Survival estimates of atraumatic restorative treatment versus traditional restorative treatment: a systematic review with meta-analyses

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Key points

No significant differences in survival percentages between ART and traditionally-produced single-surface restorations in primary and permanent (pre)molars were observed.

No significant differences in survival percentages between ART and traditionally-produced multiple-surface restorations in primary molars were observed.

The high-viscosity glass-ionomer cements tested can be used to replace amalgam in single-surface cavities in primary and permanent (pre)molars and in multiple-surface cavities in primary teeth treated according to ART.

Abstract

Objectives The hypothesis tested was that there is no significant difference between the survival estimates of atraumatic restorative treatment/high-viscosity glass-ionomer cement (ART/HVGIC) restorations, in posterior primary and permanent teeth, and traditional amalgam and resin composite restorations.

Data sources The databases PubMed, DOAJ, LILACS, IndMed, Google Scholar and CNKI were searched.

Data selection Using inclusion and exclusion criteria led to 14 eligible randomised trials. A low risk of bias was observed for two reports. Homogeneity was obtained for single-surface ART restorations after one and two years in the primary dentition.

Data synthesis No statistically significant difference was found between the weighted mean survival percentages of ART/HVGIC and traditional treatments in both single- and multiple-surface restorations in primary molars and in single-surface restorations in posterior permanent teeth at years 1, 2, 3 and 5. At years 4.3 and 6.3, the difference between the two treatments was statistically significant, favouring the ART/HVGIC restorations. No statistically significant difference was found between the weighted mean survival percentages of ART/HVGIC and traditional treatments in multiple-surface restorations in posterior permanent teeth.

Conclusion The ART method using HVGICs can be considered as a replacement for traditional restorations in single- and multiple-surface cavities in primary molars, and in single-surface cavities in posterior permanent teeth, particularly for amalgam.

Introduction

Atraumatic restorative treatment (ART) is a treatment concept that is considered to be one of the components of the minimal intervention dentistry philosophy[1,2] and an example of the contemporary recommendations on carious tissue removal.[3] Its beneficial effect has become apparent particularly in child oral healthcare[4,5] and in healthcare for the elderly worldwide.[6,7] Most of the ART restoration survival investigations have taken place in primary molars and posterior permanent teeth of children and adolescents.[8] In primary teeth, the survival of ART/high-viscosity glass-ionomer cement (HVGIC) restorations has been compared to amalgam and resin composite restorations in systematic reviews and meta-analyses. The outcomes have not shown a significant difference between the two treatments.[9,10,11,12] In permanent teeth, the ART/HVGIC restorations have been predominantly compared to amalgam restorations and have shown the same outcomes as reported for primary teeth.[9,10]

As a result of the Minamata Treaty, amalgam is on its way out as a restorative in dental care. As replacements, resin composite-based and HVGIC-based materials are being considered.[13,14,15,16] In 2019, the FDI World Dental Federation issued a policy statement that recommended the use of these two types of materials for restoring dentine cavities in primary and permanent teeth.[17] However, the statement restricted the use of HVGICs to single and smaller multiple-surface cavities in both dentitions and the use of the ART method to primary dentitions. The reason for these restrictions may be that the flexible strength of HVGICs obtained in large multiple-surface restorations has been insufficiently high for the restoration to be effective over a long period.

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Resin composites, on the other hand, have the disadvantage of leaking monomers (BPAs) into the patient's body system, which may cause potential health threats.[18,19,20] Although the levels of monomers from polymer-based sealants and restorative materials found in blood and saliva vary and appear to be relatively low,[21,22] their release adds to the total human exposure to BPAs derived from food packaging, inner coating of cans, jar caps and other products.[23] Exposure to monomers from dental polymer materials can be controlled through producing monomer-free resin composites[24,25] and through improving the effectiveness of the polymerisation process, which has only reached 65–75%[26] and 50%.[18]

However, a more serious disadvantage of resin composites concerns their potential to damage the environment. The recently launched European Union's (EU's) Green Deal sets out to 'restore the natural function of ground and surface water' through 'addressing sources of pollution such as micro-plastics and chemicals'.[27] This Green Deal encompasses the EU's Strategy for Plastic in a Circular Economy.[28] These plans may affect resin composites as the material can be considered a 'plastic' which does not dissolve in the earth after burying and releases toxic substances into the air during the cremation process. Yet these are some of the reasons that the United Nations, the EU and individual countries use to call for a ban and/or pose restrictions on the use of amalgam. HVGICs, in contrast, are biodegradable and do not affect the environment negatively.

Other advantages of HVGIC concern its availability in a powder-liquid version, which increases coverage, making it less costly and easier to obtain than resin composite, which is often costly and unavailable in public health services in resource-strapped countries. Findings from a study involving a low socioeconomic community point to the cost-effectiveness of ART/HVGIC restorations as a replacement for amalgam restorations in primary dentitions in a public health service system.[29]

Because of the potential threat that resin composite will follow the same path as amalgam and because of newly published ART/HVGIC and traditional restoration comparison studies, it is opportune to investigate the quality of HVGICs in the ART method for restoring posterior dentine cavities in primary and permanent dentitions.

The present systematic review with meta-analyses investigated whether or not the combination of ART and HVGIC is a worthy replacement of the traditional restorative treatments using amalgam and resin composite. The hypothesis tested was that there is no significant difference in the survival estimates of ART/HVGIC restorations in posterior primary and permanent teeth in comparison with the traditional amalgam and resin composite restorations.

Materials and methods

This systematic review with meta-analyses was conducted and reported on following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[30]

Data collection

The databases PubMed, DOAJ, LILACS, IndMed and Google Scholar were searched up to 26 April 2018 using several strings of search terms (Table 1). In addition, a journal hand search was conducted. The CNKI database was searched up to 25 July 2018. These two searches were updated on 27 June 2019 and 14 July 2019, respectively, and yielded a total of 17,012 citations, including duplications. Of these, 16,898 citations were excluded as not being relevant. A total of 118 trial reports were found in line with the selection criteria: prospective, controlled study design; high-viscosity glass-ionomer used as test intervention; study published in 1990 and onwards; comparison against amalgam and/or resin composite; and length of trial follow-up one year or longer. These trials were provisionally included. Of these, 51 reports were excluded for the following reasons: no comparison against amalgam and/or resin composite (N = 43); length of trial follow-up <1 year (N = 4); duplicate (N = 2); control intervention not specified (N = 1); and no prospective study design (N = 1). A total of 67 trial reports were provisionally accepted for further review, of which 27 were trial reports that had compared conventional glass-ionomer cement with traditional single- and multiple-surface restorations and thus were excluded (Table 2). Three of these were follow-up reports to the ten-year comparison study of HVGIC and resin composite restorations.[31] The remaining 24 non-ART trial reports were also excluded because of missing or incorrect information (number of restorations at evaluation points; those failed and/or survived missing; root surface and/or class IV or V restorations studied; no survival analyses performed). This left 40 trial reports that had compared ART/HVGIC with traditional restorations. Application of ART-related inclusion criteria[8] resulted in the exclusion of 29 reports: duplicate (N = 5); incomplete or incorrect description of the ART restoration method with (N = 16) and without (N = 1) incorrect (or missing) statistical survival analysis as an additional reason (total N = 17); and incorrect or missing information as a single reason (N = 4). Three studies were follow-ups,[32,33,34,35,36,37] which brought the number of included ART/HVGIC versus traditional restoration trials to 11. One eligible ART/HVGIC versus traditional restoration trial was known to the authors before it was published.[38] The total number of included trials for analysis reached 12 and these compared ART/HVGIC with traditional, amalgam or resin composite in single- and multiple-surface restorations in primary molars and posterior permanent teeth. The Pan American Health Organisation (PAHO) study[39] was considered to consist of three independent studies, which brought up the number of eligible trials in the database to 14.

Figure 1 shows the PRISMA flowchart and Table 2 shows the reason(s) for exclusion of trial reports after the application of the inclusion criteria. The main characteristics of the included studies are presented in Table 3.

Evaluator agreement

The English and Chinese publications were independently retrieved and evaluated by QZ and JF, and QZ and SL, respectively. In case of a disagreement about extracted data between the evaluators, consensus was reached through discussion without the need for external consultation.

Quality of included publications

Following De Amorim *et al.*,[8] nine main quality criteria were examined: 1) generation of randomisation sequence; 2) allocation concealment; 3) training of operators in the ART method; 4) independence of evaluators; 5) calibration of evaluators; 6) blinding of operators/evaluators; 7) completeness of follow-up; 8) implementation of a prevention programme alongside the investigation; and 9) report of the sample baseline caries experience. The quality assessment was performed qualitatively by classifying each of the study criteria as 'yes' (low risk of bias), 'no'

(high risk of bias) or 'unclear' (information not precisely reported or uncertainty about the potential for bias). A dropout rate of up to 30% was considered a low risk of bias and a dropout rate not reported or of more than 30% was considered a high risk of bias. Data related to the quality assessment of the English publications were obtained from De Amorim et al.[8] and JF and QZ, and from QZ and SL for the Chinese publications. The results are presented in Table 4.

Statistical analysis

A statistician carried out the analyses. The 95% confidence interval (CI) was obtained from the statistical tables in cases where only survival percentages and number of restorations had been presented in the publications included. CIs were used to calculate the standard error (SE) for the survival percentages according to the following equation: SE = (upper - lower CI)/4. Survival percentages per year within selected groups were combined by meta-analysis, which resulted in weighted mean survival percentages. If these percentages showed homogeneity, a fixed-effect model was applied. In case of heterogeneity, a random-effect model was used. The decision criterion was the p value for the homogeneity test. I^2 values were used to grade the level of heterogeneity of the weighted mean survival percentages per survival year. Categorisation of the level of heterogeneity followed the suggestion presented by the Cochrane Research Group.[40] The meta-analyses were performed in R version 3.3.1 using the survcomp package.[41]

Results

Characteristics of included trial reports

Five trials concerned primary dentition, eight permanent dentition and one both dentitions. Seven comparison trials were performed in a clinic setting and seven in the field. Fuji IX GP, Ketac Molar Easymix and EQUIA system (Fil) were the glass-ionomer-based materials predominantly used. Four comparison studies used resin composite (3x Z-350) and eight used amalgam with a variation of brands. One trial[34] did not report the restoratives used. Single-surface restorations were mostly investigated and the ART restoration assessment criteria were predominantly used (Table 3). The lengths of the trials were relatively short.

Table 1 Results of searching the literature

Database searched	Search date	Search terms
PubMed – online: http://www.ncbi.nlm.nih.gov/pubmed	27 June 2019	[1] (((tooth restoration) OR tooth filling) OR dental filling) OR "Dental Restoration, Permanent"[Mesh] Sort by: PublicationDate Filters: Clinical Trial; Abstract; Humans [2] (amalgam OR composite OR glass-ionomer OR compomer) AND restoration Sort by: PublicationDate Filters: Clinical Trial; Abstract; Humans [3] atraumatic restorative treatment (no filters) [4] composite restorations (Filters activated: Clinical Trial, Abstract.) [5] compomer restoration (Filters activated: Clinical Trial, Abstract.) [6] amalgam restoration (Filters activated: Clinical Trial, Abstract.) [7] glass ionomer restoration (Filters activated: Clinical Trial, Abstract.)
Total included from database search: 6,781		
DOAJ – online: http://www.doaj.org	27 June 2019	[1] Dental Restoration [2] composite restoration [3] compomer restoration [4] amalgam restoration [5] glass ionomer restoration [6] atraumatic restorative treatment
Total included from database search (including duplications): 2,334		
LILACS – online: http://pesquisa.bvsalud.org/portal/	27 June 2019	[1] Dental Restoration [2] composite restoration [3] compomer restoration [4] amalgam restoration [5] glass ionomer restoration [6] atraumatic restorative treatment
Total included from database search (including duplications): 345		
IndMed – online: http://indmed.nic.in/indmed.html Limit: controlled clinical trial	26 April 2018 (database discontinued)	[1] Dental AND Restoration [2] composite AND restoration [3] compomer AND restoration [4] amalgam AND restoration [5] glass ionomer AND restoration [6] atraumatic AND restorative AND treatment
Total included from database search (including duplications): 205		
Google Scholar – online: https://scholar.google.com/	27 June 2019	[1] "tooth Restoration"+"clinical trial" [2] "composite restoration"+"clinical trial" [3] "compomer restoration"+"clinical trial" [4] "atraumatic restorative treatment"+"clinical trial" [5] "glass ionomer restoration"+"clinical trial" [6] "amalgam restoration"+"clinical trial"
Total included from database search (including duplications): 6,554		
Hand search included		
CNKI – online: https://www.cnki.net/	27 July 2018	[1] 玻璃离子水门汀 [2] 光固化复合树脂 AND 修复牙 [3] 银汞合金 AND 修复牙
Total included from database search: 695		
Total citations found: 17,012		

General inclusion criteria:
- Tooth restoration longevity/survival/failure/patient satisfaction assessed
- Direct treatment on human vital teeth
- Prospective controlled clinical trial

Inclusion criteria I:
- Relevant to High-viscosity glass-ionomers (HVGIC)

Inclusion criteria II:
- Comparison HVGIC versus Amalgam or Composite resin restorations
- Length of trial follow-up minimum 12 months

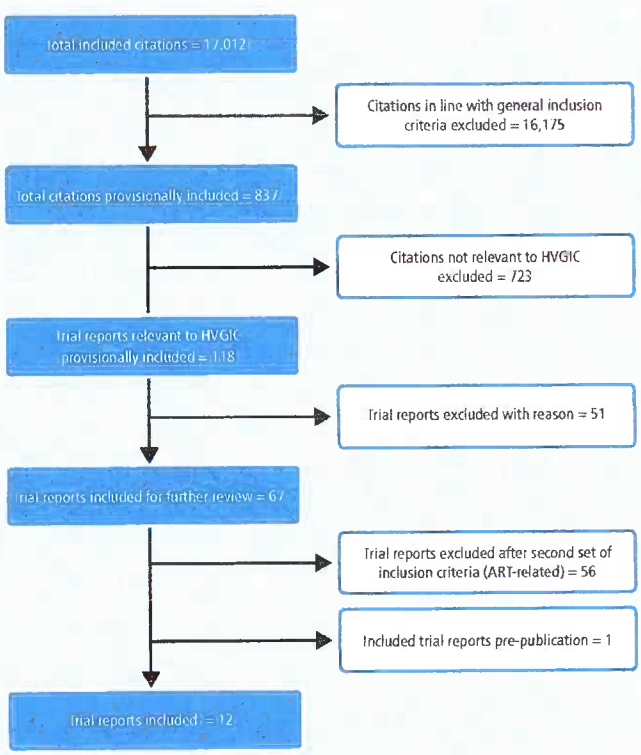
Table 2 Listing of and reasons for exclusion of publications that reported survival percentages of ART/HVGIC and traditional restorations (cont. on page 5)

Publication	Language	Comparison of non-ART/HVGIC-traditional study	Duplicate	Incomplete/ incorrect description of ART method	Non-graduated dentist/non-graduated dental therapist	Incorrect/missing: statistics/survival analysis/reporting/ no class I or II	Followed up by a publication of longer duration
Diem *et al.*[51]	English	x				x	
Gurgan *et al.*[52]	English	x					x
Firat *et al.*[53]	Turkish	x					x
Ergin *et al.*[54]	Turkish	x					x
Celik *et al.*[55]	English	x				x	
Chen & Wie[56]	Chinese	x				x	
Jiang *et al.*[57]	Chinese	x				x	
Xiong[58]	Chinese	x				x	
Chen *et al.*[59]	Chinese	x				x	
Lei & Huang[60]	Chinese	x				x	
He *et al.*[61]	Chinese	x				x	
Xiang[62]	Chinese	x				x	
Wang *et al.*[63]	Chinese	x				x	
Lei[64]	Chinese	x				x	
You & Chen[65]	Chinese	x				x	
Cao[66]	Chinese	x				x	
He[67]	Chinese	x				x	
Chen *et al.*[68]	Chinese	x				x	
Mo[69]	Chinese	x				x	
Zhou[70]	Chinese	x				x	
Wang & Kang[71]	Chinese	x				x	
Zhu & Shi[72]	Chinese	x				x	
Zhao *et al.*[73]	Chinese	x				x	
Zhou & Liu[74]	Chinese	x				x	
Liao[75]	Chinese	x				x	
Mijan *et al.*[76]	English					x	
Molina *et al.*[77]	English	x				x	
Gao *et al.*[14]	English		x				
Yip *et al.*[35]	English		x				
Yu *et al.*[36]	English		x				
Rahimtoola & Van Amerongen[44]	English		x				
Peng *et al.*[78]	Chinese		x				
Zanata *et al.*[79]	English			x			
Taifour *et al.*[33]	English						x
Yip *et al.*[35]	English						x
Yip *et al.*[37]	English						x
De Miranda[80]	Spanish					x	
Li & Dou[81]	Chinese					x	
Chen *et al.*[82]	Chinese			x		x	
Li *et al.*[83]	Chinese					x	
Wang & Ding[84]	Chinese			x		x	

Table 2 Listing of and reasons for exclusion of publications that reported survival percentages of ART/HVGIC and traditional restorations (cont. from page 4)

Publication	Language	Comparison of non-ART/HVGIC-traditional study	Duplicate	Incomplete/ incorrect description of ART method	Non-graduated dentist/non-graduated dental therapist	Incorrect/missing: statistics/survival analysis/reporting/ no class I or II	Followed up by a publication of longer duration
Ling & Wang[85]	Chinese					x	
She *et al.*[86]	Chinese			x		x	
Qui[87]	Chinese			x		x	
Ye *et al.*[88]	Chinese			x		x	
Wu *et al.*[89]	Chinese			x		x	
Zhang *et al.*[90]	Chinese			x		x	
Lin & Ye[91]	Chinese			x		x	
Hu[92]	Chinese			x		x	
Huang[93]	Chinese			x		x	
Liu[94]	Chinese			x		x	
Zeng & Pan[95]	Chinese			x		x	
Ling & Wang[96]	Chinese			x		x	
Wang[97]	Chinese			x		x	
Weng[98]	Chinese			x		x	
Mo[99]	Chinese			x		x	

Fig. 1 PRISMA flowchart of included and excluded trial reports



Quality assessment of trial reports

The assessment results regarding the quality of the included reports are presented in Table 4. Blinding of operators and evaluators in a study with distinguishable restoratives is not possible and that affected all included reports. A low risk of bias was observed for two reports,[42,43] while seven reports were considered to have moderate bias.[34,36,38,39,42,44,45,46] None of the reports presented a high risk of bias for all the assessed criteria. One report after 2 years[36] and one after 3.3 years[32] reported a loss to follow-up of more than 30% of restorations.

Homogeneity of survival results

The level of heterogeneity, expressed as the statistic I^2, of weighted mean restoration survival percentage results by dentition, type of cavity and survival year for the two treatment groups is presented in Table 5. Homogeneity was obtained for the weighted mean survival percentages of single-surface ART restorations after one and two years in the primary dentition. For all other types of ART restorations in both dentitions, heterogeneity was predominantly of a substantial/considerable or considerable level. The latter assessment level was also applicable for the heterogeneity of traditional restorations in both dentitions.

Table 3 Main characteristics of included studies (GIC = glass-ionomer cement)

Publication	Age (years)	Dentition	Study environment	GIC	Composite	Amalgam	Cavity class		Study length	Evaluation criteria
Honkala *et al.*[42]	2–9 (mean 5.7)	Primary	Dental clinic	Chem-Flex		Megalloy	I	II	2 years	ART/USPHS
Taifour *et al.*[43]	6–7	Primary	Dental clinic	Fuji IX Ketac Molar		Avalloy	I	II	3 years	ART
Yu *et al.*[36]	7–9	Primary	Dental Clinic	Fuji IX GP Ketac Molar Aplicap		GK amalgam alloy	I	II	2 years	ART
Ersin *et al.*[45]	6–10 (mean 8.07)	Primary	Field	Fuji IX GP	Surefil		I	II	2 years	USPHS
Hilgert *et al.*[100]	6–7 (mean 6.8)	Primary	Field	Ketac Molar Easymix		Permite Regular set	I	II	3 years	ART
Molina *et al.*[46]	3–39 (mean 13.6)	Primary and permanent	Dental clinic	Equia system Chemfil Rock	Filtek Z-350		I	II	3 years	ART
Molina *et al.*[38]	3–39 (mean 13.6)	Permanent	Dental clinic	Equia system Chemfil Rock	Filtek Z-350		I	II	5 years	ART
Menezes-Silva *et al.*[101]	8–19	Permanent	Field	Equia system	Filtek Z-350			II	1 year	ART/USPHS
Frencken *et al.*[32]	6–9	Permanent	Dental clinic	Fuji IX Ketac Molar		Avalloy	I	II	6.3 years	ART
PAHO[39]	7–9	Permanent	Field	Not reported		Not reported	I		2 years	USPHS
Rahimtoola & Van Amerongen[44]	6–16 (mean 11.4)	Permanent	Field	Fuji IX		Tytin	I		2 years	Modified ART
Gao *et al.*[34]	Mean 34.6	Permanent	Dental clinic	Fuji IX GP Ketac Molar Aplicap		GK amalgam alloy	I		2 years	Colour photograph, replica, visual inspection

Table 4 Quality assessment of included studies

Study	Quality assessment criteria								
	Generation randomisation sequence	Allocation concealment	Training operators in ART	Independence evaluators	Calibration evaluators	Blinding operators/ evaluators	Completeness of follow-up (years)	Implementation preventive programme	Caries experience at baseline
Honkala *et al.*[42]	Yes	No	Yes	No	Unclear	Np	Yes	No	No
Taifour *et al.*[43]	Yes	Yes	Yes	Yes	Yes	Np	Yes	Yes	No
Yu *et al.*[36]	Yes	Unclear	No	Unclear	No	Np	Yes (2 years)*	No	No
Ersin *et al.*[45]	Yes	No	No	Yes	Yes	Np	Yes	No	Unclear**
Hilgert *et al.*[100]	Yes	No	Yes	Yes	Yes	Np	Yes	Yes	Yes
Molina *et al.*[46]	No	No	No	Yes	Yes	Np	Yes	No	Yes**
Molina *et al.*[38]	No	No	No	Yes	Yes	Np	Yes	No	Yes**
Menezes-Silva *et al.*[101]	Yes	No	Yes	Unclear	Yes	Np	Yes	Yes	Yes
Frencken *et al.*[32]	Yes	Yes	Yes	Yes	Yes	Np	Yes (6.3 years)*	Yes	Yes
PAHO[39]	Yes	Yes	Yes	Yes	Yes	Np	Yes	No	No
Rahimtoola & Van Amerongen[44]	Yes	No	Yes	No	Unclear	Np	Yes	No	Yes
Gao *et al.*[34]	No	No	Unclear	Unclear	Unclear	Np	Yes	No	No

Key
* = loss to follow-up more than 30%
** = dfmt/ DMFT provided for the whole sample examined
Np = not possible (restoratives used were originally distinguishable on visual assessment)

Difference in primary molars

No statistically significant difference was found between the weighted mean survival percentages of ART/HVGIC and traditional treatments in both single- and multiple-surface restorations in the primary molars (Table 6).

Difference in posterior permanent teeth

There was no statistically significant difference between the weighted mean survival percentages of ART/HVGIC and traditional treatments in single-surface restorations in posterior permanent teeth at years 1, 2, 3 and 5 (Table 7). At years 4.3 and 6.3, the difference between the two treatments was statistically significant, favouring the weighted mean survival percentage of ART/HVGIC restorations. There was no statistically significant difference between the weighted mean survival percentages of ART/HVGIC and traditional treatments in multiple-surface restorations in the posterior permanent teeth.

Discussion

Methodological aspects

A large number of databases were searched, including those that contain publications in the Chinese, English, Portuguese and Spanish languages. Notwithstanding the large number of publications retrieved initially, the number of eligible trial reports was not very high.

The larger proportion of included trials (67%) was published between 2002 and 2006, and concerned amalgam as the reference material. During that period, the first batches of improved HVGICs had become available and were being put to the test. From then onwards, the mechanical properties of HVGICs have improved and they were found to be strong enough to be applied in multiple-surface cavities in posterior permanent teeth also. Four reports covered three trials that had used resin composite as the reference material. Of these, three reports of two trials were published in 2018 and 2019, most probably as a reaction to the Minamata Treaty. These reports compared traditionally-produced resin composite and ART/HVGIC restorations that had been placed in single- and multiple-surface cavities in posterior permanent teeth.

Trial reports were excluded largely because of 'no comparison against amalgam and/or resin composite performed', 'missing or incorrect information provided', 'non-ART' trials' and 'incomplete or incorrect description of the ART restoration method'. 'Missing or incorrect information' referred to the absence of the

Table 5 Level of heterogeneity (I^2 square) of weighted mean restoration survival results by dentition, type of cavity and survival year by treatment group (N/A = not applicable)

Dentition	Type of cavity	Survival year	Heterogeneity p value	I^2 (%)	Level
ART/HVGIC					
Primary	Single	1	0.3549	3.5	Low/important
		2	0.3661	5.4	Low/important
		3	0.0000	94.6	Considerable
	Multiple	1	0.0971	57.1	Substantial
		2	0.0117	77.5	Substantial/ considerable
		3	0.0003	87.6	Substantial/ considerable
Permanent	Single	1	0.0000	95.3	Considerable
		2	0.0000	94.5	Considerable
		3	0.0000	98.0	Considerable
		4	N/A	N/A	N/A
		5	0.0000	96.2	Considerable
		6	N/A	N/A	N/A
	Multiple	1	N/A	N/A	N/A
		2	N/A	N/A	N/A
		3	N/A	N/A	N/A
		5	N/A	N/A	N/A
Traditional					
Primary	Single	1	0.0000	95.1	Considerable
		2	0.0000	91.1	Considerable
		3	0.0024	83.5	Substantial/ considerable
	Multiple	1	0.0094	78.6	Substantial/ considerable
		2	0.0008	86.0	Substantial/ considerable
		3	0.0000	92.7	Considerable
Permanent	Single	1	0.0000	93.6	Considerable
		2	0.0000	95.2	Considerable
		3	0.0000	95.8	Considerable
		4	N/A	N/A	N/A
		5	0.0000	98.0	Considerable
		6	N/A	N/A	N/A
	Multiple	1	N/A	N/A	N/A
		3	N/A	N/A	N/A
		5	N/A	N/A	N/A

Table 6 Weighted mean survival percentages of single- and multiple-surface ART/HVGIC and traditional (amalgam and resin composite) restorations in primary molars by survival year

Type of restoration	Survival year	Nst (Am:Rc)	ART/HVGIC			Traditional			P value
			N	Surv	SE	N	Surv	SE	
Single	1	4 (3:1)	477	99.1	0.6	258	98.5	0.4	0.40
	2	4 (3:1)	245	96.7	0.2	212	93.4	2.7	0.22
	3	3 (2:1)	522	92.2	4.9	416	86.6	5.0	0.42
Multiple	1	3 (2:1)	351	83.1	0.4	325	86.6	3.7	0.35
	2	3 (2:1)	265	73.6	4.5	299	81.8	5.2	0.23
	3	3 (2:1)	686	59.9	6.9	548	56.4	8.9	0.75

Key:
Nst = number of studies; Am = amalgam; Rc = resin composite; N = number of restorations evaluated; ART = atraumatic restorative treatment; HVGIC = high-viscosity glass-ionomer cement; Surv = survival

Table 7 Weighted mean survival percentages of single- and multiple-surface ART/HVGIC and traditional (amalgam and resin composite) restorations in permanent (pre)molars by survival year

Type of restoration	Survival year	Nst (Am:Rc)	ART/HVGIC			Traditional			P value
			N	Surv	SE	N	Surv	SE	
Single	1	4 (4:0)	2,933	94.2	2.2	2,200	95.0	1.9	0.78
	2	6 (6:0)	2,506	91.6	2.8	1,775	92.0	3.2	0.93
	3	2 (1:1)	430	91.8	7.2	291	89.5	10.3	0.85
	4.3	1 (1:0)	288	80.4*	2.1	218	69.5	2.9	0.003
	5	2 (1:1)	244	85.6	9.1	137	83.2	16.8	0.90
	6.3	1 (1:0)	153	68.9*	3.3	108	59.7	3.3	0.049
Multiple	1	1 (0:1)	77	94.8*	2.8	77	98.7	1.8	0.24
	2	1 (0:1)	19	90.3*	5.5	6	66.7	19.4	0.25
	3	1 (0:1)	19	85.5*	7.2	6	66.9	19.0	0.37

Key:
Nst = number of studies; Am = amalgam; Rc = resin composite; N = number of restorations evaluated; ART = atraumatic restorative treatment; HVGIC = high-viscosity glass-ionomer cement; Surv = survival
* = no weighted mean

number of restorations at evaluation points and/or the number that had failed and/or survived, which made it impossible to calculate the weighted mean survival percentage and its SE. Many studies reported on had investigated a comparison of treatments in root surfaces and/or in class IV or V restorations in anterior teeth. Also, simple descriptive analyses instead of appropriate survival analyses were frequently used to obtain the trial outcomes. A substantial number of trials just used the term 'ART' without describing how the method was carried out. One trial reported the use of the 'modified ART' approach in which the cavity is opened with a drill and the resulting cavity excavated with hand instruments.

In the present systematic review, the quality assessment was incorporated only qualitatively. In only three of the nine included trials, in which the component 'generation of randomisation sequence' was assessed as having taken place, was adequate allocation concealment reported. This shows a high risk of selection bias in the included reports. In none of the trial reports could 'blinding of operators/evaluators' be performed. This quality component is very important for preventing bias in any medical material/drug trial. However, in dental clinical trials that compare visibly different restorative materials, it is impossible to adhere to this quality component. Operators have to follow a treatment protocol and trained evaluators will notice the difference between HVGIC and amalgam and resin composite restorations. Only if HVGICs are produced that are aesthetically similar and have a similar texture to resin composites will blinding of evaluators be possible. While it is not possible to adhere to blinding principles in clinical dental material trials, blinding should not be neglected in those trials that compare visibly similar restorative materials in order to reduce the risk of detection bias. Excluding the category 'blinding operator/evaluators', only two trial reports were assessed as having a low level of bias and seven reports as having a moderate level. This finding calls for interpreting the results of the current meta-analysis with some caution.

In a meta-analysis, it is important to establish whether the outcomes of the individual trials are consistent. Consistency is dependent on the extent of the overlap of the error measurement. If the overlap is poor, then a statistical heterogeneity may be present.[47] Quantification of inconsistency uses the statistic I^2, which is dependent on the magnitude and direction of effects and strength of evidence for heterogeneity.[47] In the present meta-analyses, which included studies from different countries with different trial backgrounds, the level of heterogeneity of the weighted mean survival percentages for the ART/HVGIC restorations was predominantly substantial to considerable. Two studies had a level of homogeneity (single-surface restorations in primary teeth after one and two years). Heterogeneity for the weighted mean survival percentages of traditional restorations was substantial to considerable.

It is concluded that the methodological requirements for performing a systematic review and a meta-analysis to the highest possible level were met, considering the data available.

Main findings

The weighted mean survival percentages of single-surface ART/HVGIC and traditional restorations in primary molars after one, two and three years were very high and were not significantly different. The difference in weighted mean survival percentages for multiple-surface ART/HVGIC and traditional restorations in primary molars after one, two and three years was also not significantly different, but the survival percentages for both treatments were lower than those obtained for single-surface restorations. On the basis of current evidence, it is therefore fair to conclude that the ART method using HVGIC can be considered a replacement for traditional restorations in single- and multiple-surface cavities in primary molars, particularly for amalgam restorations. The hypothesis was therefore accepted.

For posterior permanent teeth, the weighted mean survival percentages of single-surface ART/HVGIC and traditional restorations after 4.3 and 6.3 years showed a significant difference. The difference was based on one comparison trial and showed a borderline significance after 6.3 years. As only one comparison trial had used resin composite, it is fair to conclude that, based on current evidence, the ART method using HVGIC can be considered a replacement for traditional amalgam restorations in single-surface cavities in posterior permanent teeth. The hypothesis was accepted for amalgam, but because only one trial tested ART/HVGIC against resin composite restorations, the hypothesis for resin composite was considered inconclusive. Only one trial of a one-year duration and one trial each of a three- and five-year duration constituted the evidence for testing the difference between the survival percentages of multiple-surface ART/HVGIC and traditional restorations in posterior permanent teeth. Although there was no significant difference between the survival percentages of the two treatments, the number of trials was too low to carry out a meta-analysis, making the hypothesis inconclusive.

The findings of the present meta-analyses concur with outcomes of systematic reviews and meta-analyses performed in the past that had included fewer trial reports and fewer trials with a resin composite arm: primary molars[9,11,12,48] and posterior permanent teeth.[9,10,14,48] The meta-analyses did not include cavity size as a possible explanatory variable for success/failure. Future comparison trials should investigate the effect of this variable on the total failure percentage of multiple-surface ART/HVGIC restorations in both dentitions. This information will greatly assist the dental practitioner in deciding when or when not to use HVGICs in ART (hand) and in traditionally (drill)-prepared multiple-surface cavities in posterior teeth.

Alternatives to amalgam

The Minamata Treaty affects oral health services in all countries. These countries have differently operating oral healthcare delivery services and have to adopt the change incurred through the Treaty in the best possible way. The ART method was the topic of the current investigation as it is applied both in countries with a well-developed oral healthcare delivery system and in those with a less well-developed system. The findings of the present meta-analyses showed that amalgam can be replaced by HVGIC in the ART method in primary molars and in single-surface cavities in posterior permanent teeth. This finding is particularly important for countries that run a public healthcare system that has relied on amalgam and that find it difficult, for whatever reason(s), to change to resin composite.

Because of the low number of trials that had used resin composite materials as a reference, the current investigation was unable to provide sufficient evidence for whether HVGICs can be considered a replacement for resin composite materials. However, the number of trials investigating this topic could be increased if HVGIC restorations produced by hand and by drill were combined in a systematic review. In contrast to the view of Schwendicke *et al.*,[15] there is, in principle, no difference in the material performance of both kinds of treatment. A search of the literature covering July–December 2019 showed a number of trials that compared drill-prepared cavities and HVGIC with resin composite restorations in posterior permanent teeth.[31,49,50] It is expected that more such trials will be published in the near future.

Conclusions

The following conclusions can be drawn: 1) the number of included trials was low, of short duration, moderately biased and contained findings of substantial to considerable heterogeneity; 2) no significant differences between the survival estimates of single- and multiple-surface ART/HVGIC and traditional restorations in primary molars and in single-surface restorations in posterior permanent teeth were obtained; 3) there is evidence that ART/HVGIC can replace traditional amalgam restorations in primary molars and in single-surface cavities in posterior permanent teeth; 4) despite the increase in trials with a resin composite arm, replacing the traditional resin composite treatment with the ART/HVGIC treatment was found to be inconclusive; and 5) considering the potential environmental threats related to resin composite-based materials after death, more trials that investigate the effectiveness of traditional HVGICs or environmentally friendly alternatives and resin composite restorations are urgently required.

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Conflict of interest

J. E. Frencken is the originator of the ART approach and as such could be considered to have a conflict of interest. S. Liang and Q. Zhang declare that they have no conflict of interest.

Author contributions

J. E. Frencken contributed to the conception, design, data collection, data extraction and construction of the manuscript. S. Liang contributed to data extraction and construction of the manuscript. Q. Zhang contributed to data collection, data extraction and construction of the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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