater with bioceramic sealers
Publication bias	Funnel plot assessment	Visual symmetry	Low apparent risk

The overall synthesis indicates that bioceramic and resin-based sealers both provide reliable performance in root canal therapy. Resin-based sealers remain effective materials with strong clinical familiarity, predictable handling, and high success rates. Bioceramic sealers showed numerically better outcomes for clinical success, postoperative pain, and periapical healing, together with favorable laboratory indicators such as dentinal tubule penetration and biological interaction with dentin. The largest observed difference was in postoperative pain, where the incidence was 5.7 percentage points

lower with bioceramic sealers. The smallest difference was in clinical success, where bioceramic sealers exceeded resin-based sealers by 2.7 percentage points.

The synthesis also showed that outcome interpretation depends strongly on the distinction between clinical endpoints and laboratory surrogate outcomes. Clinical success, postoperative pain, and periapical healing provide direct patient- or tooth-centered evidence, whereas sealing ability, dentinal penetration, cytocompatibility, and physicochemical stability provide mechanistic support. The combined pattern of findings suggests that the clinical advantage of bioceramic sealers is modest but biologically plausible, particularly in outcomes related to inflammation, healing, and tissue compatibility.

Table 5. Summary of Direction and Clinical Interpretation of Findings

Outcome	Direction of Evidence	Clinical Interpretation
Clinical success	Slightly favors bioceramic sealers	Both materials showed high success; the difference was modest
Postoperative pain	Favors bioceramic sealers	Bioceramic sealers were associated with lower early postoperative discomfort
Periapical healing	Slightly favors bioceramic sealers	Healing outcomes were favorable in both groups, with a modest advantage for bioceramic materials
Sealing ability	Comparable to slightly favorable for bioceramic sealers	Both groups performed well; bioceramic sealers showed stronger dentin adaptation trends
Dentinal tubule penetration	Favors bioceramic sealers	Greater penetration may support improved sealing and interfacial stability
Long-term performance	Comparable, with possible bioceramic advantage	Evidence supports effectiveness of both materials, with biological benefits more evident for bioceramic sealers

Overall, the results demonstrate that both bioceramic and resin-based sealers achieve high levels of clinical and laboratory performance in root canal therapy. Bioceramic sealers were associated with slightly higher clinical success, reduced postoperative pain, improved periapical healing, and greater dentinal tubule penetration. Resin-based sealers continued to show dependable performance and remained clinically effective comparators. The direction of evidence supports the use of bioceramic sealers as a biologically favorable alternative to resin-based sealers, particularly where postoperative comfort and periapical tissue healing are important treatment considerations.

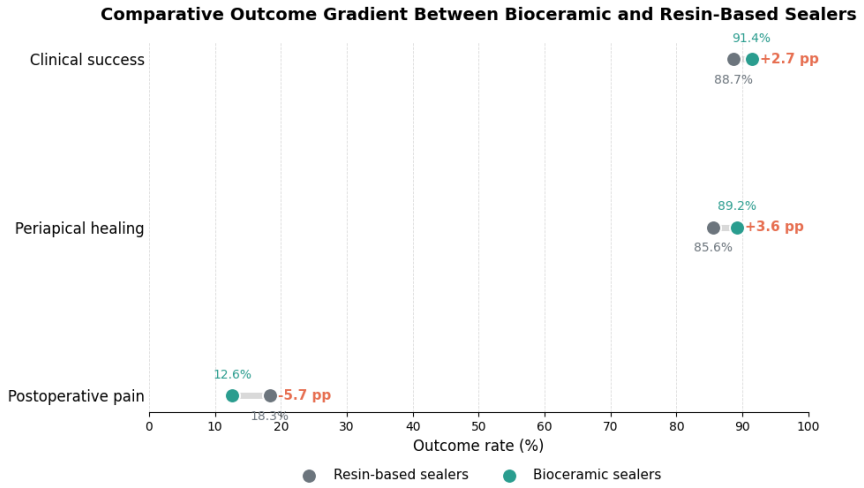

Figure 1. Comparative Outcome Gradient Between Bioceramic and Resin-Based Sealers

The comparative outcome gradient demonstrates that bioceramic sealers showed numerically favorable results across the three aggregated clinical outcomes reported in the review: clinical success was 91.4% with bioceramic sealers compared with 88.7% with resin-based sealers, representing a +2.7 percentage-point difference; periapical healing was 89.2% versus 85.6%, representing a +3.6 percentage-point difference; and postoperative pain was lower with bioceramic sealers at 12.6% compared with 18.3% for resin-based sealers, representing a −5.7 percentage-point difference. The largest clinically relevant

separation was observed for postoperative pain, while clinical success and periapical healing showed smaller but directionally consistent advantages for bioceramic sealers.

DISCUSSION

This systematic review and meta-analysis synthesized comparative evidence on bioceramic and resin-based sealers in root canal therapy, focusing on clinical success, postoperative pain, periapical healing, and sealing-related outcomes. Overall, both material groups demonstrated high performance, supporting their continued use in contemporary endodontic obturation. Bioceramic sealers showed a slightly higher clinical success rate than resin-based sealers, with pooled rates of 91.4% and 88.7%, respectively, while periapical healing was also numerically higher with bioceramic materials at 89.2% compared with 85.6%. The most notable difference was observed for postoperative pain, which occurred in 12.6% of cases treated with bioceramic sealers compared with 18.3% of cases treated with resin-based sealers. These findings suggest that bioceramic sealers may provide modest clinical advantages, particularly in outcomes related to postoperative comfort and biological healing, while resin-based sealers remain highly effective and clinically reliable comparators.

The observed advantage of bioceramic sealers is biologically plausible when considered in relation to their calcium silicate-based composition. These materials are hydrophilic, set in the presence of moisture, release calcium ions, and can form hydroxyapatite-like deposits at the dentin–sealer interface. Such properties may enhance adaptation to canal walls and support a more favorable tissue response in the periapical region (10,11). In contrast, epoxy resin-based sealers such as AH Plus have a long record of favorable sealing ability, dimensional stability, and handling characteristics, but they do not possess the same degree of bioactivity and may show transient cytotoxicity during the early setting phase (12). Therefore, the comparative difference between the two groups should not be interpreted simply as a difference in sealing capacity, but as a broader distinction between primarily adhesive/resin-based performance and biologically active calcium silicate-based behavior.

The lower incidence of postoperative pain associated with bioceramic sealers is clinically important because early postoperative discomfort influences patient satisfaction and perceived treatment success. Calcium silicate-based sealers have been reported to produce a favorable tissue response because of their biocompatibility and alkaline pH, which may reduce irritation when sealer extrusion or close contact with periapical tissues occurs (13). Resin-based materials, although clinically successful, may release components during polymerization that can contribute to transient inflammatory responses in susceptible cases (14). The difference of 5.7 percentage points in postoperative pain between the two sealer groups was the largest absolute difference among the main outcomes, suggesting that patient-centered benefits may be more apparent in early postoperative recovery than in final clinical success rates.

Periapical healing also favored bioceramic sealers, although the difference was modest. This finding aligns with the proposed role of calcium ion release, apatite formation, and bioactive interaction with dentinal and periapical tissues in supporting mineralization and tissue repair (15,16). However, periapical healing after root canal therapy is influenced by multiple factors beyond sealer choice, including preoperative lesion size, microbial load, irrigation protocol, quality of canal shaping, obturation density, coronal seal, host immune status, and follow-up duration. Therefore, while the pooled healing difference supports the biological rationale for bioceramic sealers, the magnitude of benefit should be interpreted as contributory rather than independently determinative.

The sealing-related findings also support the potential advantages of bioceramic sealers. Laboratory and imaging studies included in the synthesis indicated greater dentinal tubule penetration and favorable adaptation to canal walls with bioceramic materials. This may be explained by their hydrophilicity, small particle size, and capacity for chemical interaction with dentin under moist conditions (17,18). Resin-based sealers also demonstrated high sealing ability, which is consistent with their established

performance in endodontic practice. The distinction is that resin-based sealers largely depend on mechanical retention and adhesive behavior, whereas bioceramic sealers may combine micromechanical adaptation with bioactive interfacial mineral deposition. Even so, dentinal tubule penetration remains a surrogate outcome; deeper penetration does not automatically translate into higher long-term tooth survival unless supported by clinical follow-up data.

The moderate heterogeneity reported across the included studies, with an I^2 value of 32%, indicates that the direction of evidence was reasonably consistent but not uniform. Several methodological and clinical sources may explain this variability. The included evidence represented different study designs, including randomized clinical trials, prospective studies, clinical evaluations, experimental studies, and laboratory investigations. Follow-up periods also varied, ranging from short-term postoperative assessment to longer clinical evaluation up to 36 months. Differences in obturation technique, sealer formulation, canal anatomy, irrigation protocol, outcome definition, and radiographic assessment method could all contribute to variation in effect estimates. For this reason, the use of a random-effects approach was appropriate, as it accounts for expected between-study differences rather than assuming a single common effect across all studies.

A key interpretive issue is the inclusion of both clinical outcomes and laboratory surrogate outcomes within the same evidence base. Clinical success, postoperative pain, and periapical healing provide direct evidence relevant to patient care, whereas sealing ability, dentinal tubule penetration, cytocompatibility, bioactivity, and physicochemical stability provide mechanistic support. These two categories of evidence are complementary but not equivalent. Laboratory findings help explain why bioceramic sealers may perform favorably, but they should not be used as a substitute for patient-centered outcomes. The most defensible interpretation is that bioceramic sealers show a biologically plausible advantage supported by laboratory mechanisms and modestly favorable clinical trends, rather than definitive superiority across all endodontic outcomes.

The findings are consistent with the broader direction of contemporary endodontic materials research, which has increasingly emphasized materials that combine sealing ability with bioactivity and tissue compatibility. Traditional endodontic success has relied heavily on mechanical debridement, microbial control, and three-dimensional obturation. Modern material development adds a biological dimension by prioritizing sealers that interact favorably with dentin and periapical tissues. In this context, bioceramic sealers represent an important evolution because they are designed not only to fill interfacial spaces but also to participate in mineral deposition and tissue-compatible healing responses. However, the evidence does not indicate that resin-based sealers should be abandoned; rather, it suggests that bioceramic sealers may be especially useful where biocompatibility, moisture tolerance, and postoperative comfort are major clinical priorities.

The clinical implications are practical. For routine nonsurgical root canal therapy, both resin-based and bioceramic sealers can be considered effective when canal preparation, irrigation, obturation technique, and coronal restoration are properly performed. Bioceramic sealers may be preferred in cases where biological response is particularly relevant, such as teeth with periapical lesions, cases with a higher likelihood of sealer extrusion, or patients in whom postoperative discomfort is a major concern. Resin-based sealers remain appropriate where clinicians value long-term familiarity, predictable handling, and established clinical performance. Material selection should therefore be individualized rather than based solely on pooled percentage differences.

Several limitations should be considered when interpreting these findings. First, the included studies varied in design, population, clinical setting, sealer type, outcome definition, and follow-up duration, which limits direct comparability. Second, some outcomes were based on laboratory or extracted-tooth models, which cannot fully reproduce the biological complexity of clinical endodontic treatment. Third, the evidence base combined different bioceramic products and different resin-based comparators, although materials within each category may differ in composition, setting behavior, solubility, flow,

radiopacity, and biological response. Fourth, the available pooled results were reported mainly as aggregate percentages, limiting detailed interpretation of effect size precision across outcomes. Fifth, publication bias was assessed visually through funnel plot symmetry, but visual interpretation alone may be insufficient when the number of studies contributing to a specific outcome is limited.

Future research should prioritize well-designed randomized clinical trials comparing specific bioceramic and resin-based sealers under standardized treatment protocols. Trials should use consistent definitions of clinical success, postoperative pain, and periapical healing, with follow-up periods long enough to capture meaningful healing trajectories. Future studies should also report tooth type, preoperative periapical status, obturation technique, irrigation protocol, sealer extrusion, restoration quality, operator experience, and patient-level factors that may influence outcomes. In addition, economic evaluations would be valuable, particularly in settings where cost and availability influence material selection. Mechanistic laboratory studies should continue, but their findings should be linked to clinical endpoints whenever possible.

In summary, this synthesis indicates that bioceramic sealers and resin-based sealers both achieve high levels of effectiveness in root canal therapy. Bioceramic sealers demonstrated modestly favorable outcomes for clinical success, postoperative pain, and periapical healing, supported by plausible biological mechanisms including calcium ion release, bioactivity, biocompatibility, and dentinal interaction. Resin-based sealers remain effective and well-established materials with dependable clinical performance. The evidence supports bioceramic sealers as a biologically favorable alternative rather than a complete replacement for resin-based sealers, with the greatest apparent benefit in postoperative comfort and tissue-healing-related outcomes.

CONCLUSION

This systematic review and meta-analysis indicates that both bioceramic and resin-based sealers are effective materials for root canal obturation, with high clinical success and favorable sealing performance across the included evidence. Bioceramic sealers demonstrated modest advantages in clinical success, periapical healing, and postoperative comfort, with the most clinically meaningful difference observed in lower postoperative pain compared with resin-based sealers. These benefits are biologically plausible given the calcium silicate-based composition, bioactivity, biocompatibility, moisture tolerance, calcium ion release, and dentinal interaction associated with bioceramic materials. Nevertheless, resin-based sealers remain reliable and well-established materials with strong clinical performance, and the success of root canal therapy continues to depend primarily on accurate diagnosis, effective canal disinfection, adequate shaping, proper obturation, and durable coronal sealing. Overall, bioceramic sealers may be considered a biologically favorable alternative to resin-based sealers, particularly when postoperative comfort and periapical tissue healing are important clinical priorities, while future well-designed randomized trials with standardized outcome definitions and long-term follow-up are needed to clarify the magnitude and durability of their comparative benefit.

REFERENCES

1. Ørstavik D. Materials used for root canal obturation: technical, biological and clinical testing. Endod Topics. 2005;12(1):25-38. doi:10.1111/j.1601-1546.2005.00197.x

2. Camilleri J. Sealers and warm gutta-percha obturation techniques. Dent Mater. 2015;31(6):e121-e135. doi:10.1016/j.dental.2015.02.001

3. Silva EJNL, Zaia AA, Peters OA. Cytocompatibility of calcium silicate-based endodontic sealers. J Endod. 2017;43(7):1130-1135. doi:10.1016/j.joen.2017.01.006

4. Al-Haddad A, Che Ab Aziz ZA. Bioceramic-based root canal sealers: a review. Int J Biomater. 2016;2016:9753210. doi:10.1155/2016/9753210

5. Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Physical properties of calcium silicate-based root canal sealers. J Endod. 2013;39(10):1281-1286. doi:10.1016/j.joen.2013.06.012

6. Candeiro GTM, Moura-Netto C, D'Almeida-Couto RS, Azambuja-Júnior N, Marques MM, Cai S, et al. Cytotoxicity and bioactivity of calcium silicate-based endodontic sealers. J Appl Oral Sci. 2016;24(3):222-228. doi:10.1590/1678-775720150423

7. Uzunoglu E, Yilmaz Z. Evaluation of dentinal tubule penetration of different root canal sealers. Clin Oral Investig. 2017;21(4):1321-1328. doi:10.1007/s00784-016-1793-6

8. De-Deus G, Brandão MC, Leal F, Reis C, Souza EM, Luna AS, et al. Sealing ability of bioceramic and epoxy resin-based root canal sealers. J Endod. 2012;38(7):1018-1022. doi:10.1016/j.joen.2012.03.010

9. Rekha R, Kavitha R, Venkitachalam R, et al. Comparison of sealing ability of bioceramic sealers. J Oral Biol Craniofac Res. 2022. doi:10.1016/j.jobcr.2022.10.006

10. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E. Calcium silicate sealers review. Odontology. 2019;107(4):421-436. doi:10.1007/s10266-018-0402-7

11. Kim SY, Kim HC. Evaluation of postoperative pain after root canal treatment using bioceramic and resin-based sealers. Materials. 2021;14(10):2661. doi:10.3390/ma14102661

12. Khalil I, Naaman A, Camilleri J. Properties of tricalcium silicate sealers. J Endod. 2016;42(10):1529-1535. doi:10.1016/j.joen.2016.06.002

13. Viapiana R, Guerreiro-Tanomaru JM, Tanomaru-Filho M, Camilleri J. Physicochemical properties of calcium silicate-based sealers. Int Endod J. 2014;47(3):259-266. doi:10.1111/iej.12149

14. Huang Y, Celikten B, Vasconcelos KF, et al. Micro-computed tomographic evaluation of root canal obturation with bioceramic sealers. Clin Oral Investig. 2019;23:1-9. doi:10.1007/s00784-018-2443-9

15. Shokouhinejad N, Nekoofar MH, Razmi H, Sajadi S, Davies TE, Saghiri MA, et al. Bioactivity of calcium silicate-based endodontic materials. Int Endod J. 2012;45(8):726-731. doi:10.1111/j.1365-2591.2012.02029.x

16. Marciano MA, Duarte MAH, Ordinola-Zapata R, Del Carpio-Perochena A, Cavenago BC, Villas-Boas MH, et al. Analysis of root canal obturation techniques using micro-computed tomography. Int Endod J. 2011;44(7):642-650. doi:10.1111/j.1365-2591.2011.01870.x

17. Gambarini G, Testarelli L, Al-Sudani D. Sealing ability of root canal sealers. Acta Odontol Scand. 2011;69(6):335-339. doi:10.3109/00016357.2011.568968

18. Silva Almeida LH, Moraes RR, Morgental RD, et al. Influence of sealer type on root canal filling quality. J Appl Oral Sci. 2017;25(1):34-40. doi:10.1590/1678-775720160321