Submitted: 15 October, 2025 Accepted: 09 December, 2025 Published: 03 May, 2026 DOI:10.22514/jocpd.2026.059

SYSTEMATIC REVIEW

Journal of Clinical Pediatric Dentistry

Survival of smart restoratives in pediatric dentistry: a PRISMA-guided meta-analysis of randomized trials

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Abstract

Background: Smart and ion-releasing restorative systems are widely used for pediatric posterior restorations, yet their survival compared with resin composites remains uncertain. This review synthesized randomized clinical evidence on restoration survival and failure in children. **Methods**: PubMed (MEDLINE), Embase (Ovid), and Cochrane CENTRAL were searched from inception to 18 September 2025 without language or year restrictions. Eligible studies were randomized controlled trials using parallel, split-mouth, or cluster designs in children receiving direct posterior restorations. The primary comparison was smart materials versus resin composites in primary teeth. Outcomes followed Atraumatic Restorative Treatment or United States Public Health Service Ryge failure criteria at the longest follow-up. Random-effects meta-analyses were performed when at least two studies contributed, using DerSimonian-Laird tau-squared and Hartung-Knapp confidence intervals. Time-to-event outcomes were synthesized separately. Risk of bias was assessed using the Cochrane Risk of Bias 2 tool. **Results**: Of 380 records identified, 16 trials met inclusion criteria. For primary teeth, two trials pooled at 12 to 24 months showed a non-significant trend favoring resin composites, with a risk ratio of 1.74 and a 95 percent confidence interval of 0.67 to 4.57, and low heterogeneity. Technique-related signals suggested that retentive grooves reduced failure compared with no grooves in Class II Atraumatic Restorative Treatment restorations in a single randomized trial. Effects of rotary excavation and medicated liners were imprecise and based on single studies. In pediatric permanent teeth, two trials comparing smart materials showed no clear difference in survival. **Conclusions**: At 12 to 24 months, smart ion-releasing materials do not outperform resin composites for primary posterior restorations. Operative technique, particularly retentive features in Atraumatic Restorative Treatment restorations, may be more influential than material choice. Evidence in pediatric permanent teeth remains limited and inconclusive. Larger, well-reported trials with longer follow-up and standardized outcomes are required. **The PROSPERO Registration**: CRD420251090030.

Keywords

Atraumatic restorative treatment; Glass-ionomer cement; Ion-releasing restorative materials; Meta-analysis; Pediatric dentistry; Primary teeth; Randomized controlled trial; Resin composite

1. Introduction

Dental caries remains one of the most prevalent chronic conditions in childhood and a major cause of tooth pain, infection, and missed school days worldwide [1, 2]. Because restoration failures often require re-intervention—leading to increased treatment burden, higher costs, and reduced acceptability for children—restoration longevity has significant clinical and public health implications, especially in school-based and community dental programs where follow-up may be limited. In primary molars, multisurface lesions and moisture-control challenges frequently complicate restorative care, particularly in pediatric and outreach settings where time, cooperation, and isolation are constrained.

Conventional resin composites are widely used for posterior restorations but are technique-sensitive and rely on optimal bonding and field control—conditions that may not always be achievable in children [3, 4]. Smart or ion-releasing restorative systems were introduced to address some of these limitations by coupling chemical adhesion with ion release. To streamline this section, instead of detailing the full range of subclasses, we summarize their shared clinical features: chemical bonding to dentin, fluoride or calcium/phosphate release, and relative tolerance to moisture. These materials include high-viscosity glass-ionomer cements (HVGICs), glass-hybrid formulations,

resin-modified or bioactive Resin Modified Glass Ionomer Cements (RMGICs), giomer/Surface Pre-Reacted Glass-ionomer (S-PRG) systems, and alkasites such as Cention [5, 6]. These common mechanisms, rather than subclass-specific distinctions, form the practical basis for their use in pediatric restorative dentistry.

Despite these advantages, uncertainties remain regarding whether ion-releasing materials achieve comparable survival to resin composites in primary teeth. Previous pediatric syntheses have shown mixed or inconclusive findings, with some evidence suggesting trends favoring composites in multisurface lesions [7]. At the same time, atraumatic restorative treatment (ART) literature indicates that technique and case selection may influence outcomes as much as material choice [8]. Given the expanding global use of ion-releasing materials in minimally invasive pediatric dentistry—including ART and community-based programs—the question of their comparative longevity remains clinically meaningful and relevant.

The present systematic review synthesizes randomized clinical evidence on the survival of smart/ion-releasing restorative materials in children, focusing primarily on comparisons with conventional resin composites in primary molars. Secondary objectives include head-to-head comparisons among ion-releasing materials, evaluation of technique-level modifiers within Glass Ionomer Cement (GIC)-based protocols, and contextual interpretation of emerging formulations [9].

2. Materials and methods

This systematic review was conducted according to Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 guidelines [10] and registered in PROSPERO (CRD420251090030). A complete checklist file has been added to the **Supplementary material 1**.

2.1 Selection criteria

Eligibility was defined using a pediatric restorative Patient/Problem, Intervention, Comparison, Outcome (PICO) framework (Table 1). Randomized controlled trials (parallel, split-mouth, or cluster/child-level) involving children or adolescents receiving direct posterior restorations were included. Interventions included ion-releasing restorative systems or GIC-related technique modifications, with resin composites as the primary comparator. Trials reporting extractable arm-level failure outcomes based on ART or USPHS/Ryge criteria at any follow-up were eligible. Non-randomized studies, adult-only cohorts, prevention-only trials, and protocols without results were excluded. In addition to the primary comparison of ion-releasing materials versus composite, trials comparing different ion-releasing formulations (*e.g.*, GIC *vs.* GIC) were included to address the prespecified secondary objective of evaluating within-class differences.

2.2 Data sources and search strategy

Systematic searches of PubMed (MEDLINE), EMBASE (Ovid), and Cochrane CENTRAL were performed from inception to 18 September 2025 with no language or year restrictions. Strategies combined controlled vocabulary and free-text terms for pediatric dentition, ion-releasing restorative materials, and randomized trial designs. Full database-specific search strings are provided once in **Supplementary Table 1** to avoid repeating similar terms within the text. Reference lists of all included studies and relevant reviews were manually screened for additional records. All citations were managed in Zotero for de-duplication before screening.

2.3 Selection of studies

Two reviewers independently screened titles/abstracts and full texts using predefined eligibility criteria. Disagreements were resolved by discussion or third-reviewer adjudication. Prevention-only trials were catalogued separately and not pooled with restoration-failure analyses. The PRISMA flow diagram (Fig. 1) summarizes study selection. Prevention-only trials identified during screening were excluded from all restoration-survival analyses but are briefly summarized separately to maintain PRISMA-compliant reporting transparency.

2.4 Data extraction

A standardized, piloted extraction form captured study identifiers, design characteristics, participant age range, tooth type, intervention/comparator details, and outcome assessment. Data extraction also included allocation concealment and specification of dentition type (primary or permanent) for each trial. Arm-level failures and totals at the longest follow-up were recorded for risk ratio calculation, and hazard ratios were extracted for time-to-event studies. Multi-arm, split-mouth, and cluster trials were handled with appropriate combination or design-effect adjustments. All extracted data were double-checked by two reviewers.

2.5 Risk-of-bias assessments

Risk of bias was assessed using the Cochrane RoB 2 tool [11] for failure outcomes at the longest follow-up. Two reviewers conducted assessments independently, resolving differences by consensus or third-reviewer input. Domain-level and overall judgments are summarized in **Supplementary Table 2** (Ref. [9, 12–26]).

2.6 Meta-analytic methods

The primary effect measure was the risk ratio (RR) for restoration failure comparing ion-releasing materials with composites in primary teeth. Random-effects models (DerSimonian-Laird τ^2, Hartung-Knapp confidence interval (CI)) were used when $\geq$2 studies contributed data. For survival outcomes, log-hazard ratios and standard errors were synthesized separately. Prespecified subgroup analyses examined tooth type, material class, evaluation criteria, and technique/adjunct comparisons. All analyses were conducted in R using the *meta* and *metafor* packages.

3. Results

TABLE 1. Selection criteria employed in the study.

Domain	Inclusion criteria	Exclusion criteria
Study design	Randomized controlled trials (parallel, split-mouth, or cluster/child-level) with a clearly described allocation process.	Non-randomized or quasi-experimental designs, before-and-after without control, cross-sectional studies, case series/reports, protocols without results.
Participants	Children/adolescents; mixed-age studies are eligible only if pediatric data are separately extractable.	Adult-only populations or studies where pediatric data cannot be separated.
Dentition/indication	Direct posterior restorations in primary teeth (primary analysis) or permanent teeth in children (analyzed as a separate subgroup).	Prevention-only interventions (sealants/varnish) without a restorative failure endpoint; indirect restorations/crowns without a comparable failure outcome; purely endodontic outcomes without restoration data.
Interventions	Smart/ion-releasing restorative materials (*e.g.*, HVGIC, glass-hybrid GIC, RMGIC/bioactive RMGI, giomer/S-PRG, alkasite/Cention) and GIC-related adjuncts/techniques (*e.g.*, retentive grooves, medicated liners).	Non-restorative agents alone (*e.g.*, varnish only) unless part of a restorative protocol; non-smart materials without a smart comparator.
Comparators	Conventional resin composite (primary comparison) or alternative GIC formulations/techniques (secondary comparisons).	Comparisons unrelated to restorative material or technique (*e.g.*, oral-hygiene instruction *vs.* none).
Outcomes	Restoration failure/retention/survival defined by ART or USPHS/Ryge at any follow-up; time-to-event measures accepted for separate survival synthesis.	Outcomes not reflecting restoration performance (*e.g.*, pain only, QoL only) and trials reporting only prevention outcomes (new caries/lesion arrest)—summarized separately, not pooled with RQ1.
Follow-up	Any duration; the longest time point is prioritized for primary synthesis, and earlier time points are retained for sensitivity/subgroup analyses.	No follow-up beyond immediate post-operative assessment.
Setting/language/year	Any clinical setting; no language or year restrictions (translations attempted as feasible).	*In vitro*, *ex vivo*, or animal studies.

HVGIC: high-viscosity glass-ionomer cement; ART: atraumatic restorative treatment; GIC: Glass Ionomer cement; RMGIC: Resin modified Glass Ionomer Cements; S-PRG: Surface Pre-Reacted Glass-ionomer; QoL: Quality of Life; RQ1: first research question.

3.1 Study selection

Database searches identified 380 records (PubMed 153; Cochrane 173; EMBASE 54). After removal of 227 duplicates, 153 records remained for title/abstract screening. Of these, 115 were excluded, and 38 full-text articles were assessed for eligibility. Sixteen randomized trials [9, 12–26] met the inclusion criteria and were included in the review; the remaining 22 full-texts were excluded with documented reasons (*e.g.*, non-randomized design, prevention-only outcomes, no extractable arm-level data, or protocol-only). The study selection process is depicted in the PRISMA 2020 flow diagram in Fig. 1.

3.2 Characteristics of included studies

The 16 included Randomized controlled trials (RCTs) [9, 12–26] were conducted in school, community, and university settings across Asia, South America, and Europe. Most evaluated posterior restorations in primary molars using ART or USPHS/Ryge criteria at 12–24 months. Two trials were conducted on permanent molars in children, including teeth affected by molar incisor hypomineralization (MIH). Interventions comprised high-viscosity or glass-hybrid GICs, resin-modified/bioactive GICs, giomer/S-PRG systems, alkasites, and GIC-related technique modifications. Key characteristics are detailed in **Supplementary Table 3** (Ref. [9, 12–26]).

3.3 Risk-of-bias assessment

Sixteen randomized trials were assessed. Overall, most were judged to have some concerns of risk of bias, reflecting frequent uncertainties in sequence concealment and potential unblinding of outcome assessment. One trial was judged low risk overall, one was judged high risk, and the remaining fourteen had some concerns The summary of the characteristics of the included RCTs is given as **Supplementary Table 3**. For example, unclear allocation concealment was noted in several

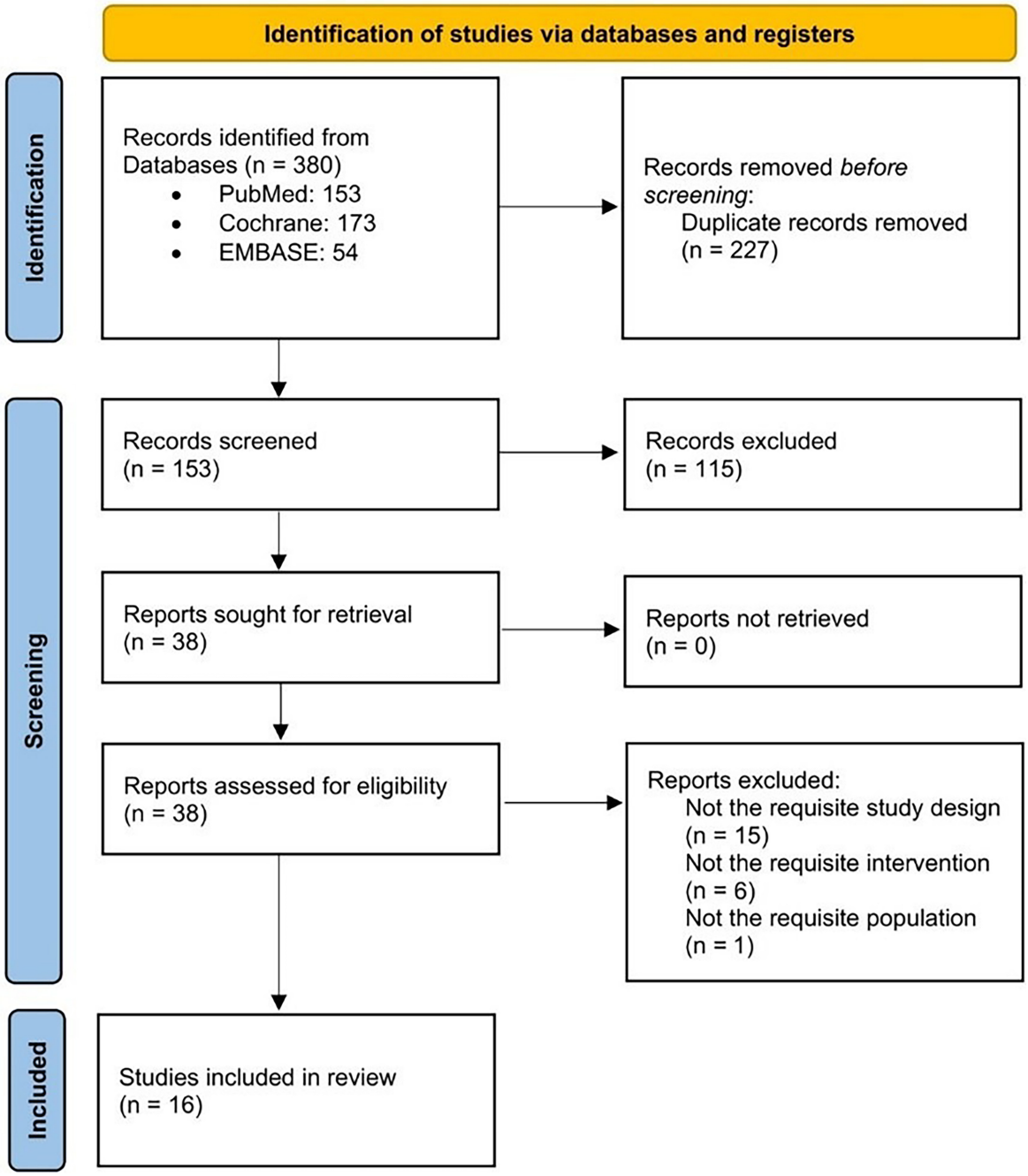

FIGURE 1. PRISMA 2020 flow diagram of study selection.

trials such as Maru *et al.* [13], Deepika *et al.* [14], and Phonghanyudh *et al.* [15]. Potential lack of assessor masking was evident in studies where material appearance could reveal allocation, including Akman *et al.* [12] and Pesaressi *et al.* [9]. Missing outcome data at the longest follow-up contributed to "some concerns" ratings in trials such as Garbim *et al.* [19] and Moura *et al.* [25]. These study-specific methodological issues are detailed in **Supplementary Table 2** and are referenced here to improve transparency.

By domain, concerns most commonly arose in the randomization process (unclear allocation concealment in several parallel and split-mouth designs) and in measurement of the outcome (assessor masking sometimes uncertain or infeasible due to recognizable material appearance, despite use of standardized criteria such as ART or USPHS/Ryge). Missing outcome data was generally low to moderate—attrition was typically balanced and below thresholds likely to bias results, though a few studies reported notable losses by the longest follow-up. Deviations from intended interventions were largely low risk given standardized clinical protocols, and selection of the reported result was usually low risk where protocols or prespecified outcomes were available.

For the primary meta-analysis set (smart/ion-releasing *vs.* composite in primary teeth), both contributing trials were rated with some concerns overall (unclear concealment and/or potential assessor unblinding). Technique/adjunct comparisons within GICs also raised some concerns, while the single low-risk judgment arose in a permanent-tooth trial (MIH). These patterns should be considered when interpreting the pooled effects.

3.4 Qualitative synthesis

Sixteen randomized trials with results were included in the narrative synthesis. The studies were conducted in school or university settings across Asia, South America, and Europe, and enrolled children from preschool age to adolescence. Designs were predominantly parallel-group randomized trials, with several split-mouth studies. Outcomes were most often assessed with ART or USPHS/Ryge criteria at 12–24 months, and one trial reported survival using hazard ratios. Risk of bias was commonly judged as "some concerns", typically owing to unclear allocation concealment and the practical difficulty of masking examiners when materials were visibly distinct in **Supplementary Table 2**. These technique-related trials are presented as an exploratory subgroup because they evaluate procedural modifications within ART/GIC protocols; however, the interventions themselves are mechanistically different, and the results should therefore be interpreted cautiously.

For the primary question—smart/ion-releasing restorative materials versus conventional composites in primary teeth—two trials contributed data at the longest follow-up. Akman *et al.* [12] (2020) compared a high-viscosity glass-ionomer (Equia Fil) against multiple composite comparators under USPHS at 12 months and observed very few failures overall, with a numerical advantage for composites. Maru *et al*. [13] (2022) contrasted Equia Forte with a silorane composite using Roeleveld criteria at 24 months and reported more failures in the GIC arm than in the composite arm. Considered together, these trials provide no clear evidence that smart/ion-releasing materials outperform conventional composites over 12–24 months; the findings trend toward fewer failures with composites but remain imprecise because of limited study numbers and differing outcome frameworks.

Head-to-head comparisons within ion-releasing systems did not reveal consistent superiority of any single class. Deepika *et al*. [14] (2022) compared a Resin-Modified Glass Ionomer (RMGI)/bioactive material (ACTIVA) with a giomer in a split-mouth design and found comparable retention at 12 months. Garbim *et al.* [19] (2024) compared two GIC formulations (Equia Forte versus Riva Self Cure) using survival analysis over 24 months and reported no significant difference in hazard of failure. Moura *et al.* [25] (2020) reported larger arm totals for Ketac versus Vitro at 12 months but did not permit the extraction of explicit per-arm failure counts from the published tables; adjusted analyses favoured Ketac. Faustino-Silva *et al*. [27] (2019) followed toddlers for 1–4 years and found high overall ART success without clear between-material differences. Collectively, ion-releasing materials appeared to perform similarly to one another over the observed time frames, with signals dependent on outcome definitions and follow-up length.

Technique and adjunct modifications within GIC showed clearer signals. Pesaressi *et al.* [9] (2024) demonstrated that adding retentive grooves to Class II ART preparations reduced failures relative to no grooves at 12 months, suggesting a tangible benefit of additional mechanical retention in proximal lesions. Phonghanyudh *et al.* [15] (2011/2012) observed numerically fewer failures when GIC restorations followed rotary burr caries removal rather than hand excavation at 12 months, although the difference was modest and derived from a single study. Ferreira *et al.* [16] (2013) reported substantially fewer overall failures when a medicated antibiotic liner was used beneath a GIC compared with a conventional liner at 12 months, but the composite endpoint and small sample size warrant cautious interpretation. These trials together indicate that how GICs are applied—particularly the use of retentive grooves—can materially influence clinical performance.

Two trials in permanent teeth of children (adolescents and MIH-affected molars) compared GIC variants and reported broadly similar failure rates. D'Costa *et al.* [17] (2020) contrasted metal-reinforced with high-strength GIC at 18 months, and Mahfouz *et al.* [18] (2025) compared zirconia-reinforced with glass-hybrid GIC at 12 months in MIH. Pooled estimates for this subgroup did not identify a clear difference and showed moderate heterogeneity attributable to differences in material class, clinical context, and follow-up.

Four randomized trials addressed prevention rather than restoration survival and were summarized separately. Lam *et al.* [20] (2024) found no difference between Sodium fluoride (NaF) varnish and GIC sealant for 12-month progression to dentinal caries in child-randomized cohorts, alongside low sealant retention. Guler *et al.* [21] (2013) reported lower caries presence and better retention with Fuji VII relative to an ormocer sealant at 24 months in a split-mouth design. Schraverus *et al.* [22] (2021) showed that GIC sealants reduced new dentinal caries versus no sealant over 12 months in MIH without affecting posteruptive breakdown. Rodrigues *et al.* [23] (2021) demonstrated substantially higher lesion arrest with RMGIC sealants compared with fluoride varnish at 12 months in erupting molars. These studies support sealant-based prevention in appropriate pediatric contexts but are not commensurate with restoration-failure outcomes.

Adverse events and safety outcomes were rarely detailed; where reported, no serious adverse events were attributed to the restorative materials or techniques, and postoperative sensitivity or pulp complications were uncommon within the follow-up horizons.

Overall, the randomized clinical evidence in children indicates no demonstrable advantage of smart/ion-releasing materials over conventional composites for restoration survival in primary teeth at 12–24 months. Differences among ion-releasing systems are small and inconsistent, whereas certain technique choices—most notably the incorporation of retentive grooves for Class II ART—appear to improve performance. These patterns, together with the prevalent "some concerns" risk-of-bias judgments and variability in outcome criteria and follow-up, inform the quantitative results and the certainty assessments presented subsequently.

3.5 Quantitative synthesis/meta-analytic findings

Two randomized trials by Akman *et al*. [12] and Maru *et al*. [13] contributed data at the longest follow-up (12 and 24 months). Using a random-effects model (DerSimonian-Laird τ^2 with Hartung-Knapp adjustment), the pooled risk ratio (RR) for restoration failure favored composites but was not statistically significant: RR = 1.74 (95% CI: 0.67–4.57).

Between-study heterogeneity was low ($I^2 \approx 12\%$, $\tau^2 \approx 0.18$). A continuity correction (0.5) was applied to the Akman *et al.* [12] study due to a zero cell in the composite arm. These findings indicate no clear survival advantage for smart/ion-releasing materials over conventional composites at 12–24 months. Fig. 2 (Ref. [12, 13]) shows the study-wise effects and pooled estimate.

Technique influenced outcomes in several trials. In the study by Pesaressi *et al.* [9], adding retentive grooves to Class II ART preparations reduced failures compared with no grooves at 12 months (10/122 *vs.* 29/127; RR ≈ 0.36). Phonghanyudh *et al.* [15] observed numerically fewer failures after rotary burr excavation than hand (ART) excavation at 12 months (10/88 *vs.* 15/89; RR ≈ 1.49; imprecise, single trial). Ferreira *et al.* [16] reported fewer overall failures with a medicated antibiotic liner under GIC than a conventional liner at 12 months (4/20 *vs.* 14/16; RR ≈ 0.23), noting the composite failure definition (clinical + radiographic) and small sample. These point estimates are summarized in Fig. 3 (Ref. [9, 15, 16]).

Across ion-releasing systems, no consistent superiority was identified. Deepika *et al.* [14] (2022) found similar retention at 12 months for ACTIVA RMGI *vs.* giomer (0/33 *vs.* 1/33; continuity-corrected RR ≈ 0.33). Garbim *et al.* [19] (2024) compared Equia Forte *vs.* Riva Self Cure using survival analysis and reported HR = 1.31 (95% CI: 0.85–2.01), indicating no significant difference in hazard of failure. Moura *et al.* [25] (2020) favored Ketac over Vitro in adjusted analyses, but per-arm failure counts were not extractable for pooling. Because D'Costa *et al.* [17] and Mahfouz *et al.* [18] differed in both patient populations (healthy *vs.* MIH-affected molars) and material types (metal-reinforced *vs.* zirconia-reinforced GIC), this subgroup is clinically heterogeneous, and the pooled estimate should be regarded as exploratory. Although the statistical heterogeneity was low, this does not imply that the studies are truly comparable; the substantial clinical and methodological differences—particularly in substrate condition, material type, and outcome criteria—limit the validity of pooling, and the combined estimate should therefore be regarded as exploratory.

Two trials contributed to a separate pooled analysis in permanent molars (adolescents/MIH). The random-effects estimate suggested no clear difference between GIC variants: RR = 0.52 (95% CI: 0.21–1.31), with moderate heterogeneity ($I^2 \approx 45\%$, $\tau^2 \approx 0.20$). The corresponding forest appears in Fig. 4 (Ref. [17, 18]).

Observed heterogeneity was low for the primary comparison and moderate for the permanent-tooth subgroup; likely sources include follow-up duration (12 *vs.* 24 months), lesion class, outcome criteria (ART *vs.* USPHS), and material formulation. Sensitivity checks prespecified in the protocol (restriction to 12-month outcomes; exclusion of studies at higher overall risk of bias; removal of non-standard failure definitions) either reduced the evidence to single-study estimates or did not alter

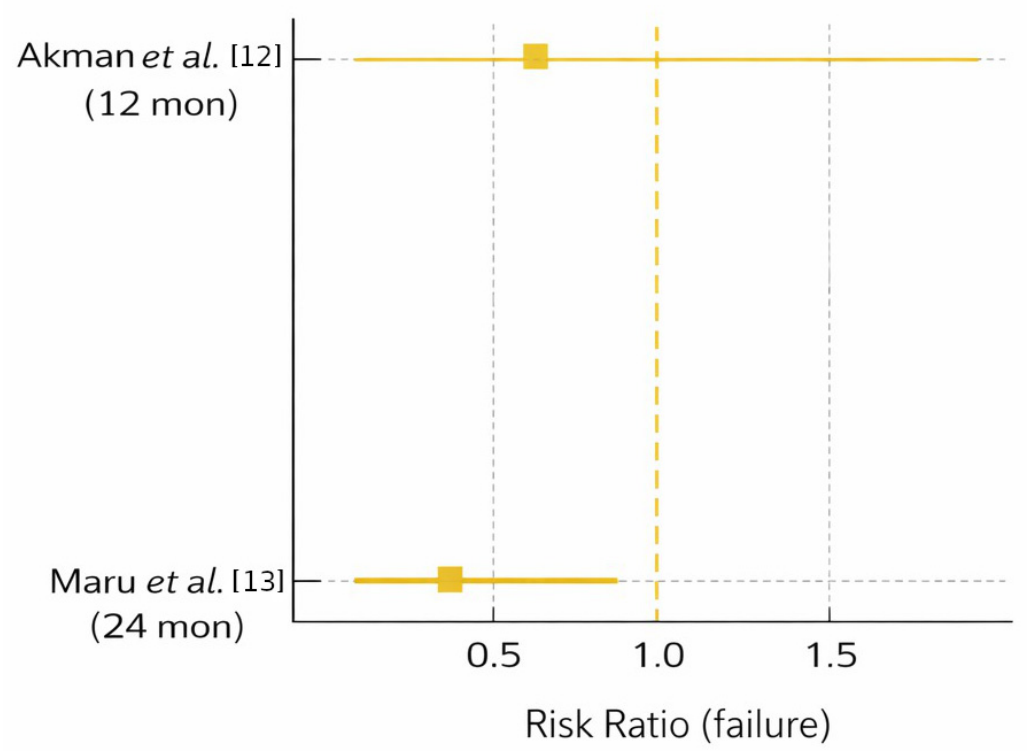

FIGURE 2. Forest plot—primary teeth (smart/ion-releasing *vs.* composite). Study-specific risk ratios (RRs) for restoration failure at the longest follow-up (Akman *et al.* [12], 12 months; Maru *et al.* [13], 24 months). Points show RRs; horizontal bars show 95% CIs; the vertical dashed line indicates no effect (RR = 1). Effect measure: RR of failure comparing smart/ion-releasing materials with conventional composites (RR <1 favors smart/ion-releasing; RR >1 favors composite). Random-effects model (DerSimonian-Laird τ^2; Hartung-Knapp CI) used for pooling in the text: pooled RR = 1.74 (95% CI: 0.67–4.57), $I^2 \approx 12\%$. A 0.5 continuity correction was applied to one study with a zero cell. Outcomes were assessed using USPHS or ART-style criteria.

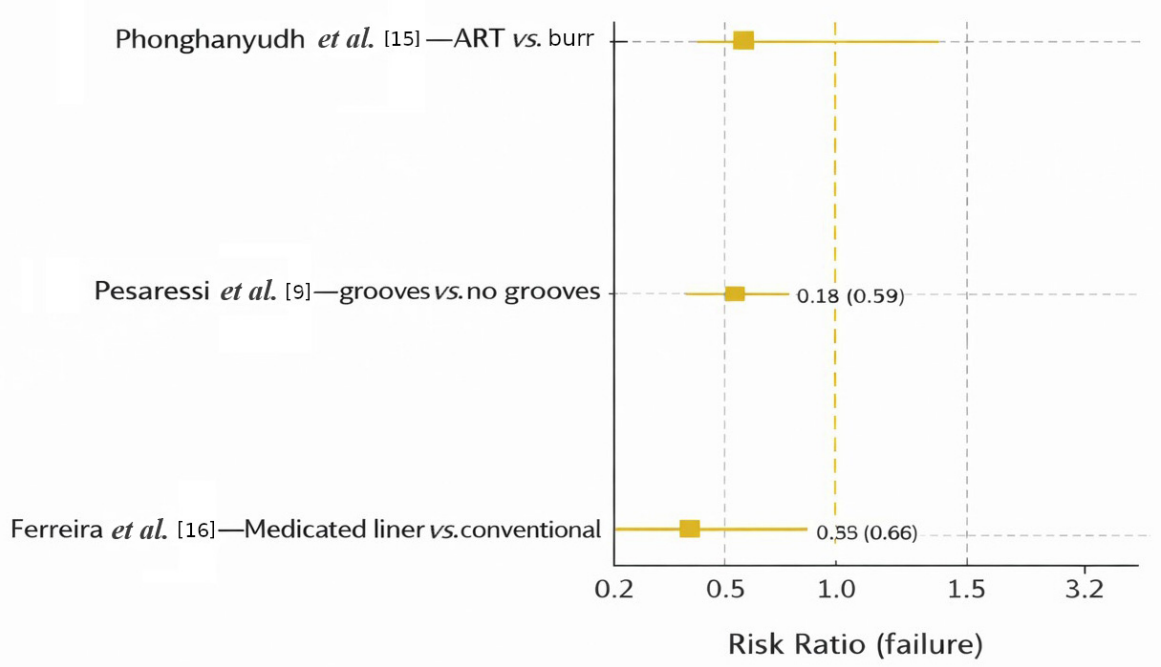

FIGURE 3. Technique/adjunct within GIC—single-study effects (log scale). Risk ratios for failure at 12 months for: (i) retentive grooves *vs.* no grooves (Pesaressi *et al.* [9], Class II ART), (ii) hand excavation (ART) *vs.* rotary bur (Phonghanyudh *et al.* [15]), and (iii) medicated antibiotic liner *vs.* conventional liner under GIC (Ferreira *et al.* [16]). Points show trial RRs with 95% CIs on a logarithmic x-axis; the dashed line indicates no effect. RR <1 favors the first-listed technique/adjunct. Estimates are single-study and not pooled. ART: atraumatic restorative treatment.

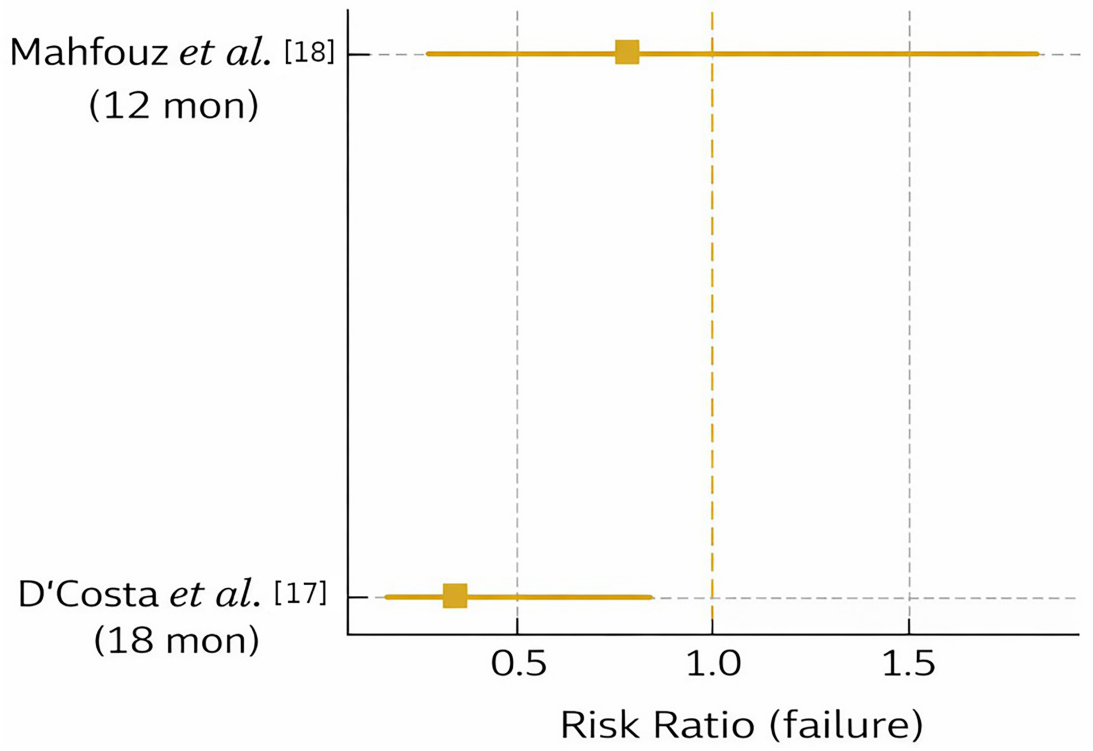

FIGURE 4. Forest plot—permanent teeth in children (smart *vs.* smart). Study-specific RRs for restoration failure at the longest follow-up D'Costa *et al.* [17], 18 months; Mahfouz *et al.* [18], 12 months in MIH. Points show RRs; horizontal bars show 95% CIs; the vertical dashed line indicates no effect (RR = 1). Effect measure: RR comparing the first-listed smart/ion-releasing material with the comparator (RR <1 favors the first-listed material). With only two studies, the random-effects pooled estimate may not lie midway between individual study effects. Random-effects pooled estimate: RR = 0.52 (95% CI: 0.21–1.31), $I^2 \approx$ 45%.

the direction of effect. Funnel plots and Egger's tests were not conducted because each quantitative set included fewer than 10 studies.

Across pediatric RCTs, smart/ion-releasing materials did not demonstrate superior survival to composites for primary molar restorations over 12–24 months. Technique choices—notably retentive grooves for Class II ART—appear to improve outcomes, while head-to-head differences among ion-releasing systems are small or inconsistent under current evidence.

Given the limited number of eligible trials and variation in outcome criteria, the meta-analytic estimate should be interpreted as exploratory, with the primary interpretive value derived from the narrative synthesis summarizing trends and research gaps.

4. Discussion

Across randomized trials in children, smart/ion-releasing restorative materials did not demonstrate superior survival to resin composites for direct posterior restorations in primary teeth at 12–24 months. The pooled estimate from two RCTs by Akman *et al.* [12] and Maru *et al.* [13] favored composites but was imprecise and not statistically significant. Head-to-head comparisons among ion-releasing formulations were generally neutral [14, 19, 26, 27], whereas technique choices within GIC protocols—particularly the use of retentive grooves in Class II ART—were associated with fewer failures [9]. Trials in permanent teeth similarly showed no clear difference between GIC variants [18]. Prevention studies (Lam *et al.* [20]; Guler *et al.* [21]; Schraverus *et al.* [22]; Rodrigues *et al.* [23]) support sealant-based strategies in appropriate contexts but are not comparable with restoration-survival endpoints.

The overall direction of these findings aligns with recent evidence syntheses comparing HVGIC or glass-hybrid materials with composites, which likewise report no clear superiority and sometimes a trend favouring composites at 1–3 years [7]. Literature on the ART approach similarly shows comparable survival to conventional treatments in primary teeth, underscoring that material choice alone is rarely the main determinant of success [8, 28, 29]. The significant benefit observed with retentive grooves is consistent with the only randomized trial that directly evaluated this modification [9].

Comparisons among smart/ion-releasing materials continue to show equivalence rather than superiority. A split-mouth RCT found similar outcomes for ACTIVA BioACTIVE and giomer at 12 months [14], and a two-year non-inferiority trial likewise reported comparable results for ACTIVA versus compomer in Class II primary molars [30]. These findings reinforce the interpretation that, with contemporary ion-releasing systems, technique and case selection exert greater influence on longevity than specific material brands or subclasses.

The separation of prevention trials from restoration-survival analyses is consistent with Cochrane guidance. Current evidence suggests very low certainty when comparing resin-based sealants with fluoride varnish, although sealants clearly outperform no sealant in several settings [31]. This mirrors the heterogeneous but generally supportive prevention outcomes observed in the included pediatric trials.

For Class II primary molar restorations where isolation is achievable, resin composites remain a reasonable choice given the nonsignificant trend toward fewer failures and the broader literature [7, 12, 13]. Ion-releasing GICs, however, remain valuable in clinical scenarios with moisture-control challenges, higher caries risk, or when minimally invasive or ART-based care is preferred, and outcomes can be improved with retentive grooves in proximal preparations [9]. In permanent molars, including those affected by MIH, available evidence does not support selecting among GIC variants based solely on expected survival; considerations such as substrate condition, fluoride release, procedural efficiency, and cost may be more relevant [18].

Strengths of this review include prespecified eligibility criteria, harmonized outcome mapping across ART and USPHS/Ryge frameworks, and prioritization of the longest follow-up for synthesis. Limitations include the small number of trials available for the primary comparison, frequent "some concerns" risk-of-bias judgments—particularly regarding allocation concealment and outcome masking—variation in lesion class and outcome criteria, and incomplete reporting of arm-level failures in several studies. These issues are consistent with broader challenges noted in pediatric restorative research [7, 28].

Future trials should incorporate longer follow-up (≥24–36 months), clearly distinguish Class I and Class II lesions, and report arm-level failures at all time points alongside time-to-event curves. Studies examining technique-level determinants such as retention features, liners, or surface protection within factorial designs would help clarify their contribution. Further research in MIH and erupting permanent molars using standardized outcome criteria and including patient-centered measures would strengthen the evidence base. Evaluation of cost-effectiveness and acceptability would additionally support translation to routine pediatric and community dentistry.

5. Conclusions

Smart/ion-releasing materials showed no survival advantage over resin composites for primary-tooth posterior restorations at 12–24 months; head-to-head comparisons among ion-releasing systems were largely neutral, and pediatric permanent-tooth trials also showed no clear differences. Technique matters—notably, retentive grooves in Class II ART reduced failures. Material choice should be context-specific: composites when isolation is reliable; ion-releasing GICs where minimally invasive care, fluoride release, speed, or compromised isolation are priorities. Certainty is limited by small k, heterogeneity, and frequent some-concerns risk of bias; larger, longer, well-reported RCTs with standardized outcomes are needed.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

AUTHOR CONTRIBUTIONS

HAB—designed the research study; performed the research; analyzed the data; wrote the manuscript. The author has contributed to editorial changes in the manuscript. The author has read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

ACKNOWLEDGMENT

The author would like to thank and acknowledge Sarah Bahammam of Taibah University, Salma Alharbi and. Bassam Zidane of King Abdulaziz University, for their invaluable contribution in conducting this review.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The author declares no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2049722168256675840/attachment/Supplementary%20material.zip.

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How to cite this article: Hammam Ahmed Bahammam. Survival of smart restoratives in pediatric dentistry: a PRISMA-guided meta-analysis of randomized trials. Journal of Clinical Pediatric Dentistry. 2026; 50(3): 41-50. doi: 10.22514/jocpd.2026.059.