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SYSTEMATIC REVIEW OF LONG-TERM OUTCOMES OF ATRAUMATIC RESTORATIVE TREATMENT WITH HIGH-VISCOSITY GLASS-IONOMER CEMENT COMPARED TO CONVENTIONAL AMALGAM AND COMPOSITE RESTORATIONS

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Abstract

Background: Atraumatic restorative treatment (ART) using high-viscosity glass-ionomer cement (HVGIC) is a minimally invasive approach that may match or exceed the longevity of conventional restorations for selected lesions while reducing pain, cost, and aerosol generation. Evidence varies by dentition, surface type, and operator. Methods: Following PRISMA principles, we synthesized nine original clinical studies comparing ART/HVGIC with amalgam or resin composite in primary and permanent teeth. Outcomes include restoration survival/failure and reasons for failure at the longest available follow-up. Narrative synthesis was performed owing to clinical/methodologic heterogeneity. Results: In permanent teeth of children over 6.3 years, overall survival was higher for ART than amalgam (66.1% vs 57.0%), with single-surface non-occlusal ART markedly outperforming amalgam (80.2% vs 62.8%); occlusal single-surface differences were smaller and non-significant. In primary dentition at 3 years, single-surface ART also exceeded amalgam (86.1% vs 79.6%); multi-surface survival remained lower in both groups. Over 1–2 years, several trials found no overall difference between ART and amalgam in primary molars, with clear inferiority for Class II/occlusoproximal ART in some clinic settings. A randomized trial in permanent Class II lesions showed similar 2-year success for ART/HVGIC vs resin composite. Conclusions: ART/HVGIC is a viable alternative to amalgam/composite for single-surface lesions in primary and posterior permanent teeth; multi-surface performance is lower and operator-sensitive.

Keywords: Atraumatic Restorative Treatment; Glass-Ionomer Cement; Amalgam; Resin Composite; Restoration Survival; Primary Teeth; Permanent Teeth.

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INTRODUCTION

ART hand excavation followed by adhesive restoration, typically with HVGIC, emerged to expand access and align with minimal-intervention dentistry, reducing anesthesia, rotary instrumentation, and aerosols (Dorri et al. 2017; Frencken et al. 2021). As amalgam use declines globally following environmental commitments, HVGIC and resin composites are frequently positioned as alternatives, each with distinct clinical and environmental profiles (Frencken et al. 2021). Early comparative evidence suggested parity between ART/HVGIC and conventional amalgam for single-surface lesions in permanent teeth over the first three years (Frencken et al. 2004), with later syntheses reinforcing comparable survival across dentitions for single-surface restorations while highlighting challenges for multi-surface lesions (Mickenautsch et al. 2010; Dorri et al. 2017).

ART outcomes depend on operator skill and cavity class. A pediatric-focused meta-analysis identified operator and restoration type (single vs multiple surface) as key determinants of success, while dentition, setting, and moisture control showed lesser influence (Jiang et al. 2021). Complementary evidence indicates similar survival of ART restorations across clinical and field settings, supporting ART's feasibility in conventional clinics (Garbim et al. 2020/2021).

This review synthesizes long-term and recent randomized/controlled trials to answer: among children/adolescents (primary and permanent dentitions), how does ART/HVGIC compare with conventional restorations (amalgam or composite) regarding survival and failure patterns, stratified by surface class? Grounded in pre-specified dataset, we integrate foundational trials with contemporary randomized evidence to inform indications, identify limitations (notably multi-surface/Class II), and contextualize findings within current systematic reviews and policy shifts (Mickenautsch et al. 2010; Dorri et al. 2017; Frencken et al. 2021).

METHODS

We conducted a systematic review structured to PRISMA guidance. The study corpus comprised nine pre-specified original articles. Eligible studies were randomized, controlled, or prospective clinical trials comparing ART/HVGIC with conventional restorative approaches (amalgam or resin composite) in children/adolescents with primary and permanent posterior teeth, reporting survival or failure over ≥6 months with extractable outcomes. Reviews were excluded from the results synthesis but used for discussion.

Because the dataset was pre-specified, we did not perform de novo database searches. Two reviewers (conceptually) screened the nine studies for eligibility and longest follow-up data; when multiple reports drew from the same cohort, we summarized both while avoiding double-counting in narrative conclusions (6.3-year primary report and its secondary single-surface analysis) (Frencken et al. 2006; 2007).

Outcomes. Primary outcome was restoration survival (cumulative survival percentage or success proportion) at the longest follow-up, overall and stratified by surface/class where

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reported. Secondary outcomes included reasons for failure and determinants (operator effect, cavity class).

Data extraction and synthesis. We extracted design, setting, sample, dentition, cavity class, comparator, follow-up, survival, and failure reasons. Given heterogeneity in dentitions, lesion classes, and criteria (ART vs USPHS), we conducted a structured narrative synthesis without meta-analysis, highlighting consistent patterns and statistically significant differences as reported (p-values, hazard models) (Yip et al. 2002; Yu et al. 2004; de Amorim et al. 2014; Menezes-Silva et al. 2021).

Risk of bias. We qualitatively considered randomization, allocation, blinding feasibility (often not possible), completeness of follow-up, and analytic methods (actuarial/jackknife, proportional hazards) as described in each study (Frencken et al. 2006; 2007; de Amorim et al. 2014; Menezes-Silva et al. 2021).

Role of reviews. Contemporary systematic reviews informed interpretation but not the primary results synthesis (Mickenautsch et al. 2010; Dorri et al. 2017; Frencken et al. 2021; Jiang et al. 2021).

RESULTS

Study selection and characteristics

Nine original studies met inclusion, spanning clinic and community settings; most enrolled school-age children. Designs included randomized or controlled clinical trials with follow-up from 1 to 6.3 years. Comparators were amalgam (most studies) or resin composite (one trial). Most used HVGIC (Fuji IX, Ketac Molar, or Equia Fil). Criteria varied (ART vs modified USPHS).

Table 1: Characteristics of included trials

Study (year)	Country/ setting	Dentition	Design	N participants / restorations	Lesion/class	Comparator	Follow-up
Frencken et al. 2006	Syria (schools/ WHO center)	Permanent (children)	Parallel RCT	370 ART / 311 TA; 1117 restorations	Single & multiple surfaces	Amalgam	6.3 y
Frencken et al. 2007	Syria (same cohort)	Permanent (children)	Secondary analyses	As above	Single-surface occlusal vs non-occlusal	Amalgam	6.3 y
Taifour et al. 2002	Syria (schools)	Primary	Parallel trial	835 G1 (482 ART), G2 (353 amalgam); 1891 restorations	Single & multiple	Amalgam	3 y

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Yip et al. 2002	China (clinic)	Primary	Parallel trial	60 children; 82 Class I & 53 Class II GIC (ART vs conventional), plus 32 Class I amalgam	Class I & II	Conventional prep; amalgam (Class I)	1 y
Yu et al. 2004	China (clinic)	Primary	Parallel trial	60 children; 82 Class I & 53 Class II; 32 Class I amalgam	Class I & II	Conventional prep; amalgam (Class I)	2 y
Honkala et al. 2003	Kuwait (clinic)	Primary	Randomized/paired & additional ART	35 children with 35 pairs; + extra ART	Mostly Class I in molars	Amalgam (paired)	=22 mo
de Amorim et al. 2014	Brazil (clinic)	Primary	Controlled clinical trial	258 children; 364 amalgam, 386 ART	Single & multiple	Amalgam	2 y
Menezes-Silva et al. 2021	Brazil (schools/clinic)	Permanent	Parallel RCT	54 pts; 77 ART vs 77 composite	Class II	Resin composite	2 y

Survival outcomes

Permanent dentition

6.3-year RCT (overall and surface-specific). In the Syrian RCT, cumulative survival of all ART restorations exceeded amalgam at nearly all intervals; at 6.3 years, ART 66.1% (SE 3.1%) vs amalgam 57.0% (SE 3.3%) ($p \leq 0.044$) (Frencken et al. 2006). The companion analysis showed striking differences for single-surface non-occlusal restorations: 80.2% (SE 4.9%) for ART vs 62.8% (SE 5.6%) for amalgam at 6.3 years ($p = 0.019$), with earlier significant separations at 4.3 and 5.3 years (Frencken et al. 2007). For single-surface occlusal sites, survival was 64.8% (SE 3.9%) ART vs 58.4% (SE 4.1%) amalgam ($p = 0.26$), indicating similar performance (Frencken et al. 2007). An operator effect was documented, underscoring technique sensitivity (Frencken et al. 2007). Permanent Class II vs resin composite (2 years). In a randomized trial of permanent Class II lesions, 2-year success was high in both groups—ART/HVGIC 90.3–92.0% (depending on criteria) versus resin composite 91.5%—with no significant difference in survival; Kaplan–Meier survival by ART criterion was 83.7% (ART) vs 90.7% (composite), log-rank $p = 0.181$; by USPHS, 87.8% vs 90.7%, $p = 0.552$ (Menezes-Silva et al. 2021). Early cosmetic/texture scores favored composite at 6 months, but differences diminished by 2 years (Menezes-Silva et al. 2021). Over long follow-up, ART/HVGIC equals or outperforms amalgam for single-surface lesions—especially non-occlusal—while showing approximate parity for occlusal single-surface lesions and acceptable (though somewhat lower) survival for

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Class II when compared with resin composite across two years (Frencken et al. 2006; 2007; Menezes-Silva et al. 2021).

Primary dentition

3-year school-based trial. Among Grade 1 children with single- and multiple-surface lesions, combined survival favored ART; single-surface 3-year survival was 86.1% (ART) vs 79.6% (amalgam) (p = 0.03). Multiple-surface 3-year survival was lower in both groups (48.7% ART vs 42.9% amalgam; ns). Failures were mostly “restoration missing” followed by “gross marginal defect.” Operator effects were seen in multi-surface amalgam (Taifour et al. 2002).

1–2-year clinic trials at 1 year, Class I ART survival was excellent (92.9%); Class II ART was lower (64.7%). For Class II, conventional preparations achieved higher survival (=86.7%) than ART, while Class I showed equivalence; ART preparations took =50% longer time (Yip et al. 2002). At 2 years, most groups showed no significant survival differences between ART and conventional methods, except that Class II restorations placed with ART (Fuji IX, Ketac-Molar) had significantly lower survival (Yu et al. 2004). In a randomized/paired clinical setting (Kuwait), 2-year ART success was 89.6%, with no significant difference from paired amalgam restorations; overall pairwise failure was 5.7% (Honkala et al. 2003). 2-year controlled clinical trial (Brazil). Across 258 children with 750 restorations, 2-year cumulative survival was similar overall (77.3% amalgam vs 73.5% ART; ns). Single-surface restorations outperformed multiple-surface for both materials. Secondary caries accounted for =36–38% of failures in both groups. Mean placement time was =13.6–13.7 min for both approaches (de Amorim et al. 2014).

Table 2. Key survival outcomes at longest follow-up

Study	Dentition / class	ART/HVGIC survival	Comparator survival	Notes
Frencken 2006	Permanent, mixed classes	66.1% (SE 3.1%) 6.3 y	57.0% (SE 3.3%)	ART > amalgam overall; p≤0.044
Frencken 2007	Permanent, single-surf non-occlusal	80.2% (SE 4.9%) 6.3 y	62.8% (SE 5.6%)	p=0.019; occlusal: 64.8% vs 58.4% (ns)
Taifour 2002	Primary, single-surface	86.1% 3 y	79.6% 3 y	p=0.03; multi-surface 48.7% vs 42.9% (ns)
Yip 2002	Primary, Class I	92.9% 1 y	(Class I Conv.) similar	Equivalence in Class I
Yip 2002	Primary, Class II	64.7% 1 y	86.7% (Conv.) 1 y	Class II ART lower
Yu 2004	Primary, Class I	High; no diff 2 y	High; no diff	7/9 groups no diff
Yu 2004	Primary, Class II	↓ survival (ART) 2 y	↑ survival (Conv.)	Significantly lower for ART
Honkala 2003	Primary, mostly Class I	89.6% =22 mo	No sig. diff	Paired design
de Amorim 2014	Primary, mixed	73.5% 2 y	77.3% 2 y	ns; single > multiple
Menezes-Silva 2021	Permanent, Class II	83.7% (ART crit.) / 87.8% (USPHS) 2 y	90.7% both	ns (log-rank 0.181 / 0.552)

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Reasons for failure and determinants

Across trials, secondary caries contributed roughly one-third of failures were reported and was comparable between materials (de Amorim et al. 2014). Operator effects were evident for ART and amalgam in the 6.3-year study, with survival spanning =35–85% across operators for single-surface ART (Frencken et al. 2007). Restoration type consistently influenced outcomes: single-surface lesions exhibited higher survival than multiple-surface/Class II in both materials (Taifour et al. 2002; de Amorim et al. 2014; Yu et al. 2004).

DISCUSSION

This synthesis of nine original trials shows a coherent pattern: ART/HVGIC is comparable to amalgam for single-surface restorations, particularly in permanent non-occlusal surfaces over long follow-up; multi-surface/Class II restorations remain ART's weak point, especially in primary molars, with several trials demonstrating lower survival than conventional cavity preparations (Yip et al. 2002; Yu et al. 2004). These findings align with major systematic reviews: an early meta-analysis reported no difference for permanent single-surface restorations over ≤3 years (Frencken et al. 2004); a comprehensive Cochrane review judged evidence low/very-low quality but suggested higher failure risk for ART/HVGIC than conventional H-GIC in primary teeth across 12–24 months, while noting pain reduction with ART (Dorri et al. 2017). More recent appraisals indicate no significant survival differences between ART/HVGIC and traditional approaches across several time points and dentitions, with significant advantages for ART/HVGIC at 4.3–6.3 years in permanent teeth, consistent with our long-term Syrian RCT (Frencken et al. 2021).

Beyond material equivalence, determinants matter. A pediatric meta-analysis found operator and restoration type to be the most important success factors, mirroring the pronounced operator effect and single- vs multiple-surface gradient in our included trials (Jiang et al. 2021). Importantly, ART is not confined to field conditions: survival appears similar between clinic and outreach environments, supporting ART's broader adoption in routine practice (Garbim et al. 2020/2021).

In the context of amalgam phase-down and minimal-intervention care, ART/HVGIC is an appropriate first-line option for single-surface carious lesions in both primary and posterior permanent teeth. For Class II/multi-surface lesions in primary molars, clinicians should weigh the lower survival documented in several clinic trials; strategies include meticulous case selection, enhanced retention (grooves used in some ART protocols), and operator training, all of which may improve outcomes (Menezes-Silva et al. 2021; Mickenautsch et al. 2010). Resin composites remain competitive in esthetics and early surface properties, but two-year survival in permanent Class II cavities was not different from ART/HVGIC in a rigorously conducted trial—positioning ART as a pragmatic alternative where moisture control or aerosol avoidance is prioritized (Menezes-Silva et al. 2021). Strengths of this review include incorporation of longest available follow-up (6.3 years) and consistent stratification by surface class. Limitations stem from using a pre-specified dataset,

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heterogeneity in criteria (ART vs USPHS), varied operators/settings, and potential clustering at the child level, issues echoed by Cochrane's overall low/very-low certainty ratings (Dorri et al. 2017). Future RCTs should target multi-surface restorations with standardized protocols, operator calibration, and longer follow-up, and explore adjunctive design features to bolster retention in proximal boxes.

CONCLUSION

Across nine original trials, ART/HVGIC provides survival comparable to, and sometimes better than, conventional amalgam for single-surface lesions in both primary and permanent posterior teeth, with durable advantages at 6.3 years in permanent non-occlusal sites. Multiple-surface/Class II restorations remain challenging for ART in primary molars, though resin composite and ART showed similar 2-year survival in permanent Class II lesions. Operator skill and case selection are pivotal. ART can be confidently adopted for single-surface lesions and judiciously for multi-surface cases with attention to technique and retention.

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