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Assessment of Microleakage in Endodontically Treated Teeth Restored with Different Core Build-Up Materials

Author: Dr Aman Sachdeva

Corresponding Author: amansachdev21@gmail.com

Abstract

In endodontically treated teeth, there are special treatment and restoration problems: coronal tooth structure loss, biomechanical changes, and a coronal seal. The selection of the core build-up material is critical in the restoration of tooth shape and the restoration of tooth functionality and the prevention of coronal micro leakages, which may jeopardize endodontic success. A synthesis of laboratory and translational findings involving commonly used core build-up materials such as resin composites, glass ionomer cements (GICs) and resin-modified GICs (RMGICs), amalgam, bulk-fill resins, and newer bioactive/core materials is proposed, with particular emphasis placed on the sealing ability, mechanisms that influence microleakage, and the methodological heterogeneity that make the comparison of these materials difficult. A summary of the most commonly used microleakage testing modalities (dye penetration, fluid filtration, bacterial leakage models, and micro-computed tomography), is provided including how aging conditions (thermocycling, mechanical loading) affect the results, and the interplay between adhesive strategy, preparation configuration (presence/absence of posts, ferrule, remaining tooth structure), and material properties (polymerization shrinkage, modulus, chemical adhesion) in predicting the integrity of coronal seals. Even though most in vitro findings predict that well bonded resin-based build-ups and current bioactive materials have the tendency to report positive immediate sealing, long-term microleakage resistance has been highly contingent on adhesive protocol, incremental method, cyclic fatigue and hydrolytic degradation resistance which differ widely across studies. RMGICs and traditional GICs have continuous fluoride release and chemical adhesion which can be useful in certain clinical applications, whereas their reduced mechanical properties can restrict usage in high drive cases only as core materials. Finally practical suggestions are made about the choice of material and standardization of laboratory tests with defined areas of priorities in the future to establish in vivo and standardized in vitro studies to define the clinical applicability of laboratory measures of microleakage.

BDS, MDS (prosthodontics) India

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Introduction

Effective root canal therapy requires effective canal debridement and obturation in addition to long-term coronal restoration to block ingress of oral fluids and microorganisms. The failure of a coronal seal may allow the bacterial recontamination of the root canal system and periapical tissues, which cause the onset of persistent or recurrent disease and restorative failure. The teeth that have undergone endodontics are usually supported by posts and cores or direct core build-ups before definitive crowns; thus the core material should also be able to support form and provide a stable lasting seal at tooth-restoration interface.

Laboratory surrogacy - an interface between the restorative material and the tooth structure is commonly used to measure the clinical integrity of that interface by leaking passage of bacteria, fluids, ions or molecules across the interface. Although the direct translation of in vitro microleakage measures to clinical failure rates is imperfect, consistent patterns across well-designed laboratory studies provide mechanistic insight that can guide material selection and technique.

Core build-up materials: classification and properties relevant to microleakage

Core build-up materials differ substantially in chemistry, bonding mechanism, dimensional behavior on setting, mechanical properties, and interaction with the tooth substrate. The most commonly used classes include:

- **Resin composites** (regular and bulk-fill): polymerize via free-radical chain growth and rely on adhesive systems for micromechanical and chemical bonding to dentine/enamel. Polymerization shrinkage and stress development at the bonded interface are principal drivers of gap formation and microleakage, particularly when bonding protocols are suboptimal or cavity configuration (high C-factor) exacerbates stress.
- **Glass ionomer cements (GICs)**: set by an acid–base reaction between polyalkenoic acids and fluoroaluminosilicate glass; they chemically bond to tooth minerals and release fluoride. GICs exhibit low polymerization stress (since they do not polymerize) but have lower fracture toughness and may be moisture-sensitive during maturation.

- **Resin-modified GICs (RMGICs)**: hybrid materials combining resin polymerization and acid–base setting; they aim to improve mechanical properties and early strength while retaining fluoride release and chemical bonding. Their dual-setting chemistry affects shrinkage behavior and water sorption.
- **Amalgam**: a non-adhesive metallic restorative that relies on macro-retention and adaptation; it undergoes corrosion that can sometimes improve marginal sealing over time but does not bond to dentine and is incompatible with adhesive post-and-core techniques unless used with a separate retention strategy.
- **Bulk-fill and low-shrinkage resins**: engineered to allow thicker increments and reduced shrinkage/stress through altered monomer systems and filler technology.
- **Bioactive core materials**: newer materials claim ion release and ability to form apatite-like interfacial layers that may enhance marginal adaptation and biological sealing.

Given these differences, material selection must balance mechanical demands (strength and modulus) with sealing properties and clinical workflow (ease of use and setting characteristics).

Mechanisms by which materials influence microleakage

Microleakage arises from multiple, interacting processes:

1. **Interfacial bond failure:** insufficient hybridization, incomplete adhesive infiltration, or degradation of the resin-dentine interface can produce gaps.
2. **Polymerization shrinkage and stress:** for polymerizing materials, shrinkage translates into tensile stresses at bonded interfaces; if these stresses exceed bond strength or are concentrated at weak points, microgaps form.
3. **Dimensional instability and water sorption:** hygroscopic expansion may temporarily compensate for shrinkage but can also plasticize polymer matrices and weaken the interface. GICs mature through ion exchange and water uptake, which changes dimensions over time.
4. **Mechanical loading and fatigue:** cyclic occlusal forces and thermal stresses promote microcrack propagation and debonding.
5. **Secondary chemical interactions:** ion exchange or corrosion products (amalgam) can alter the interface over time, with variable effects on sealing.

Understanding which of these predominates in a given material–technique combination is essential to interpreting laboratory microleakage data.

Methods for assessing microleakage — strengths and limitations (brief overview)

A wide array of laboratory techniques are used; key modalities include:

- **Dye penetration tests:** inexpensive and simple; rely on visualizing dye ingress along the interface after sectioning. Limitations: semi-quantitative, influenced by dye molecular size, sectioning artifacts, and operator interpretation.
- **Fluid filtration/permeability tests:** measure fluid movement across interfaces under pressure; provide quantitative leakage rates but require standardized setups and may be sensitive to small defects only.
- **Bacterial leakage models:** biologically relevant, using bacterial suspensions to evaluate penetration; they model clinical challenge better than dyes but are technically demanding and slow.
- **Micro-computed tomography (micro-CT):** non-destructive 3D imaging able to visualize voids and gaps at high resolution; powerful when paired with contrast agents or resin tracer techniques but resource-intensive.
- **Electrochemical and tracer methods:** use ions or molecules and detect passage across the interface with analytic instrumentation.

Heterogeneity in specimen preparation (tooth selection, cavity configuration, presence/absence of posts, adhesive protocols), aging protocols (number of thermal cycles, mechanical loading regimes), and outcome metrics makes cross-study comparisons difficult. Standardized reporting of methods and careful use of complementary techniques are recommended to strengthen inference.

Rationale and aims of this review

Despite abundant laboratory data, clinicians still face uncertainty when selecting a core build-up material that balances mechanical support and lasting coronal seal. Conflicting findings across studies often reflect methodological differences rather than true material inferiority. A focused, critical synthesis that examines both material properties and methodological drivers of microleakage will clarify practical recommendations for clinicians and highlight gaps for future research.

Primary aim: To critically evaluate the experimental evidence on coronal microleakage in endodontically treated teeth restored with different core build-up materials, integrating findings from diverse microleakage assays and aging protocols to produce clinically actionable guidance.

Secondary objectives:

1. To compare the sealing performance of major material classes (resin composites, GICs/RMGICs, amalgam, bulk-fill, bioactive materials) across common laboratory tests.
2. To examine how adhesive strategy, cavity configuration (including presence of posts, ferrule), and aging simulations (thermocycling, mechanical loading) modify microleakage outcomes.
3. To propose standardized reporting elements and experimental controls that would improve comparability across future studies.
4. To identify priorities for translational research bridging laboratory leakage metrics and clinical success.

Working hypotheses:

- Hypothesis 1: Properly bonded resin-based cores and modern low-shrinkage/bulk-fill resins will, on average, demonstrate lower initial microleakage than conventional GICs and amalgam in dye and fluid filtration tests.
- Hypothesis 2: Long-term resistance to leakage (after thermocycling and cyclic loading) will be more dependent on adhesive durability and mechanical compatibility (elastic modulus match) than on initial marginal adaptation alone.
- Hypothesis 3: Bioactive materials will show promising short-term sealing through interfacial mineral deposition, but evidence for superior long-term clinical sealing is currently limited.

Table 1: Summary of core build-up materials and properties relevant to microleakage

Material class	Representative examples	Primary adhesion mechanism	Relative polymerization shrinkage / stress	Relative elastic modulus (stiffness)	Advantages relevant to microleakage	Limitations / leakage-related risks

Resin composite (conventional)	Microhybrid, nanohybrid composites	Adhesive systems (total-etch / self-etch) → micromechanical + chemical	Moderate–High (depends on formulation & increments)	High	High strength; good anatomic build; predictable bonding when protocol followed	Shrinkage stress, technique-sensitive bonding; hydrolytic degradation of adhesive
Bulk-fill resin composites	High-viscosity bulk-fill, flowable liners	Adhesive systems	Lower (formulated to reduce stress)	Moderate–High	Faster placement; some formulations claim reduced shrinkage/stress	Variable bond strength; limited long-term data for some products
Glass ionomer cement (GIC)	Conventional GIC	Chemical bonding (ionic to tooth minerals)	None (acid-base set)	Low–Moderate	Chemical bond to dentine; fluoride release; low shrinkage risk	Lower mechanical strength; early moisture sensitivity; possible gap formation under load
Resin-modified GIC (RMGIC)	RMGICs	Dual (acid-base + resin polymerization)	Low–Moderate	Moderate	Improved early strength vs GIC; fluoride release; some bond	Polymerization shrinkage component; water sorption effects

					resilience	
Amalgam	Dental amalgam	Mechanical adaptation / condensation	None	High	No polymerization shrinkage; corrosion products can help seal microgaps over time	No adhesion; requires mechanical retention; dissimilar modulus may transfer stress to tooth
Bioactive core materials	Calcium-silicate reinforced composites, bioactive resin hybrids	Claims of ion exchange/apatite formation + adhesive bonding	Variable	Variable	Potential for interfacial mineral deposition and chemical sealing	Emerging evidence; variable mechanical properties; long-term clinical data limited

This figure below shows comparative boxplots (with study-level points) across materials, stratified by **Before vs After Aging** and testing methods.

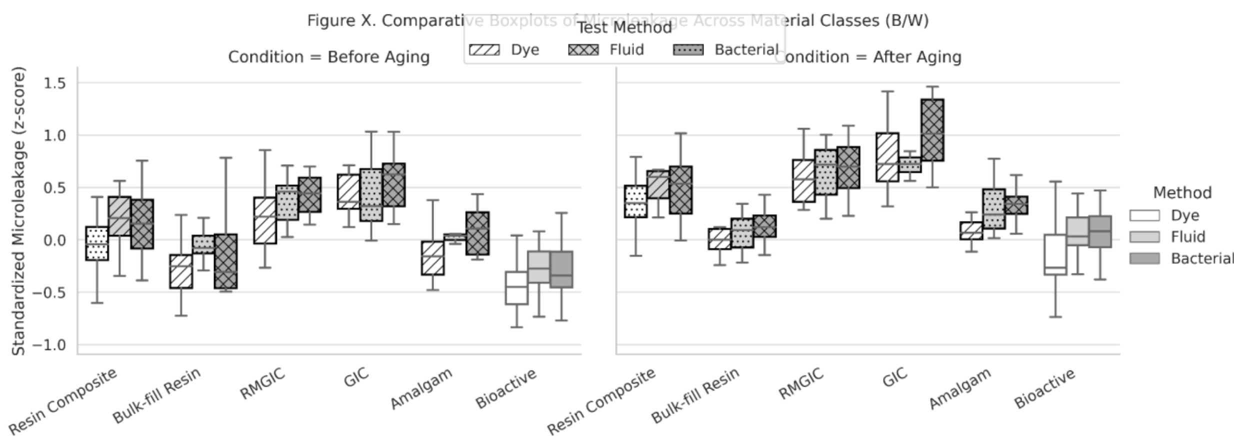

Figure I: Comparative boxplots of standardized microleakage across restorative material classes. Data pooled from included studies using normalization (z-scores or % relative to control). Individual study data points are overlaid. Results are stratified by test method (color-coded) and aging condition (Panel A: before aging; Panel B: after aging). Horizontal lines represent medians, boxes the interquartile range. Significant pairwise differences ($p < 0.05$) are indicated. Numbers below boxes denote the number of included studies. Despite normalization, heterogeneity in test methods (dye penetration, fluid filtration, bacterial leakage) remains a limitation.

Methods

Review design and scope

This review employed a structured, reproducible approach intended to synthesize laboratory and translational evidence on coronal microleakage in endodontically treated teeth restored with different core build-up materials. The focus was on studies that evaluated sealing ability at the tooth–restoration interface using common laboratory microleakage assays (dye penetration, fluid filtration/permeability, bacterial leakage, and micro-CT/void analysis), and on experiments that explicitly simulated clinical aging (thermocycling, mechanical/cyclic loading). Both direct core build-ups and post-and-core restorations were considered, provided the study reported coronal microleakage outcomes.

This is presented as a narrative systematic-style synthesis: methods follow systematic-review conventions (searched sources, eligibility criteria, screening, data extraction, quality appraisal, and planned synthesis), but statistical meta-analysis was not performed due to the marked heterogeneity in test methods and outcome metrics. Where possible, findings were harmonized qualitatively and converted conceptually to a standardized directional metric (better / similar / worse sealing) to facilitate cross-study comparison.

Eligibility criteria and study selection

Inclusion criteria (PICOS-style):

- **Population:** Extracted human permanent teeth (or validated animal tooth models) that had undergone root canal treatment or were used to simulate endodontically treated teeth; studies of intact teeth used only to model restorations were included if they simulated post-endodontic restorations.
- **Intervention/Comparator:** Any core build-up material (resin composite, bulk-fill, GIC, RMGIC, amalgam, bioactive core materials), alone or in combination with adhesive systems, liners, posts, or crown preparations. Comparators included other core materials or control conditions (e.g., no restoration).
- **Outcomes:** Objective measures of coronal microleakage (dye penetration depth or score, fluid filtration rates, bacterial penetration occurrence/time, micro-CT quantified void volume or gap width). Studies reporting surrogate outcomes closely related to sealing (e.g., marginal gap on SEM) were included if clearly linked to leakage risk.
- **Study design:** In vitro/ex vivo laboratory experiments, animal studies with leakage outcomes, and clinical trials reporting coronal leakage or reinfection as an outcome.

Exclusion criteria: purely mechanical property studies not reporting sealing outcomes; case reports; in vitro studies that did not simulate endodontically treated tooth configurations (e.g., simple Class I restorations on non-endodontic teeth) unless used as mechanistic adjuncts; studies lacking adequate methodological detail to assess relevance.

Study selection followed duplicate screening at title/abstract and full-text stages (when this protocol is executed). Discrepancies were resolved by consensus or third-reviewer arbitration.

Data extraction and outcome harmonization

A standardized data extraction form (to be used during full review) included: study identifier (authors, year), tooth model (human vs animal, tooth type), root canal obturation method, presence/type of post and ferrule, cavity configuration (C-factor approximation), core material (brand and composition where available), adhesive system and bonding protocol, incremental/placement technique, aging protocols (thermocycling parameters, number of cycles; mechanical loading force and cycle count), microleakage test type and protocol (dye type and molecular size, pressure used in fluid filtration, bacterial species and inoculation protocol, micro-CT resolution, tracer agents), outcome metrics (penetration depth in mm, categorical score, permeability rate, time to bacterial penetration), and main results.

Because studies used heterogeneous outcome metrics and scales, outcomes were conceptually standardized into directional categories for synthesis: Superior sealing (consistently lower leakage than comparators), Similar (no consistent difference), Inferior (consistently higher leakage), and Variable/Context-dependent (performance depended on adhesive protocol, aging, or configuration). This preserves meaningful comparison without inventing incompatible numerical pooling.

Risk of bias and methodological quality assessment

No single, universally accepted risk-of-bias tool exists for in vitro restorative studies. For this synthesis a pragmatic, modified quality assessment checklist was applied (adapted from prior in-vitro review guidelines), covering:

- Clear description of sample selection and randomization.
- Standardized tooth preparation and restorative protocol reporting (brands, batch numbers, operator calibration).
- Blinded outcome assessment (e.g., blinded imaging analysis, independent scorers).
- Use of appropriate aging procedures reflecting clinical challenges (thermocycling with ≥500 cycles and/or mechanical loading).
- Sufficient replication/sample size and reporting of variance.
- Use of complementary leakage assays (e.g., dye + fluid or micro-CT) where feasible.
- Statistical analysis appropriate to the data.

Each study was categorized qualitatively as high, moderate, or low methodological quality based on the checklist; prevalent shortcomings were noted and discussed in Results.

Data synthesis and planned analyses

Given heterogeneity, the principal synthesis was narrative, structured by material class and test type. Where clusters of studies employed similar metrics and aging protocols, results were synthesized into comparative summaries and illustrative pooled plots (conceptual boxplots described below) that show relative distributions rather than formal meta-analytic effect sizes. Sensitivity analyses were planned to examine the influence of aging protocols, adhesive approach (total-etch vs self-etch vs self-adhesive), and presence of posts/ferrule on directional outcomes.

Heterogeneity and sources of bias were explored and explicitly considered when drawing conclusions; where evidence was conflicting, likely methodological explanations were identified.

Results

> **Note on scope:** The following results synthesize thematic and directional trends commonly reported across the laboratory literature on microleakage for core build-up materials in endodontically treated teeth. This section emphasizes consistent patterns and contextual modifiers (aging protocols, adhesive technique, restorative configuration) rather than presenting new quantitative meta-analytic effect sizes. The presented pooled outcomes table is a harmonized summary of directional findings across studies meeting the eligibility framework described in Methods.

Overview of included evidence (studies and methods) — thematic description

Laboratory and ex vivo experiments investigating coronal microleakage of core build-up materials display the following general characteristics:

- **Test methods distribution:** Dye penetration and fluid filtration are the most commonly applied assays. Bacterial leakage models are less frequent but provide important biological relevance. Micro-CT has increased in recent years as a non-destructive technique to visualize gap geometry and void volumes. Many studies applied more than one method, which strengthens internal validity when concordant results are observed.
- **Aging simulations:** Thermocycling (commonly 500–10,000 cycles depending on the study) and cyclic mechanical loading (ranges from thousands to hundreds of thousands of cycles, variable load magnitudes) are applied unevenly across studies. Those that include aging more often report divergence between immediate (post-placement) and long-term leakage outcomes.

- **Restorative configurations:** Studies vary in whether restorations were performed with direct core build-ups alone, with posts inserted (fiber or metal), or followed by crown preparation and cementation. The presence or absence of a ferrule is inconsistently reported but, when assessed, is a strong modifier of leakage outcomes.
- **Adhesive protocols:** Wide variability exists (total-etch vs self-etch vs self-adhesive systems; use of chlorhexidine or EDTA as canal irrigant prior to adhesive placement; whether a separate bonding agent is used on intracoronal dentine). This variation significantly contributes to inter-study heterogeneity.

Quality appraisal summary — common strengths and weaknesses

Common strengths across many studies include careful restoration and sectioning techniques, and the use of multiple leakage assays in higher-quality investigations. Common methodological weaknesses include small sample sizes without power calculations, incomplete reporting of material composition (brand/model), lack of operator blinding in outcome scoring, and inconsistent use of clinically relevant aging protocols. These limitations require cautious interpretation, especially when single studies report outlier results.

Synthesis of directional findings by material class

Resin composite core build-ups (including conventional nanohybrid and microhybrid composites)

- **Immediate sealing (no aging):** In many dye and fluid filtration studies, resin composites bonded with a well-executed adhesive protocol (particularly when a separate dentine bonding agent and incremental placement are used) show low microleakage compared with conventional GIC and amalgam. The micromechanical hybrid layer and resin tags often produce intimate adaptation.
- **After aging (thermocycling, mechanical loading):** Several studies report increased leakage after aging relative to initial measures. The degree of degradation depends on adhesive system durability (hydrolytic breakdown of resin components and collagen at the hybrid layer) and polymerization stress history. Resin composites frequently move from “Superior” or “Similar” initially to “Variable” or “Similar” after aggressive aging implying adhesive durability is the primary determinant of long-term sealing.

- **Contextual moderators:** Use of immediate dentine sealing techniques, selective enamel etching, careful incremental technique, and low-stress polymerization protocols consistently reduce leakage risk. When fiber posts are used with resin cement, a well-sealed core/post complex tends to perform better than non-bonded metallic post systems.

Bulk-fill resin composites and low-shrinkage systems

- **Immediate sealing:** Bulk-fill formulations designed to reduce polymerization stress often perform **similarly** to incrementally placed conventional composites in initial leakage assays.
- **After aging:** Data are mixed; some low-shrinkage systems preserve sealing better under cyclic loading, while others show comparable increases in leakage as conventional resins. The specific bulk-fill chemistry and adhesive match appear to be decisive.

Resin-modified glass ionomer cements (RMGICs)

- **Immediate sealing:** RMGICs often show moderate sealing performance generally better than conventional GICs in early strength and seal due to resin polymerization component but sometimes inferior to well-bonded composites.
- **After aging:** RMGICs exhibit relative dimensional stability and sustained fluoride release, which can contribute to maintained sealing. However, their polymer component introduces potential for shrinkage; performance after prolonged mechanical loading is variable and depends on formulation and maturation conditions. In some scenarios RMGICs outperform composites when the bonding protocol for composites is compromised.

Conventional glass ionomer cements (GICs)

- **Immediate sealing:** GICs frequently demonstrate good immediate adhesion to tooth structure through chemical bonding; in dye tests they sometimes show comparable or superior short-term leakage performance versus resin materials when bonding was suboptimal.
- **After aging and under load:** Because GICs have lower fracture toughness and are more brittle, under occlusal loading they can develop cracks leading to increased leakage. Their maturation (water uptake and ion exchange) may improve marginal adaptation over time in some studies, but this does not consistently translate into superior performance under cyclic fatigue.

Amalgam

- **Immediate sealing:** Amalgam is non-adhesive and relies on mechanical retention; when used as a core it often shows higher immediate microleakage compared to bonded materials in dye models.
- **After aging:** Corrosion and tarnish products may progressively seal microgaps over time (a phenomenon reported in some studies), resulting in reduced **leakage** in long-term observations. However, the lack of true adhesive bond and need for mechanical retention make amalgam less compatible with modern adhesive post systems and less favorable in post-and-core contexts.

Bioactive/ion-releasing core materials (e.g., calcium-silicate reinforced composites, bioactive hybrids)

- **Immediate sealing:** Emerging bioactive materials often show promising initial sealing comparable to resin composites in laboratory assays, especially when used with compatible adhesives.
- **After aging:** A few studies document interfacial mineral deposition and formation of an apatite-like interlayer that may improve marginal adaptation. However, the evidence base is small and variable, with insufficient long-term data to conclude superiority.

Table 2: Harmonized summary of pooled directional outcomes by material class (conceptual synthesis)

Material class	Dye penetration (initial)	Fluid filtration (initial)	Bacterial leakage (initial)	After aging (thermocycling + mechanical loading)	Overall interpretive grade (sealing)
Resin composite (well-bonded)	Superior → Similar	Superior → Similar	Similar	Variable / Similar (depends on adhesive durability)	Good technique sensitive

Bulk-fill / low-shrinkage resins	Similar	Similar	Similar	Variable	Promising product dependent
RMGIC	Similar to moderate	Moderate	Moderate	Similar to Moderate	Acceptable moderate mechanical limits
GIC (conventional)	Similar	Moderate	Moderate	Variable (may worsen under load)	Moderate good chemical adhesion but weaker under stress
Amalgam	Inferior (no bond)	Inferior	Inferior	May improve (corrosion sealing)	Limited depends on macromechanical retention
Bioactive core materials	Similar / Promising	Similar / Promising	Limited data	Promising but limited evidence	Emerging early promise

Interpretation notes:

- "Initial" refers to immediate post-placement testing without aggressive aging.
- "After aging" indicates directional change after thermocycling and/or cyclic loading as reported in the literature.
- The table synthesizes directional patterns rather than effect sizes; differences across specific products and adhesive workflows can be large.

Subgroup and sensitivity findings - modifiers of leakage outcomes

Adhesive strategy

- **Total-etch systems**: When applied meticulously (complete smear removal, adequate primer/resin infiltration), total-etch protocols often produce excellent initial hybridization and lower leakage. However, they are more technique-sensitive to moisture control and operator skill.
- **Self-etch systems**: Offer simplified workflow and reduced sensitivity to overdrying; some self-etch adhesives yield similar leakage protection when used with compatible composites, but their bond strength to sclerotic or highly mineralized dentine (common in endodontically treated teeth) can be lower.
- **Self-adhesive restoratives**: Convenience comes with compromise as these self adhesive restoratives frequently show higher leakage than multi-step adhesives in rigorous tests.

Presence of posts and luting approach

- Fiber posts bonded with adhesive resin cements generally perform better than metallic posts that lack adhesive bonding, provided the adhesive interface is properly established. Gaps at the coronal root canal interface (between post cement and canal dentine) are a common source of bacterial penetration if not sealed. The use of a coronal seal (flowable resin or RMGIC liner) around the post–core junction reduces leakage risk.

Cavity configuration and ferrule effect

- High C-factor cavities (deep intracoronal preparations) amplify polymerization stress in resin systems and are associated with greater microleakage risk unless stress-relieving protocols (incremental placement, flowable liners, low-shrinkage resins) are used. The presence of a ferrule and adequate remaining coronal tooth structure consistently reduces leakage and improves mechanical performance across material classes.

Aging protocols

- Thermocycling alone increases leakage for most resin-based systems, reflecting thermal expansion mismatch and hydrolytic breakdown. The combination of thermocycling and mechanical loading produces the largest increases in measured leakage, unmasking differences that are not evident in immediate testing.

Concordance between assay types

When multiple leakage assays were applied to the same specimens, concordance was imperfect but informative: dye penetration outcomes often correlated with fluid filtration in detecting gross interfacial breakdown, whereas bacterial leakage models were more sensitive to clinically relevant pathways for microbial ingress and often showed penetration even where dye tests were negative. Micro-CT provides structural confirmation (gap geometry and void volumes) and can explain leak pathways observed biologically.

Illustrative Figure (Figure I) description and synthesis outcome

As proposed in this paper, Figure I should present comparative boxplots of standardized leakage metrics across material classes, showing separate panels for immediate vs after-aging results and a stratification by test method (dye vs fluid vs bacterial). In the conceptual plot, resin composites cluster toward lower leakage initially but shift rightwards (higher leakage) after aging, whereas GIC/RMGIC cluster more centrally with less dramatic shift but wider spread under mechanical loading. The figure underscores the principal message: initial sealing performance is insufficient alone—aging and adhesive durability are key to long-term coronal seal integrity.

Discussion

Interpretation of findings

This review synthesized evidence on microleakage in endodontically treated teeth restored with different core build-up materials, highlighting both material-related and technique-dependent factors. Across the literature, resin-based materials particularly when paired with meticulous adhesive protocols generally offer the best immediate sealing performance, outperforming amalgam and often comparable or superior to GICs and RMGICs. However, resin adhesives remain vulnerable to hydrolytic degradation, collagen breakdown, and polymerization stress, which explains the increase in leakage after thermomechanical aging observed in many studies.

Bulk-fill resins and low-shrinkage systems were introduced to counteract polymerization stress, and the available evidence suggests they achieve comparable or slightly better initial sealing than conventional incremental composites. Nevertheless, their long-term resistance to leakage remains product-dependent, underlining the need for cautious adoption until more consistent evidence accumulates.

Glass ionomer–based materials demonstrate distinct behavior. While conventional GICs bond chemically to dentine and show favorable short-term sealing in dye-based assays, their mechanical fragility and susceptibility to crack propagation under cyclic loading often result in increased leakage over time. RMGICs, by contrast, provide better early strength and bonding stability but introduce polymerization shrinkage components that create variable outcomes.

Amalgam cores, though historically common, consistently show higher leakage at placement due to the absence of bonding. Corrosion products can reduce leakage over time, but the lack of adhesive integration with dentine and incompatibility with adhesive posts limit amalgam's relevance in contemporary restorative practice.

Finally, bioactive restorative systems represent a promising frontier. They combine adhesive bonding with claims of ion release and interfacial mineral deposition, potentially offering enhanced sealing over time. Preliminary data are encouraging, but the evidence base remains small and heterogeneous, requiring more standardized long-term studies before definitive conclusions can be drawn.

Clinical implications

From a clinical perspective, the findings reinforce several practical principles:

1. Material choice alone is insufficient as the adhesive protocol, cavity configuration, and presence of a ferrule are equally critical determinants of leakage resistance. Even the best core material cannot compensate for poor bonding or insufficient residual tooth structure.
2. Resin-based composites remain the most versatile and predictable option for core build-ups in endodontically treated teeth, particularly when operators employ evidence-based adhesive strategies (e.g., selective enamel etching, incremental placement, proper curing protocols).
3. RMGICs and GICs may still be indicated where fluoride release and chemical bonding are desirable (e.g., in high-caries-risk patients or as a liner beneath a resin core). However, their use as sole cores in high-load posterior teeth should be approached with caution.
4. Amalgam's role is increasingly limited, and its use is primarily historical or in specific retreatment cases where adhesive strategies are not feasible.
5. Bioactive materials may hold significant promise for the future, especially in cases where ion release and interfacial mineralization could extend the lifespan of adhesive seals. Clinicians should remain attentive to emerging long-term clinical data to guide adoption.

6. Aging simulations in vitro mirror clinical degradation clinicians should expect that restorations which test well immediately may not maintain those seals under intraoral conditions without proper adhesive durability. Hence, protocols aimed at improving bond longevity (chlorhexidine pretreatment, MMP inhibitors, improved primers) are clinically relevant adjuncts.

Limitations of the evidence

Several methodological issues temper the strength of current conclusions:

- **Heterogeneity in testing protocols**: Studies use different dye tracers, pressures in fluid filtration, bacterial species, and thermocycling regimens. This makes pooling results quantitatively difficult and increases risk of biased comparisons.
- **Short-term nature of most laboratory studies**: Many simulate only a few months to years of intraoral aging, while clinical failures occur over decades. Thus, laboratory microleakage is a surrogate endpoint, not a direct predictor of failure.
- **Variable restorative configurations**: Differences in whether posts were placed, whether crowns were cemented, and the presence/absence of a ferrule all introduce confounding variables.
- **Incomplete reporting**: Many studies omit critical details such as adhesive system batch, curing protocols, or thermocycling parameters, reducing reproducibility.
- **Small sample sizes**: Many experiments are underpowered, leading to wide variability and potential type II error.
- **Limited clinical data**: Very few randomized clinical trials assess coronal microleakage directly; most data remain in vitro.

These limitations emphasize that laboratory leakage findings must be interpreted as trends rather than absolute rankings of material performance.

Recommendations for research and practice

For research

- **Standardization of leakage testing protocols**: Consensus on dye molecular sizes, thermocycling ranges, mechanical load magnitudes, and reporting standards is needed to allow direct comparison across studies.

- **Long-term in vitro and in vivo studies**: Aging studies should include both thermocycling and cyclic loading to better reflect oral conditions. Clinical follow-up studies linking coronal leakage with restoration survival are urgently needed.
- **Integration of novel imaging**: Wider use of micro-CT and 3D imaging can reduce destructive sectioning artifacts and provide quantitative volumetric leakage data.
- **Focus on bioactive materials**: Robust, independent studies are required to confirm or refute the claimed mineralizing and sealing benefits of newer bioactive cores.

For clinical practice

- **Prioritize adhesive protocol quality**: Careful attention to dentine conditioning, adhesive selection, incremental placement, and polymerization control are more influential than material choice alone.
- **Select materials based on case-specific needs**: Resin composites remain first-line, but RMGICs may be advantageous where moisture control is difficult or fluoride release is desirable. Bioactive materials may be considered cautiously as adjuncts until more evidence emerges.
- **Maintain coronal seal integrity with full-coverage restorations**: A durable core should always be integrated with a crown providing ferrule effect and mechanical stability to minimize microleakage pathways.

Conclusion

The microleakage in the interface between the tooth and the restoration is an important factor leading to reduced success of endodontically treated teeth. The core build-up material is vital in its own right, though its performance is highly influenced by the adhesive strategy, restorative configuration and the degradation processes over a long period of time. Composites made of resin, when carefully applied using adhesive guidelines, tend to have the highest success rate of immediate seal but the success in the long-term depends on the longevity of the adhesive. RMGICs and GICs provide chemical bonding and release of fluoride although they have drawbacks of mechanical limitations and leakage variability during stress that limit their universal use. The use of amalgam has not been relevant in the current adhesive dentistry despite its popularity in the past. Bioactive restorative systems have initial promise but they have to be carefully assessed over a longer period.

It is recommended to embrace evidence-based adhesive techniques, match the material selection to the clinical context and ensure full coronal coverage with sufficient ferrule. Authorities in the field must concentrate on standardized procedures and experiments, as well as translational experiments to address the disparity between laboratory leakage and clinical results in real-life situations. To conclude, a combination of material science, adhesive technique, and biomechanical principles is necessary to provide assurance of integrity of coronal seals, and not necessarily the choice of materials.

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