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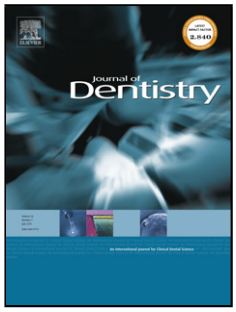

Title: Comparison of ART and conventional techniques on clinical performance of glass-ionomer cement restorations in load bearing areas of permanent and primary dentitions: A systematic review

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Comparison of ART and conventional techniques on clinical performance of glass-ionomer cement restorations in load bearing areas of permanent and primary dentitions: A systematic review

Review article

Title:

Comparison of atraumatic restorative treatment and conventional techniques on clinical performance of glass-ionomer cements restored in load bearing areas of permanent and primary dentitions: A review

Short title:

Comparison of atraumatic restorative treatment and conventional techniques on clinical performance of glass-ionomer cements

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Keywords:
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Conventional technique

Survival rate
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ABSTRACT

Objectives: To review the clinical performance of GIC restorations using calculated annual failure rates and qualitative descriptions based on conventional and ART techniques from two aspects: occlusal and approximal cavities in permanent or deciduous posterior teeth.

Sources: Search strategies was undertaken of the PubMed database from January 1983 to March 2018. Additional articles were collected by hand searching.

Study Selection: The following basic search terms, "(glass ionomer cement) and (clinical performance or survival or ART or atraumatic restorative or high viscosity)" with inclusion and exclusion criteria according to PRISMA flow diagram.

Data: At total of 904 articles were initially identified. Finally, 67 articles were included for quantitative and qualitative analysis after applying the inclusion and exclusion criteria. Assessment of risk of bias was performed for all included studies using ROBINS-I.

Conclusions: For single-surface occlusal or multi-surface GIC restorations, the conventional technique showed better survival than ART technique regardless of dentition type (primary or permanent). When comparing in the same treatment technique, AFRs of approximal or multi-surface GIC restorations were greater than those of single-surface (occlusal) restorations, irrespective of dentition type. RMGIC-conventional technique seems to be promising for restoring approximal cavities of primary teeth compared to other restorative materials.

Clinical significance: The GIC-ART technique is an alternative option for single-surface (occlusal) restorations in permanent and primary teeth. However, the application of the GIC-ART technique for load-bearing approximal restorations should be carefully considered before employing this option, especially in primary teeth.

Keywords:
Glass-ionomer cement
Atraumatic restorative treatment technique
Conventional technique
Survival
Annual failure rate

1. Introduction

Amalgam has been the material of choice for posterior restorations over many decades as a result of its excellent mechanical properties contributing to well-established long-term survival rates [1,2]. Notwithstanding the evidence, the use of amalgam has become limited due to poor aesthetics. In addition, its mercury content has been discussed with respect to the environmental burden by the World Health Organization (WHO), the European Union (EU) and the World Dental Federation (FDI) [3]. The recent Minamata Convention, initiated by the United Nations Environment Programme (UNEP) and supported by the WHO, was formally adopted in Japan in 2013, and aims to reduce the use of mercury, mercury containing products and its use in industrial processes. In the Convention, there is a 'phase down' approach for dental amalgam. By mid-September 2017, 75 nations have ratified the Convention [3,4].

Resin composites have been clinically proven to be all-purpose direct restorative materials for use in anterior and posterior teeth where aesthetic outcomes are paramount [5,6]. However, the longevity of resin composites is critically dependent on the operator who needs to have impeccable skills due to technique-sensitive steps during placement as well as specialized equipment [7,8]. Therefore, resin composite is possibly not always suitable as an alternative to amalgam with respect to various treatment environments, such as rural community hospitals and geographic regions where reticulated water and electricity may be limited.

Apart from amalgam and resin composite, glass-ionomer cements (GICs) have been gradually developed as another choice of an 'easy-to-use' restorative material. GIC was originally invented by Wilson and Kent in the early 1970s [9,10] and was launched into the market soon after. Conventional GICs consist of a fluoroaluminosilicate glass powder, usually a calcium or strontium salt, that can be mixed with a liquid of polyalkenoic acids (e.g. polyacrylic acid, polymaleic acid and itaconic acid) for the setting via an acid-base reaction [11,12]. Since then, GICs have been used as a part of the dental restorative armamentarium mainly for its specific properties such as fluoride release [13,14], biocompatibility [15,16] and reliable chemical bond to enamel and dentine [17]. On the other hand, GICs lower flexural and tensile strengths, fracture toughness and a higher rate of wear compared to other restorative materials, are the principal drawbacks influencing survival rates when placed in load bearing areas [3,18,19].

Later, a resin-modified glass ionomer cement (RMGIC) was developed [20,21] to overcome some of the problems of conventional GICs, e.g. moisture sensitivity and low mechanical properties during the initial 24 hours after placement. RMGICs are glass-ionomer cements containing a resin monomer, commonly 2-hydroxyethylmethacrylate (HEMA). Therefore, the fundamental setting reactions are composed of an acid-base reaction as well as a free-radical polymerization (self-cure and/or photocure) of the resin [11,15]. Concurrently, conventional GICs have been further developed for use especially in rural communities, where electricity and reticulated water may not exist and only hand instruments are reliably available. The 'high viscosity' GICs (HVGICs) were developed specifically for that purpose called the Atraumatic Restorative Treatment (ART) technique [22,23]. A smaller glass particle size and an increase of the powder: liquid ratio, compared to 'normal viscosity' GICs, results in better mechanical properties [15,24,25] including compressive strength and surface hardness [26]. Moreover, greater cross-linking in the high-viscosity GIC's matrix is an essential key to improve wear resistance, compressive and flexural strengths, surface hardness, and solubility compared to conventional GICs [27]. From the development of GICs mentioned, several attempts have been made to use them for direct load-bearing restorations in both occlusal and approximal cavities in permanent and primary teeth using conventional rotary cavity preparation techniques or ART.

Nowadays, several clinical studies of GICs have been published to ascertain the clinical performance after laboratory development. Nevertheless, to date, there has been a lack of studies reviewing posterior single- and multi-surface GIC restoration survival in either the primary or permanent dentitions, as well as comparing the survival of restorations placed using either conventional or ART techniques including their failure characteristics. In addition, it would be instructive to include the role of GICs in prevention/inhibition clinically.

Therefore, the objectives of this study were to review the clinical performance of GIC restorations using calculated annual failure rates and qualitative descriptions based on conventional and ART techniques from two aspects: occlusal and approximal cavities in permanent or deciduous posterior teeth.

2. Methods

2.1. Search strategy, inclusion and exclusion criteria

A literature search was undertaken of the PubMed database on 29 March 2018 using the following basic search terms, "(glass ionomer cement) and (clinical performance or survival or ART or atraumatic restorative or high viscosity)" which are also illustrated in Fig 1. After the search, 904 articles published between January 1983 and March 2018 were initially identified. Screening was initially conducted using exclusion criteria as follows: laboratory and *in-situ* GIC studies, GICs for cervical lesions, GIC sealants, GICs as a base or liner, tunnel preparation, orthodontic uses of GIC, GIC luting cements. Then full-text articles were identified by specific reasons for additional exclusion (Follow-up period ≤ 1 year, mixed results of cavity classification, shorter-term studies that had another longer-term studies used the same subjects, and others (Table 1)). The inclusion criteria were English publications, clinical studies (randomised controlled trials with split-mouth or parallel designs, longitudinal uncontrolled (single-arm) studies and retrospective studies) of GICs restored by conventional or ART techniques in occlusal and approximal cavities in the either the permanent or primary dentitions.

After the procedures, 62 publications remained eligible for inclusion. Additional articles were collected by cross-referencing and hand search, which yielded a further 5 articles (Fig 1, Table 1), resulting in 67 articles for analysis. Four articles (Molina et al. 2018; van Gemert-Schriks et al. 2007; Lo et al. 2001; Yee et al. 2001) [28-31] were used to analyse for clinical performance of GICs in permanent and deciduous posterior teeth) because both dentitions (permanent and primary teeth) were included in those studies. Therefore, 31 (Table 2) and 40 articles (Table 3) that related to two clinical applications (conventional or ART) in permanent and deciduous dentitions, respectively were recorded.

2.2. Reporting of results

Quantitative and qualitative results derived from each study were reported by evaluation of annual failure rates (AFRs) and descriptions, respectively. AFRs of restorations reported in each study were calculated using the formula: $(1-y)^Z = (1-x)$, where 'y' is the mean AFR and 'x' is the total failure rate at 'z' year [32]. Percent-AFR is the value of y multiplied by 100. Major AFR analyses were performed in GICs that were divided into either permanent or deciduous dentitions and 4 subgroups, namely, conventional technique or ART in occlusal and approximal cavities. AFR analyses of other materials were provided as controls. If included studies had more than 1 group of restorations, the AFRs of each group were included. Seven articles, 2 studies of permanent dentitions (Turkun & Kanik 2016; Diem et al. 2014) [33,34] and 5 studies of deciduous dentitions (Abo-Hamar et al. 2015, Fuks et al.

2000; Kemoli & Amerongen 2011; Kemoli et al. 2011; and Kemoli 2009) [35-39], were used for qualitative description only.

2.3. Risk assessment of individual studies

Quality assessment for individual studies was determined using ROBINS-I tool (risk of bias in non-randomised studies of interventions) from Cochrane collaboration [40]. The criteria comprised key domains to consider 7 biases: confounding; selecting participants; classification of intervention; performance; missing data (attrition); detection; and outcome reporting. There were 5 grading scales (low, moderate, serious, critical, and no information) in each domain.

3. Results

3.1. Risk of bias in included studies

The results of risk of bias in summary are illustrated in Fig 2. No studies had critical risk of bias in each individual domain (7 domains). Most studies (n=52; 77.6%) were considered as having low or moderate risks of bias in each domain. And some studies (n=7; 10.4%) were considered as having low or moderate (including one 'no information') risks of bias in each domain. However, further 7 studies (10.4%) showed a serious risk of bias in one damain (n=6 for detection bias, n=1 for confounding bias). Only one study (1.5%) had two serious risks of bias (confounding and detecting biases). Concern for all studies, having serious detection bias, was based on non-blinded examiners, whereas, concern for serious confounding bias was due to to unspecified proper inclusion criteria. In addition, the risks of bias in each study are shown in the 4th column of Tables 3 and 4.

3.2. Clinical performance of GICs for restoring permanent posterior teeth

3.2.1. GICs for single-surface occlusal restorations

Average AFRs of GIC-conventional technique (mean 1.17%, median 0.13%, range 0-4.68%) from 7 studies (article 1-5, 21-22; mean follow-up period (MF) 3.79 years) [18,41-46] were lower than those of GIC-ART technique (mean 8.0%, median 5.38%, range 0-40.56%) from 20 studies (article 11, 13-31; MF 3.19 years) [28-30,45-61] (Tables 2-3).

3.2.2. GICs for approximal or multi-surface posterior restorations

Table 2 illustrates the AFRs of posterior approximal GIC restorations using the conventional technique (7 studies; article 1-7; MF 3.86 years) [18,41-44,62,63], which ranged from 1.33% to 22.94% (Mean 6.90%). While those using ART technique (6 studies; article 10, 12-15, 26; MF 4.83 years) [31,47,48,54,55,64] varied between 0% and 35.81% and showed a higher mean AFR (10.7%) than conventionally placed restorations. Approximal posterior restorations showed higher mean AFRs than single-surface occlusal restorations (1.17% and 8.0% for conventional and ART techniques, respectively) irrespective of the restorative technique (Table 3).

3.3. Clinical performance of GICs for restoring primary posterior teeth

3.3.1. GICs for single-surface occlusal restorations

Outcomes of conventional GIC technique (6 studies; article 36, 40-42, 46, 61; MF 2.83 years) [65-69] in the deciduous dentition showed higher mean AFR (4.78%) than those in the permanent dentition (1.17%). On the other hand, mean AFR (8.95%) of GIC-ART technique in the primary

dentition (12 studies; article 17, 24-25, 53, 55, 58-64; MF 2.29 years) [28-30,70-78] was comparable to that in the permanent dentition (8.0%) but still higher compared to the conventional technique in the same dentition (Tables 2,4).

3.3.2. GICs for approximal or multi-surface posterior restorations

Approximal conventional GIC technique in the primary dentition (18 studies; article 32-48, 61; MF 2.88 years) [65-69,79-90] provided acceptable mean AFR (9.46%) but were slightly higher than that in permanent dentition (6.90%). However, if only RMGIC was included (11 studies; MF 3.14 years), the conventional technique showed lower mean AFR (6.25%). It was observed that silver-reinforced and normal-viscosity GIC were identified as factors influencing the high AFR (9.46%) of approximal conventional GIC restorations. The mean AFRs of silver-reinforced and normal-viscosity GIC were 20.39% and 14.91%, respectively. Regarding approximal ART-GIC technique in the primary dentition (17 studies; article 10, 17, 24, 51-64; MF 2.35 years) [28,30,31,70-78,91-95], the outcome showed substantially higher mean AFR (25.77%) than that of conventional technique (9.46%), and was higher than that of ART technique in the permanent dentition (10.7%) (Tables 2,4).

3.4. Reasons for failure of GIC restorations in primary and permanent dentitions

3.4.1 Single occlusal restorations

Regarding occlusal GIC restorations in the permanent and deciduous dentitions, the main reasons for failure of conventional technique related to mechanical failure such as restoration fracture [18,69], marginal fracture at the cavosurface margin [65], resotation loss [69] and material wear [68], For occlusal ART restorations in both dentitions, similar failure causes were found namely, restoration loss [48,70,76], restoration fracture [45,52], marginal defect [45,48,49], and excessive wear [48]. In addition, dentine carious lesion development only and combined marginal defect with carious dentine lesion development [49] were also identified as reasons for failure. However, Ziraps et al. reported that no restoration fracture was observed after 2 years of ART restoration in permanent teeth [53], however, two reasons for failure in this study were identified as shallow cavity preparation and replacement by another dentist for unknown reasons [53]. One study of permanent teeth pooled the data of GICs from ART and conventional technique and reported high occlusal wear of two GICs (118.8 or 95.6 μm) and surface void (31%) over 3 years [46]. Furthermore, colour match of those GICs improved after 6 months [46].

3.4.2 Approximal or multi-surface restorations

With respect to failure of conventionally-used GIC approximal restorations in permanent teeth, the main cause of failure was still restoration fracture similar to occlusal GIC restorations [44]. From the observations of Frankenberger et al., they found that the presence of an occlusal contact point in the proximal box area was more prone to bulk fracture of a restoration [44]. In contrast, the study of Scholtanus et al. did not find failure of GIC from bulk fracture [62]. Furtheremore, one study showed that all approximal restorations failed due to marginal ridge fracture [41]. Similarly, further three studies showed that some restorations failed from chipping of the marginal ridge [33,42,62]. This may be related to the width of proximal box that exceeded the half of the intercuspal distance [33,42]. However, the other reason for failure, such as the loss of the approximal contact due to wear of the restoration or consequently an edge fracture of the marginal ridge, resulting in food impaction was also identified [44,62]. A four-year clinical study on 2-surface GIC approximal restorations reported 7.5% of

restorations needed to be replaced due to a poor proximal contact. If including restorations that needed to be repaired to restore the proximal contact, the overall failure rate was approximately 30% [18]. Interestingly, one study showed that another common cause of failure was progressive loss of GIC in the approximal region, just apical the contact area, which was noted to have initiate after 2 years of clinical service. The defect was crater-like and seemed not to involve the fracture surface but occurred from dissolution or erosion by biofilm acids [62]. For approximal conventional GIC restorations in primary teeth, bulk fracture [84] and loss of retention [85] were the most common causes of failure.

The main reasons for failure in posterior approximal ART-GIC restorations in permanent and deciduous dentitions were in the order: loss of restoration [47,48,64,70,71,76, 78] (mostly, total loss related to retention [47]); gross marginal defects [64,70,71,76,78] and restoration fracture [48,76], respectively. Other reasons in the permanent dentition were recurrent caries associated with marginal fracture of GIC (10.4%), poor anatomic form (2.5%), surface texture (2.5%), and colour match (3.7%) [64] For the deciduous dentition restored with ART, operator experience, cervical marginal gaps due to improper GIC adaptation by the operator, and post restorative meal consumption were the factors associated with higher failures [36-38].

3.4.3. Failure characteristics in each catagory

For GIC conventional occlusal and approximal restorations, USPHS and some criteria were often used to evaluate restorations for each category in both dentitions. In permanent dentition, survival percentage over 2-6 years of marginal adaptation marginal discolouration, anatomic form and surface texture of HVGIC was recorded in 84.6-100% [33,41,43], 95.6-100% [33,41], 79.5-100% [33,41,43,44], and 83.5-100% [41,43,44], respectively. One study reported no significant difference of marginal adaptation and marginal discolouration between HVGIC and resin composite over 6 years [41]. On the other hand, in another study, moderate marginal fracture of GIC (unable to be removed by polishing) was also found in GIC (3-4% over 3 years) but was not detected for comparable resin composite restorations [34]. For colour matching to adjacent tooth structures, one study showed improvement of colour match of the GIC restoration over 3 years which was eventually comparable to resin composite [34]. In addition, another study on occlusal and approximal restorations reported similar colour matching of resin composite (Gradia Direct) and GIC (EquiaFil with resin coating) over 5 years; however, at the 6-year recall the resin composite showed better match than the GIC [41].

Regarding 2- to 3-year studies in primary dentition, RMGIC and HVGIC (with resin coating) showed the percentage of score A for marginal adaptation in the range of 75-100% [35,68,88] with the survival percentage of 83.3-100% [35,68,83,86,88]. For other GIC types, normal-viscosity and silver-reinforced GICs exhibited obviously lower percentage of score A in marginal adaptation (16-33%) [67,89] but still provided 80% in survival [67]. For marginal discoloration, HVGIC with resin coating provided 90% and 100% of score A for occlusal and approximal restorations [66], whereas RMGIC showed lower percentage (69% and 73%) in occlusal restorations [35]. GIC restorations showed good survival percentage for anatomic form (89-100%) [35,67,83,86]; however, one study reported that resin composite (79.6%) had higher percentage of score A than RMGIC (36.7%) [83]. Resin composite also showed better surface appearance and colour match than RMGIC [39].

4. Discussion

4.1 Methodology

The current review literature used ROBINS-I as a tool for risk of bias assessment since this tool can be used for non-randomised studies of interventions. Therefore, with this tool, retrospective studies and single-arm clinical trials can be evaluated. The authors included non-randomised studies apart from randomised controlled trials as a number of the former studies [48,50,55,57-59,62,66,68,80,86] had long follow-up periods (3-6 years) which are beneficial for analyses as well as providing more useful information from a clinical standpoint. Furthermore, no critical risk of bias was found in any domains of each study. With this method, this review is able address the epidemiological trends of GIC restoration survial for posterior load bearing areas in children and adult dentitions based on comparisons between conventional and ART techniques. A follow-up period of greater than 1 year was used in the eligility criteria as a means to obtaining more useful data from the aspect of restoration longevity.

4.2. Single occlusal posterior restoration in permanent and deciduous dentitions

In the permanent dentition, the calculated AFR of conventional-GIC restorations (1.17%) was lower than that of ART-GIC restorations (8.0%). Similarly, in the primary dentition, the AFR of conventional-GIC restorations (4.78%) was still lower than that of ART-GIC restorations (8.95%) (Table 1). It seems that the conventional-GIC technique for occlusal restorations provided better survival than ART-GIC technique regardless of the whether restorations were placed in primary or permanent dentitions. In general, one of the factors, that might be used for explanation, was the well-controlled condition of conventional technique, achieving better field isolation and helping operators to perform a more controlled cavity preparation. Another factor may be attributed to immediate finishing to attain the correct occlusal relationship in the conventional technique.

The mean AFR of conventional-GIC restorations in permanent teeth (1.17) was the lowest. From the data of Table 3 (article 1-5, 21-22), most studies used Equia Fil, a HVGIC with nanofilled resin coating as the experimental material, which provided slightly lower AFRs (0-0.31%) [18,41-43] than other GICs (4.08-4.48%) in some studies [44,45]. It might be explained that Equia Fil with the nanofilled resin coating would show improved outcomes due to the reduce potential for moisture contamination during GIC setting as well as lessened failure from early forces of mastication [33]. In addition, the nanofilled resin coating (average thickness 35-40 μm) can infiltrate the GIC surface to seal any defects, thus retarding crack propagation [34,42]. Although the effectiveness of the nanofilled resin coating has been equivocal [34], some studies showed it was able to significantly increase flexural strength of Equia Fil [96,97] and is beneficial in reducing occlusal wear [34]. The potential of Equia Fil with resin coating provided similar survival (AFR=0%) to resin composite in single surface occlusal restorations over 6 years [41]. In addition, the mean calculated AFR of occlusal conventioal GIC restorations (1.17%) was still lower than that of conventional amalgam restorations (5.01%) (Table 2). From the study of Friedl, although the survival rate of occlusal restorations was 100% over 2 years, some restorations showed acceptable but a distinct volume loss from occlusal surface (3.8%) and perceptible roughness (11.2%), whereas no distinct marginal disintegrity was reported [43]. The authors also explained that the small amount of occlusal volume loss may have been caused by an effect of resin coating of GIC [43]. Another study found no significant difference of marginal staining among Fuji IX GP Extra with or without resin coating and resin composite in occlusal restorations [34].

Regarding the permanent dentition, although a short-term study (1 year) still reported no significant difference in survival rates of small occlusal GIC restorations restored with either the ART or conventional techniques [98]. The AFR of ART-GIC restorations (8.0%), calculated from longer follow-up studies (MF 3.79 years), is higher than that of conventionally placed GICs (1.17%) in the

permanent dentition. Nevertheless, it can be observed that the range of ART-GIC AFRs varied greatly from 0% to 40.56% (Table 2). Wang et al. [50] reported that the three-year survival of Ketac Molar was only 21% (AFR 40.56%) which was far lower than most other studies. The study of Frencken et al. [49] demonstrated the effect of the operator on the success rates of occlusal ART restorations. In Wang's study, operators were trained dental students without assistants, whereas other studies used general dentists or trained dentists who are likely to have more experience than dental students. This might be the reason for the greater failure rate in Wang's study. Another reason might be participants in Wang's study exhibited a much higher DMFT score (5.92) compared to those in the other studies. Also, failure due to recurrent caries was detected as a level of 22.8% of failed restorations which was an uncommon cause of failure in occlusal conventional GIC restorations. This cause of failure increased the failure rate in Wang's study apart from mechanical failure. Another study by van Gemert-Schriks et al. reported poor performance of ART-GIC restorations in permanent teeth of children residing in a rain forest setting (AFR=33.36%) [30]. The authors discussed possible reasons that might involve such as cultural dietary influences (eating hard fruits) as well as no supervision for avoiding post-restorative meal consumption. Some restorations (9.2%) were reported as being contaminated with saliva during procedures, which also may be related to high failure. The two lowest AFRs in the studies of Wang et al. and van Gemert-Schriks et al brought about the powerful effect on a distribution of AFR's data, reflecting considerable difference between the mean (8.0%) and median (5.38%) (Table 2). If the median AFR of ART-GIC occlusal restorations (5.38%) is used instead of the mean to compare failure rates of occlusal amalgam restorations (4.89%), then the occlusal ART technique may be seen as an alternative choice of treatment for the permanent dentition based on acceptable performance with good patient feedback due to less discomfort with this approach [99]. Two studies used amalgam as a comparison [45,49], and reported similar survival between amalgam and ART-GIC restorations. In contrast, Kalf-Scholte et al. found a slightly better success rate of amalgam (90.4%) compared with a silver-reinforced GIC (81%) over 3 years [52]. It was possible that final polishing of the amalgam included in the procedure influenced the results, which led to better anatomic form and improved occlusion [100] as well as removing marginal excess of amalgam, thereby preventing the amalgam from marginal fracture.

Occlusal conventional GIC restorations in the primary dentition showed obviously higher AFR (4.78%) than the same technique used in the permanent dentition (1.17%), whereas, occlusal ART-GIC restorations (8.95%) had almost comparable AFR to the similar technique restored in permanent dentition (8.0%). It seems that Equia Fil with nano-resin coating, usually used in the studies of permanent teeth, might lead to different results of conventionally-used restorations between both dentitions. When considering the GIC system of conventional restorations in primary teeth (Table 4), most studies used GICs without resin coating except the study of Rutar et al. (used Fuji IX and resin coating). This study consequently provided excellent results of 0% of AFR over 3 years.

Regarding the effect of GIC type on occlusal restorations, the only data of ART technique in the permanent dentition (AFR=8.0%) was enough for discussion. Notwithstanding, it was still unclear whether a normal-viscosity self-cured GIC (Fuji II, Chemfil) as well as silver reinforced GICs (Chelon Silver, Miracle Mix) can be properly used for single-surface occlusal ART restorations. Two studies provided good results (Chelon Silver and Miracle Mix: AFR=6.78% [52]; Fuji II: AFR=6.46% [45]). In contrast, another three studies reported lower AFRs than the mean AFR (non-ART GIC: AFR=18.15% [29]; Fuji II: AFR=15.24% [57]; Chemfil: AFR=14.73% [60]). One study reported that Vitremer (RMGIC) had a significantly superior survival rate (100%) compared to Ketac Molar (high-viscosity GIC) (80.9%) over 2 years [47].

With respect to the ART-GIC restorations for the primary dentition, it seems the operator might be a factor that was related to GIC survival if inexperienced operators were included, similar to the ART-GIC restorations in the permanent dentiton described above. Three studies [29,77,78] investigated restorative procedures performed by undergraduate students or health care workers and showed high AFRs (22.54%, 18.15-29.29%, and 10.4%) compared to other studies using dentists as operators. If these three studies [29,77,78] mentioned were excluded from our analysis, AFRs would be reduced from 8.95% to 5.24% (Median 3.62%). These values were almost similar to AFRs of conventional occlusal GIC restorations (Mean 4.78%, Median 5.13%) and those of conventional occlusal amalgam (Mean 4.32%, Median 4.68%) in primary teeth. Our observation was in accordance with the study of Yu et al. which compared ART and conventional technique and then reported no significant difference of AFRs among ART (5.1% or 5.3%) and conventional GIC restorations (5.6% or 3.2%) over 2 years [74]. These analyses also seemed be have been undertaken in the same way as other studies that showed similar results of ART-GIC and amalgam restorations [70,71,74,76] or ART-GIC and resin composite restorations [73] in deciduous teeth.

4.3 Approximal or muti-surface posterior restorations in permanent and deciduous dentitions

In the permanent dentition, the calculated AFR of conventional-GIC restorations (6.90%) was lower than that of ART-GIC restorations (10.7%). Similarly, in the primary dentition, the AFR of conventional-GIC restorations (9.46%) was still lower than that of ART-GIC restorations (25.77%) (Table 2). When comparing the two restorative techniques, conventional-GIC restorations still provided lower AFRs than ART-GIC restorations irrespective of the dentition type as the same trend of single-surface occlusal restorations mentioned above.

Interestingly, Basso et al. reported higher survival rates (2-surface premolar 100%, molar 86.67%; 3-surface premolar 94.74%, molar 95.83%) of approximal conventional GIC restorations with functional oppositing teeth over 4 years [42]. This might result from using Equia Fil with resin coating, and included patients who have good oral hygiene and exclusion of patients with bruxism [42]. There were also no significant differences in the effect of rubberdam and tooth vitality (vital vs non-vital teeth) when using conventional GIC technique for approximal restorations [42]. Regarding different proprietary brands of material, Equia Fil showed significantly better marginal adaptation, anatomic form and retention rate of approximal restorations than Riva over a 6-year observation period [33]. Several attempts have been made to investigate GICs for multisurface restorations (including MOD) with AFR between 1.06-8.78% [18,42,43,62]. These good outcomes must, however, be interpreted carefully, as most studies did not use the strict inclusion criteria that GIC restorations needed to have opposite functional occlusal relationship as well as the anatomic form of the approximal contour was not evaluated strictly for survival. If the survial criteria excluded these critical factors, it might not represent good functional restorations. In addition, when comparing of 2- or 3-surface approximal restorations, 3-surface restorations exhibited more volume loss, roughness and marginal disintegrities than 2-surface and occlusal restorations, respectively. The volume loss of muti-surface restorations often resulted from an insufficient proximal contact [43]. Surprisingly, from our analysis, approximal cavities in permanent teeth from all studies were restored with high viscosity GIC, there is a gap in the knowledge as to whether RMGICs, which are mostly used in primary teeth (Table 4), provide the better outcomes.

Approximal ART-GIC restorations in the permanent dentiton (10.7%) had higher AFR than conventionally-used restorations (6.90%). These results were possibly related to reasons that might be specific to the ART technique, in that approximal cavities are difficult to prepare using only hand

instruments, and achieving the correct anatomic form of the marginal ridge and proximal area without rotary instruments is challenging. One study recommended the use of rotary instruments in order to minimally access the restorative site [101]. Unfortunately, most research on ART was done in rural areas where dental rotary instruments are often not available [48,49]. Another explanation may be the GIC mixing method of GIC used. Most studies for the conventional technique usually used the newer encapsulated type GIC, Equia Fil, whereas the ART technique always used a hand-mixed high-viscosity GIC (e.g. Ketac Molar or Fuji IX). Accordingly, one study showed superior performance of an encapsulated GIC compared to a hand-mixed GIC used for ART restorations in permanent teeth [102]. In addition, the type of GIC might influence survival of approximal ART restorations in permanent teeth. One study reported that a RMGIC (AFR=0%) showed superior survival compared to a high-viscosity GIC (AFR=10.06%) over 2 years [47]. Interestingly, HVGIC with resin coating has been recently used for approximal ART-GIC. The results showed a low AFR (3.34%) with HVGIC system that had a significant superior performance than a resin composite (AFR=16.3%) in patients with intellectual disability [31].

In deciduous dentition, according to the analyses in the current review, type of GIC related to clinical performance of conventional-GIC restorations. RMGICs provided good results (AFR=6.25%) similar to HVGIC (AFR=6.24%). On the other hand, survival of silver-reinforced and normal-viscosity GICs were lower (AFR = 20.39% and 14.91%, respectively) (Table 2). The overall AFR of conventional GIC restorations was 9.46%, being comparable to AFRs calculated from conventional amalgam (11.61%) or resin composite restorations (11.03%). Furthermore, three studies compared posterior approximal RMGIC restorations using conventional techniques with amalgam [103] or resin composite [82] or both of them [39] over 1-2 years. There was little difference in survival rates among the three test materials. Moreover, the review article by Qvist et al., that collected their own data from four 4 to 8-year clinical studies for conventional approximal restorations [104], reported no difference mean survival time of RMGIC (3.8 years), amalgam (3.8 years) and resin composite (4 years), however, lower mean survial time (1.4 years) was observed in normal-viscosity GIC. Despite the good results for RMGIC, there were interesting details that should be considered when selecting materials. On the one hand, amalgam possessed better maintenance of anatomic form related to its higher resistance to wear [103], whereas it was more prone to exhibit recurrent caries compared to RMGIC [103]. In accordance with the clinical results of another study [82], RMGIC was the most successful material regarding biologic considerations but had a slightly lower survival rate (71.9%) than resin composite (77.5%). While another study addressed the radiographic defects at the cervical area of resin composite (47%) > RMGIC (13%) > amalgam (11%) [39]. However, RMGIC possessed poorer surface appearance and colour match [39]. Besides, a result of a further study found that a survival rate of RMGIC (90.3%) was between that of compomer (100%) and resin composite (80.6%) [81]. However, surface roughness, anatomic form and marginal adaptation of RMGIC was worse than that of compomer and resin composite, respectively [81]. These aspects should be carefully evaluated before selecting the restorative materials (RMGIC, amalgam or resin composite) for each clinical situation in approximal lesions of the primary dentition.

The performance of GIC when combined with ART in posterior approximal or multi-surface restorations in deciduous teeth (AFR=25.77%) was notably inferior to the results observed for permanent teeth (AFR=10.7%) (Table 2). This may be related to difficulties in simultaneously dealing with paediatric patients and approximal ART procedures, and it would also seem that ART is inferior for posterior approximal restorations compared to the conventional technique irrespective of the dentition. One study revealed the effect of cavity size on posterior approximal restorations, and reported

that medium-sized cavities (2-3 mm of mesio-distal, bucco-lingual and occlusal-gingival dimensions, with restoration volumes ~ 10-19.9 mm^3), showed the highest survival rate when comparing small and large cavities. In the authors' view, inadequate access and visibility might be problems for small cavities, whereas the large restorations failed more easily possibly from bulk fracture and pulpal involvement [105]. In addition, it should be noted that distal cavities also showed statistically lower survival rates of GIC when compared to mesial cavities [94] This may be related to greater difficulty of access and moisture control.

The effect of operator on survival rates of GICs with approximal ART in the primary dentition was clearly demonstrated by a couple of studies [38,94]. Similarly, the data from Table 4 shows several studies that used less experienced operators and reported higher mean AFR (28.62%) [36,78,94] compared to the overall mean (25.77%). The availability of experienced dental assistants was another factor promoting higher survival rates of approximal GIC restorations with ART, for example, a better GIC mixing technique may have been used [38]. Therefore, if an approximal ART restoration has to be done, well-trained clinicians and assistants should be required. The effect of less experienced operators on ART was mentioned; it appeared to lead to greater cervical marginal gaps due to improper GIC adaptation that significantly increased the failure rates [37]. To solve this problem, the bilayer technique was proposed which uses a thin flowable GIC, with a lower powder-liquid ratio than a high-viscosity GIC, placed on the gingival floor of cavities before the insertion of the high-viscosity GIC [92,106]. This technique significantly improved the survival rate of posterior approximal restorations [92]. Apart from reducing gingival margin gaps, the data from a finite element analysis study revealed a lower stress concentration on the occlusal surface of bilayer GIC restorations compared to single-layer GIC restorations [107]. This might be another factor potentially promoting the higher survival of bilayer GIC restorations. To summarize from our review based on the data mentioned, operator significantly affected survival of approximal ART restorations in primary teeth. It is also most likely to influence on occlusal ART in primary and permanent teeth.

4.4. Clinical caries preventive effect of GICs

In this review, a focus was also put on the effect of GICs to prevent recurrent caries after restoration and enhancing remineralization or inhibiting demineralization of neighbouring areas related to GICs.

4.4.1. The effect of GICs on prevention of recurrent caries after restoration in load bearing areas

Regarding the permanent dentition, most studies over 4-6 years that assessed recurrent caries adjacent to GICs in occlusal and approximal lesions with a conventional technique, revealed that no recurrent caries was observed [33,41,62,109,110]. For the ART technique, recurrent caries was not detected over a 1-year observation [111]. Nevertheless, varied results were reported for longer evaluations. Five per cent of teeth exhibited recurrent caries in a 6-year investigation of Ketac Molar [48]. The study by Wang et al. showed 22.8% of Ketac Molar restorations failed from caries located at the cavosurface margin of the restoration [50]. Furthermore, a 10-year evaluation of Fuji IX ART advocated that recurrent caries detection was related to mechanical failures [64]. When comparing recurrent caries between GIC and amalgam, one study showed that GICs exhibited lower caries recurrence [45]. Additionally, one 6-year clinical study found no recurrent caries for both GIC and resin composite restorations [41].

4.4.2. Enhancement of remineralisation and inhibition of demineralisation of neighbouring areas related to GICs

Qvist et al. compared the cariostatic effect between an amalgam and a conventional GIC by evaluation of initial caries of approximal surfaces in teeth adjacent to approximal restorations of amalgam or GIC. The results showed that the progression of carious lesions on adjacent teeth related to amalgam needed intervention in 30% of sites, whereas that related to the GIC required intervention in only 16% of sites [112]. Another study of Qvist et al. showed a similar cariostatic effect on teeth adjacent to a GIC and a RMGIC [113]. Trairatvorakul et al. investigated efficacy of a GIC on remineralization of approximal caries lesions using a split-mouth clinical trial where Fuji VII (Fuji Triage) was applied on initial approximal caries lesions of the test group after tooth separation by elastic orthodontic rings. After a 12-month observation, the results affirmed that incipient caries lesions treated with the GIC still remained in enamel or regressed to its outer half [114]. From the three studies described, it seems that GICs have a promising clinical cariostatic effect for adjacent areas.

5. Conclusions

Within the limitations of this review of the literature (including all types of study e.g. split-mouth, parallel, longitudinal and retrospective designs, and using of AFRs calculated from our analysis for comparison in survival), it can be concluded that:

1. For single-surface occlusal GIC restorations in permanent and deciduous teeth, although the conventional technique showed better survival, the clinical performance of the ART technique was satisfactory and likely to be comparable outcomes to conventional technique if ART is performed by experienced trained operators using newer strength-improved materials. Therefore, ART-GIC approach can be an alternative restoration option for single-surface occlusal GIC restorations;
2. The AFRs of approximal or multi-surface GIC restorations were greater than those of single-surface occlusal restorations when comparing in the same technique of treatment, irrespective of type of the dentition;
3. In clinical conditions where GICs are required to restore approximal or multi-surface cavities in both dentitions, the conventional technique is preferred to the ART technique especially in the deciduous dentition due to lower mean AFRs.
4. RMGIC-conventional technique seems to be promising for restoring approximal cavities of primary teeth compared to other restorative materials.
5. The main cause of failure for GIC posterior occlusal or approximal restorations was restoration loss due to fracture or dislodgement. For approximal lesions, loss of proximal contact from marginal ridge chipping should also be a concern;
6. Recurrent caries is not such a major problem in GICs for posterior restorations especially when using a conventional technique. However, it was unclear if GICs provided superior survival in this aspect compared to other restorative materials.

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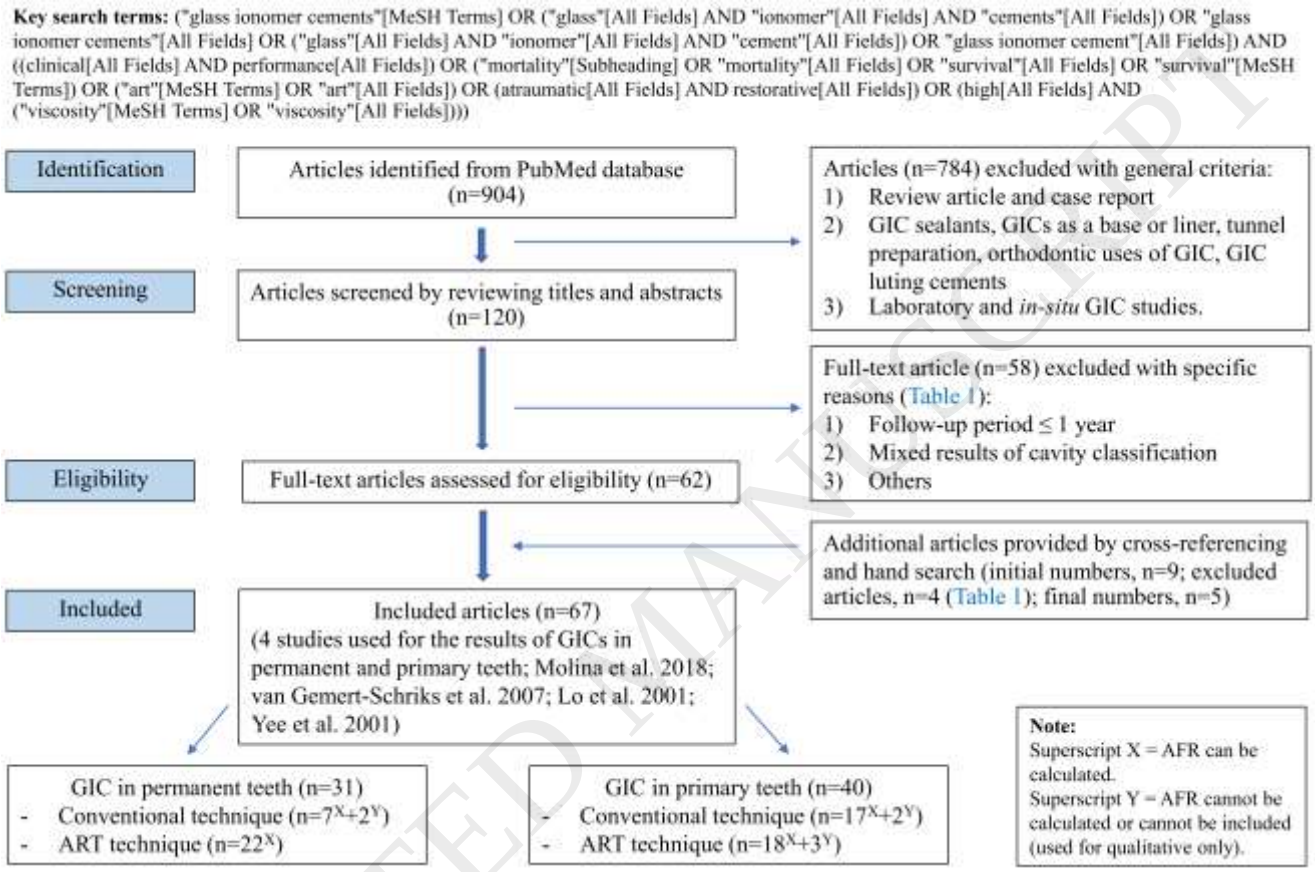

Fig. 1. Flowchart of studies through eligibility criteria according to PRISMA diagram.

Table 1

Articles, excluded from the results of this study, illustrates authors, titles, and reasons for exclusion.

Arthors and Journal	Year	Title	Reasons for exclusion
Freitas MCCA et al. J Appl Oral Sci	2018	Randomized clinical trial of encapsulated and hand- mixed glass-ionomer ART restorations: one year follow up	1-year study
Tseveenjav B et al. Int J Paediatr Dent	2018	Survival of extensive restorations in primary molars: 15-year practice-based study	Include GIC,RMGIC & PMRC in the same group
Anna Luisa de Brito P et al. Braz Oral Res	2017	One year survival rate of Ketac Molar versus Vitro Molar for occlusoproximal ART restorations: a RCT	1-year study
Ladewig NM et al. BMJ Open	2017	Efficacy of conventional treatment with composite resin and atraumatic restorative treatment in posterior primary teeth: study protocol for a randomized controlled trial	Study protocol
de Medeiros Serpa EB et al. J Indian Soc Pedod Prev Dent	2017	The effect of atraumatic restorative treatment on adhesive restorations for dental caries in deciduous molars	1-year study
Olegario IC et al. J Dent	2017	Low-cost GICs reduce survival rate in occlusal ART restorations in primary molars after one year: A RCT	1-year study
Olegario IC et al. BMC Oral Health	2017	Effectiveness of conventional treatment using bulk-fill composite resin versus atraumatic restorative treatments in primary and permanent dentition: a pragmatic randomized clinical trial	Study protocol
Casagrande L et al. Clin Oral Investig	2017	Longevity and associated risk factors in adhesive restorations of young permanent teeth after complete and selective caries removal: a retrospective study	Unclassified tooth preparation (Cl I, II) and non-identified location (anterior or posterior teeth)
Hesse D et al. Trials	2016	Atraumatic restorative treatment compared to the Hall technique for occluso-proximal cavities in primary molars: study protocol for a randomized controlled trial	Study protocol
Hilgert LA et al. Int J Paediatr Dent	2016	A study on the survival of primary molars with intact and with defective restorations	Results evaluated with different objectives compared to this review
Da Mata C et al. J Dent $$	2015	A two-year survival of ART restorations placed in elderly patients: a randomised controlled clinical trial	Mixed results of occlusal and incisal restorations
Pinto Gdos S et al. J Dent	2014	Longevity of posterior restorations in primary teeth: results from a paediatric dental clinic	Mixed results of class I and II restorations
Molina GF et al. BMC oral health	2014	One year survival of ART and conventional restorations in patients with disability	1-year study and presence of the relevant article with longer follow-up
Casagrande L et al. Am J Dent	2013	Randomized clinical trial of adhesive restorations in primary molars. 18-month results	Mixed results of class I and II restorations
Luengas-Quintero E et al. BMC Oral Health	2013	The atraumatic restorative treatment (ART) strategy in Mexico: two-years follow up of ART sealants and restorations	Mixed results of class I, III, and V restorations
Burke FJT, Bardha JS. Br Dent J $$	2013	A retrospective, practiced-based, clinical evaluation of Fuji IX restorations aged over five years placed in load-bearing cavities	Mixed results of class I and II restorations
Konde S et al. J Int Soc Prev Community Dent	2012	Clinical evaluation of a new art material: nanoparticulated resin-modified glass ionomer cement	1-year study
Gjorgievska E. Prilozi	2011	Clinical performance of fluoride-releasing dental restoratives	Mixed results of class I and V restorations
Ibiyemi O et al. Int Dent J	2011	Assessment of atraumatic restorative treatment (ART) on the permanent dentition in a primary care setting in Nigeria	Samples in this study are subset of those in study of Ibiyemi 2011 Afr J Med Med Sci
Deepa G, Shobha T. Int J Paediatr Dent	2010	A clinical evaluation of two glass ionomer cements in primary molars using atraumatic restorative treatment technique in India: 1 year follow up	1-year study
Farag A et al. Clin Oral Investig	2011	Survival of ART restorations assessed using selected FDI and modified ART restoration criteria	Use same samples as the study of Farag et al. 2009 but have a different objective
Daou MH et al. J Clin Pediatr Dent	2009	Two-year clinical evaluation of three restorative materials in primary molars	Mixed results of class I and II restorations
Kemoli AM, van Amerongen WE. Int J Paediatr Dent	2009	Influence of the cavity-size on the survival rate of proximal ART restorations in primary molars	1-year study
Faccin ES et al. J Clin Pediatr Dent	2009	Clinical performance of ART restorations in primary teeth: a survival analysis	Mixed results between single-surface anterior and single-surface posterior restorations
Yassen G. J Dent Child	2009	One-year survival of occlusal ART restorations in primary molars placed with and without cavity conditioner	1-year study
Zhang H. J Evid Based Dent Pract	2009	Chlorhexidine-containing cavity disinfectant may not benefit the clinical performance of high-viscosity glass-ionomer cement following ART after 24 months	Summary and commentary of the study of Ersin et al. 2008 that was already included in this review
dos Santos MP et al. J Am Dent Assoc	2009	A randomized trial of resin-based restorations in class I and class II beveled preparations in primary molars: 24-month results	Presence of the study having a longer follow-up.
Barata TJ et al. J Appl Oral Sci	2008	Comparison of two minimally invasive methods on the longevity of glass ionomer cement restorations: short-term results of a pilot study	1-year study
Burke FJ, Lucarotti PS. Br Dent J	2009	How long do direct restorations placed within the general dental services in England and Wales survive?	Non-identified the classification of the GIC result
Daou MH et al. Schweiz Monatsschr Zahnmed	2008	Clinical evaluation of four different dental restorative materials: one-year results	1-year study

Table 1 (*continue*)

Arthors and Journal	Year	Title	Reasons for exclusion
Cefaly DF et al. J Dent Child	2007	Clinical evaluation of multiple-surface ART restorations: 12 month follow-up	1-year study
Prabhakar AR et al. J Contemp Dent Pract	2008	Evaluation of the clinical behavior of resin modified glass ionomer cement on primary molars: a comparative one-year study	1-year study
Burke FJ et al. Br Dent J	2007	Clinical performance of reinforced glass ionomer restorations placed in UK dental practices	Mixed results of class I and II restorations
Roeleveld AC et al. Eur Arch Paediatr Dent	2006	Influence of residual caries and cervical gaps on the survival rate of class II glass ionomer restorations	1-year study
Lo EC et al. J Dent Res	2006	ART and conventional root restorations in elders after 12 months	Root surface restorations
Menezes JP J Dent Child	2006	Clinical evaluation of atraumatic restorations in primary molars: a comparison between 2 glass ionomer cements	1-year study
Frencken JE et al. J Dent Res	2006	Survival of ART and amalgam restorations in permanent teeth of children after 6.3 years	Use almost same samples as the study of Frencken et al. 2007 and presence of the mixed results of class I and II restorations
Yilmaz Y et al. J Contemp Dent Pract	2006	A one-year clinical evaluation of a high-viscosity glass ionomer cement in primary molars	1-year study
Dugergil CT et al. Med Princ Pract	2005	Atraumatic restorative treatment with resin modified glass ionomer material: short-term results of a pilot study	6-month study
Bresciani E et al. J Appl Oral Sci	2005	Six-month evaluation of ART one-surface restorations in a community with high caries experience in Brazil	6-month study
Cefaly DF et al. J Appl Oral Sci	2005	Clinical evaluation of multisurface ART restorations	6-month study
de Souza EM et al. Oral Health Pre Dent	2003	Clinical evaluation of the ART technique using high density and resin-modified glass ionomer cements	8-month study
Taifour D et al. Community Dent Oral Epidemiol	2003	Comparison between restorations in the permanent dentition produced by hand and rotary instrumentation-survival after 3 years	Presence of the relevant article with longer follow-up (Frencken JE et al. 2007)
Abid A et al. East Mediterr Health J	2002	Atraumatic restorative treatment and glass ionomer selants in Tunisian children: survival after 3 years	Mixed results of single non-occlusal and occlusal restorations in anterior and posterior teeth
Louw AJ et al. SADJ	2002	One-year evaluation of atraumatic restorative treatment and minimum intervention techniques on primary teeth	1-year study
Yip KH et al. J Am Dent Assoc	2002	The effects of two cavity preparation methods on the longevity of glass ionomer cement restorations: an evaluation after 12 months	1-year study
Yip KH et al. Quintessence Int	2002	Comparison of atraumatic restorative treatment and conventional cavity preparations for glass-ionomer restorations in primary molars: one-year results	1-year study
Motsei SM et al. SADJ	2001	Evaluation of atraumatic restorative treatment restorations and sealants under field conditions	1-year study
Mandari et al. Caries Res	2001	Effectiveness of three minimal intervention approaches for managing dental caries: survival of restorations after 2 years	Presence of the relevant article with longer follow-up (Mandari et al. 2003)
Dutta BN et al. J Indian Soc Pedod Prev Dent $$	2001	Silver amalgam versus resin modified GIC class-II restorations in primary molars: twelve month clinical evaluation	1-year study
Mickenautsch S et al. SADJ	2000	Clinical evaluation of the ART approach and materials in peri-urban farm schools of the Johannesburg area	1-year study
Rutar J et al. Pediatr Dent	2000	Clinical evaluation of a glass ionomer cement in primary molars	Presence of the relevant article with longer follow-up (Rutar et al. 2002)
Welbury RR et al. Br Dent J	2000	Clinical evaluation of paired compomer and glass ionomer restorations in primary molar: final results after 42 months	Mixed results of cl I and II restorations
Marks LA et al. J Dent Child $$	2000	Ketac Molar versus Dyract Class II restorations in primary molar: twelve month clinical results	1-year study
Luo Y et al. Chin J Dent Res	1999	Clinical investigation of a high-strength glass ionomer restorative used with the ART technique in Wuhan, China: one-year results	1-year study
Mickenautsch S et al. Int Dent J	1999	The impact of the ART approach on the treatment profile in a mobile dental system (MDS) in South Africa	1-year study
Frencken JE et al. Caries Res	1996	Atraumatic restorative treatment and glass-ionomer sealants in a school oral health programme in Zimbabwe: evaluation after 1 year	1-year study and presence of the relevant article with longer follow-up
Frencken JE et al. Int Dent J	1994	An atraumatic restorative treatment (ART) technique: evaluation after one year	1-year study and presence of the relevant article with longer follow-up
Papathanasiou AG et al. Pediatr Dent	1994	The influence of restorative material on the survival rate of restorations in primary molars	Unclassified tooth preparation of GIC (Class I or II or etc)
Smales RJ et al. J Dent	1991	Survival predictions of four types of dental restorative materials	Unclassified tooth preparation of GIC (Class I or II or etc)
Welbury RR et al. Br Dent J	1991	The 5-year results of a clinical trial comparing a glass polyalkenoate (ionomer) cement restoration with an amalgam restoration	Mixed results of cl I and II restorations
Knibbs PJ, Plant CG. J Oral Rehabil	1990	An evaluation of a rapid setting glass ionomer cement used by general dental practioners to restore deciduous teeth	6-month study

$$, the studies were identified by cross-referencing or hand search.

Table 2
AFR calculated of data provided from main articles in this study.

Condiiton	Number of studies included	Number of groups included	Mean AFR (%)	Median AFR (%)	Min AFR (%)	Max AFR (%)
Permanent teeth						
1.1 Single surface occlusal posterior restorations						
GIC-Conventional treatment	7	8	1.17	0.13	0	4.68
GIC-ART treatment	20	28	8.0	5.38	0	40.56
Conventional amalgam (control)	4	5	5.01	4.89	0	9.82
1.2 Approximal or multi-surface posterior restorations						
GIC-Conventional treatment	7	11	6.90	6.57	1.33	22.54
GIC-ART treatment	6	7	10.7	8.42	0	35.81
Deciduous teeth						
2.1 Single surface occlusal posterior restorations						
GIC-Conventional treatment	6	7	4.78	5.13	0	9.14
GIC-ART treatment	12	16	8.95	4.40	1.17	29.29
Conventional amalgam (control)	6	6	4.32	4.68	1.26	7.32
2.2 Approximal or multi-surface posterior restorations						
GIC-Conventional treatment (all types of GICs)	18	24	9.46	6.68	0.67	26.32
- RMGIC-Conventional treatment	11	13	6.25	3.84	0.67	17.25
- High-viscosity GIC-Conventional treatment	3	4	6.24	4.66	2.25	13.40
- Silver reinforced GIC-conventional treatment	3	3	20.39	19.03	18.76	23.37
- Normal-viscosity GIC-Conventional treatment	4	4	14.91	13.27	6.78	26.32
GIC-ART treatment	17	27	25.77	22.67	5.71	50.4
Conventional amalgam (control)	7	7	11.61	13.51	0	24.58
Conventional resin composite (control)	6	6	11.03	12.68	5.65	14.36
Conventional compomer or giomer (control)	3	5	6.82	3.31	0	18.3

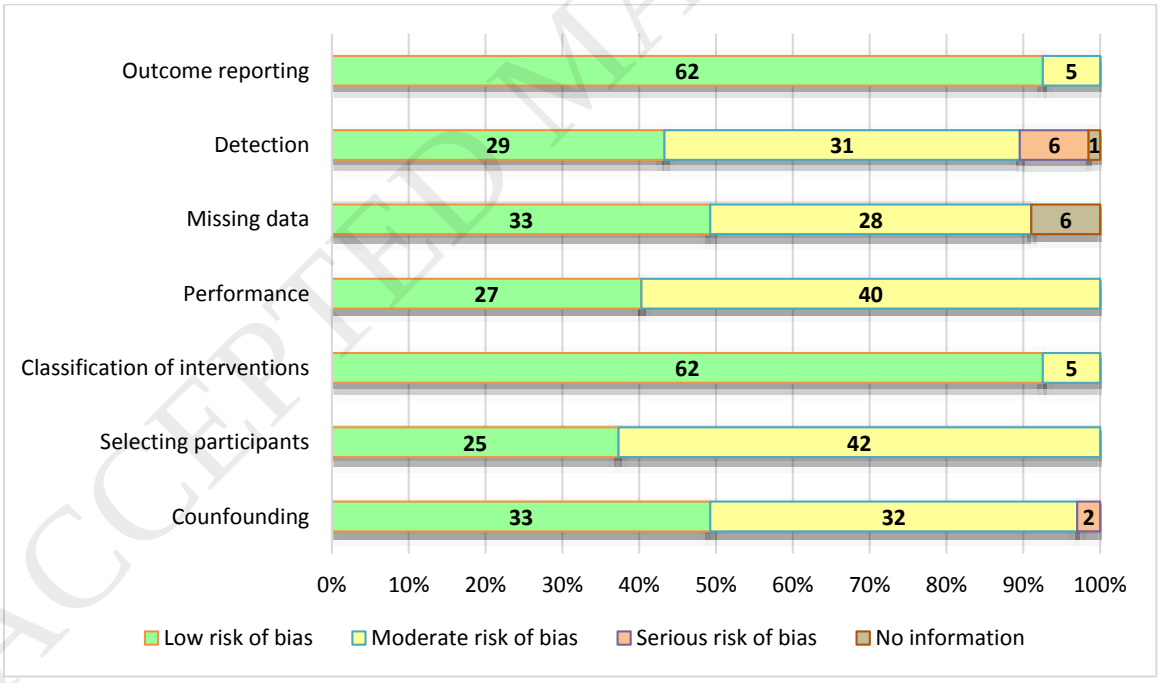

Fig. 2. Risk of bias analysis using ROBINS-I; proportion of studies (%) with low, moderate, serious, critical , and no information (no studies identified by the critical risk of bias); the numbers in the bar chart identify the number of studies in each grading criteria.

Table 3

Some characteristics of clinical studies of GICs for restoring posterior restorations in permanent teeth.

References	GV Black Classifi-cation	Study design[1]	Location/ Risk assessment[2]	Follow-up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ No.of restoration/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
a. Conventional technique (AFR can be calculated)										
1. Gurgan S. et al 2017 [41]	I	Parallel	Turkey (School of dentistry) LMLMLML	6y	15-37y	2 experienced dentists	Equia Fil + Equia coat (n=40^{A}) Gradia Direct (composite) +G-Bond (n=40^{A}) (DR=20.4%)	Conditioner Encapsulated Conservative preparation (all enamel margin)	USPHS criteria	6-year survival rates of each material were 100%, AFR =0%
	II						Equia Fil + Equia coat (n=30^{A}) Gradia Direct (composite) +G-Bond (n=30^{A}) (DR=20.4%)			6-year survival rates & (AFR) of 2 materials: Equia =92.3,(1.33)% Gradia Direct composite =100,(0)%
2. Klinke T. et al 2016 [18]	I	Parallel	Germany (Dental clinics) LLLMMLL	4y	20-80y	111 dentists from 144 clinics	EquiaFil + resin coating (n=166^{B}) Fuji IX GP Fast + resin coating (n=146^{B}) (DR=21.88%)	Conditioner Encapsulated 2 materials used were coated with each resin coating	FDI criteria	No significant difference between materials 4-year success rate =98% 4-year survival rate (included repair) =99% AFR =0.25%
	II						EquiaFil 2 surfaces n=211^{B} 3 surfaces n=21^{B} Fuji IX GP Fast 2 surfaces n=225^{B} 3 surfaces n=13^{B} (DR=21.88%)			Success rates, survival rates (included repair) and AFR are illustrated, respectively **(Note)** **2 surfaces** EquiaFil =69.19,(90.52),[2.46]% Fuji IX =57.33,(88),[3.15]% **3 surfaces** EquiaFil =33.33,(76.19),[6.57]% Fuji IX =46.15,(69.23),[8.78]%
3. Basso M. et al 2015 [42]	I	Long.	Italy (Dental clinic of Institute) MMLMLSL	4y	Unknown Good oral hygiene	4 experienced operators	Equia Fil + resin coating (n=82^{B}) premolar=23, molar=59 (DR=20%)	No con. Encapsulated Use of rubber dam whenever possible	Frencken & Zanata criteria	4-year survival rate, (AFR) =98.78,(0.31)% 4-year survival rates of Premolar =95.65%, Molar =100%
	II						Equia Fil + resin coating (2, 3 and 4+ surfaces; n=135^{B}) 2 surfaces n=58 3 surfaces n=43 4+ surfaces n=49 (DR=20%)			4-year survival rate, (AFR) =90,(2.60)% 4-year survival rates of: **2 surfaces** Premolar=100% Molar=86.67% **3 surfaces** Premolar=94.74% Molar=95.83% **4+ surfaces** Premolar=72.22% Molar=87.1%
4. Friedl K. et al 2011 [43]	I	Retro.	Germany MLMMLLL	2y	Unknown	6 experienced dentists	Equia + nanofilled coating (n=26^{B})	No con. Encapsulated	Modified USPHS criteria	2-year survival rate of class I =100% AFR =0%
	II						Equia + nanofilled coating ClassII 2 surfaces (n=84^{B}) Class II 3 surfaces (n=41^{B})			2-year survival rate of each group (no need to replacement), (AFR): **(Note)** 2 surf =84.5,(8.08)%, 3 surf =92.6,(3.77)%
Note: However, in most criteria, 2-surface restorations exhibited better clinical performance than 3-surface restorations.										
5. Franken-berger R. et al 2009 [44]	I	Long.	Germany (University dental clinic) MMLMMML	2y	Average 32.3y	4 experienced dentists	Ketac Molar (n=21^{A}) (DR=76%)	Conditioner Encapsulated	Modified USPHS criteria	2-year survival rate, (AFR) =92,(4.08)%
	II						Ketac Molar (n=94^{A}) (DR=76%) Coating on class I and II GICs			2-year survival rate, (AFR) =60,(22.54)%
6. Scholtanus JD,Huysmans MCDNJM. 2007 [62]	II	Retro.	Netherlands (General dental practice) MMMMLML	6y	unknown	2 experienced dentists	Fuji IX GP (n all =116^{A}), MO (n=30^{A}), DO (n=40^{A}), MOD (n=46^{A})	Conditioner Encapsulated	**(Note 1)**	18, 42, 72 month-survival rates, (AFR) =100,(0)%, 93,(2.05)% and 60,(8.16)%, respectively **(Note 2)**
Note 1: Absolute failure was defined as the need for intervention(repair, partial/total replacement)**,** **Note 2:** The common cause of failure was a progressive loss of GIC in proximal area, just below contact area.										
7. Mjor IA, Jokstad A. 1993 [63]	II small	Parallel	Norway LMLMMSL	3y **(Note)**	Average 13y	3 dentists	Ketac Silver (n=95^{A}) (DR=54%) Amalgam (n=88^{A}) (DR=62%) Composite (n=91^{A}) (DR=60%)	No data con. No data mix.	USPHS criteria	3-year failure rates, (AFR): Ketac =23.16, (8.41)%; Amalgam =4.55,(1.54)%; Composite =9.89,(3.41)%
Note: The follow-up period of the study was 5 year but 5-year data was incomplete. Therefore, only 3-year results were used for analysis in this review.										

Table 3 (*continued*)

References	GV Black Classification	Study design[1]	Location/ Risk assessment[2]	Follow-up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ No.of restoration/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
b. Conventional technique (AFR cannot be calculated)										
8. Turkun LS, Kanik O. 2016 [33]	II (medium size to large) and I	Parallel	Turkey (School of Dentistry) LLLLLLL	6y	17-55y Good oral hygiene	1 experienced dentist	EquiaFil+resin coat, EquiaFil+vanish Riva SC+resin coat, Riva SC+vanish (DR=31.25%; all gr.) Class II (n=132^{A} for all groups) Class I (n=124^{A} for all groups)	Conditioner Encapsulated	Modified USPHS criteria	**Equia** showed acceptable clinical performance in class I and class II moderate to large sizes over 6 years. (failure 4 from 88 restorations). **Riva SC** failed from retention, anatomic and marginal adaption especially class II. **(Note)**
		Note: This study did not illustrate results of success rate for each class, The combination of coating had no effect on the overall success of material. No significant difference between both materials, however, EquiaFil showed slightly better performance when including all cavities.								
9. Diem VT. et al 2014 [34]	I	Parallel	Vietnam (Semi-rural school) LMLMLLL	3y	11-12y	4 clinicians	Fuji IX GP Extra (F IX) (n=87^{A},69^{B}) F IX + G-Coat plus (n=84^{A},65^{B}) Solare (composite) (n=83^{A},64^{B})	Conditioner Encapsulated	Hickel et al criteria Cast criteria	F IX + nanofilled resin coating exhibited significantly less wear than F IX only for one- and two-year evaluation.
c. Atraumatic restorative technique (AFR can be calculated)										
10. Molina GF et al. 2018 ** [31] **(Note)**	II	Parallel	Argentina (Dental school) LMLLLML	3y	Intellectual disability	1 operator	ART (Equia/Chemfil Rock with coating), Conventional (Filtek Z250 with 3-step adhesive; rubber dam was used for this group) (DR=0%)	Conditioner Encapsulated	ART criteria	3-year survival rates, (AFR) GIC =90.3,(3.34)% Resin composite =66.7,(12.63)%
		Note: The results of single surface restorations were excluded from this review due to mixed results of class I, V.								
11. Ibiyemi O. et al 2011 [61]	I	Split.	Nigeria in Idikan LLLLLLL	2y	8-19	1 dentist	Fuji IX GP + conditioner (n=93^{A}) Fuji IX GP without conditioner (n=93^{A}) (DR=0.01%)	Hand-mixed	ART criteria	2-year survival rates, (AFR) GIC with conditioner =93.5,(3.30)% GIC without conditioner =88.5,(5.93)%
12. Zanata RL. et al 2011 [64]	II (include MOD & involved cusp)	Parallel	Brazil (8 public health centers) MMLLMLL	10y	Average 19y Pregnant patients DMFT 15.9	1 trained dentist	Fuji IX (n=107^{A},62^{B}) (DR=52.9%) Zinc oxide eugenol (ZOE) 90.8% of ZOE failed within 2 years, only GIC group was evaluated	Conditioner for GIC Hand-mixed	USPHS & ART criteria	The survival rates,(AFR) of Fuji IX, ART criteria: 1 year: 91.2,(8.80)%, 2 year: 86.8,(6.83)%, 10 year: 30.6,(11.17)%
		Note1: The results of single surface restorations were excluded due to mixed results of class I, V. **Note 2:** Main causes of failure (% of total failure):Total loss 22%, Marginal defects 11%								
13. Ercan E. et al 2009 [47]	I	Split.	Turkey (Rural districts) LMLLLLL	2y	7-12y (poor OH) DMFT 5.2	1 experienced dentist	Ketac Molar (n=22^{A}), Vitremer (n=31^{A}) (DR~3.3%)	Conditioner Hand-mixed	USPHS/ART criteria	2-year survival rates, (AFR) (Sig.b/w 2 gr) Ketac M =80.9,(10.06)%, Vitremer =100,(0)%
	II						Ketac Molar (n=21^{A}), Vitremer (n=17^{A}) (DR~3.3%)			2-year survival rates, (AFR) (Sig.b/w 2 gr) Ketac M =41.2,(35.81)%, Vitremer =100,(0)%
14. Farag A. et al 2009 [54]	I	Parallel	Egypt MMLMMLL	5y	14-15y	1 operator	Fuji IX GP Fast (n=60^{A},41^{B})	Conditioner Encapsulated	ART criteria	5-year survival rate of cl I, (AFR)=85,(3.2)%
	II						Fuji IX GP Fast (n=30^{A},20^{B}) **(Note)**			5-year survival rate of cl II, (AFR)=77,(5.09)%
		Note: The survival rates of ART with (85%; n=45^{A},34^{B}) and without disinfection (80%; n=45^{A},27^{B}) were not different.								
15. Lo EC. et al 2007 [48]	I	Long.	China (4 schools) MMLMLLL	6y	12-13y DMFT 0.6	5 assistant dentists	Ketac Molar (n=230^{A}) (DR=43%)	Conditioner Hand-mixed	USPHS criteria	6-year survival rate, (AFR) =76,(4.47)% The main cause of failure is the loss of filling.
	II (large restorations)						Ketac Molar Large restorations (n=64^{A}) Class II (n=16^{A} from 64) (DR=39%)			6-year survival rate, (AFR) =59,(8.42)% Main course of failure is loss of filling. (Note: large restoration = > half of involved surface or > 1 surface)

Table 3 (*continued*)

References	GV Black Classifi-cation	Study design[1]	Location/ Risk assessment[2]	Follow-up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ No.of restoration/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
16. Frencken JE. et al 2007 [49]	I-small	Parallel	Syria MMLMNML	6.3y	Average 13.8y DMFT 5.5	8 dentists	Fuji IX, Ketac Molar (n=222^{A}) Amalgam (n=116^{A})	Conditioner Hand-mixed	ART criteria	6.3-year survival rates, (AFR) ART GICs =69.2,(5.72)%, Amalgam =63.4,(7.03)% **(Note)**
	I-large (cover M, D, central pits)						Fuji IX, Ketac Molar (n=70^{A}) Amalgm (n=108^{A})			6.3-year survival rates, (AFR) of large cavities ART GICs =55.8,(8.91)%, Amalgam =52.4,(9.82)% **(Note)**
		Note: An operator effect was observed on both treatments, Common causes of failure for both restorations were dentin carious lesion development and mechanical defect.								
17. van Gemert-Schriks MCM. et al 2007 ** [30]	I	Parallel **(Note1)**	Suriname **(Note2)** LLLMMLL	3y	6y	4 dentists	Ketac Molar (n=54^{A}) (DR=4.63%)	No data con. No data mix.	ART criteria	3 year-survival rate, (AFR) =29.6,(33.36)% Blood & saliva contamination =9.3% Main reasons for failure were secondary caries and gross marginal defects
		Note1: Parallel by tooth type (permanent and primary dentitions); **Note2:** The trial was done in the area of rain forest of Suriname in South America.								
18. Wang L. et al 2004 [50]	I	Long.	Brazil (5 schools) MMLMMLL	3y	7-12y DMFT 5.92	2 trained dental students (no assistants)	Ketac Molar (n=150^{A},57^{B}) (DR=62%)	Conditioner Hand-mixed	ART criteria	6-month survival rate, (AFR) =71.8,(48.45)% 3-year survival rate, (AFR) =21,(40.56)%
19. Zanata RL. et al 2003 [51]	I	Parallel	Brazil (8 health centers) MMLLMLL	2y	Average 19.1y pregnant women	1 dentist	Fuji IX (n=143) Reinforced ZOE (n=134)	Hand-mixed	Frencken ART criteria	2-year survival rates, (AFR): Fuji IX =92.45,(3.85)%, Reinforced ZnO =12.71,(64.35)%
		Note: The results of class II restorations in this study were excluded due to presence in the relevant article with longer follow-up period (Zanata RL et al. 2011).								
20. Kalf-Scholte SM. et al 2003 [52]	I	Split.	Malawi (Fully equipped dental clinic) LMLMLML	3y	14-20y	2 dentists	Chelon Silver Miracle Mix (n of 2 GICs = 89^{A}) Amalgam (n=89^{A}) (DR~27% for both groups)	No data con. Hand-mixed Polishing amalgam	USPHS/ Ryge criteria	3-year survival rates, (AFR): Silver reinforced GICs (2 groups) =81,(6.78)% Amalgam =90.4,(3.31)% (Sig. difference) A common cause of failure for all materials was fracture.
21. Mandari GJ. et al 2003 [45]	I	Partial split (em-ployed for 2 mate-rials)	Tanzania (3 urban & 2 rural schools) LLLLMML	6y	Average 11y	1 dental therapist	Fuji II (n=215^{A}: 3 sub-gr) Amalgam (n=215^{A}: 3 sub-gr) 3 subgroups of each material -C-gr (full equipment) -MC-gr (portable unit & electric supply) -U-gr (ART), (DR=20.7%)	No con. Hand-mixed	USPHS/ Ryge criteria	6-year survival rates, (AFR) C gr: Am=74,(4.89)%; GIC=75,(4.68)% MC gr: Am=74,(4.89)%; GIC=78,(4.06)% ART: Am=70,(5.77)%; GIC=67,(6.46)% AFRs of 2 C gr (Am & GIC) and ART-GIC were used to analyse in this review **(Note)**
		Note: Common causes of failure: Amalgam: fracture, marginal defect, GIC: loss of material								
22. Gao W. et al 2003 [46]	I	Parallel	China (Dental school hospital) LMLMMML	2.5y	Healthy adults	3 dentists	Fuji IX GP -ART (n=29^{A},8^{B}) -Conv (n=32^{A},4^{B}) Ketac Molar -ART (n=26^{A},9^{B}) -Conv (n=33^{A},8^{B}) Amalgam (n=29^{A},6^{B}) (DR=76.5%)	Conditioner Encapsulated No polishing of amalgam	USPHS/ Ryge criteria	One restoration from ART Fuji IX group failed from caries associated with marginal fracture. SR, (AFR) of ART Fuji IX =96.55,(1.39)% Survival rates of other groups were 100%. AFR for other 4 groups =0% Small surface voids were observed in the GICs (31%) at 30 months.
23. Ziraps A, Honkala E. 2002 [53]	I	Parallel	Latvia (Dental Institute) MLLLMLL	2y	8-14y	1 experienced dentist	Chemflex (n=40^{A},27^{B}) Fuji IX (n=23^{B},18^{B}) (DR=12.7%)	No data con. No data mix.	ART criteria	2-year survival rates, (AFR) Chemflex =92.5,(7.5)%, Fuji IX =94.4,(5.6)% No significant difference between materials

Table 3 (*continued*)

References	GV Black Classifi-cation	Study design[1]	Location/ Risk assessment[2]	Follow-up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ No.of restoration/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
24. Lo EC. et al 2001 ** [28]	I	Split.	China (2 schools) LLLLLLL	2y	6-14y	1 experienced dentist	Chemflex (n=55^{A}), Fuji IX (n=55^{A}) (DR=8.9%)	Conditioner Hand-mixed	ART and USPHS criteria	2-year survival rates, (AFR) Chemflex =95,(2.53)%, Fuji IX =96,(2.02)%
25. Yee R. et al 2001 ** [29]	I	Parallel	Nepal (7 rural schools) MMLMMLL	2y	Unknown	4 health care workers & 2 dentists	Fuji IX (ART GIC) (n=21^{B}) Dentspy & SS white (non-ART GIC) (n=39^{B}) (DR=31%)	No data con. No data mix.	ART criteria	2-year survival rates, (AFR) ART GIC =100,(0)% Non-ART GIC =67,(18.15)%
	Note: The result of class II in this study was not included due to mixed data of primary and permanent dentitions.									
26. Holmgren CJ. et al 2000 [55]	I small I large	Long.	China (4 secondary schools) MMLMLML	3y	12-13y	5 local dentists	Ketac Molar (n=206^{B}) Ketac Molar (n=47^{B}) (DR for small & large cl I=0.06%)	Conditioner No data mix.	ART and USPHS criteria	3-year survival rate, (AFR) =92,(2.74)% 3-year survival rate, (AFR) =76,(8.74)% (Note: large restoration = > half of involved surface or > 1 surface)
	II						Ketac Molar (n=14^{B}) (DR=0.13%)			3-year survival rate, (AFR) =57,(17.07)%
27. Ho TF. et al 1999 [56]	I	Parallel	Hong Kong LLLLMLL	2y	Average 26.69y	1 dentist	Fuji IX (n=55^{A},47^{B}) Chemfil Superior (n=45^{A},37^{B})	Conditoner Hand-mixed	USPHS-Ryge criteria	2-year failure rate, (AFR) of all restorations =7,(3.56)% Mean cumulative wear: Fuji IX (83.1µ), Chemfil (104µ) (no sig.)
28. Frencken JE. et al 1998 [59]	I	Long.	Zimbabwe (6 secondary schools) MMLMLML	3y	Average 14.1y	2 dentists, 2 senior & 2 junior dental therapists	Fuji IX (n=297^{A},206^{B}) (DR=30.6%)	Conditioner Hand-mixed	ART criteria	3-year survival rate, (AFR) =88.3,(4.06)% 3-year survival rates per operator (65.4-94.3%) (sig. a dentist vs a junior therapist)
29. Mallow PK. et al 1998 [57]	I	Long.	Cambodia (1 school) MMLLLLL	3y	12-17y	1 dental nurse	Fuji II (n=23^{B}) (DR=20.5%)	No con. Hand-mixed	ART criteria	3-year survival rate, (AFR) =60.9,(15.24)%
30. Frencken JE. et al 1998 [58]	I	Long.	Zimbabwe (6 secondary schools) MMLMLML	3y	Average 13.9y	2 dentists, 2 qualified therapists	Chemfil Superior (n=307^{A}) (DR=35.8%)	Conditioner Hand-mixed	ART criteria	3-year survival rate, (AFR) =85.3,(5.16)% Operator factor influenced 3-year survival rates
31. Phantumva-nit P. et al 1996 [60]	I	Parallel	Thailand (3 villages) LMLMMML	3y	Children & adult (unspecified ages)	1 dentist, 2 dental nurses	Single-surface restorations Chemfil (n=241^{A}) (DR=28%) Amalgam (n=205^{A}) (DR=34%) Regarding class I Chemfil (n=153^{A})	Conditioner Hand-mixed	ART criteria	3-year survival rates, (AFR) GIC =71,(10.79)%; Class I GIC=62,(14.73)% Amalgam =85,(5.27)% Only AFR of cl I GIC was used for analysis.

[1], Study design: Long. = Longitudinal study (Non-controlled prospective study), Parallel. = Parallel randomised clinical trial, Split. = Split-mouth randomised clinical trial, Retro. = Retrospective clinical study; [2], Risk assessment using Robin-I consisting of 5 codes (L = low risk. M = moderate risk, S = serious risk, C = critical risk, N = no information] arranged from left to right in the order of 7 domains [1) bias due to confounding, 2) bias in selecting participant, 3) bias in classification of intervention, 4) performance bias, 5) bias due to missing data, 6) detecting bias, 7) bias in outcome reporting]; [3], Pt. = Patient; [4], no. = Number; Number of filling: A superscript is a number of filling at first visit, B superscript is number of filling after final recall visit; **, the studies reported data of permanent and deciduous dentitions; [5], Specific conditions, Conditioner = conditioner for GIC, No con. = no conditioner, No data con. = unknown for whether use conditioner, Encapsulated = encapsulated GIC, Hand-mixed = hand-mixed GIC, No data mix. = the mixing method of GIC is unknown.

Table 4

Some characteristics of clinical studies of GICs for restoring posterior restorations in primary teeth.

References	GV Black's classifica-tion	Study design[1]	Location/ Risk assessment[2]	Follow - up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ Number of filling/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results

a. Conventional technique (AFR can be calculated)										
32. Tal E. et al 2017 [79]	II	Retro.	Israel (Private clinic) MMMMLLL	22mo	6.2-11.8y	Unknown	Equia (n=93[B]); Rubber dam was used	No data con. No data mix.	Specific criteria	22-mo survival rate, (AFR) =93.5,(3.61)%
33. Bektas Donmez S. et al 2016 [81]	II	Split.	Turkey (Dental school) LLLLLML	18mo	4-7y	1 author	RMGIC (Photac-fil) (n=31[A],29[B]) Compomer (Dyract extra) (n=31[A],30[B]) Resin composite (Esthet-X) (n=31[A],27[B]) Rubber dam was used.	No con. Encapsulated (for RMGIC)	FDI criteria	18 mo-Survival rates, (AFR) RMGIC = 90.3,(6.58)% Compomer = 100,(0)% Composite = 80.6,(13.39)%
34. Webman M. et al 2016 [80]	II slot design	Retro.	US (Private clinic) MMMLLML	At least 3 y	2.7-10.9y	1 pedodontist	RMGIC (Vitremer with primer) (n=427[B])	Hand-mixed **(Note)**	Specific criteria	Survival rate, (AFR) =97.42,(0.87)%
Note: Nitrous oxide, local anesthesia and rubber dam were used.										
35. Sengul F, Gurbuz T. 2015 [82]	II outer half of dentine	Parallel	Turkey (University of Health Sciences) LLLMLML	2y	5-7y High-caries risk	1 practitioner	Composite (Valux Plus) RMGIC (Fuji II LC) Compomer (Dyract AP) Giomer (Beautiful) (n=146[A] for all restorations) (DR=0%)	No data con. No data mix. Rubber dam was used before restoration	FDI criteria	2-year survival rates, (AFR) **(Note)** Composite =77.5,(11.97)% RMGIC =71.9,(15.21)% Compomer =66.7,(18.3)% Giomer =78.9,(11.17)%
Note: However, RMGIC was the most successful material regarding the biologic consideration.										
36. Alves dos Santos MP. et al 2010 [65]	I	Split.	Brazil (Dental school) LLLMMMM	4y	3-9y	Operators	RMGIC (Vitremer+primer) (n=33[A],27[B]) PMRC (Freedom) (n=36[A],29[B]) Composite (TPH spectrum) (n=30[A],23[B])	-	Modified USPHS criteria	4-year survival rates, (AFR): RMGIC =74.1,(7.22)%; PMRC =93.1,(1.77)%; Composite =78.3,(5.93)%
	II conser-vative						RMGIC (Vitremer+primer) (n=13[A],11[B]) PMRC (Freedom) (n=15[A],11[B]) Composite (TPH spectrum) (n=14[A],13[B]) (DR=0.11%)			4-year survival rate, (AFR): RMGIC =54.5,(14.08)%; PMRC =45.5,(17.87)%; Composite =53.8,(14.36)%
37. Andersson-Wenckert I, Sunnegardh-Gronberg K. 2006 [83]	II	Split.	Sweden LLLMLML	2y	5-11y	5 dentists	RMGIC (Vitremer) **(Note1)** (n=66[A],50[B]) Composite (Tetric Flow with 2-step etch & rinse adhesive) (n=66[A],50[B])	Rubber dam was not used	Modified USPHS criteria	2-year failure rates, (AFR): RMGIC=10.6,(5.45)% Flowable composite=13.6,(7.05)% **(Note2)**
Note1: unknown for whether primer was used. **Note2:** Main failure of resin composite was secondary caries but RMGIC failed from wear and excessive dissolution.										
38. Qvist V. et al 2004 [84]	II	Parallel	Denmark (Danish public dental health service) MLLMMML	7y	3.6-14.9y	15 clinicians	Fuji II LC (n=385[B]), Photact-Fil (n=413[B]), Vitremer (n=393[B]), Dyract (n=374[B]) Each group was divided into the materials with and without conditioner. (n=1,565[A] for all restorations) (DR=7%)	Conditioner & Primer Rubber dam was not used	Specific criteria	7-year failure rates, (AFR) %Fuji + cond=19,(2.97); - cond=19,(2.97) %Pho + cond=20,(3.14); - cond=24,(3.84) %Vit + cond=14,(2.13); - cond=19,(2.97) %Dyr + cond=9,(1.34); - cond=21,(3.31)
Note: RMGIC and compomer were both suitable materials for class II restorations in primary teeth., Conditioner had less effect than operators.										
39. Hubel S, Mejare I. et al 2003 [85]	II **(Note 1)**	Major split. **(Note2)**	Sweden (Dental School) LLLLMML	3y	4-7y	1 operator	RMGIC (Vitremer) (n=53[A]) GIC (Fuji II) (n=62[A]) Conditioner with polyacrylic acid for 2 gr	Rubber dam was not used	Modified USPHS criteria	3-year survival rates, (AFR) **(Note 3)** Vitremer =94,(2.04)%, Fuji II =81,(6.78)%
Note 1: Lesion depth; 63% outer half of dentin, **Note 2:** Major split. other remaining used parallel, **Note 3:** The most common type of failure was the loss of retention.										

Table 4 (*continued*)

References	GV Black's classifica-tion	Study design[1]	Location/ Risk assessment[2]	Follow - up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ Number of filling/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
	I	Long.	Australia	3y	Unknown	Unknown	Fuji IX (n=56[A],19[B]) (DR=66.07%)	Conditioner	USPHS criteria	3-year survival rate,(AFR) =100,(0)%

40. Rutar J. et al 2002 [66]	II slot design		MMLLMNL				Fuji IX (n=73[A],27[B]) (DR=63.01%) Fuji IX with resin coating for cl I, II	Encapsulated		3-year survival rate,(AFR) =93.4,(2.25)%
41. Croll TP. et al 2001 [68]	I	Retro.	US (Private clinic) MMMMLML	At least 3y	1-10y	2 dentists	RMGIC (Vitremer with primer) (n=393[B])	Hand-mixed Rubber dam was used	Modified USPHS	Survival rate, (AFR) =92.6,(2.53)%
	II						RMGIC (Vitremer with primer) (n=406[B])			Survival rate, (AFR) =93.3,(2.29)%
42. Kramer N, Frankenberger R. 2001 [67]	I	Long.	Germany (Dental school) SMLLLML	2y	3-11y	1 experienced dentist	Metal-reinforced GIC (Hi-Dense) (n=19[A])	No con.	Modified USPHS criteria	2-year survival rate, (AFR) =92,(4.08)%
	II						Metal-reinforced GIC (Hi-Dense) (n=35[A]) (DR=0% in class I & II)	No data mix. Resin coating		2-year survival rate, (AFR) =66,(18.76)%
43. Donly KJ. et al 1999 [88]	II	Split.	US LLLLLML	3y	Unknown	1 dentist	RMGIC (Vitremer with primer) (n=19[B]) Amalgam (n=19[B])	Hand mixed Rubber dam was used	Modified USPHS criteria	3-year failure rates, (AFR): RMGIC= 43.33,(17.25)%; Amalgam=43.7,(17.43)%
44. Espelid I. et al 1999 [87]	II small	Split.	Norway LLLLMML	3y	Unknown	2 trained dentists	RMGIC (Vitremer) (n=49[A],25[B]), Silver reinforced GIC (Ketac Silver) (n=49[A],20[B])	Follow instructions	USPHS criteria	3-year survival rates, (AFR): RMGIC= 98,(0.67)%; Ketac Silver=45,(23.37)%
45. Folkesson UH. et al 1999 [86]	II	Long.	Sweden SMLMMSL	3y	4-12y	6 dentists	RMGIC (Vitremer with primer) (n=174[A], 68[B])	-	Modified USPHS criteria	3-year failure rate, (AFR) =19.8,(7.09)%
46. Qvist V. et al 1997 [69]	I	Parallel	Denmark (2 municipalities) MLLMMSL	3y	3-13y	14 dentists	Ketac Fil (n=87[A]) Amalgam (n=73[A]) Ketac Fil (n=384[A]) Amalgam (n=456[A]) (**Note)**	No con. Encapsulated	Specific criteria	3-year failure rates, (AFR): GIC =25, (9.14)%, Amalgam =15,(5.27)% 3-year failure rates, (AFR): GIC=42, (16.6)%, Amalgam =18,(6.40)%
	II									
Note: DR=4% and 8% for GIC and amalgam respectively; Exfoliated teeth =31% and 35% for GIC and amalgam respectively										
47. Kilpatrick NM. et al 1995 [89]	II	Split.	UK LMLMLSL	2.5y	4-11y	1 dentist	Ketac Fil with resin coating Ketac Silver with resin coating (N=92) (DR=0%)	Conditioner Encapsulated	USPHS criteria	2.5-year failure rates, (AFR) Ketac Fil =23,(9.93)% Ketac Silver =41,(19.03)%
48. Ostlund J. et al 1992 [90]	II	Parallel	Sweden (1 Public clinic) MMLLLSL	3y	4-6y	2 dentists	Chemfil (n=25) Amalgam (n=25) Resin composite (n=25) (DR=0%)	No data con. Hand-mixed **(Note)**	USPHS criteria	3-year failure rates, (AFR) GIC=60,(26.32)%, Amalgam=8,(2.74)%, Composite=16,(5.65)%
Note: Rubber dam was applied for resin composite and GIC; Delay polishing (1 week) for all restorations; All GIC restoration failed by fracture restoration, mainly in the isthmus area.										
b. Conventional technique (AFR cannot be calculated)										
49. Abo-Hamar SE. et al 2015 [35]	I	Split.	Egypt LLLLNLL	2y	5-8y	1 clinician	Nanofilled RMGIC (Ketac Nano) (n=30[A]) RMGIC (Vitremer) (n=30[A]) Rubber dam was used	Use each primer Hand-mixed	Modified USPHS criteria	There was no significant difference between two materials.
50. Fuks AB. et al 2000 [39]	II	Parallel	Brazil (Dental school) LLLLMLL	2y	8-10y	1 operator	RMGIC (Vitremer+primer) (n=40[A]) Resin composite (Z100) + 3-step etch & rinse adhesive (n=38[A]) Amalgam (n=24[A])	Hand-mixed Rubber dam was used	Modified Cvar & Ryge criteria	At 2y evaluation, Z100 > Vitremer for surface appearance and colour match. For radiolucent defects at cervical margin (%), Z100(47) >Vitremer(13) > amalgam(11).

Table 4 (*continued*)

References	GV Black's classifica-tion	Study design[1]	Location/ Risk assessment[2]	Follow - up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ Number of filling/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results

c. Atraumatic restorative technique (AFR can be calculated)										
10. Molina GF et al. 2018 ** [31]	II	Parallel	Argentina (Dental school) LMLLLML	3y	Intellectual disability	1 operator	ART (Equia/Chemfil Rock with coating) Conventional (Filtek Z250 with 3-step adhesive) (with rubber dam) (DR=0%)	Conditioner Encapsulated	ART criteria	3-year survival rates, (AFR) GIC =81.6,(6.55)% Resin composite =64.2,(13.73)%
		Note The results of single surface restorations were excluded from this review due to mixed results of class I, V								
51. Hesse D et al. 2016 [92] (samples are difference from the article no. 52)	II	Parallel	Brazil 2 cities: Barueri & Recife LLLLMLL	2y	6-7y	4 trained undergraduate students	Fuji IX was used 1) ART + petroleum jelly (PJ) (n=114[A]) 2) Bi-layer ART + PJ (n=71[A]) 3) ART + coating (n=105[A]) 4) Bi-layer ART + coating (n=99[A]) (DR=13.11%)	Conditioner Hand-mixed	Roleveld et al criteria	2-year survival rates, (AFR) Overall =46.4,(31.88)% Group 1 =27.7,(47.37)% Group 2 =61.7,(21.45)% Group 3 =47.2,(31.30)% Group 4 =56.9,(24.57)%
52. Hesse D et al. 2016 [91] (samples are difference from the article no. 51)	II	Parallel	Brazil in Barueri (26 schools) LMLLLLL	3y	6-7y	4 trained undergraduate students	Fuji IX was used 1) ART + petroleum jelly (PJ) (n=55[A]) 2) Bi-layer ART + PJ (n=54[A]) 3) ART + coating (n=42[A]) 4) Bi-layer ART + coating (n=57[A]) (DR=9.1%)	Conditioner Hand-mixed	Roleveld et al criteria	3-year survival rates, (AFR) Overall =52.8,(19.18)% Group 1 =30.9,(32.39)% Group 2 =64.2,(13.73)% Group 3 =53.7,(18.72)% Group 4 =64.9,(13.42)%
53. Hilgert LA. et al 2014 [70]	I II multi-surface restora-tions	Parallel	Brazil (Public primary schools) MMLLMML	3y	6-7y	3 trained pedodontists	Ketac Molar (n=116[A],92[B]) Amalgam (n=105[A],73[B]) Ketac Molar (n=270[A],190[B]) Amalgam (n=259[A],178[B])	Conditioner No data mix.	ART criteria	3-year survival rates, (AFR) **(Note 1)** Ketac=90.1,(3.42)%, Am=93.4,(2.25)% 3-year survival rates, (AFR) **(Note 2)** Ketac=56.4,(17.38)%, Am=64.7,(13.51)%
		Note 1: Am = Amalgm. The main causes of failure were mechanical reasons (94.8%), **Note 2:** The main causes of failure were mechanical reasons (94.8%), especially loss of restoration (70.6%, 63.6% for Ketac Molar and amalgam, respectively).								
54. Kemoli AM. 2014 [93]	II	Parallel	Kenya (30 local schools) MMLMNLM	2y	6-8y	Dentists, dental students, community officers (all were trained)	Fuji IX Ketac Molar Ketac Molar Applicap (encapsulated) (N=648[B])	Conditioner Hand-mixed & Encapsulated	Specific criteria	2-year survival rate, (AFR) =30.8,(44.5)% Room temperature, type & mixing time of GICs have no influence on survival rates. Experience of operators & assistants affected survival rates.
55. de Amorim RG. et al 2014 [71]	I II multi-surface restora-tions	Parallel	Brazil (6 public schools) MMLLMML	2y	6-7y	3 trained pedodontists	Ketac Molar (n=116[A],102[B]) Amalgam (n=105[A], 75[B]) Ketac Molar (n=270[A],197[B]) Amalgam (n=259[A],183[B])	Conditioner Hand-mixed	ART criteria	2-year survival rates, (AFR) Ketac Molar =92.8,(3.67)% Amalgam =97.5,(1.26)% Two-year survival rates, (AFR) Ketac Molar =64.9,(19.44)% Amalgam =69.5,(16.63)% **(Note)**
		Note: The main cause of failure was the loss of restoration (42.0%, 32.3% for Ketac Molar and amalgam, respectively).								

Table 4 (*continued*)

References	GV Black's classifica-tion	Study design[1]	Location/ Risk assessment[2]	Follow - up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ Number of filling/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results

56. Bonifacio CC. et al 2013 [95]	II	Parallel	Brazil in Barueri LMLLLLL	18mo	6-7y	4 trained undergraduate students	Fuji IX was used 1) ART (n=110^{A}) 2) Bi-layer ART (n=98^{A}) (DR=6%)	Conditioner Hand-mixed	ART criteria adapted for proximal restorations	18mo-survival rates, (AFR) Overall =68,(22.67)% ART =67,(23.43)% Bi-layer =68,(22.67)%
57. Bonifacio CC. et al 2013 [94]	II	Parallel	Brazil in Itatiba (36 public schools) LLLLLLL	3y	5-8y	2 final-year trained dental students	Fuji IX (n=86^{A}) Hi-Dense (n=88^{A}) Maxxion R (n=88^{A}) (n=262^{A} for overall) (DR=17.6%)	Conditioner Hand-mixed	ART criteria adapted for proximal restorations	3-year survival of restorations = 24% (AFR 37.86%) There was no significant difference of success rate among 3 materials. **(Note)**
Note: Factor affected survival rate e.g. operator, distal cavity										
58. da Franca C. et al 2011 [78]	I	Long.	Brazil (Schools) MMLMMML	2y	6-7y	2 final-year students	Ketac Molar (n=65^{B}) (DR=30.1%)	Conditioner Hand-mixed	Gemert-Schriks's criteria	2-year survival rate,(AFR) =60,(22.54)%
	II						Ketac Molar (n=47^{B}) (DR=51.5%)			2-year survival rate,(AFR) =27.6,(47.46)%
Note: The main cause of failure was the loss of restoration (class I =92.3%, class II =97%)										
59. Ersin NK. et al 2008 [72]	I	Split.	Turkey in Izmia LLLMLLL	2y	6-8y	3 dentists	Ketac Molar without (n=56^{A},51^{B}) with chlorhexidine (CHX) (n=53^{A},46^{B})	Condiitoner Hand-mixed	USPHS/Ryge's criteria	2-year survival rates of cl I, (AFR) GIC without disinfectant =97.7,(1.17)% GIC with disinfectant =95.2,(2.43)%
	II						Ketac Molar without (n=70^{A},58^{B}) with CHX (n=70^{A},47^{B})			2-year survival rates of cl II, (AFR) GIC without disinfectant =69.4,(16.69)% GIC with disinfectant =63.9,(20.06)%
Note: Cavity disinfectant (2% CHX) did not influence the survival rates of Ketac Molar restorations irrespective of classification.										
17. van Gemert-Schriks MCM. et al 2007 ** [30]	I	Parallel **(Note1)**	Suriname (Rain forest) LLLMMLL	3y	6y	4 dentists	Ketac Molar (n=133^{A}) (DR=4.63%)	No data con. No data mix.	ART criteria **(Note2)**	3y-survival rate, (AFR) =43.4,(24.29)%
	II						Ketac Molar (n=342^{A}) (DR=4.63%)			3y-survival rate, (AFR) =12.2,(50.40)%
Note1: Parallel by tooth type (permanent and primary dentitions) and cavity classification (class I and II) **Note2:** Blood & saliva contamination of cl I, II restorations =9.8 % and 32.2 %, respectively; Main reasons for failure of class I & II were gross marginal defects and total or partial losses.										
60. Ersin NK. et al 2006 [73]	I	Split.	Turkey (10 primary schools) LLLMLLL	2y	6-10y (DMFT= 2.13)	3 dentists (authors)	ART-SureFill (composite) (n=111^{A},95^{B}) ART-Fuji IX GP (n=119^{A}, 106^{B})	Conditioner Composite with one-step self etch adhesive	USPHS/Ryge's criteria	2-year survival rates, (AFR): SureFill =91,(4.61)%, Fuji IX GP =96.7,(1.66)%
	II						ART-SureFill (composite) (n=93^{A},73^{B}) ART-Fuji IX GP (n=96^{A},70^{B})			2-year survival rates, (AFR): SureFill =82,(9.45)%, Fuji IX GP =76.1,(12.76)%
61. Yu C. et al 2004 [74]	I	Partial split. (em-ployed for 2 tech-niques)	China LMLMMML	2y	Average 7.4 ±1.24y	2 experienced dentists	**Conventional technique (Note 1)** F IX (n=24^{A},11^{B}), Ketac (n=21^{A},10^{B}) Am (n=32^{A},11^{B}) **ART technique** F IX (n=20^{A},10^{B}), Ketac (n=17^{A},7^{B})	No data con. Encapsulated	Frencken's ART criteria	**Survial rates, (AFR) of conv. technique** F IX =90.0,(5.13)%, Ketac =89.6,(5.34)% Am =88.9,(5.71)% **Survival rates, (AFR) of ART technique** F IX =89.2,(5.55)%, Ketac =93.8,(3.15)%
	II						**Conventional technique (Note 1)** - F IX (n=7^{A},3^{B}), Ketac (n=11^{A},7^{B}) **ART technique** - F IX (n=15^{A},10^{B}), Ketac (n=20^{A},14^{B})			**Survival rates, (AFR) of conv. technique** F IX =75.0,(13.4)%, Ketac =88.9,(5.71)% **Survival rates, (AFR) of ART technique** F IX =49.1,(29.93)%, Ketac =55.0,(25.84)%
Note1: F IX = Fuji IX GP, Ketac = Ketac Molar, Am = Amalgam, Conv = Conventional **Note2:** Restoration failures were attributed to losses mainly from bulk and marginal fractures.										

Table 4 (*continued*)

References	GV Black's classifica-tion	Study design[1]	Location/ Risk assessment[2]	Follow - up period	Age of Pt.[3]/ Hygiene	Operator type & no.[4]	Materials/ Number of filling/ Dropout rate; DR	Specific conditions[5]	Criteria for evaluation	Results
62. Honkala E. et al 2003 [75]	I	Split.	Kuwait LLLMLML	2y	2-9y High caries risk	2 dentists	Chemflex (n=26[B]) Amalgam (Am) (n=26[B])	No data con. Hand-mixed	ART criteria and USPHS criteria	2-year survival rates, (AFR): GIC =92.3,(3.93)%, Am =92.0,(4.08)%
	II						Chemflex (n=9[B]) Amalgam (Am) (n=9[B])			2-year survival rates, (AFR): GIC =88.9,(5.71)%, Am =100,(0)%
63. Taifour D. et al 2002 [76]	I	Parallel	Syria (18 schools) MMLMMML	3y	6-7 y	8 dentists	FujI IX n=319[A] Ketac Molar n=157[A] Amalgam n=380[A] (DR=22.1%)	No data con. Hand-mixed	Frencken ART criteria	3-year survival rates, (AFR) of single-surface restorations: ART-GIC =86.1, (4.87)%, Amalgam =79.6,(7.32)% (Sig.)
	multi-surface restora-tions						FujI IX n=384[A] Ketac Molar n=226[A] Amalgam n=425[A] (DR=22.1%)			3-year survival rates, (AFR) of multiple-surface restorations: ART-GIC =48.7, (21.32)%, Amalgam =42.9,(24.58)% (Sig.)
		Note: The main causes of failure for occlusal and multiple surface restorations were the restoration missing followed by the gross marginal defect.								
24. Lo EC. et al 2001 ** [28]	I	Split.	China (Schools) LLLLLLL	2y	6-14y	1 experienced dentist	ChemFlex (n=26[A]), Fuji IX GP (n=26[A]) (DR=8.9%)	Conditioner Hand-mixed	ART criteria and USPHS criteria	2-year survival rates, (AFR): ChemFlex = 93,(3.56)%, Fuji IX =90,(5.13)% (no sig.)
	II						ChemFlex (n=13[A]), Fuji IX GP (n=13[A]) (DR=8.9%)			2-year survival rates, (AFR): ChemFlex = 40,(36.75)%,Fuji IX =46,(32.18)%(no sig.)
25. Yee R. et al 2001 ** [29]	I	Parallel	Nepal (7 rural schools) MMLMMLL	2y	unknown	4 health care workers & 2 dentists	Fuji IX (ART GIC) (n=21[B]) Dentspy & SS white (non-ART GIC) (n=10[B]) (DR=31%)	No data con. No data mix.	ART criteria	2-year survival rates, (AFR) ART GIC =67,(18.15)% Non-ART GIC =50,(29.29)%
		Note: The result of class II in this study was not included due to mixed data of primary and permanent dentitions.								
64. Lo EC, Holmgren CJ. 2001 [77]	I	Long.	Southern China (Pre-school children) MMLMLLL	30mo	5.1y High caries risk	7 final-year dental students	Ketac molar (n=53[A],46[B])	Conditioner Hand-mixed	ART criteria	2.5-year survival rate, (AFR) =76,(10.4)%
	II						Ketac molar (n=32[A],28[B])			2.5-year survival rate, (AFR) =54,(21.84)%
d. Atraumatic restorative technique (AFR cannot be included in this review)										
65. Kemoli AM, Amerongen WE. 2011 [37] **(Note)**	II	Parallel	Kenya (30 schools) MMLMNMM	2y	6-8y	7 operators	Fuji IX Ketac Molar Easymix Ketac Molar Applicap (encapsulated) (N=766[A], N=648[B]) (DR=15.4%)	Conditioner Hand-mixed & Encapsulated	Specific criteria	Restorations with residual caries and cervical marginal gap showed lower survival compared to restorations with or without residual caries.
		Note: This study used almost same samples of the study of Kemoli et al 2014 but different analyses were done (AFR from the study of Kemoli 2014 was used as a representative in this review).								
66. Kemoli AM. et al 2011 [36] **(Note)**	II	Parallel	Kenya (30 schools) MMLMNLM	2y	6-8y	7 operators	Fuji IX Ketac Molar Easymix Ketac Molar Applicap (encap.) (N=648[B])	Conditioner Hand-mixed & Encapsulated	Specific criteria	There was no significant different among 3 brands. Post restorative meal consumption associated with lower survival rate of GICs.
		Note: This study used almost same samples of the study of Kemoli et al 2014 but difference analyses were done (AFR from the study of Kemoli 2014 was used as a representative in this review).								
67. Kemoli AM. et al 2009 [38] **(Note)**	II	Parallel	Kenya (30 schools) MMLMNLM	2y	6-8y	7 operators	Fuji IX Ketac Molar Easymix Ketac Molar Applicap (encap.) (N=648[B])	Conditioner Hand-mixed & Encapsulated	Specific criteria	The most experience operator paired with any experience assistants using rubber dam provided higher survival rates of GICs
		Note: This study used almost same samples of the study of Kemoli et al 2014 but difference analyses were done (AFR from the study of Kemoli 2014 was used as a representative in this review).								

1, Study design: Long. = Longitudinal study (Non-controlled prospective study), Parallel. = Parallel randomised clinical trial, Split. = Split-mouth randomised clinical trial, Retro. = Retrospective clinical study; 2, Risk assessment using Robin-I consisting of 5 codes (L = low risk. M = moderate risk, S = serious risk, C = critical risk, N = no information] arranged from left to right in the order of 7 domains [1) bias due to confounding, 2) bias in selecting participant, 3) bias in classification of intervention, 4) performance bias, 5) bias due to missing data, 6) detecting bias, 7) bias in outcome reporting]; 3, Pt. = Patient; 4, no. = Number; Number of filling: A superscript is a number of filling at first visit, B superscript is number of filling after final recall visit; **, the studies reported data of permanent and deciduous dentitions. [5], Specific conditions, Conditioner = conditioner for GIC, No con. = no conditioner, No data con. = unknown for whether use conditioner, Encapsulated = encapsulated GIC, Hand-mixed = hand-mixed GIC, No data mix. = the mixing method of GIC is unknown.