Dental Materials 39 (2023) e1–e17

Contents lists available at ScienceDirect

Dental Materials

journal homepage: www.elsevier.com/locate/dental

The preventive effect of glass ionomer cement restorations on secondary caries formation: A systematic review and meta-analysis

Kelsey Xingyun Ge [a], Ryan Quock [a,b], Chun-Hung Chu [a], Ollie Yiru Yu [a,*]

[a] Faculty of Dentistry, The University of Hong Kong, Hong Kong, China

[b] Department of Restorative Dentistry and Prosthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, TX, USA

ARTICLE INFO

Keywords:
Glass ionomer cement
Restoration
Caries
Prevention
Systematic review

ABSTRACT

Objective: The objective is to compare the preventive effect on secondary caries of glass ionomer cement (GIC) restorations with amalgam or resin-composite restorations.

Methods: Two independent researchers conducted a systematic search of English publications in PubMed, Web of Science, Cochrane and Scopus. They selected randomized clinical trials comparing secondary caries incidences around GIC restorations (conventional GIC or resin-modified GIC) with amalgam or resin-composite restorations. Meta-analysis of the secondary-caries incidences with risk ratio (RR) and 95% confidence interval (95% CI) as the effect measure was performed.

Results: This review included 64 studies. These studies included 8310 GIC restorations and 5857 amalgam or resin-composite restorations with a follow-up period from 1 to 10 years. Twenty-one studies with 4807 restorations on primary teeth and thirty-eight studies with 4885 restorations on permanent teeth were eligible for meta-analysis. The GIC restorations had a lower secondary caries incidence compared with amalgam restorations in both primary dentition [RR= 0.55, 95% CI:0.41–0.72] and permanent dentition [RR= 0.20, 95% CI:0.11–0.38]. GIC restorations showed similar secondary caries incidence compared with resin-composite restorations in primary dentition [RR= 0.92, 95% CI:0.77–1.10] and permanent dentition [RR= 0.77, 95% CI:0.39–1.51]. Conventional GIC restorations showed similar secondary caries incidence compared with resin-modified GIC-restored teeth in both primary dentition [RR= 1.12, 95% CI:0.67–1.87] and permanent dentition [RR= 1.63, 95% CI:0.34–7.84].

Conclusions: GIC restorations showed a superior preventive effect against secondary caries compared to amalgam restorations, and a similar preventive effect against secondary caries compared to resin-composite restorations in both primary and permanent teeth. [PROSPERO Registration ID: CRD42022380959]

1. Introduction

Secondary caries, or recurrent caries, refers to caries lesions occurring adjacent to an existing restoration [1]. Secondary caries is responsible for 60% of restoration failure in dental practice [2]. The treatment for secondary caries has historically involved the replacement of restoration [3]. The repetitive operative procedure of restoration replacement causes the removal of more tooth hard tissue, weakens the remaining tooth, and eventually leads to tooth loss [3]. Moreover, the replacement of restorations placed a heavy burden on health care expenditure [4]. In the Delphi survey on restorative dentistry, the prevention of secondary caries was recognized as an oral health issue with the highest importance over the next 20 years [5].

The selection of restorative materials may affect the incidence of secondary caries [6,7]. Amalgam, resin-composite and glass ionomer cement (GIC) are commonly used dental restorative materials [8]. Dental amalgam has been used as a dental restorative material for over 150 years [9]. It is strong, durable, easy to operate, and cost-effective [10]. Because amalgam contains several metal contents such as silver and copper, it was believed that the amalgam restoration has a preventive effect on secondary caries formation [11]. Resin-composite is another common restorative material with great physical and aesthetic properties [12]. The major limitation of resin-composite is the polymerization shrinkage, which could cause microleakage between the tooth and the restoration and lead to secondary caries [13]. GIC includes conventional GIC or resin-modified GIC [14]. As a restorative material,

* Correspondence to: Faculty of Dentistry, The University of Hong Kong, 34 Hospital Road, Hong Kong, China.
E-mail address: ollieyu@hku.hk (O.Y. Yu).

https://doi.org/10.1016/j.dental.2023.10.008
Received 27 April 2023; Received in revised form 19 September 2023; Accepted 5 October 2023
Available online 12 October 2023

it has moderate mechanical and aesthetic properties compared to resin-composite. Because of the remineralizing effects on dental hard tissue, GIC was believed to have the potential to prevent secondary caries [15].

GIC has several favourable properties for secondary caries prevention. GIC can release and recharge fluoride sustainably, which promotes remineralization. Its remineralizing effects on dental hard tissue have been reported in several laboratory and clinical studies [15,16]. GIC demonstrates antibacterial properties that contribute to its cariostatic effects, although these antibacterial effects significantly weaken after the material sets [17–19]. The physiochemical bond between the GIC and the tooth structure may prevent microleakage between GIC and cavity walls [20]. *In vitro* studies have concluded that GIC shows inhibitory effects on secondary caries formation [21]. Moreover, clinical studies found that GIC restoration failures are seldom caused by secondary caries [22].

The World Health Organization (WHO) have added GIC to the WHO Model List of Essential Medicines since 2021, which represents the most efficacious, safe and cost-effective medicines for priority conditions [23]. Although the physical property of GIC raised some concern on its use in occlusal loading areas [24], the replacement of defective restoration in primary teeth is not always necessary [25]. With this recent WHO endorsement, an increase in the use of GIC is plausible. Thus, an updated systematic quantitative evaluation focusing on the preventive effect of GIC restorations on secondary caries, compared with amalgam or resin-composite restorations of will lend continuing scientific support for GIC use. Therefore, this review aimed to evaluate the preventive effect of GIC restorations (conventional GIC or resin-modified GIC) on secondary caries compared with amalgam or resin-composite restorations in primary and permanent teeth.

2. Methods

2.1. Research questions and protocols

This systematic review evaluates the clinical evidence on the research question, 'What is the effectiveness of glass ionomer cement (conventional GIC or resin-modified GIC) restorations on preventing secondary caries formation in primary or permanent teeth compared with amalgam or resin-composite restorations of dental restorations?'.

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement. It was registered in the International Prospective Register of Systematic Reviews (PROSPERO Registration ID: CRD42022380959).

2.2. Search strategy

A comprehensive literature search was conducted to identify the available studies evaluating the caries preventive effect of GIC restorations (conventional GIC or resin-modified GIC) with no limits of publication year. The literature search was conducted in four databases, including PubMed/ Medline, Web of Science, Cochrane and Scopus. The last search was performed on 3rd Jan 2023.

The search strategy was developed as follows.

1 "caries" "carious" OR "tooth decay" OR "teeth decay" OR "dental caries" OR "caries susceptibility" OR "secondary caries" OR "recurrent caries"

2 "glass ionomer cement" OR "glass ionomer" OR "GIC" "glass polyalkenoate cement" OR "glass-ionomer cement" OR "ART" OR "atraumatic restorative procedure" OR "RMGIC" OR "resin-modified glass ionomer cement"

3 "#1′ AND "#2′.

Two independent reviewers (KXG & OYY) conducted the study selection. Both authors independently screened titles, compared findings and included full texts after de-duplication. The third author (CHC) was consulted when there was disagreement. Studies with the consensus being reached through discussion were included.

2.3. Eligibility criteria

The inclusion criteria were developed based on population, intervention, comparison, outcome and study design (PICOS) strategy.

The PICOS strategy was as follows:

Population (P) - Studies with participants of all ages were included.

Intervention (I) - GIC restorations (conventional GIC or resin-modified GIC) for restorative application.

Comparison (C) - Amalgam or resin-composite restorations.

Outcome (O) - Secondary caries incidences at various follow-up periods.

Study design (S) – Randomized controlled clinical trials (RCTs).

The exclusion criteria of the studies were:

1. To be the in vitro studies, animal studies, reviews, letters to the editor, case reports/series retrospective clinical and observational studies.
2. To investigate amalgam or resin-composite restorations but did not include the GIC restorations (conventional GIC or resin-modified GIC).
3. To investigate GIC for nonrestorative application in the clinic (i.e., fissure and sealant, liners/bases or cement).
4. To output data that did not contain the secondary caries incidence.

2.4. Data extraction

Two independent reviewers (KXG & OYY) performed data extraction of the eligible studies independently and in duplicate. They reviewed each paper and extracted systematically the data. The data included publication details (authors name, publication year and duration), tooth characteristics (type of teeth and number of restorations for each type of restoration), outcome information (assessment and caries incidence) and patients' information (risk of caries).

2.5. Assessment of the quality and risk of bias assessment of the studies

Two independent reviewers performed the risk of bias assessment of the study following the Cochrane Handbook for Systematic Reviews of Interventions 5.4.1 for assessing the risk of bias in RCTs. Six domains of bias were evaluated: selection bias-random sequence generation and allocation concealment; performance bias-blinding of participants and personnel; detection bias-blinding of outcome assessment; attrition bias-incomplete outcome data; reporting bias-selective outcome reporting; other bias-other possible sources of bias. In case of disagreements between the reviewers, a consensus was reached through discussion, and if needed, by consulting a third reviewer (CHC).

2.6. Data synthesis and analysis

Meta-analysis of the secondary caries incidence after GIC restorations (conventional GIC or resin-modified GIC) was carried out from the selected studies and analysed using Review Manager 5.4. Data on secondary caries incidence of the eligible studies were extracted for meta-analysis. The results of the intervention effect were presented as risk ratio (RR) utilizing 95% confidence intervals (95% CI). Fixed-effects models were applied, and heterogeneity was tested using Cochran's Q test and the I^2 index. $P < 0.05$ was considered statistically significant. The follow-up periods were classified as short- (1 year), medium- (2–4 years) or long-term ($\geq$ 5 years).

3. Results

3.1. Search result and study selection

A total of 5458 records were found in the initial search. 2586 duplicates were identified and removed. 2872 studies were eligible for screening. After the screening of titles and abstracts, 2275 studies other than randomized controlled clinical trials were excluded. Full texts of 337 articles were assessed. Finally, 64 studies that reported the secondary caries preventive effect of the GIC restorations were included in this review. Among them, 21 studies on primary teeth and 38 studies on permanent teeth were eligible for meta-analysis, while 5 studies were excluded from the meta-analysis. 4 of the excluded studies employed Danish Public Dental Health Service (Danish PDHS) criteria (3 studies) [26–28]or radiograph (1 study) [29] for the diagnosis of secondary caries. However, the details of Danish PDHS and radiograph were not provided in the original studies. In addition, studies using different criteria to assess outcomes may introduce methodological heterogeneity into the meta-analysis. Therefore, we excluded these 4 articles to reduce the heterogeneity of the included studies and enhance the certainty of evidence. Additionally, 1 study [30] was excluded from meta-analysis because it was the only study that employed FDI criteria for the diagnosis of secondary caries in permanent teeth. As a result, we are unable to compare and synthesize the results of this study with other studies.

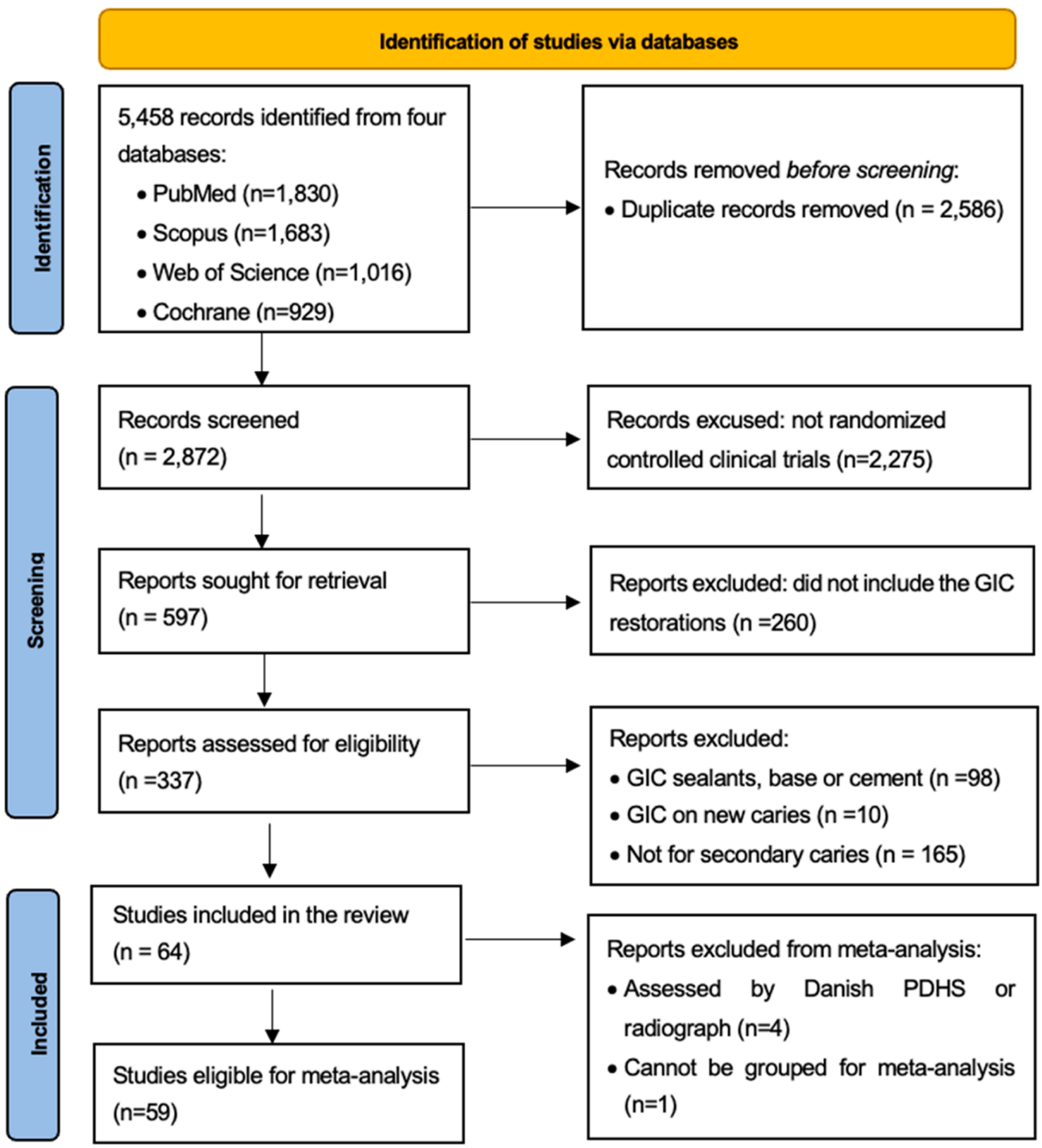

Fig. 1. Flow diagram of the systematic review on glass ionomer cement (GIC). *Danish PDHS: Danish Public Dental Health Service criteria.*

The details of the literature search are presented in a flowchart (Fig. 1).

3.2. Study characteristics

A total of 64 included studies were published between 1997 and 2022, with a follow-up period of 1–10 years. Details about 64 articles selected for this review are shown in Tables 1 and 2. All included studies were randomized controlled clinical trials. The included studies involved 14,167 restorations, including 5073 conventional GIC, 3273 resin-modified GIC, 2282 amalgam and 3575 resin-composite restorations. The number of restorations involved in the systematic review is shown in Table 3.

Secondary caries incidence was the main outcome of interest of this systematic review, which was assessed with Modified United States Public Health Service (USPHS) criteria in 56 studies, FDI World Dental Federation (FDI) criteria in 5 studies and Danish Public Dental Health Service (Danish PDHS) criteria in 3 studies.

Table 1
Randomized controlled clinical trials of glass ionomer cements (GIC) in primary teeth (n = 26).

Authors, Year [Ref]	Groups (n = number of restorations): Caries incidence in %	Duration In years	Assessment method	Significance ($p < 0.05$)	Included meta-analysis	Risk of caries
Daou et al. 2009[31]	Conventional GIC (n = 23):13.0% vs Amalgam (n = 21):14.3%	2	USPHS	No	Yes	Low
Fuks et al. 2000[32]	Conventional GIC (n = 9): 0 vs Amalgam (n = 9):11.1%	2	USPHS	No	Yes	Unclear
Hilgert et al. 2014[33]	Conventional GIC (n = 386): 3.6% vs Amalgam (n = 386): 6.2%	3	USPHS	No	Yes	Low
Taifour et al. 2002[34]	Conventional GIC (n = 1086): 4.9% vs Amalgam (n = 805):9.5%	3	USPHS	Yes	Yes	Unclear
Qvist et al. 1997[26]	Conventional GIC (n = 515): 0.2% vs Amalgam (n = 543): 2.0%	3	Danish PDHS	Yes	No	Unclear
Qvist et al. 2004[27]	Conventional GIC (n = 281): 1.4% vs Amalgam (n = 309): 2.8%	8	Danish PDHS	No	No	Unclear
Arora et al. 2022[35]	Conventional GIC (n = 77):0 vs Resin-composite (n = 77):0	1	USPHS	No	Yes	Low
Gok Baba et al. 2021[36]	Conventional GIC (n = 168):0 vs Resin-composite (n = 83):0	1	USPHS	No	Yes	Low
Akman et al. 2020[37]	Conventional GIC (n = 34):0 vs Resin-composite (n = 100):0	1	USPHS	No	Yes	Low
De Medeiros et al. 2019 [29]	Conventional GIC (n = 79):20.2% vs Resin-composite (n = 79):7.6%	1	Radiograph	Yes	No	Low
Marks et al. 2000[38]	Conventional GIC (n = 52):1.9% vs Resin-composite (n = 48):4.2%	1	USPHS	No	Yes	Unclear
Passaro et al. 2022[39]	Conventional GIC (n = 78):6.4% vs Resin-composite (n = 83): 3.6%	2	USPHS	No	Yes	Unclear
Pani et al. 2018[40]	Conventional GIC (n = 106): 67.0% vs Resin-composite (n = 146): 69.2%	2	USPHS	No	Yes	Unclear
Daou et al. 2009[31]	Conventional GIC (n = 23): 13.0% vs Resin-composite (n = 26):15.4%	2	USPHS	No	Yes	Low
Ersin et al. 2006[41]	Conventional GIC (n = 70): 27.1% vs Resin-composite (n = 73): 24.7%	2	USPHS	No	Yes	Unclear
Fuks et al. 2000[32]	Conventional GIC (n = 9): 0 vs Resin-composite (n = 8): 12.5%	2	USPHS	No	Yes	Unclear
Kupietzky et al. 2019[42]	Conventional GIC (n = 58): 0 vs Resin-composite (n = 58): 3.4%	3	USPHS	No	Yes	Unclear
Mufti et al. 2014[43]	Conventional GIC(n = 20): 45.0% vs Resin-modified GIC (n = 20): 65.0%	1	USPHS	No	Yes	Unclear
Daou et al. 2009[31]	Conventional GIC (n = 23):13.0% vs Resin-modified GIC (n = 23): 17.4%	2	USPHS	No	Yes	Low
Hubel et al. 2003[44]	Conventional GIC (n = 56): 7.1% vs Resin-modified GIC (n = 56):0	3	USPHS	No	Yes	Unclear
Espelid et al. 1999[45]	Conventional GIC (n = 39): 10.2% vs Resin-modified GIC (n = 44): 2.3%	3	USPHS	No	Yes	Unclear
Qvist et al. 2004[46]	Conventional GIC (n = 451): 3.0% vs Resin-modified GIC (n = 543): 3.0%	8	Danish PDHS	No	No	Unclear
Daou et al. 2009[31]	Resin-modified GIC (n = 23):17.4% vs Amalgam (n = 21):14.3%	2	USPHS	No	Yes	Low
Donly et al.1999[47]	Resin-modified GIC (n = 19): 21.1% vs Amalgam (n = 19): 31.6%	3	USPHS	No	Yes	Low
Daou et al. 2009[31]	Resin-modified GIC (n = 23):17.4% vs Resin-composite (n = 26):15.4%	2	USPHS	No	Yes	Low
Ei-Houssei et al. 2019[48]	Resin-modified GIC (n = 54): 0 vs Resin-composite (n = 54): 0	1	USPHS	Yes	Yes	Unclear
Casagrande et al. 2013[49]	Resin-modified GIC (n = 38): 0 vs Resin-composite (n = 94): 0	1	USPHS	No	Yes	Low
Dermata et al. 2018[50]	Resin-modified GIC (n = 54): 7.4% vs Resin-composite (n = 47): 12.7%	2	USPHS	No	Yes	Unclear
Sengul et al. 2015[30]	Resin-modified GIC (n = 32): 0 vs Resin-composite (n = 78): 5.1%	2	FDI	Yes	No	High
Andersson et al. 2006[51]	Resin-modified GIC (n = 50): 0 vs Resin-composite (n = 50): 10%	2	USPHS	No	Yes	Low
Qvist et al. 2004[28]	Resin-modified GIC (n = 1191): 1.1% vs Resin-composite (n = 374): 1.3%	7	Danish PDHS	No	No	Unclear

Table 2
Randomized controlled clinical trials of glass ionomer cements (GIC) in permanent teeth (n = 38).

Authors, Year [Ref]	Groups (n = number of restorations): Caries incidence in %	Duration in year	Assessment method	Significance (p < 0.05)	Included meta-analysis	Risk of caries
Haveman et al. 2003[52]	Conventional GIC (n = 61): 13.1% vs Amalgam (n = 34): 44.0%	2	USPHS	Yes	Yes	High
Mandari et al. 2003[53]	Conventional GIC (n = 274): 1.1% vs Amalgam (n = 156): 10.2%	6	USPHS	Yes	Yes	Unclear
Fatma et al. 2020[54]	Conventional GIC (n = 67): 0 vs Resin-composite (n = 67): 0	1	USPHS	No	Yes	High
Menezes et al. 2019[55]	Conventional GIC (n = 71): 2.8% vs Resin-composite (n = 74): 0	1	USPHS	No	Yes	Low
Gladys et al. 1998[56]	Conventional GIC (n = 122): 0.8% vs Resin-composite (n = 32): 0	1	USPHS	No	Yes	Low
Molina et al. 2021[57]	Conventional GIC (n = 136): 0 vs Resin-composite (n = 136): 0	2	USPHS	No	Yes	Low
Balkaya et al. 2020[58]	Conventional GIC (n = 34): 0 vs Resin-composite (n = 75): 0	2	USPHS	No	Yes	Low
Menezes et al. 2021[59]	Conventional GIC (n = 62): 4.8% vs Resin-composite (n = 66): 3.0%	2	USPHS	No	Yes	Low
Hatirli et al. 2021[60]	Conventional GIC (n = 56): 0 vs Resin-composite (n = 56): 1.8%	2	USPHS	No	Yes	Low
Diem et al. 2014[61]	Conventional GIC (n = 134): 1.5% vs Resin-composite (n = 64): 1.5%	3	USPHS	No	Yes	Low
Gurgan et al. 2015[62]	Conventional GIC (n = 70): 0 vs Resin-composite (n = 70): 0	4	USPHS	No	Yes	Low
Gurgan et al. 2017[63]	Conventional GIC (n = 70): 0 vs Resin-composite (n = 70): 0	6	USPHS	No	Yes	Low
Gurgan et al. 2020[64]	Conventional GIC (n = 70): 0 vs Resin-composite (n = 70): 0	10	USPHS	No	Yes	Low
Celik et al. 2015[65]	Conventional GIC (n = 67): 0 vs Resin-composite (n = 67): 0	1	FDI	No	Yes	Low
Mc comb et al. 2002[66]	Conventional GIC (n = 4): 0 vs Resin-composite (n = 26): 30.8%	2	FDI	No	Yes	High
Fotiadou et al. 2019[67]	Conventional GIC (n = 42): 0 vs Resin-composite (n = 43): 0	3	FDI	No	Yes	Unclear
Celik et al. 2019[68]	Conventional GIC (n = 67): 0 vs Resin-composite (n = 67): 0	3	FDI	No	Yes	Low
Gladys et al. 1998[56]	Conventional GIC (n = 122): 0.8% vs Resin-modified GIC (n = 33): 3.0%	1	USPHS	No	Yes	Low
Dulgergil et al. 2005[69]	Conventional GIC (n = 39): 0 vs Resin-modified GIC (n = 52): 0	1	USPHS	No	Yes	Low
Ercan et al. 2009[70]	Conventional GIC (n = 39): 5.1% vs Resin-modified GIC (n = 52): 0	2	USPHS	No	Yes	High
Mc comb et al. 2002[66]	Conventional GIC (n = 4): 0 vs Resin-modified GIC (n = 9): 11.1%	2	FDI	No	Yes	High
Gladys et al. 1998[56]	Resin-modified GIC (n = 33): 3.0% vs Resin-composite (n = 32): 0	1	USPHS	No	Yes	Low
Van Dijken et al. 2019[71]	Resin-modified GIC (n = 82): 3.7% vs Resin-composite (n = 82): 0	1	USPHS	No	Yes	High
De Medeiros et al. 2015 [72]	Resin-modified GIC (n = 30): 0 vs Resin-composite (n = 30): 0	1	USPHS	No	Yes	Low
Perdigão et al. 2012[73]	Resin-modified GIC (n = 26): 0 vs Resin-composite (n = 27): 7.4%	1	USPHS	No	Yes	Low
De Oliveria et al. 2012 [74]	Resin-modified GIC (n = 41): 0 vs Resin-composite (n = 40): 0	1	USPHS	No	Yes	Low
Adeleke et al. 2012[75]	Resin-modified GIC (n = 170): 0 vs Resin-composite (n = 168): 0	1	USPHS	No	Yes	Unclear
Chinelatti et al. 2004[76]	Resin-modified GIC (n = 29): 0 vs Resin-composite (n = 58): 1.7%	1	USPHS	No	Yes	Unclear
Santiago et al. 2003[77]	Resin-modified GIC (n = 35): 0 vs Resin-composite (n = 35): 0	1	USPHS	No	Yes	Low
Popescu et al. 2016[78]	Resin-modified GIC (n = 73): 0 vs Resin-composite (n = 74): 0	2	USPHS	No	Yes	Low
Santiago et al. 2010[79]	Resin-modified GIC (n = 35): 0 vs Resin-composite (n = 35): 0	2	USPHS	No	Yes	Low
Onal et al. 2004[80]	Resin-modified GIC (n = 24): 0 vs Resin-composite (n = 106): 0	2	USPHS	No	Yes	Unclear
Brackett et al. 2003[81]	Resin-modified GIC (n = 37): 0 vs Resin-composite (n = 37): 0	2	USPHS	No	Yes	Unclear
Brackett et al. 2001[82]	Resin-modified GIC (n = 32): 0 vs Resin-composite (n = 32): 9.4%	2	USPHS	No	Yes	Unclear
Goncalves et al. 2021[83]	Resin-modified GIC (n = 100): 0 vs Resin-composite (n = 100): 0	3	USPHS	No	Yes	Low
Ozgunaltay et al. 2002 [84]	Resin-modified GIC (n = 50): 0 vs Resin-composite (n = 48): 0	3	USPHS	No	Yes	Low
Folwaczny et al. 2001[85]	Resin-modified GIC (n = 82): 0 vs Resin-composite (n = 115): 0	3	USPHS	No	Yes	Unclear
Alessandro et al. 2003 [86]	Resin-modified GIC (n = 16): 0 vs Resin-composite (n = 16): 0	5	USPHS	No	Yes	Low
Van Dijken et al. 1999[87]	Resin-modified GIC (n = 41): 0 vs Resin-composite (n = 49): 2.0%	5	USPHS	No	Yes	Unclear
Van Dijken et.al 2001[88]	Resin-modified GIC (n = 41): 0 vs Resin-composite (n = 49): 2.0%	6	USPHS	No	Yes	Unclear
Fagundes et.al 2014[89]	Resin-modified GIC (n = 23): 0 vs Resin-composite (n = 13): 7.7%	7	USPHS	No	Yes	Low
Mc comb et al. 2002[66]	Resin-modified GIC (n = 9): 11.1% vs Resin-composite (n = 26): 30.8%	2	FDI	No	Yes	High

3.2.1. Studies on primary teeth

26 included studies published between 1999 and 2022 investigated the preventive effect of the GIC-restored primary teeth on secondary caries. The included studies involved 9282 restorations, including 3588 conventional GIC, 2124 resin-modified GIC, 2092 amalgam and 1478 resin-composite restorations.

3.2.2. Studies on permanent teeth

38 included studies published between 1997 and 2022 investigated the preventive effect of GIC-restored permanent teeth on secondary caries. The included studies involved 4885 restorations, including 1485 conventional GIC, 1113 resin-modified GIC, 190 amalgam and 2097 resin-composite restorations.

3.3. Risk of bias of the studies

The risk of bias of the 64 studies included in the systematic review was assessed (Fig. 2 and Table 3). 17 studies presented a low risk of bias. 2 studies showed an unclear risk of bias. 45 studies had a high risk of bias. Specifically, 41 studies did not report random sequence generation, and 28 studies did not report allocation concealment. 13 studies and 23 studies did not perform the blinding of participants and outcome assessment, respectively. No attrition bias, reporting bias or other bias was noticed in any of the included studies.

3.4. Meta-analysis

3.4.1. GIC vs other restorations

Generally, teeth with GIC restorations showed a lower secondary caries incidence compared to teeth with amalgam or resin-composite restorations in primary dentition [RR= 0.74, 95% CI:0.63–0.86] (Fig. 3A) and permanent dentition [RR= 0.38, 95% CI:0.25–0.60] (Fig. 3B). The risk ratio of secondary caries incidence of different types of materials was summarized in Tables 5 and 6.

Table 3
Number of restorations and restorative materials included in the review.

Restoration material	Glass ionomer cement		Amalgam	Resin-composite	Total
No. of restoration (No. of studies)	Conventional	Resin-modified			
No. of restoration in primary teeth (26 studies)	3588	2124	2092	1478	9282
No. of restorations in permanent teeth (38 studies)	1485	1113	190	2097	4885
Total no. of restorations (64 studies)	5073	3237	2282	3575	14,167

3.4.1.1. GIC vs amalgam. GIC-restored teeth exhibited a lower secondary caries incidence compared with amalgam-restored teeth in primary dentition [RR= 0.55, 95% CI:0.41–0.72] (Fig. 3A) and permanent dentition [RR= 0.20, 95% CI:0.11–0.38] (Fig. 3B).

3.4.1.2. GIC vs resin-composite. GIC-restored teeth showed a similar secondary caries incidence compared with composite restored teeth in primary dentition [RR= 0.92, 95% CI:0.77–1.10] (Fig. 3A) and permanent dentition [RR= 0.77, 95% CI:0.39–1.51] (Fig. 3B).

3.4.2. Conventional GIC/Resin-modified GIC vs amalgam with different follow-up periods

3.4.2.1. Conventional GIC vs amalgam. Conventional GIC-restored primary teeth presented a lower secondary caries incidence compared to amalgam-restored primary teeth in 2–4 years follow-up period [RR= 0.54, 95% CI:0.40–0.72] (Fig. 4A). A similar trend was observed in conventional GIC-restored permanent teeth in 2–4 years [RR= 0.30, 95% CI:0.14–0.63] and ≥ 5 years [RR= 0.11, 95% CI:0.03–0.36] follow-up period (Fig. 4B).

3.4.2.2. Resin-modified GIC vs amalgam. Resin-modified GIC-restored primary teeth showed similar secondary caries incidence compared with amalgam-restored primary teeth in 2–4 years [RR= 0.75, 95% CI:0.31–1.81] (Fig. 5). No studies on resin-modified GIC-restored permanent teeth were included in this study.

3.4.3. Conventional GIC/Resin-modified GIC vs resin-composite with different follow-up periods

3.4.3.1. Conventional GIC vs resin-composite. Conventional GIC-restored primary teeth showed no statistical difference in secondary caries incidence compared to resin-composite-restored primary teeth in 1 year [RR= 0.46, 95% CI:0.04–4.93] and 2–4 years [RR= 0.98, 95% CI:0.82–1.17] (Fig. 6A). A similar outcome was identified in conventional GIC-restored permanent teeth in 1 year [RR= 2.49, 95% CI:0.33–18.59] and 2–4 years [RR= 1.02, 95% CI:0.30–3.52] (Fig. 6B).

Conventional GIC-restored permanent teeth assessed by FDI criteria showed no statistical difference in secondary caries incidence compared to resin-composite-restored permanent teeth in 2–4 years [RR= 0.32, 95% CI:0.02–4.67] (Fig. 6C).

3.4.3.2. Resin-modified GIC vs resin-composite. Resin-modified GIC-restored primary teeth presented no statistical difference in secondary caries incidence compared to resin-composite-restored primary teeth in 2–4 years [RR= 0.35, 95% CI:0.12–1.03] (Fig. 7A). A similar outcome was observed in resin-modified GIC-restored permanent teeth in 1 year [RR= 1.37, 95% CI:0.41–4.63], 2–4 years [RR= 0.14, 95% CI:0.01–2.66] and ≥ 5 years [RR= 0.26, 95% CI:0.04–1.56] (Fig. 7B).

3.4.4. Conventional GIC vs Resin-modified GIC with different follow up periods

Conventional GIC-restored teeth showed similar secondary caries incidence compared with resin-modified GIC-restored teeth in primary dentition [RR= 1.12, 95% CI:0.67–1.87] (Fig. 8A) and permanent dentition [RR= 1.63, 95% CI:0.34–7.84] (Fig. 8B).

Conventional GIC-restored primary teeth showed no statistical difference in secondary caries incidence compared to resin-modified GIC-restored primary teeth in 1 year [RR= 0.69, 95% CI:0.39–1.24] and 2–4 years follow-up period [RR= 2.16, 95% CI:0.82–5.70] (Fig. 8A). A similar observation was noted in conventional GIC-restored permanent teeth in 1 year [RR= 0.27, 95% CI:0.02–4.21] and 2–4 years follow-up period [RR= 6.63, 95% CI:0.33–134.20] (Fig. 8B).

Conventional GIC-restored permanent teeth assessed by FDI criteria showed no statistical difference in secondary caries incidence compared to resin-modified GIC-restored permanent teeth in 2–4 years [RR= 0.67, 95% CI:0.03–13.60] (Fig. 8C).

4. Discussion

In this study, we found that overall GIC restorations were more effective in preventing secondary caries compared to amalgam or resin-composite restorations in primary dentition and permanent dentition. GIC contains silicon aluminum fluoride glasses and can release fluoride [90] [91]. The dentinal walls underneath a GIC restoration may contain up to 5000–6000 ppm fluoride [92]. Previous studies reported that fluoride at a concentration of as low as 0.03–0.07 ppm can stop mineral loss and promote mineral deposition in dental hard tissue [93]. Therefore, the fluoride release may contribute to the preventive effect of GIC secondary caries formation by decreasing demineralization and enhancing remineralization of dental hard tissues [15]. In addition, GIC materials are “rechargeable”, they take up and re-release fluoride and prolonged the fluoride release [92]. The sustainable fluoride release may enhance the secondary caries preventive effect of GIC [94,95].

GIC restorations were more effective in preventing secondary caries compared to amalgam restoration in primary dentition and permanent dentition. GIC restoration includes conventional GIC and resin-modified GIC restoration. Only one study on primary teeth (and no study on permanent teeth) was included in this review that compared the secondary caries incidence of resin-modified GIC restorations and amalgam restorations [96]. The meta-analysis of this study [96] did not rule out a difference in secondary caries preventive effect between resin-modified GIC restoration and amalgam restoration with the statistical power. Therefore, the superior preventive effect of GIC on secondary caries compared to amalgam may be due to the effect of conventional GIC in the pool of the collected data. Further high-quality randomized control trials on the secondary caries preventive effect of resin-modified GIC are needed to support the results.

GIC-restored teeth showed similar secondary caries incidence compared with resin-composite restored teeth in primary dentition and permanent dentition. A previous review found that GIC restorations resulted in a lower primary caries incidence in other teeth of the dentition compared to resin-composite restorations [95]. In comparing GIC to resin-composite, GIC restorations seem to have a greater preventive effect on new primary lesions in the surrounding dentition versus preventing secondary caries at their own margins. It could be associated with the specific characteristics of secondary caries compared to primary caries. Secondary caries follows the same pathogenesis pattern as primary caries except that it is modified by the presence of a restoration margin [6]. A defective restoration margin allows the

Table 4
Risk of bias of the included studies (n = 64).

Authors, year [Ref]	Selection bias (Random)	Selection bias (Allocation)	Performance bias	Detection bias	Attrition bias	Reporting bias	Overall bias
Adeleke et al. 2012 [75]	+	+	+	+	+	+	+
Arora et al. 2022 [35]	+	+	+	+	+	+	+
Balkaya et al. 2020 [58]	+	+	+	+	+	+	+
Celik et al. 2015 [65]	+	+	+	+	+	+	+
Celik et al. 2019 [68]	+	+	+	+	+	+	+
De Oliveria et al. 2012 [74]	+	+	+	+	+	+	+
Ercan et al. 2009 [70]	+	+	+	+	+	+	+
Fotiadou et al. 2019 [67]	+	+	+	+	+	+	+
Gok Baba et al. 2021 [36]	+	+	+	+	+	+	+
Goncalves et al. 2021 [83]	+	+	+	+	+	+	+
Gurgan et al. 2015 [62]	+	+	+	+	+	+	+
Gurgan et al. 2017 [63]	+	+	+	+	+	+	+
Gurgan et al. 2020 [64]	+	+	+	+	+	+	+
Hubel et al. 2003 [44]	+	+	+	+	+	+	+
Mandari et al. 2003 [53]	+	+	+	+	+	+	+
Menezes et al. 2019 [55]	+	+	+	+	+	+	+
Molina et al. 2021 [57]	+	+	+	+	+	+	+
Dermata et al. 2018 [50]	+	?	+	+	+	+	?
Qvist et al. 2004 [46]	?	?	+	+	+	+	?
Akman et al. 2020 [37]	+	+	+	−	+	+	−
Alessandro et al. 2003 [86]	−	+	+	+	+	+	−
Brackett et al. 2003 [81]	−	+	+	+	+	+	−
Brackett et al. 2001 [82]	−	+	+	+	+	+	−
Casagrande et al. 2013 [49]	−	+	+	+	+	+	−
De Medeiros et al. 2015 [72]	−	+	+	+	+	+	−
De Medeiros et al. 2019 [29]	−	+	+	+	+	+	−
Diem et al. 2014 [61]	−	+	+	+	+	+	−
Ersin et al. 2006 [41]	−	+	+	+	+	+	−
Fagundes et.al 2014 [89]	−	+	+	+	+	+	−
Folwaczny et al. 2001 [85]	+	+	+	−	+	+	−
Kupietzky et al. 2019 [42]	−	+	+	+	+	+	−
Mufti et al. 2014 [43]	+	+	+	−	+	+	−
Van Dijken et al. 2019 [71]	−	+	+	+	+	+	−
Andersson et al. 2006 [51]	−	?	+	+	+	+	−
Ei-Houssei et al. 2019 [48]	−	?	+	+	+	+	−
Onal et al. 2004 [80]	−	?	+	+	+	+	−
Ozgunaltay et al. 2002 [84]	−	?	+	+	+	+	−
Qvist et al. 2004 [28]	−	?	+	+	+	+	−
Van Dijken et al. 1999 [87]	−	?	+	+	+	+	−
Santiago et al. 2010 [79]	−	?	+	+	+	+	−
Chinelatti et al. 2004 [76]	−	−	+	+	+	+	−
Fatma et al. 2020 [54]	+	+	−	−	+	+	−
Hatirli et al. 2021 [60]	−	−	+	+	+	+	−
Mc comb et al. 2002 [66]	−	+	+	−	+	+	−
Menezes et al. 2021 [59]	+	+	−	−	+	+	−
Pani et al. 2018 [40]	−	−	+	+	+	+	−
Passaro et al. 2022 [39]	+	+	−	−	+	+	−
Santiago et al. 2003 [77]	−	−	+	+	+	+	−
Daou et al. 2009 [31]	−	?	+	−	+	+	−
Marks et al. 2000 [38]	−	?	+	−	+	+	−
Popescu et al. 2016 [78]	−	?	+	−	+	+	−
Dulgergil et al. 2005 [69]	−	−	+	−	+	+	−
Donly et al.1999 [47]	−	+	−	−	+	+	−
Espelid et al. 1999 [45]	−	−	+	−	+	+	−
Gladys et al. 1998 [56]	−	−	+	−	+	+	−
Fuks et al. 2000 [32]	−	?	−	−	+	+	−
Hilgert et al. 2014 [33]	−	?	−	−	+	+	−
Perdigão et al. 2012 [73]	−	?	−	−	+	+	−
Qvist et al. 1997 [26]	−	?	−	−	+	+	−
Sengul et al. 2015 [30]	−	?	−	−	+	+	−
Van Dijken et.al 2001 [88]	−	?	−	−	+	+	−
Haveman et al. 2003 [52]	−	−	−	−	+	+	−
Qvist et al. 2004 [27]	−	−	−	−	+	+	−
Taifour et al. 2002 [34]	−	−	−	−	+	+	−

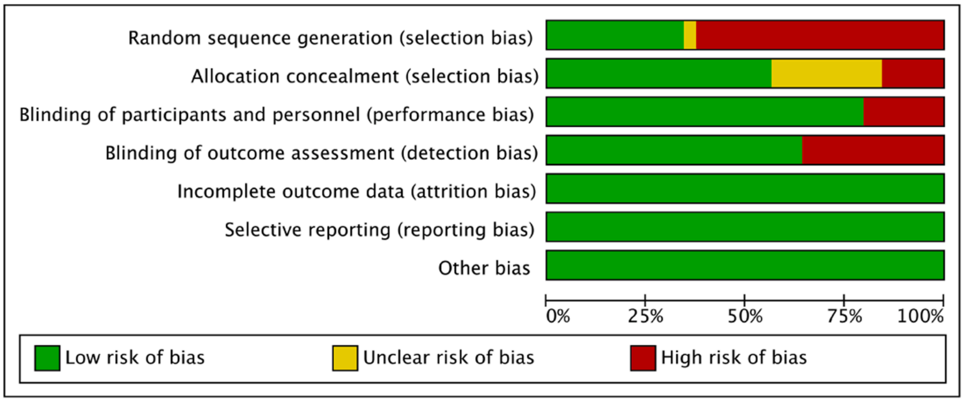

Fig. 2. Risk of bias assessment of the included studies.

cariogenic biofilm to grow in the gap of the restoration-tooth interface and cause secondary caries. Therefore, the incidence of secondary caries is related to the marginal seal of the restorative material. Since the mechanical strength of GIC is lower compared to resin-composite, fracture is easier to occur in GIC restoration and may cause microleakage around the restoration [97,98]. In addition, in the meta-analysis comparing GIC and resin-composite, we noted that 27 of 49 included studies did not report secondary caries cases in both GIC and resin-composite restored teeth. The follow-up period of these 27 studies ranges from 1 to 5 years, which is relatively short. The low incidence of secondary caries due to the short follow-up period might affect the results of the review.

Conventional GIC restorations showed similar preventive effect on secondary caries compared with resin-modified GIC restorations in primary dentition and permanent dentition. Previous studies found less microleakage around resin-modified GIC than conventional GIC [98] because of the presence of 2-hydroxyethyl methacrylate in resin-modified GIC. It leads to a hygroscopic expansion of up to 6% at 24 h. The expansion of the restoration may counteract the tendency of microleakage in the restoration margin [99]. Besides, resin-modified GIC shows a higher mechanical strength than conventional GIC and is less likely to fracture. These favourable properties of resin-modified GIC may promote its preventive effect on secondary caries compared with conventional GIC. We noted that resin-modified GIC restoration tends to be more effective in preventing secondary caries with medium-term follow-up (2–4 years) than with short-term (1 year). However, no statistical difference was observed (Fig. 8A, B). No long-term studies (more than 5 years) comparing the secondary caries preventive effect of conventional GIC and resin-modified GIC were available.

Out of 64 included studies on the secondary caries of GIC in this review, only 9 studies were on amalgam restorations while 51 studies were on resin-composite restorations. Studies on amalgam were published between 1997 and 2009, and studies on resin-composite were published between 1998 and 2022. It may be due to the decreased use of amalgam in recent years. Amalgam has been used as dental restorative material since the 1800 s [100]. Because of the negative effect of the mercury content in the amalgam on the environment, the Minamata Convention was approved in 2013, aiming to phase out the use of mercury. Dental amalgam has been required to be phased down under the convention [101]. In addition, amalgam restorations normally require extensive tooth preparation. Because the philosophy of caries management has shifted to minimal intervention dentistry, restorative materials which allow for a more conservative tooth preparation have been predominating in restorative dentistry [102]. Since the introduction of a resin-composite in the late 1960 s [103], conventional GIC in 1971 [104] and resin-modified GIC in the 1980 s [105], the selection and application of restorative material have been changing dramatically [106]. Resin-composite and GIC are more popular options [107].

We analyzed the secondary caries incidence in primary and permanent teeth separately, because the caries risk of primary and permanent teeth could be distinct [108]. Generally, the primary teeth are uniquely vulnerable to caries. Around 30% of caries occurs in the primary teeth despite their relatively short residual period in the mouth [109]. In addition, some primary teeth are restored during the mixed dentition phase, when the caries risk was relatively high [109]. The differences in caries risk may have influences on secondary caries incidences. Although the caries risk patterns may be different, the meta-analysis comparing secondary caries incidence among different types of restorative materials showed similar results in primary and permanent teeth in this study.

We analyzed the risk ratio of secondary caries incidence of teeth with different types of restorations in defined follow-up periods. We categorized the studies based on the follow-up times to obtain more reliable results at different time points. The follow-up periods were categorized as short-term (1 year), medium-term (2–4 years) or long-term (≥ 5 years). Clinical trials have shown that the incidence of secondary carious lesions increases with a longer follow-up period [110]. Nedeljkovic et al. reported that the highest mean incidence of secondary caries development was recorded after 5 years compared to less than 5 years follow-up period [3]. Therefore, we set 5 years as a long-term follow-up period for the meta-analysis with defined follow-up periods.

Only 10 of the 64 included studies had a follow-up period of ≥ 5 years. Fernandes et al. reported that amalgam showed the highest survival rates (22.5 years) with an average survival rate of 95% over 10 years, followed by resin-composite (90% over 10 years), and GIC (65% over 5 years) [12]. The shorter longevity of GIC restorations could be caused by restoration fracture due to its low fracture toughness and strength [97]. This may be the reason why the follow-up period of most included GIC studies are short. In addition, the follow-up periods are limited in primary teeth due to the natural exfoliation of the primary teeth. Further randomized control trials with longer follow-up periods are needed to confirm these results.

Secondary caries was not found in 27 of the included 64 studies. Because no case of secondary caries was found in these studies, it was not feasible to compare the difference between GIC and amalgam or resin-composite restorations within the single study. We presented the results of these studies as "Not estimable" in the forest plot. But these data were included for the overall analysis of the risk ratio of secondary caries incidence around different restorative materials. The low incidence of secondary caries in these studies might be attributed to the relatively short follow-up period, the difficulty in the diagnosis of secondary caries and the low caries risk of the patient population. Among the 64 included studies, 33 featured patients with low caries risk, 28 had unclear caries risk, and 3 involved high caries risk.

Only one study out of the 64 included studies used the radiological assessment [29], while the other 63 used the visual and tactile

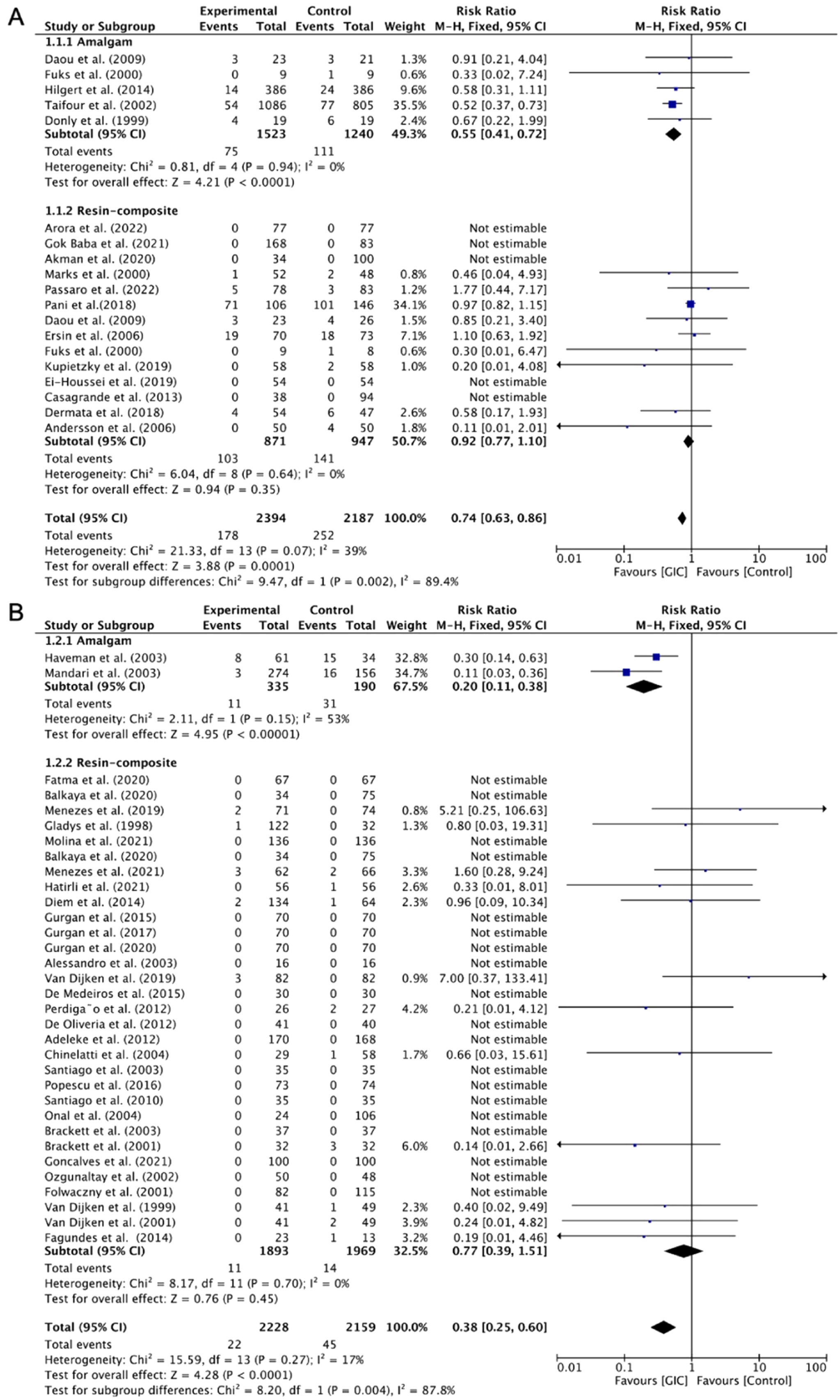

Fig. 3. Meta-analysis of secondary caries incidence in teeth with GIC restorations vs amalgam or resin-composite restorations in the primary dentition (A) and permanent dentition (B).

Table 5
The risk ratios of secondary caries in primary teeth when using different types of materials assess by the United States Public Health Service (USPHS) criteria. The risk of failure of the strategy in each row is compared against the ones in each column. * $p < 0.05$.

		Glass ionomer cement restoration		Amalgam restoration	Resin-composite restoration
		Conventional	Resin-modified		
Glass ionomer cement restoration	Conventional	-	0.89 [0.53,1.48]	1.79 [1.35, 2.39]*	1.03 [0.87, 1.23]
	Resin-modified	1.12 [0.67, 1.87]	-	1.33 [0.55, 3.21]	2.82 [0.97, 8.20]
Amalgam restoration		0.54 [0.40,0.72]*	0.75 [0.31,1.81]	-	-
Resin-composite restoration		0.97 [0.81,1.16]	0.35 [0.12,1.03]	-	-

Table 6
The risk ratios of secondary caries in permanent teeth when using different types of materials were assessed by the United States Public Health Service (USPHS) criteria. The risk of failure of the strategy in each row is compared against the ones in each column. * $p < 0.05$.

		Glass ionomer cement restoration		Amalgam restoration	Resin-composite restoration
		Conventional	Resin-modified		
Glass ionomer cement restoration	Conventional	-	0.61 [0.13, 2.94]	5.02 [2.65, 9.50]*	0.75 [0.27, 2.12]
	Resin-modified	1.63 [0.34, 7.84]	-	-	1.67 [0.71, 3.94]
Amalgam restoration		0.20 [0.11, 0.38]*	-	-	-
Resin-composite restoration		1.33 [0.47,3.74]	0.60 [0.26,1.42]	-	-

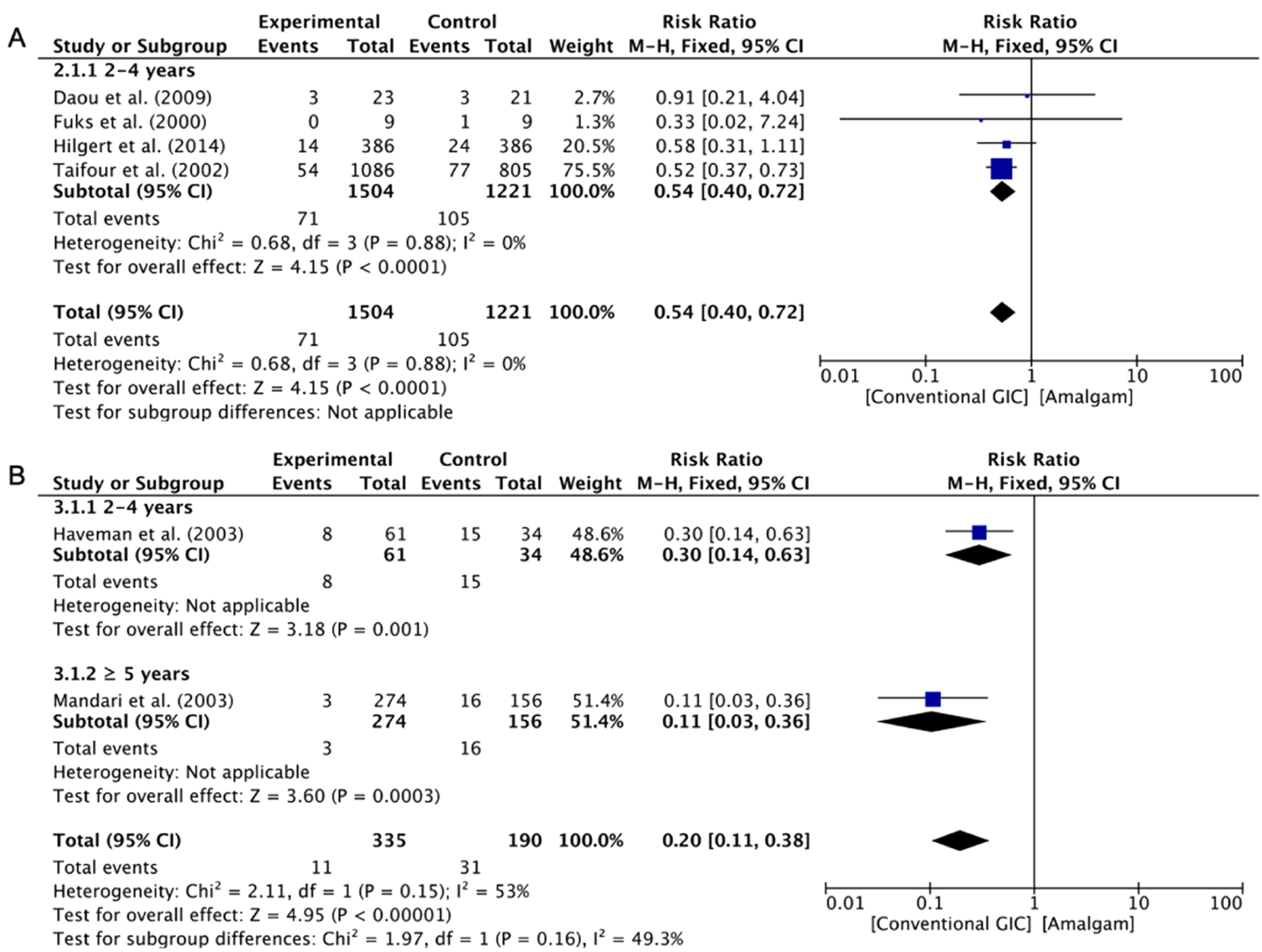

Fig. 4. Meta-analysis of secondary caries incidence in teeth with Conventional GIC restorations vs amalgam with defined follow-up period in the primary dentition (A) and permanent dentition (B).

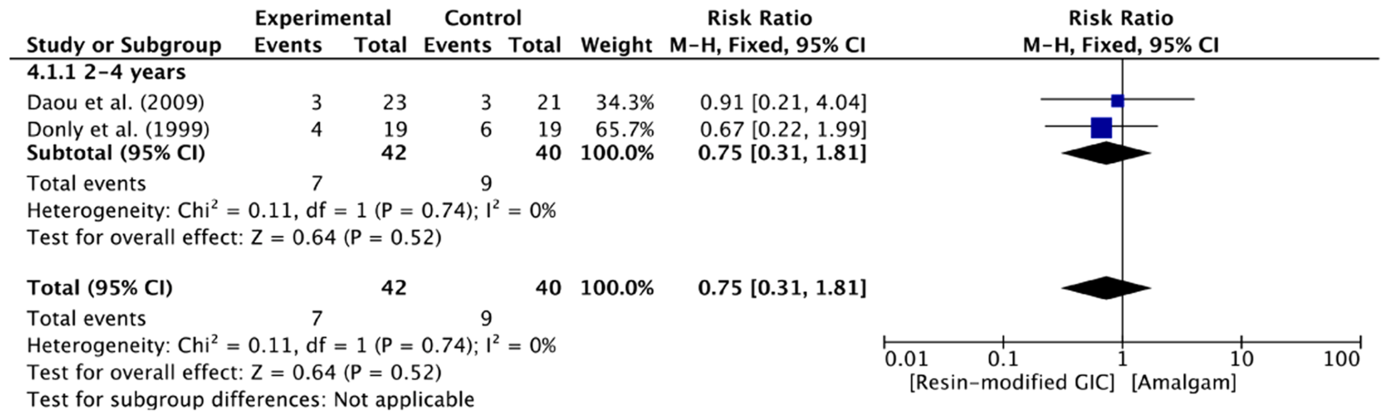

Fig. 5. Meta-analysis of secondary caries incidence in teeth with resin-modified GIC restorations vs amalgam with defined follow-up period in the primary dentition.

examination for secondary caries detection. The early detection of secondary caries is important, as it allows for less invasive treatment options to prevent further loss of dental tissues [6]. However, it is difficult to diagnose secondary caries in clinical settings. Oral examination based on visual and tactile examination combined with radiological assessment is commonly used for clinical diagnosis of secondary caries. These techniques have certain limitations. It is difficult to distinguish secondary caries from marginal discolouration or so-called "amalgam tattoos" by visual and tactile examination [111,112]. Furthermore, for tactile examination, sharp probes can be inserted even into non-carious marginal gaps or overhangs, which may not reliably predict the presence of secondary caries [113]. Radiological assessment may be influenced by the radiopacity of the restorative material when testing secondary caries [114]. The detection methods and standards may affect the reported incidence of secondary caries. Brouwer et al. reported that visual and radiographic examination for secondary caries detection had similar sensitivities (mean values, 0.53 and 0.59, respectively) and specificities (mean values, 0.78 and 0.83, respectively). The tactile examination had low accuracy, with mean values of sensitivity and specificity of 0.28 and 0.86, respectively [115]. Therefore, the incidence of secondary caries in the included studies could be underestimated or overestimated. This limitation was caused by the nature of the difficulty in the detection of secondary caries with regular clinical procedures.

The studies included in this review used 3 types of criteria to assess secondary caries incidence. Modified United States Public Health Service (USPHS) criteria were adopted in 56 studies. FDI World Dental Federation (FDI) criteria were adopted in 5 studies. Danish Public Dental Health Service (Danish PDHS) criteria were adopted in 3 studies. The USPHS criteria are commonly used for the assessment of secondary caries around restorations [116]. The USPHS criteria score the restorations as Alpha for no secondary caries and Bravo for the existence of secondary caries. It was designed to reflect differences in acceptability (Yes/No) rather than in degrees of success [117]. USPHS is highly specific, which can avoid false positive diagnoses. On the contrary, using USPHS may lead to missing many secondary caries lesions [115]. The USPHS criteria were recommended to be used in long-term clinical studies [118]. The FDI criteria were recommended in clinical trials assessing dental restorations in terms of materials, operative technique and clinical practice [119]. The FDI criteria score the restoration in 5 levels. The restorations can be scored 1–5, where 1–3 means clinically acceptable, while 4 or 5 represents failure [120]. Kim et al. reported that FDI criteria present a high intra-examiner and a slight to fair inter-examiner reliability [121]. As FDI criteria have more scoring options, it gives more sensitive results than USPHS [118]. It should be noted that high sensitivity is often accompanied by a high risk of false positive diagnoses [115]. The FDI criteria were more suitable for short-term clinical evaluation of restorations than USPHS [122,123]. Danish Public Dental Health Service (Danish PDHS) criteria were used in oral health education programs [124]. The Danish PDHS criteria were adopted in 3 studies and the authors could not find more details about the criteria.

In this systematic review, a total of 64 studies were included. Among them, 59 studies were deemed eligible for meta-analysis. In the meta-analysis, we grouped studies that were as similar as possible in terms of methodology and outcome measures. It reduces the heterogeneity of the studies and enhances the certainty of the evidence [125]. Because of the difference in the assessment criteria, studies using USPHS and FDI criteria were analyzed separately to perform the meta-analysis. 5 studies were excluded from the meta-analysis. 4 of the excluded studies employed Danish Public Dental Health Service (Danish PDHS) criteria (3 studies) [26,27] [28] or radiograph (1 study) [29] for the diagnosis of secondary caries. However, the details of Danish PDHS and radiograph were not provided in the original studies. In addition, studies using different criteria to assess outcomes may introduce methodological heterogeneity into the meta-analysis. Therefore, we excluded these 4 articles to reduce the heterogeneity of the included studies and enhance the certainty of evidence. Additionally, 1 study [30] was excluded from meta-analysis because it was the only study that employed FDI criteria for the diagnosis of secondary caries in permanent teeth. As a result, we are unable to compare and synthesize the results of this study with other independent studies.

Some studies showed high performance bias and detection bias as these studies did not perform the blinding of participants and outcome assessment. Because the nature and presentation of the used materials are different and easily identified by participants and dentists. Meanwhile, some studies showed an unclear bias for selection bias and selection bias, as they did not report the random sequence generation and allocation concealment. It should be noted that the overall risk of bias in the study was not considered as a ground for meta-analysis exclusion.

The limitation of the review was that we analyzed the data based on the type of restorations, the type of dentition and the assessment criteria for secondary caries. Secondary caries is also influenced by several other factors such as the location of the lesion, the patient's caries risk, the patient's age, socioeconomic status, and operator's skills variation [126]. In addition, the subtypes or the brands of restorative material may also affect the incidence of secondary caries. However, due to the limited information provided in the included studies, we could not include these factors in our analysis.

This systematic review indicates the potential of GIC restoration in preventing secondary caries.

In this review, we evaluated the available clinical evidence of the secondary caries preventive effect of different types of restorations. Secondary caries are a major reason for the replacement of restorative materials worldwide [127]. Secondary caries development may be related to the type of restorative materials [128]. Several studies observed significantly more caries around resin-composite restorations

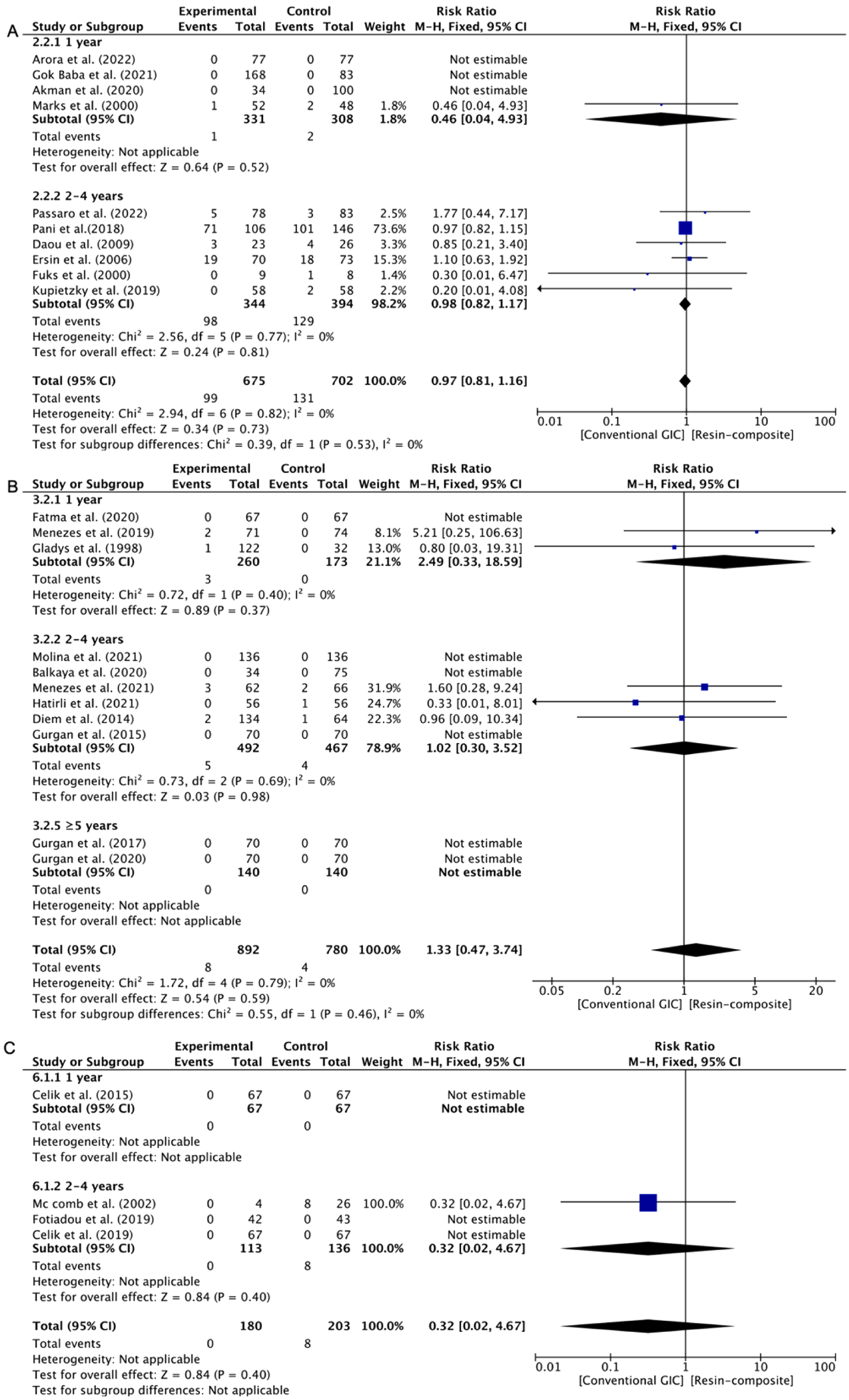

Fig. 6. Meta-analysis of secondary caries incidence in teeth with conventional GIC restorations vs resin-composite with defined follow-up period by USPHS in the primary dentition (A) and permanent dentition (B) and by FDI criteria in permanent dentition (C).

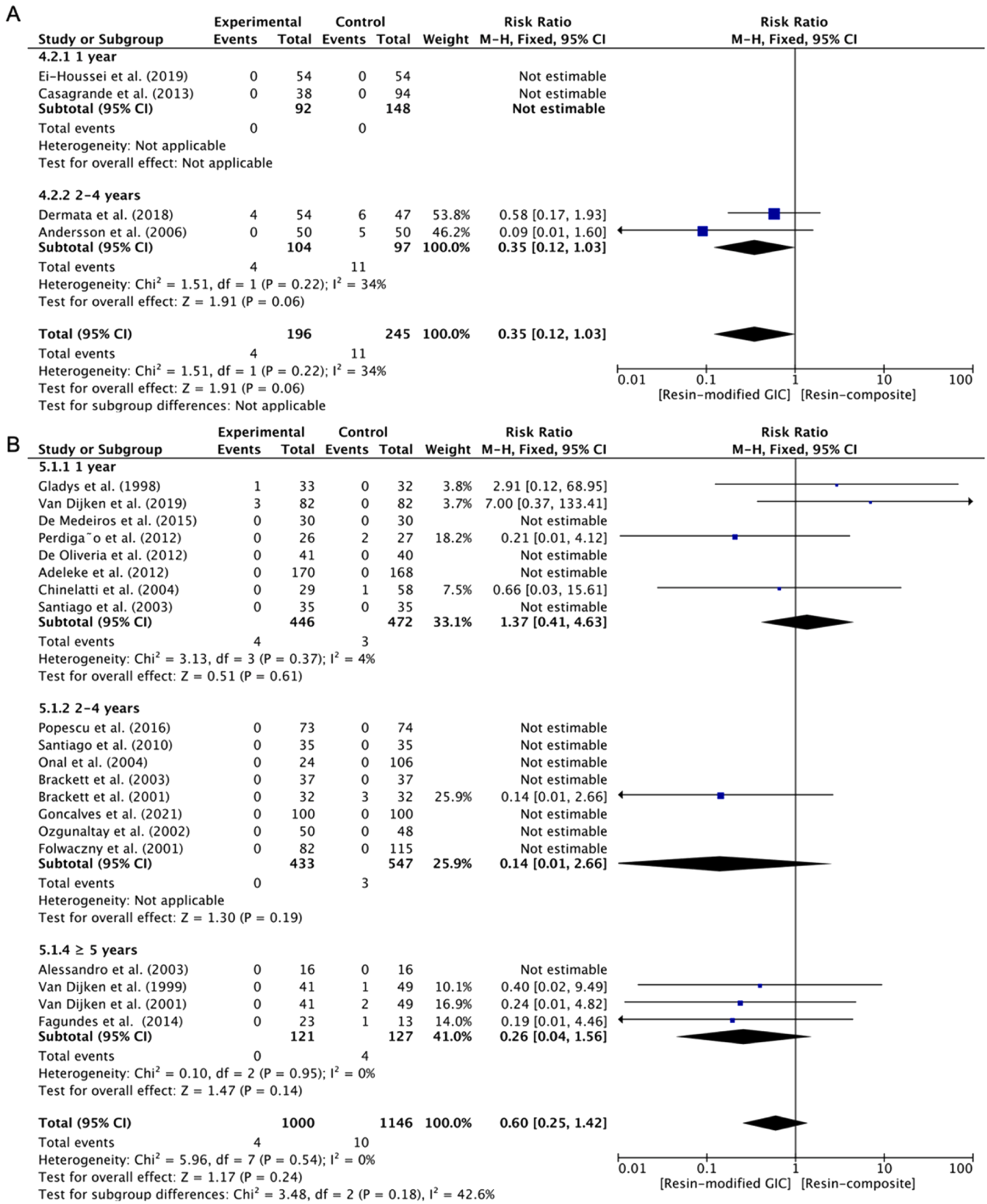

Fig. 7. Meta-analysis of secondary caries incidence in teeth with resin-modified GIC restorations vs resin-composite with defined follow-up period in the primary dentition (A) and permanent dentition (B).

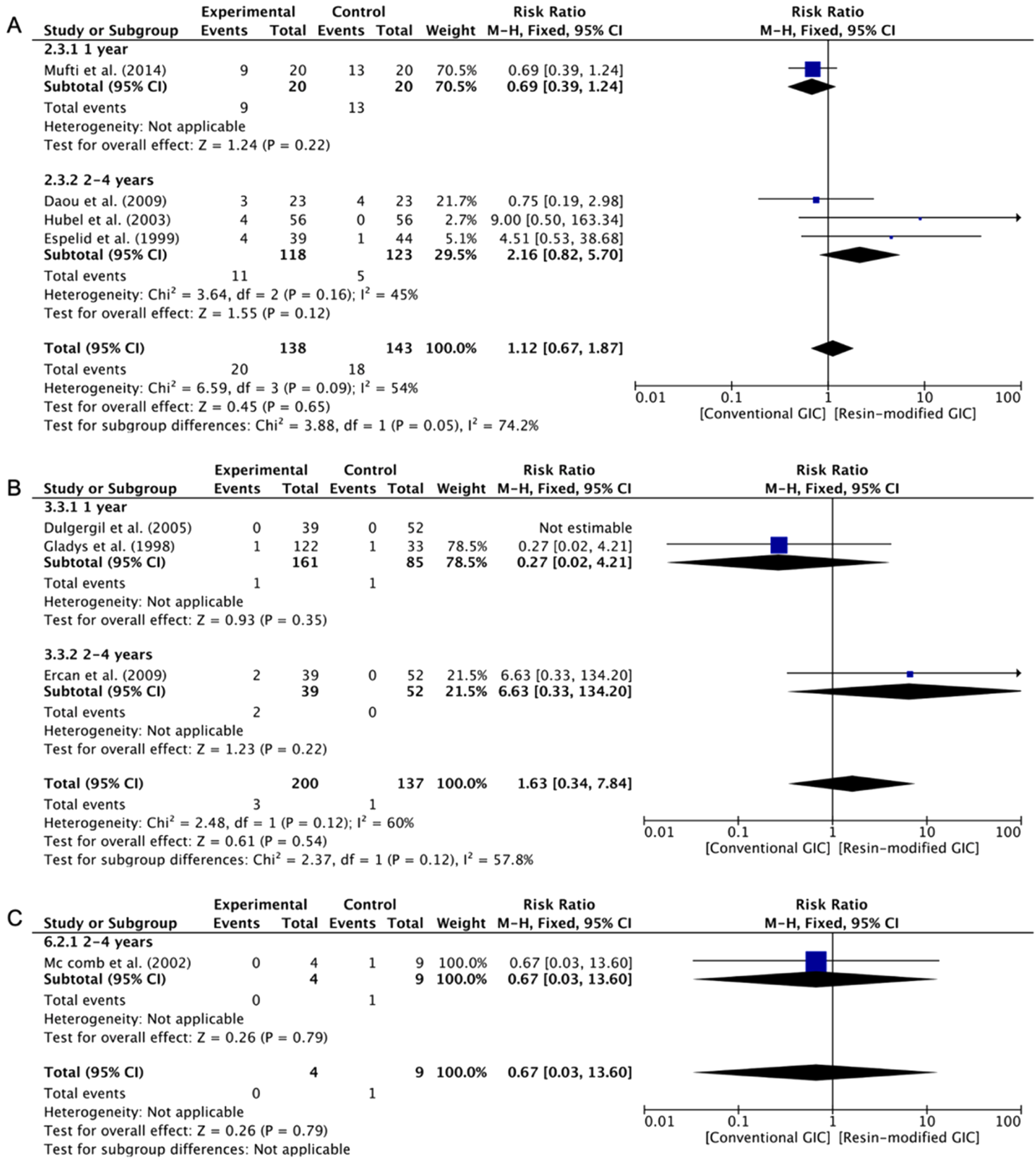

Fig. 8. Meta-analysis of secondary caries incidence in teeth with conventional GIC restorations vs resin-modified GIC with defined follow-up period by USPHS in primary dentition (A) and permanent dentition (B) and by FDI criteria in permanent dentition (C).

than amalgam restorations [3]. The result of this review affirmed the inhibitory effect of GIC on secondary caries compared with amalgam or resin-composite restorations, mainly amalgam restorations.

5. Conclusion

GIC restorations showed a better preventive effect on secondary caries compared with amalgam restorations with a follow-up period of 2–6 years. GIC restorations showed a similar preventive effect on secondary caries compared to resin-composite restorations in permanent and primary teeth with a follow-up period of 1–7 years.

Acknowledgements

The authors gratefully acknowledge the financial support from the Health and Medical Research Fund (HMRF), Food and Health Bureau (FHB) of Hong Kong SAR, China (No. 09200926).

References

[1] Askar H, Krois J, Gostemeyer G, Schwendicke F. Secondary caries risk of different adhesive strategies and restorative materials in permanent teeth: systematic review and network meta-analysis. J Dent 2021;104:1–7.
[2] Jokstad A. Secondary caries and microleakage. Dent Mater 2016;32:11–25.
[3] Nedeljkovic I, Teughels W, De Munck J, Van Meerbeek B, Van Landuyt KL. Is secondary caries with composites a material-based problem? Dent Mater 2015;31:247–77.
[4] Nedeljkovic I, De Munck J, Vanloy A, Declerck D, Lambrechts P, Peumans M. Secondary caries: prevalence, characteristics, and approach. Clin Oral Investig 2020;24:683–91.
[5] Seemann R, Flury S, Pfefferkorn F, Lussi A, Noack MJ. Restorative dentistry and restorative materials over the next 20 years: a Delphi survey. Dent Mater 2014;30:442–8.
[6] Askar H, Krois J, Göstemeyer G, Bottenberg P, Zero D, Banerjee A. Secondary caries: what is it, and how it can be controlled, detected, and managed? Clin Oral Invest 2020;24:1869–76.
[7] Hollanders ACC, Kuper NK, Maske TT. Huysmans MCDNJM. Secondary caries in situ models: a systematic review. Caries Res 2018;52:454–62.
[8] Reza Rezaie H., Beigi Rizi H., Rezaei Khamseh M.M., Öchsner A. Dental restorative materials. a review on dental materials. 1st ed, 2020.
[9] Flanders RA. Mercury in dental amalgam-a public health concern? J Public Health Dent 1992;52:303–11.
[10] Mustafa HA, Soares AP, Paris S, Elhennawy K, Zaslansky P. The forgotten merits of GIC restorations: a systematic review. Clin Oral Invest 2020;24:2189–201.
[11] Gama-Teixeira A, Simionato MRL, Elian SN, Sobral MAP. Luz MAAdC. Streptococcus mutans-induced secondary caries adjacent to glass ionomer cement, composite resin and amalgam restorations in vitro. Braz Oral Res 2007;21:368–74.
[12] Pratap B, Gupta RK, Bhardwaj B, Nag M. Resin based restorative dental materials: characteristics and future perspectives. Jpn Dent Sci Rev 2019;55:126–38.
[13] Sarrett DC. Clinical challenges and the relevance of materials testing for posterior composite restorations. Dent Mater 2005;21:9–20.
[14] Ertugrul F, Cogulu D, Özdemir Y, Ersin N. Comparison of conventional versus colored compomers for class II restorations in primary molars: A 12-month clinical study. Med Princ Pr 2010;19:148–52.
[15] Wiegand A, Buchalla W, Attin T. Review on fluoride-releasing restorative materials—fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. Dent Mater 2007;23. 343-162.
[16] Burke FJ. Dental materials–what goes where? The current status of glass ionomer as a material for loadbearing restorations in posterior teeth. Dent Update 2013;40:840–4.
[17] Ge KX, Quock R, Chu C-H, Yu OY. The preventive effect of glass ionomer restorations on new caries formation: A systematic review and meta-analysis. J Dent 2022:1–10.
[18] Ge KX, Lung CY, Lam WY, Chu CH, Yu OY. A novel glass ionomer cement with silver zeolite for restorative dentistry. J Dent 2023;133:1–12.
[19] Vermeersch G, Leloup G, Delmée M, Vreven J. Antibacterial activity of glass-ionomer cements, compomers and resin composites: relationship between acidity and material setting phase. J Oral Rehabil 2005;32:368–74.
[20] El-Bialy MR, Shaalan OO, El-Zohairy AA, El-Zoghby AF. Clinical evaluation of glass ionomer with glass hybrid technology versus conventional high viscosity glass ionomer in class i cavities in patients with high caries risk: Randomized controlled trial. J Int Oral Health 2020;12:203–12.
[21] Amend S, Frankenberger R, Lücker S, Domann E, Krämer N. Secondary caries formation with a two-species biofilm artificial mouth. Dent Mater 2018;34:786–96.
[22] Mjor IA. Clinical diagnosis of recurrent caries. J Am Dent Assoc 2005;136:1426–33.
[23] Global oral health status report: towards universal health coverage for oral health by 2030. Geneva: World Health Organization,; 2022.
[24] Nagaraja Upadhya P, Kishore G. Glass ionomer cement: The different generations. Trends Biomater. Artif Organs 2005;18:158–65.
[25] Hilgert LA, Frencken JE, de Amorim RG, Mulder J, Leal SC. A study on the survival of primary molars with intact and with defective restorations. Int J Paediatr Dent 2016;26:383–90.
[26] V. Qvist L. Laurberg A. Poulsen P.T. Teglers Longev cariostatic Eff Everyday Conv Glass-ionomer Amalgam Restor Prim teeth: three-year Results J Dent Res 76 1997 1387 1396.
[27] Qvist V, Laurberg L, Poulsen A, Teglers PT. Eight-year study on conventional glass ionomer and amalgam restorations in primary teeth. Acta Odontol Scand 2004;62:37–45.
[28] Qvist V, Laurberg L, Poulsen A, Teglers PT. Class II restorations in primary teeth: 7-year study on three resin-modified glass ionomer cements and a compomer. Eur J Oral Sci 2004;112:188–96.
[29] De Medeiros Serpa EB, Clementino MA, Granville-Garcia AF, Rosenblatt A. The effect of atraumatic restorative treatment on adhesive restorations for dental caries in deciduous molars. J Indian Soc Pedod Prev Dent 2019;35:167–73.
[30] Sengul F, Gurbuz T. Clinical evaluation of restorative materials in primary teeth class II lesions. J Clin Pedia Dent 2015;39:315–21.
[31] Daou M, Tavernier B, Meyer JM. Two-Year clinical evaluation of three restorative materials in primary molars. J Clin Pedia Dent 2009;34:53–8.
[32] Fuks AB, Araujo F, Osorio L, Hadani P, Pinto A. Clinical and radiographic assessment of Class II esthetic restorations in primary molars. Pedia Dent 2000;22:479–85.
[33] Hilgert LA, de Amorim RG, Leal SC, Mulder J, Creugers NHJ, Frencken JE. Is high-viscosity glass-ionomer-cement a successor to amalgam for treating primary molars? Dent Mater 2014;30:1172–8.
[34] Taifour D, Frencken JE, Beiruti N. van 't Hof MA, Truin GJ. Effectiveness of glass-ionomer (ART) and amalgam restorations in the deciduous dentition: results after 3 years. Caries Res 2002;36:437–44.
[35] Arora D, Jain M, Suma Sogi HP, Shahi P, Gupta I, Sandhu M. In vivo evaluation of clinical performance of Cention N and glass ionomer cement in proximal restorations of primary molars. J Indian Soc Pedod Prev Dent 2022;40:23–9.
[36] Gok Baba M, Kirzioglu Z, Ceyhan D. One-year clinical evaluation of two high-viscosity glass-ionomer cements in class II restorations of primary molars. Aust Dent J 2021;66:32–40.
[37] Akman H, Tosun G. Clinical evaluation of bulk-fill resins and glass ionomer restorative materials: A 1-year follow-up randomized clinical trial in children. Niger J Clin Pr 2020;23:489–97.
[38] Marks LA, van Amerongen WE, Borgmeijer PJ, Groen HJ, Martens LC. Ketac Molar Versus Dyract Class II restorations in primary molars: twelve month clinical results. ASDC J Dent Child 2000;67:37–44.
[39] Passaro AL, Olegario IC, Laux CM, Oliveira RC, Tedesco TK, Raggio DP. Giomer composite compared to glass ionomer in occlusoproximal ART restorations of primary molars: 24-month RCT. Aust Dent J 2022;67:148–58.
[40] Pani SC. Comparison of high viscosity glass ionomer cement to composite restorations placed in primary teeth under general anesthesia. Pedia Dent J 2018;28:154–9.
[41] Ersin NK, Candan U, Aykut A, Önçağ Ö, Eronat C, Kose T. A clinical evaluation of resin-based composite and glass ionomer cement restorations placed in primary teeth using the ART approach: Results at 24 months. J Am Dent Assoc 2006;137:1529–36.
[42] Kupietzky A, Atia Joachim D, Tal E, Moskovitz M. Long-term clinical performance of heat-cured high-viscosity glass ionomer class II restorations versus resin-based composites in primary molars: a randomized comparison trial. Eur Arch Paediatr Dent 2019;20:451–6.
[43] Mufti AS. Clinical efficacy of the conventional glass ionomer cement and resin modified glass ionomer cement in primary molars. J Ayub Med 2014;26:587–90.
[44] Hübel S, Mejàre I. Conventional versus resin-modified glass-ionomer cement for Class II restorations in primary molars. A 3-year clinical study. Int J Paediatr Dent 2003;13:2–8.
[45] Espelid I, Tveit AB, Tornes KH, Alvheim H. Clinical behaviour of glass ionomer restorations in primary teeth. J Dent 1999;27:437–42.
[46] Qvist V, Manscher E, Teglers PT. Resin-modified and conventional glass ionomer restorations in primary teeth: 8-year results. J Dent 2004;32:285–94.
[47] Donly KJ, Segura A, Kanellis M, Erickson RL. Clinical performance and caries inhibition of resin-modified - Glass ionomer cement and amalgam restorations. J Am Dent Assoc 1999;130:1459–66.
[48] Ei-Housseiny AA, Alamoudi NM, Nouri S, Felemban O. A randomized controlled clinical trial of glass carbomer restorations in Class II cavities in primary molars: 12-month results. Quintessence Int 2019;50:522–32.
[49] Casagrande L, Dalpian DM, Ardenghi TM, Zanatta FB, Balbinot CEA, García-Godoy F, et al. Randomized clinical trial of adhesive restorations in primary molars. 18-month results. Am J Dent 2013;26:351–5.
[50] Dermata A, Papageorgiou SN, Fragkou S, Kotsanos N. Comparison of resin modified glass ionomer cement and composite resin in class II primary molar restorations: a 2-year parallel randomised clinical trial. Eur Arch Paediatr Dent 2018;19:393–401.
[51] Andersson-Wenckert I, Sunnegårdh-Grönberg K. Flowable resin composite as a class II restorative in primary molars: A two-year clinical evaluation. Acta Odontol Scand 2006;64:334–40.
[52] Haveman CW, Summitt JB, Burgess JO, Carlson K. Three restorative materials and topical fluoride gel used in xerostomic patients - A clinical comparison. J Am Dent Assoc 2003;134:177–84.
[53] Mandari GJ, Frencken JE, van't Hof MA. Six-year success rates of occlusal amalgam and glass-ionomer restorations placed using three minimal intervention approaches. Caries Res 2003;37:246–53.
[54] Oz FD, Meral E, Ergin E, Gurgan S. One-year evaluation of a new restorative glass ionomer cement for the restoration of non-carious cervical lesions in patients with systemic diseases: a randomized, clinical trial. J Appl Oral Sci 2020;28:1–10.
[55] Menezes-Silva R, Velasco SRM, Bastos RS, Molina G, Honório HM, Frencken JE, et al. Randomized clinical trial of class II restoration in permanent teeth comparing ART with composite resin after 12 months. Clin Oral Invest 2019;23:3623–35.
[56] Gladys S, Van Meerbeek B, Lambrechts P, Vanherle G. Marginal adaptation and retention of a glass-ionomer, resin-modified glass-ionomers and a polyacid-

modified resin composite in cervical Class-V lesions. Dent Mater 1998;14: 294–306.
[57] Molina GF, Ulloque MJ, Mazzola I, Mulder J, Frencken J. Randomized controlled trial of class II ART high-viscosity glass-ionomer cement and conventional resin-composite restorations in permanent dentition: two-year survival. J Adhes Dent 2021;22:555–65.
[58] Balkaya H, Arslan S. A Two-year clinical comparison of three different restorative materials in Class II cavities. Oper Dent 2020;45:32–42.
[59] Menezes-Silva R, Velasco SRM, Bastos EBR, Navarro RDS. MFL. A prospective and randomized clinical trial evaluating the effectiveness of ART restorations with high-viscosity glass-ionomer cement versus conventional restorations with resin composite in Class II cavities of permanent teeth: two-year follow-up. J Appl Oral Sci 2021;29:1–10.
[60] Hatirli H, Yasa B, Çelik EU. Clinical performance of high-viscosity glass ionomer and resin composite on minimally invasive occlusal restorations performed without rubber-dam isolation: a two-year randomised split-mouth study. Clin Oral Invest 2021;25:5493–503.
[61] Diem VT, Tyas MJ, Ngo HC, Phuong LH, Khanh ND. The effect of a nano-filled resin coating on the 3-year clinical performance of a conventional high-viscosity glass-ionomer cement. Clin Oral Invest 2014;18:753–9.
[62] Gurgan S, Kutuk ZB, Ergin E, Oztas SS, Cakir FY. Four-year randomized clinical trial to evaluate the clinical performance of a glass ionomer restorative system. Oper Dent 2015;40:134–43.
[63] Gurgan S, Kutuk ZB, Ergin E, Oztas SS, Cakir FY. Clinical performance of a glass ionomer restorative system: a 6-year evaluation. Clin Oral Invest 2017;21. 2335-2243.
[64] Gurgan S, Kutuk ZB, Yalcin Cakir F, Ergin E. A randomized controlled 10 years follow up of a glass ionomer restorative material in class I and class II cavities. J Dent 2020;94:1–8.
[65] Celik E, Yilmaz F, Aka B. A randomised, controlled, split-mouth trial evaluating the clinical performance of a high viscosity glass ionomer restorations in non-carious cervical lesions: 1 year results. J Dent Res 2015:299–305.
[66] McComb D, Erickson RL, Maxymiw WG, Wood RE. A clinical comparison of glass ionomer, resin-modified glass ionomer and resin composite restorations in the treatment of cervical caries in xerostomic head and neck radiation patients. Oper Dent 2002;27:430–7.
[67] Fotiadou C, Frasheri I, Reymus M, Diegritz C, Kessler A, Manhart J, et al. A 3-year controlled randomized clinical study on the performance of two glass-ionomer cements in Class II cavities of permanent teeth. Quintessence Int 2019;50: 592–602.
[68] Celik EU, Tunac AT, Yilmaz F. Three-year clinical evaluation of high-viscosity glass ionomer restorations in non-carious cervical lesions: a randomised controlled split-mouth clinical trial. Clin Oral Invest 2019;23:1473–80.
[69] Dulgergil CT, Soyman M, Civelek A. Atraumatic restorative treatment with resin-modified glass ionomer material: Short-term results of a pilot study. Med Princ Pr 2005;14:277–80.
[70] Ercan E, Dülgergil CT, Soyman M, Dalli M, Yildirim I. A field-trial of two restorative materials used with atraumatic restorative treatment in rural Turkey: 24-month results. J Appl Oral Sci 2009;17:307–14.
[71] van Dijken JWV, Pallesen U, Benetti A. A randomized controlled evaluation of posterior resin restorations of an altered resin modified glass-ionomer cement with claimed bioactivity. Dent Mater 2019;35:335–43.
[72] de Medeiros FCD, Santos MM, Araújo IJS, Lima IPC. Clinical evaluation of two materials in the restoration of abfraction lesions. Braz J Oral Sci 2015;14:287–93.
[73] Perdigão J, Dutra-Corrêa M, Saraceni S, Ciaramicoli M, Kiyan V. Randomized clinical trial of two resin-modified glass ionomer materials: 1-year results. Oper Dent 2012;37:591–601.
[74] de Oliveira FG, Machado LS, Rocha EP, de Alexandre RS, Fraga Briso AL, Mazza Sundefeld MLM. Clinical evaluation of a composite resin and a resin-modified glass-ionomer cement in non-carious cervical lesions: One-year results. Int J Clin Dent 2012;5:155–66.
[75] Adeleke Oginni A. Clinical evaluation of resin composite and resin-modified glass ionomer cement in non-carious cervical lesions. J West Afr Coll Surg 2012;2: 21–37.
[76] Chinelatti MA, Ramos RP, Chimello DT, Palma-Dibb RG. Clinical performance of a resin-modified glass-ionomer and two polyacid-modified resin composites in cervical lesions restorations: 1-year follow-up. J Oral Rehabil 2004;31:251–7.
[77] Santiago SL, Franco EB, Mendonça JS, Lauris JR, Navarro MF. One-year clinical evaluation of tooth-colored materials in non-carious cervical lesions. J Appl Oral Sci 2003;11:175–80.
[78] Popescu SM, Ţuculinə MJ, Manolea HO, Mercuţ V, Scrieciu M. Randomized clinical trial of adhesive restorations in non carious cervical lesions. Key Eng Mater 2016;695:3–11.
[79] Santiago SL, Passos VF, Vieira AH, Navarro MF, Lauris JR, Franco EB. Two-year clinical evaluation of resinous restorative systems in non-carious cervical lesions. Braz Dent J 2010;21:229–34.
[80] Onal B, Pamir T. The two-year clinical performance of esthetic restorative materials in noncarious cervical lesions. J Am Dent Assoc 2004;136:1547–55.
[81] Brackett WW, Dib A, Goël Brackett M, Reyes AA, Estrada BE. Two-year clinical performance of Class V resin-modified glass-ionomer and resin composite restorations. Oper Dent 2003;28:477–81.
[82] Brackett WW, Browning WD, Ross JA, Brackett MG. Two-year clinical performance of a polyacid-modified resin composite and a resin-modified glass-ionomer restorative material. Oper Dent 2001;26:12–26.
[83] Gonçalves DFM, Shinohara MS, Carvalho P, Ramos F, Oliveira LC, Omoto É, et al. Three-year evaluation of different adhesion strategies in non-carious cervical lesion restorations: a randomized clinical trial. J Appl Oral Sci 2021;29:1–10.
[84] Ozgunaltay G, Onen A. Three-year clinical evaluation of a resin modified glass-ionomer cement and a composite resin in non-carious class V lesions. J Oral Rehabil 2002;29:1037–41.
[85] Folwaczny M, Loher C, Mehl A, Kunzelmann KH, Hickel R. Class V lesions restored with four different tooth-colored materials–3-year results. Clin Oral Invest 2001;5:31–9.
[86] Loguercio AD, Reis A, Barbosa AN, Roulet JF. Five-year double-blind randomized clinical evaluation of a resin-modified glass ionomer and a polyacid-modified resin in noncarious cervical lesions. J Adhes Dent 2003;5:323–32.
[87] Van Dijken JWV. Longevity of new hybrid restorative materials in class III cavities. Eur J Oral Sci 1999;107:215–9.
[88] Van Dijken JW. Durability of new restorative materials in Class III cavities. J Adhes Dent 2001;3:65–70.
[89] Fagundes TC, Barata TJE, Bresciani E, Santiago SL, Franco EB, Lauris JRP. Seven-year clinical performance of resin composite versus resin-modified glass ionomer restorations in noncarious cervical lesions. Oper Dent 2014;39:578–87.
[90] Berzins DW, Abey S, Costache M, Wilkie CA, Roberts H. Resin-modified glass-ionomer setting reaction competition. J Dent Res 2010;89:82–6.
[91] Francois P, Fouquet V, Attal J-P, Dursun E. Commercially available fluoride-releasing restorative materials: a review and a proposal for classification. Mater 2020;13:13–23.
[92] Zafar MS, Ahmed N. Therapeutic roles of fluoride released from restorative dental materials. Fluoride 2015;48:184–94.
[93] Svanberg M, Krasse B, Ornerfeldt HO. Mutans streptococci in interproximal plaque from amalgam and glass ionomer restorations. Caries Res 1990;24: 133–46.
[94] Bansal R, Bansal T. A comparative evaluation of the amount of fluoride release and re-release after recharging from aesthetic restorative materials: an in vitro study. J Clin Diagn Res 2015;9:11–4.
[95] Ge KX, Quock R, Chu CH, Yu OY. The preventive effect of glass ionomer restorations on new caries formation: A systematic review and meta-analysis. J Dent 2022;125:1–10.
[96] Donly KJ. Demineralization inhibition at glass-ionomer cement and amalgam restoration margins in conjunction with additional fluoride regimens. Spec Care Dent 1999;19:24–8.
[97] Mustafa HA, Soares AP, Paris S, Elhennawy K, Zaslansky P. The forgotten merits of GIC restorations: a systematic review. Clin Oral Invest 2020;24:2189–201.
[98] Shankar P, Venkatesan R, Senthil D, Trophimus J, Arthilakshmi CU, Princy P. Microleakage patterns of glass ionomer cement at cement-band and cement-enamel interfaces in primary teeth. Indian J Dent Res 2020;31:291–6.
[99] Piwowarczyk A, Lauer HC, Sorensen JA. Microleakage of various cementing agents for full cast crowns. Dent Mater 2005;21:445–53.
[100] Bharti R, Wadhwani KK, Tikku AP, Chandra A. Dental amalgam: An update. J Conserv Dent 2010;13:204–8.
[101] Fisher J, Varenne B, Narvaez D, Vickers C. The minamata convention and the phase down of dental amalgam. Bull World Health Organ 2018;96:436–48.
[102] Gordan VV, Riley 3rd JL, Geraldeli S, Rindal DB, Qvist V, Fellows JL, et al. Repair or replacement of defective restorations by dentists in The Dental Practice-Based Research Network. J Am Dent Assoc 2012;143:593–601.
[103] Bowen RL, Marjenhoff WA. Dental composites/glass ionomers: the materials. Adv Dent Res 1992;6:44–59.
[104] Wilson AD, Kent B. The glass-ionomer cement, a new translucent dental filling material. J Chem Technol 1971;21:121–8.
[105] Van Noort R., Barbour M. Introduction to dental materials-e-book: Elsevier Health Sciences; 2014.
[106] Correa M, Peres M, Peres K, Horta B, Barros A, Demarco F. Amalgam or composite resin? Factors influencing the choice of restorative material. J Dent 2012;40: 703–10.
[107] Brown L, Wall T, Wassenaar J. Trends in resin and amalgam usage as recorded on insurance claims submitted by dentists from the early 1990s and 1998. J Dent Res 2000:461–5.
[108] Kazeminia M, Abdi A, Shohaimi S, Jalali R, Vaisi-Raygani A, Salari N, et al. Dental caries in primary and permanent teeth in children's worldwide, 1995 to 2019: a systematic review and meta-analysis. Head Face Med 2020;16:1–21.
[109] Lynch RJM. The primary and mixed dentition, post-eruptive enamel maturation and dental caries: a review. Int Dent J 2013;63:3–13.
[110] Opdam N, Bronkhorst E, Loomans B, Huysmans M-C. 12-year survival of composite vs. amalgam restorations. J Dent Res 2010;89:1063–7.
[111] MjÖR IA. Clinical diagnosis of recurrent caries. J Am Dent Assoc 2005;136: 1426–33.
[112] Dennison JB, Sarrett DC. Prediction and diagnosis of clinical outcomes affecting restoration margins. J Oral Rehabil 2012;39:301–18.
[113] Kidd EAM, Beighton D. Prediction of Secondary Caries around Tooth-colored Restorations: A Clinical and Microbiological Study. J Dent Res 1996;75:1942–6.
[114] Hitij T, Fidler A. Radiopacity of dental restorative materials. Clin Oral Invest 2013;17:1167–77.
[115] Brouwer F, Askar H, Paris S, Schwendicke F. Detecting secondary caries lesions: a systematic review and meta-analysis. J Dent Res 2016;95:143–51.
[116] Çakır NN, Demirbuga S. The effect of five different universal adhesives on the clinical success of class I restorations: 24-month clinical follow-up. Clin Oral Invest 2019;23:2767–76.
[117] Türkün LS, Aktener BO, Ateş M. Clinical evaluation of different posterior resin composite materials: a 7-year report. Quintessence Int 2003;34:418–26.

[118] Marquillier T, Doméjean S, Le Clerc J, Chemla F, Gritsch K, Maurin J-C, et al. The use of FDI criteria in clinical trials on direct dental restorations: A scoping review. J Dent 2018;68:1–9.

[119] Hickel R, Roulet J-F, Bayne S, Heintze SD, Mjör IA, Peters M, et al. Recommendations for conducting controlled clinical studies of dental restorative materials. Clin Oral Invest 2007;11:5–33.

[120] Bezerra IM, Brito ACM, de Sousa SA, Santiago BM, Cavalcanti YW, de Almeida LFD. Glass ionomer cements compared with composite resin in restoration of noncarious cervical lesions: A systematic review and meta-analysis. Heliyon 2020;6. 1-16.

[121] Kim D, Ahn S-Y, Kim J, Park S-H. Interrater and intrarater reliability of FDI criteria applied to photographs of posterior tooth-colored restorations. J Prosthet Dent 2017;118:18–25.

[122] Mena-Serrano A, Kose C, De Paula EA, Tay LY, Reis A, Loguercio AD, et al. A new universal simplified adhesive: 6-month clinical evaluation. J Esthet Restor Dent 2013;25:55–69.

[123] Lopes LdS, Calazans F, Hidalgo R, Buitrago L, Gutierrez F, Reis A, et al. Six-month follow-up of cervical composite restorations placed with a new universal adhesive system: a randomized clinical trial. Oper Dent 2016;41:465–80.

[124] Petersen PE. Oral health behavior of 6-year-old Danish children. Acta Odontol Scand 1992;50:57–64.

[125] Ahn E, Kang H. Introduction to systematic review and meta-analysis. Korean J Anesth 2018;71:103–12.

[126] Demarco FF, Collares K, Correa MB, Cenci MS. MORAES RRd, Opdam NJ. Should my composite restorations last forever? Why are they failing? Braz Oral Res 2017;31:92–9.

[127] Tyas MJ. Placement and replacement of restorations by selected practitioners. Aust Dent J 2005;50:81–9.

[128] van de Sande FH, Opdam NJ, Truin GJ, Bronkhorst EM, de Soet JJ, Cenci MS, et al. The influence of different restorative materials on secondary caries development in situ. J Dent 2014;42:1171–7.