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Review article

Factors affecting success rate of atraumatic restorative treatment (ART) restorations in children: A systematic review and meta-analysis

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ABSTRACT

Objectives: Aim of this systematic review was to summarize the factors that affect the success rate of atraumatic restorative treatment (ART) restorations in children.
Data/Sources: Two independent reviewers conducted a literature search in the databases PubMed, Medline and Web of Science until October 2019 with no initial time limit. Articles reporting on clinical outcomes of ART restorations placed in children were included.
Study selection: A total of 67 articles were included in this review reporting on clinical outcomes of ART restorations placed in children in 47 studies. The overall estimated success rate and 95 % confidence interval (CI) of ART restorations were 0.71 (0.65−0.77) and 0.67 (0.56−0.78) at the 12-month and the 24-month follow-up, respectively. Operator was one of the significant factors associated with the success rate of ART restorations. ART restorations placed by dental students/therapists had a significantly lower success rate compared with those placed by dentists. Besides, type of restoration (single-surface vs. multiple-surface restoration) was also associated with the success rate of ART restorations. Other factors including dentition, restorative material, clinical setting, and moisture control method had no significant influence on the success rate of ART restorations in children.
Conclusion: It is concluded that ART approach can be used to manage cavitated caries lesions in children. Operator and type of restoration are significant factors influencing the success rate of ART restorations.
Clinical significance: : This study provides valuable information on the factors that affect success rate of ART restorations in children, which helps clinicians to make informed decisions on provision of ART restorations in children.

1. Introduction

Dental caries is a dental public health problem in both developing and developed countries. Untreated caries in permanent teeth is one of the most prevalent diseases affecting 2.4 billion people worldwide [1]. Moreover, untreated caries in primary teeth affects 621 million children in the world [1]. Dental caries is a multifactorial disease involving interactions between teeth, microbial biofilm and dietary sugars, and the pathogenesis is a dynamic process of demineralization and remineralization of dental hard tissues [2]. Despite the involved role of cariogenic bacteria, modern concept of dental caries regards it as a behavioral disease with a bacterial component rather than an infectious disease. Hence, extended cavity preparation, which aims to completely remove all caries affected dental tissues and make the cavity larger than the size of the lesion itself, is no longer recommended when treating cavitated dental caries [3].

Minimal intervention dentistry (MID), which was firstly termed by Dawson and Makinson [4], is a philosophy of dental care that aims to keep teeth healthy and functional throughout a person's life. It recommends to preserve not only sound tooth tissues but also tissues with potential to remineralize so as to maximize the healing potential of the tooth [5]. Embodying the MID philosophy, the atraumatic restorative treatment (ART), which first came up in the late 1980s, evolved and became known as the ART approach in the early 1990s, is one of the minimally invasive operative approaches for management of cavitated caries lesions. The ART procedures involve removal of soft carious dental tissues using only hand instruments and local anesthesia is seldom needed. The cavity is cleaned, then restored with an adhesive

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dental material, commonly a high viscosity glass ionomer cement (GIC) [6], and the adjacent pits and fissures are sealed concurrently [7]. Resin-modified GIC (RMGIC), which presented with a better bonding performance to dental substrates compared with the conventional chemical cured GIC in laboratory tests [8], is used by some dentists in the ART approach as well.

There are several advantages of the ART approach. Firstly, free of noise and vibrations made by handpieces, and less required for local anesthesia, the ART approach is thought to be a patient-friendly treatment, especially for young children [9]. Secondly, as no electricity and running water are required, the ART approach is a good choice for outreach team to deliver dental care in a field setting with limited resources. Thirdly, ART approach is not highly equipment- and technique-demanding, so it is relatively easy and achievable to train dentists and dental auxiliaries to acquire the technique [10]. Although originally developed for provision of dental care in underserved communities, the ART approach has become an option for caries management worldwide [7].

A recent systematic review reported that single-surface ART restorations in both primary and permanent teeth had a high survival rate and therefore can be used in the clinical practice. In contrast, the survival rate of multiple-surface ART restoration was relatively low [11]. Despite this, another recent systematic review concluded that the ART approach was an alternative for restoring occlusoproximal cavities in primary teeth [12]. Hence, there are debates on whether the ART approach is as good as the conventional approach when treating dental caries [13]. In fact, the reported success rates of ART restorations vary tremendously among studies conducted in different places. Probably different study elements, e.g. restorative material, operator, and clinical setting, contribute to high heterogeneity of the results. Therefore, a systematic review with meta-analysis is needed to explore factors that affect the success rate of ART restorations to find ways to improve its clinical performance. The aims of this review were (1) to summary short- and long-term success rate of ART restorations placed in children and (2) to identify factors associated with the success rate of ART restorations placed in children. The PICO of this systematic review was to compare how the various factors (C) influence the success rates (O) of ART restorations (I) placed in children (P).

2. Material and method

2.1. Data searching

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A literature search was conducted to identify references in the databases PubMed, Medline and Web of Science until October 2019 with no initial time limit. The searching strategy was [(ART technique) AND dental] OR [atraumatic restorative treatment] OR [(ART restoration) AND (success rate)] OR [(ART restoration) AND (survival rate)] OR [(ART restoration) AND retention]. The identified references were checked for duplicates. After removal of duplicates, two independent reviewers screened the title and abstract of the identified references. The inclusion criterion was clinical studies reporting outcomes of ART restorations placed in children. The potential articles were retrieved for full-text reading. The article exclusion criteria for the purpose of the present meta-analysis were (1) no data on the success of ART restorations; (2) unclear criteria of the success of ART restorations; (3) not ART technique; (4) only reported on ART sealant; (5) evaluation based on replica/photos only; (6) study population was not children; (7) not written in English; (8) not use GIC/RMGIC; (9) being a study protocol or meeting abstract. If there was disagreement on

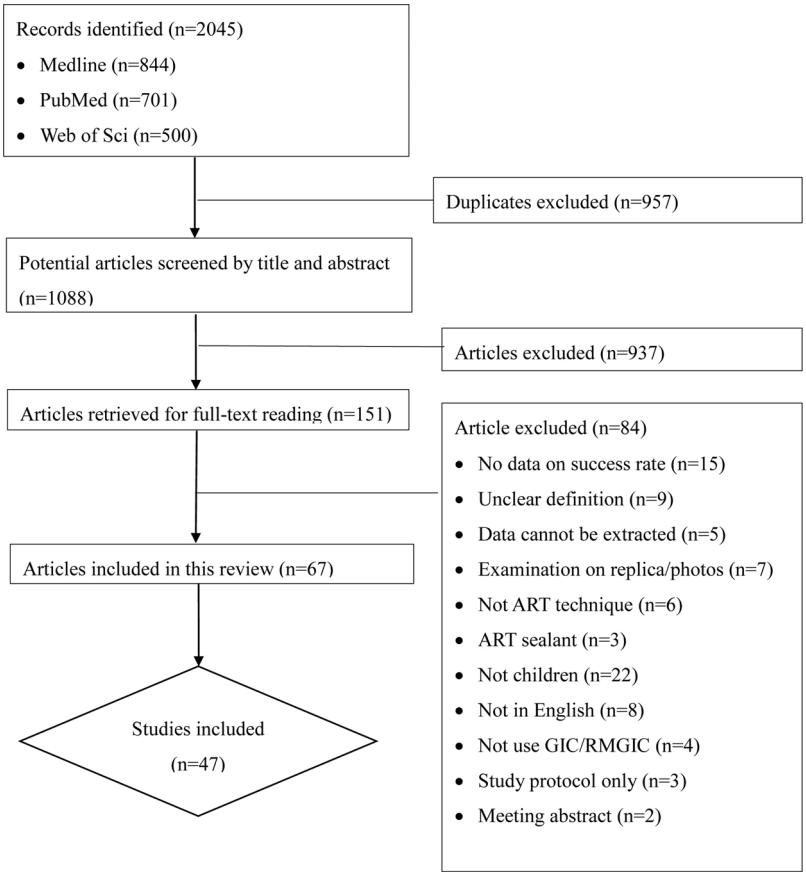

Fig. 1. Flowchart of selection process.

Table 1
Main characteristics of the included studies.

Author	Age (Year)		Study design	Location	Sample size		Dentition	Teeth
	Mean	Range			Children	Restorations		
Faustino-Silva [21]		1.5–3	Split mouth	Brazil	25	100	Primary	Posterior
Menezes-Silva [22]		8–19	Parallel group	Brazil	77	77	Permanent	Posterior
Olegário [23]	5.4	4–7	Parallel group	Brazil	173	173	Primary	Posterior
de Franca Lopes [24]	8.0	6–10	Parallel group	Brazil	33	30	Primary	Posterior
Freitas [25]	13.0	11–15	Split mouth	Brazil	40	80	Permanent	Posterior
Anna Luisa de Brito [26]		4–8	Parallel group	Brazil	117	117	Primary	Posterior
Duque [27]		3–6	Parallel group	Brazil	36	117	Primary	Posterior
Olegario [28]	6.4	4–8	Parallel group	Brazil	150	150	Primary	Posterior
Hesse [29,30]		6–7	Parallel group	Brazil	389	389	Primary	Posterior
Hilgert [31,32,33,34]	6.8	6–7	Parallel group	Brazil	154	386	Primary	Posterior
Bonifacio [35]		5–8	Parallel group	Brazil	45	45	Primary	Posterior
Bonifacio [36]		6–7	Parallel group	Brazil	208	208	Primary	Posterior
Bonifacio [37]	6.0	5–8	Parallel group	Brazil	262	262	Primary	Posterior
Luengas-Quintero [64,65]		6–13	Cohort	Mexico	304	365	Primary and Permanent	Anterior and Posterior
da Franca [38]		6–7	Cohort	Brazil	155	190	Primary	Posterior
Ibiyemi [67,68,69]	13.1	8–19	Split mouth	Nigeria	87	186	Permanent	Posterior
Kemoli [55,56,57,58,59,60,61]		6–8	Parallel group	Kenya	804	804	Primary	Posterior
Roshan [87]	6.2	5–7	Split mouth	N.R.	60	120	Primary	Posterior
Carvalho [39]		6–7	Parallel group	Brazil	232	232	Primary	Posterior
Gurunathan [53]	5.3	4–9	Split mouth	India	100	100	Primary	Posterior
Ercan [82,83]		7–12	Split mouth	Turkey	37	91	Permanent	Posterior
Yassen [54]	6.7	6–7	Split mouth	Iraq	48	96	Primary	Posterior
Cefaly [40,43]	11.6	9–16	Parallel group	Brazil	46	60	Permanent	Posterior
Frencken [75,76,77]	13.8		Parallel group	Syria	108	487	Permanent	Posterior
Van de Hoef [73]	7.5	6–12.9	Parallel group	Suriname	153	185	Primary	Posterior
Gemert-Schriks [74]	6.1		Cohort	Suriname	194	529	Primary and Permanent	Posterior
Menezes [41]		4–6	Parallel group	Brazil	110	245	Primary	Posterior
Roeleveld [79]	7.5	6–7	Parallel group	Tanzania	77	77	Primary	Posterior
Bresciani [42]		7–12	Cohort	Brazil	96	155	Permanent	Posterior
Wang [44]	10.4	7–12	Cohort	Brazil	118	150	Permanent	Posterior
Yu [47,48]	7.4		Split mouth	China	60	72	Primary	Posterior
de Souza [45]		7–12	Parallel group	Brazil	208	473	Permanent	Posterior
Honkala [62]	5.7	2–9	Parallel group	Kuwait	35	83	Primary	Posterior
Louw [71]	7.3	6–9	Parallel group	South Africa	284	570	Primary	N.R.
Rahimtoola [70]	11.4	6–16	Parallel group	Pakistan	N.R.	160	Permanent	Posterior
Taifour [78]		6–7	Parallel group	Syria	482	1086	Primary	Posterior
Ziraps [63]	11.0	8–14	Parallel group	Latvian	41	63	Permanent	Posterior
Kikwilu [80]	10.8	8–15	Cohort	Tanzania	196	296	Permanent	Anterior and Posterior
Lo [49,50]	5.1		Cohort	China	95	170	Primary	Anterior and Posterior
Lo [51]		6–14	Split mouth	China	89	202	Primary and Permanent	Posterior
Yee [66]	9.8	3–19	N.R.	Nepal	105	163	Primary and Permanent	Posterior
Holmgren [52]	12.5	12–13	Cohort	China	197	294	Permanent	Posterior
Mickenautsch [72]	10.5	6–11	Parallel group	South Africa	113	163	Permanent	N.R.
Frencken [84,86]	14.1		Cohort	Zimbabwe	142	297	Permanent	Posterior
Frencken [85]	13.9		Cohort	Zimbabwe	144	307	Permanent	Posterior
Mallow [46]		12–17	Cohort	Cambodia	53	89	Permanent	Anterior and Posterior
Frencken [81]			Cohort	Thailand	277	529	Primary and Permanent	N.R.

N.R., not reported.

the inclusion of a study, a third independent investigator would join the discussion to arrive at a consensus.

2.2. Quality assessment

Risk of bias of the included studies was assessed by the same two reviewers using two scales. The Cochrane risk of bias assessment criteria was adopted to evaluate the quality of the included randomized controlled clinical trials (RCTs) [14], while the Newcastle-Ottawa Scale (NOS) was used to assess cohort studies [15].

2.3. Data extraction

The success rate of ART restorations, which was defined as the success events divided by the total events, were extracted directly from the result section of the article or calculated using data presented in the article. The ART criteria, modified ART criteria or US Public Health Service (USPHS) criteria were adopted in the included studies to assess the success/failure of the ART restorations, and outcomes based on these assessment tools are considered consistent [16]. In order to address the missing outcome data, two calculation approaches were used. The first one was based on the total sample size at baseline as the total events, which assumes that the missing participants at the follow-up evaluations had poor results (no success events) [14]. Another method was based on only the available data at each follow-up evaluation, i.e. ignoring the missing participants [14]. For the included RCTs, only data on the success of ART restorations was extracted, while data on other dental restorations, e.g. amalgam and composite resin, reported in the included studies was not analyzed in the present review.

Furthermore, various factors which were considered as potential confounders and sources of variations of success rate of ART restorations were recorded if available, e.g. dentition (primary or permanent), restoration type (single-surface or multiple-surface), restorative material (GIC or RMGIC, hand-mixed or encapsulated), operator (dentist or student/therapist), setting (clinic or field), and moisture control method (cotton roll, saliva ejector or rubber dam). The same two independent reviewers extracted data from the included studies. Any disagreement in the data extraction between the two reviewers was resolved by discussion with a third investigator.

Table 2
Factors involved in the included studies.

Study (year)	Material				Operator		Setting		Moisture control method			Other techniques				
	GIC	RMGIC	Hand mixed	Encapsulated	Dentist	Student/ therapist	Field	Clinic	Cotton roll	Saliva ejector	Rubber dam	LA	Ca $(OH)_2$	Bilayer	No conditioning	Chlorhexidine
Faustino-Silva (2019)	√		√		N.R.			√	√							
Menezes-Silva (2019)	√			√	N.R.		√		√							
Olegário (2019)	√			√		√	√		√							
de Franca Lopes (2018)	√			√	√		N.R.		√							
Freitas (2018)	√		√	√		√		√	√			√	√			
Anna Luisa de Brito (2017)	√		√			√	√		N.R.							
Duque (2017)	√		√		√		√		√							√
Olegario (2017)	√		√			√	√		√							
Hesse (2016))	√		√			√	√		√					√		
Hilgert (2014)	√		√		√		√		√			√	√			
Bonifacio (2013c)	√		√		√	√	√		N.R.					√		
Bonifacio (2013a)	√		√			√	√			N.R.		√				
Bonifacio (2013b)	√		√			√	√		√							
Luengas-Quintero (2013)	√		√		√		√		N.R.							
da Franca (2011)	√		√			√	√		√							
Ibiyemi (2011)	√		√		N.R.		√		√						√	
Kemoli (2011)	√		√	√	√	√	√		√		√		√			
Roshan (2011)	√		√		√		√	√	N.R.							
Carvalho (2010)	√		√			√	√		√		√					
Gurunathan (2010)	√		√		N.R.			√	√							
Ercan (2009)	√	√	√		√		√		√				√			
Yassen (2009)	√		√		√		√		√						√	
Cefaly (2007)	√	√	√			√	√		√			√	√			
Frencken (2007)	√		√		√			√	√							
Van de Hoef(2007)	√		√			√	N.R.		N.R.			√				
van Gemert-Schriks (2007)	√		√		√		√		N.R.							
Menezes (2006)	√		√		N.R.			√	√	√						
Roeleveld (2006)	√		√		√	√	N.R.		√							
Bresciani (2005)	√		√		N.R.		√		√				√			
Wang (2004)	√		√			√	√		√							
Yu (2004)	√			√	√			√	√							
de Souza (2003)	√	√	√			√	√		√				√			
Honkala (2003)	√		√		N.R.			√	N.R.							
Louw (2002)	√		√		N.R.		√		√				√			
Rahimtoola (2002)	√		√		N.R.		√		N.R.				√			
Taifour (2002)	√		√		√			√	√							
Ziraps (2002)	√		√		√			√	N.R.							
Kikwilu (2001)	√		√		N.R.		√		N.R.							
Lo, Holmgren (2001)	√		√			√	√		√							
Lo, Luo (2001)	√		√		√		√		N.R.							
Yee (2001)	√		√			√	√		N.R.							
Holmgren (2000)	√		√		√		√		√							
Mickenautsch (2000)	√		√		N.R.			√	N.R.							
Frencken (1998a)	√		√		√	√	√		√							
Frencken (1998b)	√		√		√	√	√		√							
Mallow (1998)	√		√			√	√		√						√	
Frencken (1994)	√		√		√	√ (nurse)	√		N.R.							

GIC, glass ionomer cement; RMGIC, resin-modified glass ionomer cement; LA, local anesthesia used if needed; $Ca(OH)_2$, calcium hydroxide was used in the deep cavity to protect dental pulp; N.R., not reported.

Table 3
The estimated success rate of ART restorations based on the total sample size at baseline.

	6-month			12-month			24-month			36-month		
Study (year)	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight
Menezes-Silva (2019)	0.99	(0.96−1.01)	4.52	0.88	(0.81−0.96)	2.49						
Olegário (2019)	0.90	(0.85−0.94)	4.46	0.85	(0.79−0.91)	2.54	0.71	(0.64−0.78)	4.33	0.68	(0.61−0.76)	9.02
Faustino-Silva (2019)				0.94	(0.89−0.99)	2.55	0.70	(0.61−0.79)	4.28			
de Franca Lopes (2018)	0.83	(0.69−0.97)	3.80	0.80	(0.66−0.94)	2.23						
Freitas (2018)	0.70	(0.59−0.81)	4.12	0.56	(0.45−0.68)	2.36						
Anna Luisa de Brito (2017)				0.43	(0.33−0.52)	2.43						
Duque (2017)				0.39	(0.30−0.49)	2.43						
Olegario (2017)				0.65	(0.57−0.73)	2.47						
Hesse (2016)	0.63	(0.57−0.68)	4.44	0.56	(0.51−0.61)	2.54	0.40	(0.35−0.46)	4.37			
Hilgert (2014)	0.93	(0.90−0.95)	4.52	0.86	(0.82−0.90)	2.57	0.73	(0.69−0.77)	4.38	0.67	(0.62−0.72)	9.10
Bonifacio (2013a)	0.84	(0.73−0.96)	4.07	0.62	(0.47−0.77)	2.21						
Bonifacio (2013b)	0.78	(0.72−0.84)	4.41	0.72	(0.65−0.78)	2.52						
Bonifacio (2013c)	0.58	(0.52−0.64)	4.39	0.46	(0.40−0.52)	2.52	0.25	(0.19−0.30)	4.36	0.24	(0.19−0.30)	9.08
Luengas-Quintero (2013)				0.83	(0.79−0.87)	2.57	0.75	(0.71−0.80)	4.38			
Roshan (2011)	0.82	(0.74−0.89)	4.33	0.72	(0.63−0.80)	2.46						
da Franca (2011)				0.28	(0.21−0.35)	2.51	0.27	(0.21−0.34)	4.34			
Ibiyemi (2011)				0.96	(0.94−0.98)	2.59	0.94	(0.90−0.98)	4.38			
Kemoli (2011)				0.44	(0.40−0.48)	2.56	0.25	(0.21−0.28)	4.39			
Carvalho (2010)	0.65	(0.58−0.71)	4.38	0.42	(0.36−0.49)	2.51	0.16	(0.12−0.20)	4.38			
Gurunathan (2010)				0.91	(0.85−0.97)	2.53						
Ercan (2009)	0.97	(0.93−1.01)	4.48	0.87	(0.79−0.95)	2.47	0.81	(0.73−0.89)	4.31			
Yassen (2009)	0.79	(0.71−0.88)	4.26	0.57	(0.47−0.68)	2.40						
Cefaly (2007)	0.97	(0.92−1.01)	4.46	0.95	(0.89−1.01)	2.52						
Van de Hoef (2007)	0.38	(0.30−0.46)	4.28									
van Gemert-Schriks (2007)	0.58	(0.54−0.63)	4.47	0.48	(0.44−0.53)	2.56	0.39	(0.35−0.44)	4.38	0.22	(0.18−0.26)	9.13
Frencken (2007)				0.94	(0.92−0.96)	2.59	0.89	(0.86−0.92)	4.40	0.84	(0.81−0.88)	9.13
Menezes (2006)	0.62	(0.55−0.68)	4.38	0.36	(0.29−0.42)	2.52						
Roeleveld (2006)	0.31	(0.20−0.42)	4.09	0.22	(0.12−0.32)	2.42						
Bresciani (2005)	0.94	(0.90−0.98)	4.49									
Wang (2004)	0.47	(0.39−0.56)	4.27							0.08	(0.03−0.13)	9.11
Yu (2004)	0.92	(0.85−0.98)	4.37	0.81	(0.71−0.9)	2.42	0.74	(0.63−0.84)	4.24			
de Souza (2003)	0.79	(0.75−0.83)	4.49									
Honkala (2003)				0.99	(0.96−1.01)	2.59	0.71	(0.62−0.80)	4.29			
Rahimtoola (2002)	0.99	(0.97−1.01)	4.54	0.97	(0.94−1.00)	2.58	0.94	(0.91−0.98)	4.39			
Louw (2002)				0.83	(0.78−0.88)	2.55						
Taifour (2002)				0.79	(0.76−0.81)	2.58	0.73	(0.70−0.76)	4.40	0.65	(0.62−0.68)	9.14
Ziraps (2002)							0.67	(0.55−0.79)	4.19			
Lo (2001b)							0.88	(0.83−0.93)	4.37			
Lo (2001a)				0.65	(0.58−0.73)	2.49						
Kikwilu (2001)				0.77	(0.72−0.82)	2.55						
Yee (2001)							0.73	(0.63−0.82)	4.27			
Holmgren (2000)				0.95	(0.93−0.98)	2.58	0.89	(0.85−0.93)	4.39	0.82	(0.77−0.87)	9.10
Mickenautsch (2000)				0.62	(0.54−0.70)	2.47						
Frencken (1998b)				0.96	(0.94−0.98)	2.59	0.92	(0.89−0.95)	4.39	0.85	(0.81−0.90)	9.12
Frencken (1998a)				0.99	(0.97−1.00)	2.59	0.95	(0.92−0.97)	4.40	0.91	(0.87−0.94)	9.13
Mallow (1998)				0.51	(0.40−0.62)	2.38				0.26	(0.16−0.35)	8.93
Frencken (1994)				0.71	(0.67−0.75)	2.56						
pooled ESR	0.76	(0.69−0.83)	100.00	0.71	(0.65−0.77)	100.00	0.67	(0.56−0.78)	100.00	0.57	(0.39−0.74)	100.00
p-value		<0.001			<0.001			<0.001			<0.001	
I^2		98.0%			98.7 %			99.3 %			99.5 %	

ESR, estimated success rate; CI, confidence interval; I^2, variation in estimations attributable to heterogeneity.

2.4. Statistical analysis

Meta-analysis was conducted using the software Stata (version 16, StataCorp LLC, Texas, USA). The pooled estimated success rate of ART restorations at 6-month, 12-month, 24-month and 36-month were calculated. The standard error (SE) of the proportion was estimated by the normal distribution approximation based on the central limit theorem [17]. Since a child might be placed with more than one ART restoration, the clustering effect within the child could not be ignored. Hence, the SE was adjusted by using the average number of ART restorations per child and the anticipated intra-class correlation coefficient (ICC) of 0.15 [14,18]. Substantial heterogeneity between studies was quantified using the chi-square (χ^2) with p value<0.10 or I^2 statistic>50 % [14]. Due to the intention of generalization inference and the possible heterogeneity among different studies, random effect (DerSimonian-Laird) model was employed in the estimation of the success rate of ART restorations at each time point [19]. Furthermore, meta-regression as well as subgroup analysis was carried out to explore the factors as mentioned earlier in affecting the success rate of ART restorations placed in children at different follow-up times separately [20]. The statistical significance level for all tests was set at 5%.

3. Results

A total of 2045 records were identified from the selected databases (Fig. 1). After removing 957 duplicated records, 1088 potential articles were screened by title and abstract. Irrelevant articles (n = 937) were removed, and 151 articles were retrieved for full-text reading. Based on the exclusion criteria of this review, 84 articles were excluded for various reasons. Finally, 67 articles reporting on 47 studies with clinical outcomes of ART restorations placed in children were included in the present review.

Quality assessment of the included RCTs is shown in Appendix Fig. A1A Figs. A1 and A2. More than 75 % of the included RCTs were at high level or unclear bias in the aspects of allocation concealment and blinding, i.e. selection and performance bias. 'Other bias' was high or unclear in most of the RCTs, mainly because the included studies ignored the clustering effect of the restorations placed in study children when analyzing the success rate of restorations statistically. As for cohort studies included in this review, the assessed quality was fair for most of the studies, two presented with poor quality because of low follow-up rate (Appendix A Table A1).

The main characteristics of the included studies are described in Table 1. The included studies were implemented in 19 countries, namely, Brazil [21–45], Cambodia [46], China [47–52], India [53], Iraq [54], Kenya [55–61], Kuwait [62], Latvian [63], Mexico [64,65], Nepal [66], Nigeria [67–69], Pakistan [70], South Africa [71,72], Suriname [73,74], Syria [75–78], Tanzania [79,80], Thailand [81], Turkey [82, 83] and Zimbabwe [84–86]. However, one study [87] did not report the implemented location of the study. A total of 6959 children aged 2–19 were provided with 11223 ART restorations by dentists as well as dental students/therapists. Average restorations per child was around 1.7. The hand-mixed conventional GIC was the most commonly used restorative material, while RMGIC irrespective of hand-mixed or encapsulated one was also used in some studies. Majority of the studies were implemented in a field setting using cotton rolls only to achieve isolation. Additionally, other moisture control methods, such as saliva ejector and rubber dam, were adopted as well. Administration of local anesthesia was carried out in some studies. Calcium hydroxide was placed in deep cavities as an indirect pulp capping material to protect dental pulp before restoration placement in some studies. Different factors involved in the included studies are presented in Table 2.

The overall estimated success rate of ART restorations and 95 % confidence interval (CI) was 0.71 (0.65−0.77) and 0.67 (0.56−0.78) at 12-month and 24-month follow-up, respectively (Table 3). The results of sensitivity analysis based on only the available sample by ignoring the missing participants are presented in Appendix A Table A2. The results generated through two different data extraction methods were consistent without large variations.

Results of single-factor meta-regressions showed that operator was a significant factor associated with the success rates of ART restorations. ART restorations placed by dental student/therapists had a significantly lower success rate compared with those placed by dentists at 6-month ($p < 0.05$), 12-month ($p < 0.01$), and 24-month ($p < 0.001$) follow-up, but not at 36-month follow-up ($p > 0.05$). Apart from this, placement of calcium hydroxide in the deep cavity was associated with a higher success rate of ART restoration at 6-month ($p < 0.01$) and 12-month ($p < 0.05$) follow-up, but this association could not be observed at 24-month and 36-month follow-up. The other factors, including restorative material, setting, and moisture control method, were not significantly associated with the success rate of ART restorations. Additional use of other techniques, e.g. local anesthesia administration and bilayer technique, had no significant influence on the success rate of ART restorations. Subgroup analysis was conducted to show the success rates of ART restorations with each factor individually and the forest plots of the two significant factors mentioned above at 12-month and 24-month follow-up are presented for illustration (Appendix A Figs. A3 and A4).

Regarding the factors related to teeth, the results of single-factor meta-regressions indicated that dentition and type of restoration were significantly associated with the success rates. ART restorations placed in permanent teeth had a significantly higher success rate compared with those placed in primary teeth at 6-month ($p < 0.05$), 12-month ($p < 0.01$), and 24-month ($p < 0.01$) but not at 36-month ($p > 0.05$) follow-up. Besides, the success rate of single-surface restorations was significantly higher than that of multiple-surface restorations at 6-month ($p < 0.01$), 12-month ($p < 0.001$), 24-month ($p < 0.001$) but not at 36-month ($p > 0.05$) follow-up. The forest plots of these two factors at 12-month and 24-month follow-up are presented for illustration (Appendix A Figs. A5 and A6).

Table 4
Predicted success rate of ART restorations at 12-month and 24-month follow-up based on multiple meta-regression models.

Surface	Operator	12-month		24-month	
		ESR	95 %CI	ESR	95 %CI
Single	Dentist	0.81	(0.73−0.89)	0.84	(0.76−0.91)
	Student/therapist	0.68	(0.59−0.77)	0.68	(0.57−0.80)
Multiple	Dentist	0.69	(0.59−0.78)	0.50	(0.39−0.61)
	Student/therapist	0.56	(0.48−0.63)	0.35	(0.26−0.44)

ESR, estimated success rate; CI, confidence interval.

The three significant factors, i.e. operator, dentition and type of restoration, were adopted in a multiple-factor meta-regression model. At 12-month and 24-month follow-up, operator and type of restoration were significantly associated with the success rate of ART restorations ($p < 0.05$), while the association between dentition and the success rate became insignificant ($p > 0.05$). The predicted success rates of ART restorations at 12-month and 24-month follow-up using the multiple-factor meta-regression models with the two significant factors, i.e. operator and type of restoration, are displayed in Table 4. In addition, the predicted success rates based on only the available sample by ignoring the missing participants are available in Appendix A Table A3.

4. Discussion

The present review shows that operator is a significant factor affecting the success rate of ART restorations placed in children. In general, dental students who are in their learning process of operative skills, as well as dental therapists who are not as well-trained as a dentist, may not perform restorative procedures as good as dentists. Hence, dental students and therapists should be trained and practice more to gain ample clinical experience before providing ART restorations to patients. Even for the ART restorations placed by dentists, the success rates had large variations between different studies [54,70,74, 75,78]. Although the ART approach is not highly equipment- and technique-demanding, sufficient training and practice for operators are still required to obtain good success rate of restorations.

It should be pointed out that placement of calcium hydroxide in deep carious cavity was associated with a higher success rate at 6-month and 12-month, but not at longer term follow-up after the placement of ART restorations. Calcium hydroxide can be placed as a thin layer on the deep cavity surface to protect the dental pulp from irritation of amalgam or resin composite restorations [88]. However, insufficient evidence shows its superiority over GIC when used as an indirect pulp capping material [89]. Therefore, there are no definitive conclusions on whether the placement of calcium hydroxide in the deep cavity is necessary for the ART approach.

This systematic review shows that GIC material (conventional chemical-cured GIC/RMGIC, hand mixed/encapsulated) is not associated with the success rate of ART restorations. Most RMGICs contain light-curable initiators to cause material polymerization. It was reported that RMGICs had better bond strength to dental substrates in a laboratory test compared with conventional GICs [90]. However, there is insufficient clinical evidence to show a better performance of RMGIC restorations compared with conventional GIC restorations. A recent review with meta-analysis found that the correlation between bond strength test results of dental adhesive systems and clinical parameters, such as the retention loss and marginal integrity of restorations, was weak [91]. Higher bond strength of dental materials in the laboratory tests may not necessarily lead to a better clinical performance, for instance, a higher retention rate of restorations.

The powder/liquid ratio influences physical properties of GIC [92], and encapsulated GICs with a fixed ratio of powder and liquid in a sealed capsule were introduced to minimize variation in hand-mixing

procedures and were expected to achieve better clinical outcomes. Nevertheless, the results of meta-regression in this review imply no superiority of the encapsulated material in the success rate of ART restorations. Hence, it may not be necessary to use extra equipment, such as a light-cure unit for RMGIC and mixing machine for encapsulated GIC, when providing ART restorations, especially in a field setting with limit resources. Besides, it should be pointed out that, a medium-viscosity GIC might be used in late 1980s or early 1990s when the ART approach was first investigated, while a high-viscosity GIC with improved physical characteristics has been commonly used in the ART approach since mid-1990s [6]. Since the high-viscosity GIC is recommended and commonly used as the restorative material in the ART approach [6], the viscosity of GIC was not included as an investigating factor in the present review.

In the present review, other factors, such as setting (clinic or field) and moisture control method (cotton roll, saliva ejector or rubber dam), did not show a significant influence on the success rate of ART restorations. The initial purpose of introducing ART approach is to provide effective caries treatment in places with limit resources [93], but the current use of ART is no longer restricted to low- and middle-income communities in a field setting. Dentists can also choose to use the ART approach when treating children in a clinic setting. Rotary instruments and rubber dam are used by some dentists in the so-called ART approach. However, it should be noting that use of rotary instruments to open a cavity cannot be considered as the ART approach nor should the term 'modified ART' be used [94]. It should be pointed out that the number of studies investigating the influence of saliva ejector and/or rubber dam on the success of ART restorations was limited (only 3 studies included in the present review), thus, more high-quality clinical trials are needed to strengthen the evidence generated in the present review.

Regarding factors related to teeth, the success of ART restorations is associated with type of restoration. The finding that single-surface restorations have better clinical performance compared with multiple-surface restorations is consistent with a previous review [11]. It is fair to recommend ART approach to be adopted to restore single-surface cavities in primary teeth. As for multiple-surface restorations, whether ART approach should be adopted is still under debate. Although it was reported that ART restorations had a similar survival rate compared to conventional treatments (amalgam and composite resin restorations) and could be considered as an alternative for restoring occlusoproximal cavities in primary teeth [12], the success rates summarized in the present review were not high. Therefore, other than placing a restoration, different caries management methods may be considered in treating multiple-surface caries lesions in primary teeth, for example, application of topical fluoride [95] and the Hall technique [96]. Besides, cautions should be exercised when interpreting the findings in the present review, because the estimated success rates of ART restorations are based on the treatment outcomes of child patients. The clinical performance of ART restorations placed in adults or older patients, like in dental root cavities, may be different.

In the present review, meta-analysis was conducted using total sample size at baseline as total events to estimate the success rate at each time point. It is a rather conservative method because it assumes that all the missing cases failed. It is a suggestive approach in the Cochrane handbook to handle missing data to show extreme boundaries of what is theoretically possible [14]. The conservative method adopted in the present review may be one possible explanation for the lower estimated success rate of ART restorations compared with a previous systematic review [11]. In addition, sensitivity analysis based on only the available sample as the total events by ignoring the missing participants at each time point was conducted as well. This approach assumes that the data is missing at random. The success rates would be unchanged even though the statistical analyses were based on a smaller sample size rather than the original data set [14]. However, in the present review, we cannot be sure that the missing cases in the included studies were random or not. So results of meta-analysis based on both approaches are presented in this review so that the readers can have a full picture of the situation.

Quality assessment of studies was not considered as an exclusion criterion in this review. In over 75 % of the included RCTs, the allocation concealment and blinding of participants were at high level of bias or unclear. These selection and performance bias are important in assessing the quality of RCTs in which the primary objective is to make comparisons between study groups. However, in this review, we aimed to investigate the success of ART restorations which may not be significantly influenced by these potential bias [11]. Thus, it was decided not to exclude these studies. It should be cautious to interpret the findings in the present review, even though they were based on the best available evidence. Well-conducted high-quality clinical trials are in need to provide further evidence to verify the findings in the present study. Besides, in several studies, the ignorance of the clustering effect of study children - the unit of statistical analysis was the restoration, whereas the unit of randomization was the children - gives rise to another potential bias. Like in previous systematic reviews, we did not consider this as an exclusion criterion. In fact, we took clustering effect of the study child into consideration in the present meta-analysis by adjusting the SE using the Cochrane recommended approach. Despite this, it is recommended to take the clustering effect into account when designing and conducting RCTs in the future to improve the validity of study results.

There are limitations of the present systematic review. Firstly, the long-term performance of ART restorations was reviewed only up to 36 months. This is because of the insufficient data of longer time evaluation. Most of the included studies reported success rate of ART restorations at 6-month, 12-month and 24-month follow-up, while only 11 studies presented data up to 36 months. Studies with long-term follow-up of ART restorations are needed, especially for those evaluating ART restorations placed in permanent teeth, because 36 months are not long enough in a clinical situation. Secondly, only ART restorations placed in children were reviewed, but restorations placed in adults, e.g. dental root restorations, are not covered in the present review. It seems improper to pool data of restorations placed in primary teeth together with those in dental roots. Thus, a systematic review of the clinical performance of ART restorations in adults is needed in the future. Thirdly, even though we were trying to investigate all the possible factors that may affect the success of ART restorations, the factors could be studied in this review were still limited. Some factors, such as cavity size and oral hygiene condition, could not be analyzed in the present review due to a lack of relevant studies in the literature. Additionally, any unknown factor which has influence on the success rate of ART restorations may be neglected. Thus, well-designed RCTs are demanded in future to investigate factors that affect the ART restoration success.

Within the limitations of this study, it can be concluded that the ART approach can be used to manage cavitated caries lesions in children. Operator and type of restoration are significant factors influencing the success rate of ART restorations.

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Declaration of Competing Interest

The authors declare no conflict of interest.

Appendix A

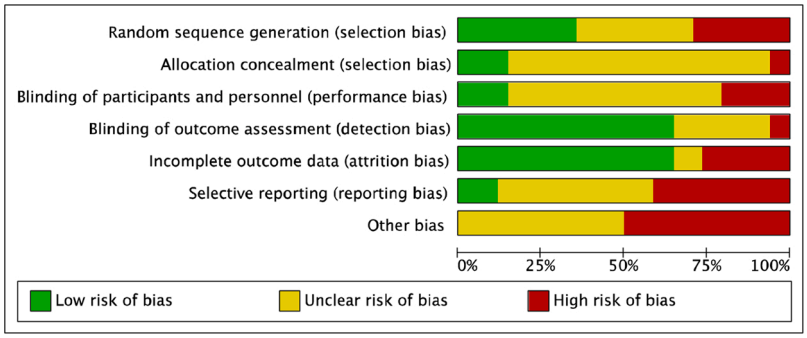

Fig. A1. Risk of bias graph of reviewers' judgements about each risk of bias item presented as percentages across all included randomized controlled trials.

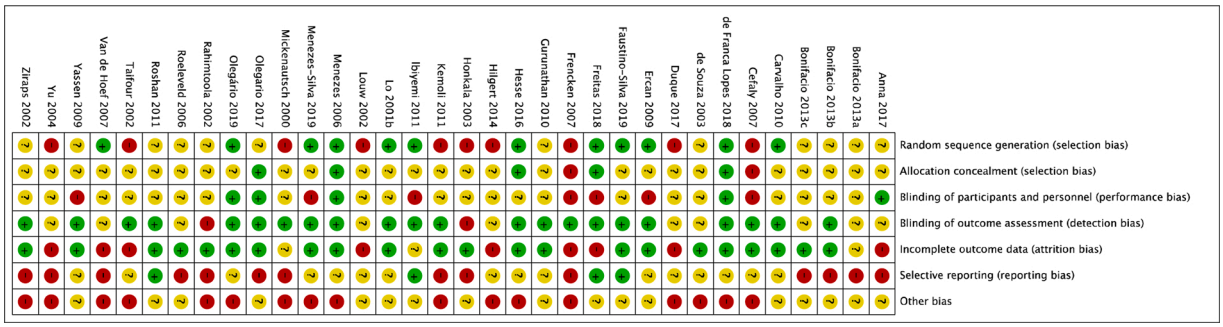

Fig. A2. Risk of bias summary on reviewers' judgements about each risk of bias item for each included randomized controlled trial.

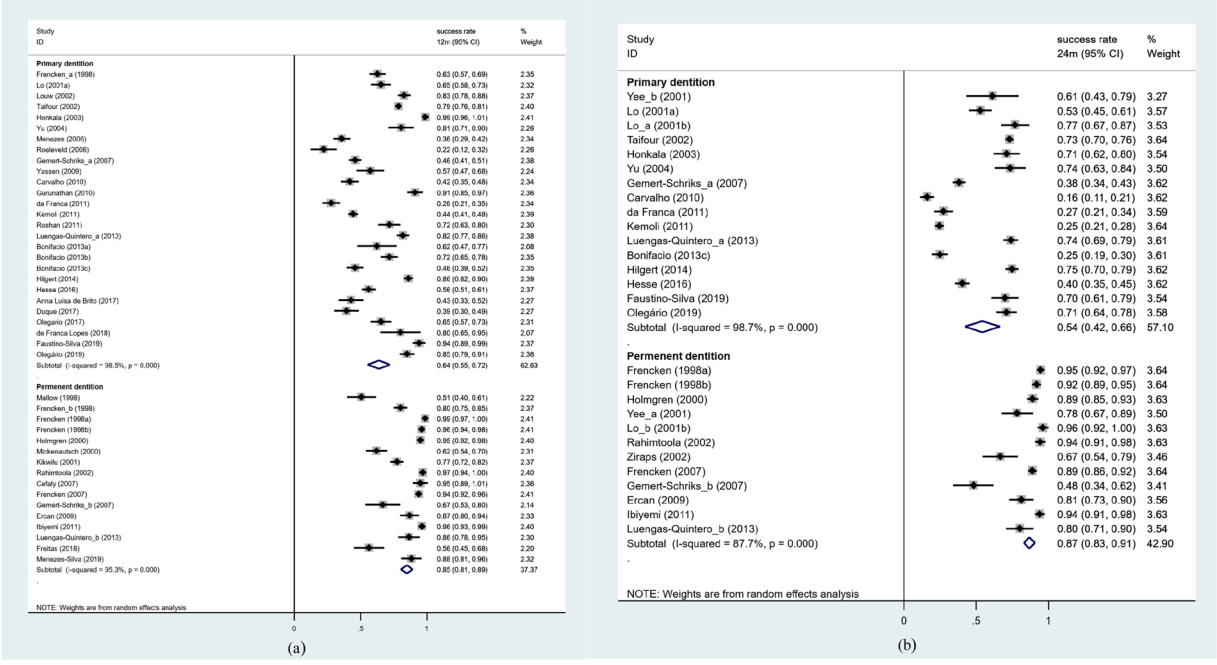

Fig. A3. Forest plots of success rates of ART restorations placed in primary and permanent teeth at 12-month (a) and 24-month (b) follow-up.

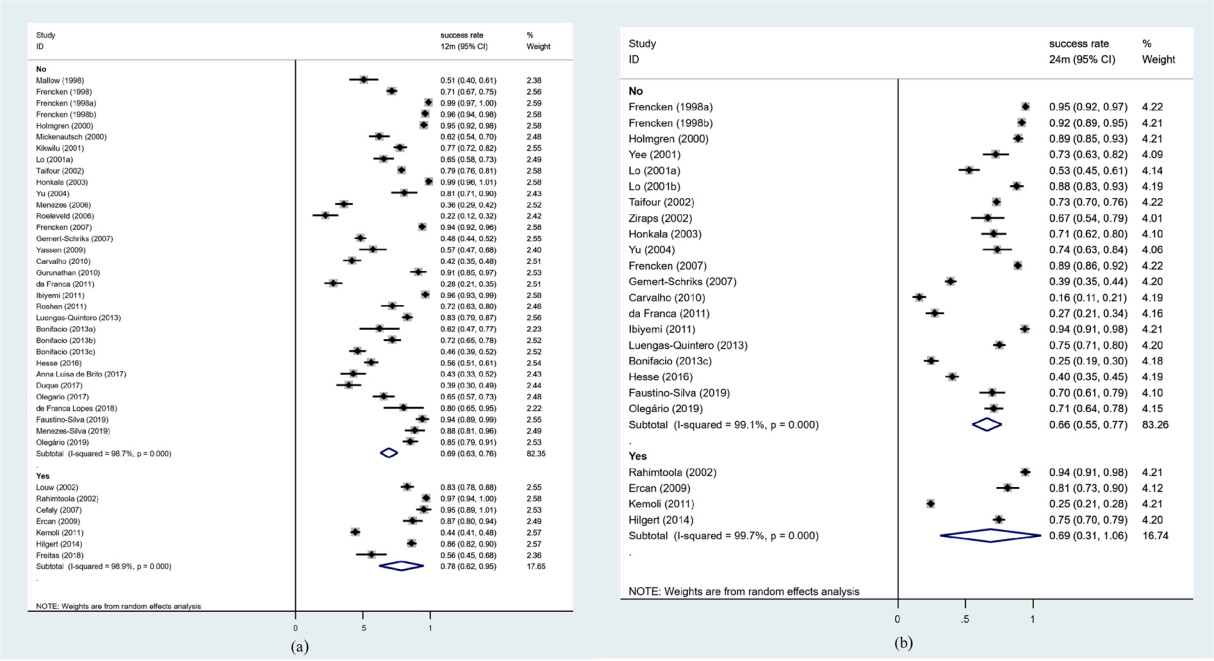

Fig. A4. Forest plots of success rates of ART restorations placed with calcium hydroxide lining at 12-month (a) and 24-month (b) follow-up.

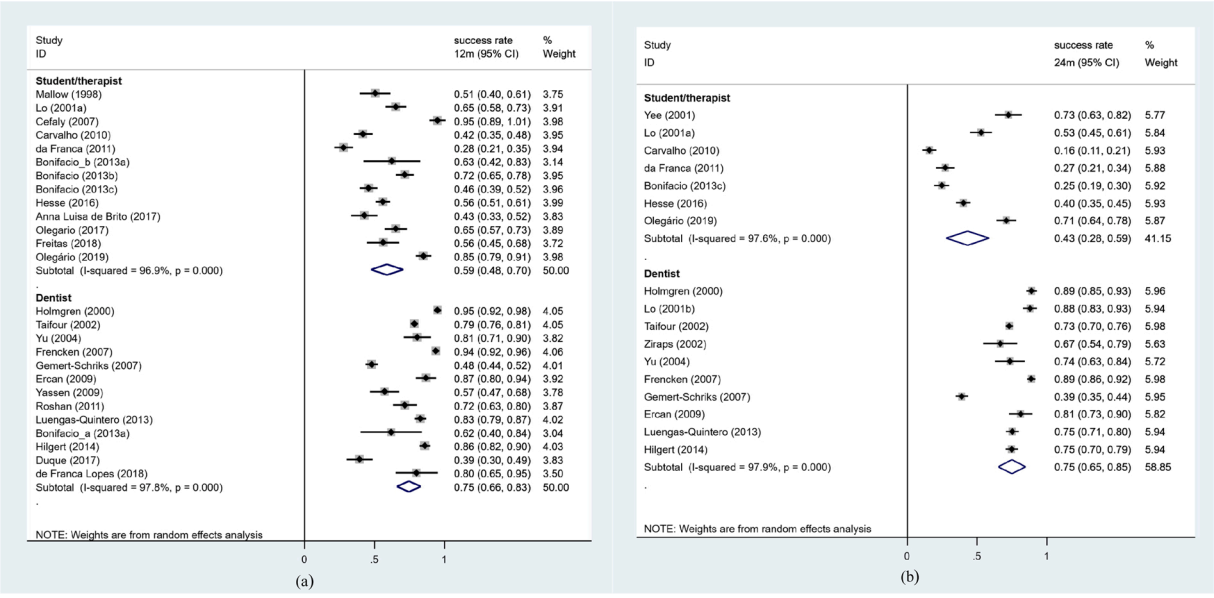

Fig. A5. Forest plots of success rates of ART restorations placed by dentists and student/therapists at 12-month (a) and 24-month (b) follow-up.

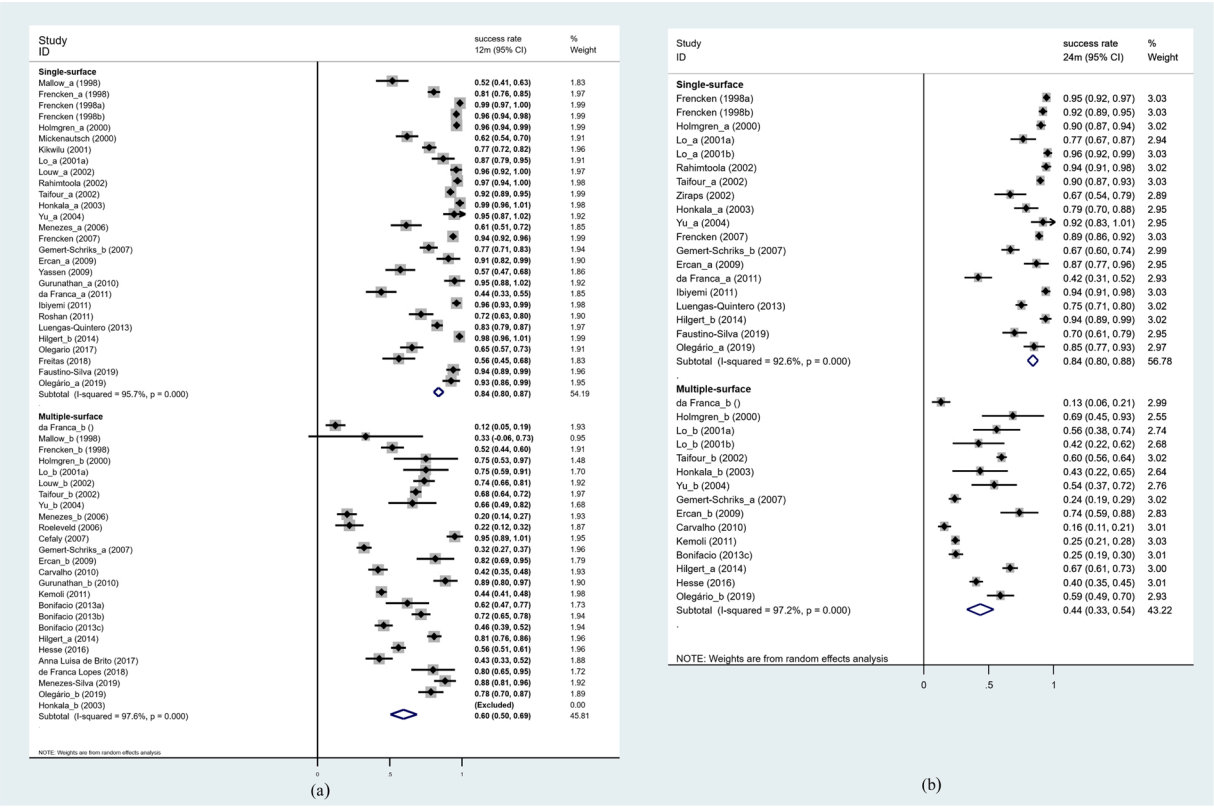

Fig. A6. Forest plots of success rates of single-surface and multiple-surface ART restorations at 12-month (a) and 24-month (b) follow-up.

Table A1
Results of quality assessment of included cohort studies.

Author	Year	S1		S2	S3		S4	C1		O1		O2		O3		Quality
Luengas-Quintero et al.	2013	b	*	c	a	*	b	a	*	a	*	a	*	c		Fair
da Franca et al.	2011	d		c	a	*	b	a	*	a	*	a	*	c		Poor
Gemert-Schriks et al.	2007	a	*	c	a	*	b	a	*	e		a	*	b	*	Fair
Bresciani et al.	2005	b	*	c	a	*	b	a	*	d		a	*	b	*	Fair
Wang et al.	2004	b	*	c	a	*	b	a	*	a	*	a	*	c		Fair
Kikwilu et al.	2001	b	*	c	a	*	b	a	*	d		a	*	b	*	Fair
Lo, Holmgren et al.	2001	b	*	c	a	*	b	a,b	**	a	*	a	*	b	*	Fair
Holmgren et al.	2000	a	*	c	a	*	b	a	*	a	*	a	*	b	*	Fair
Frencken et al.	1998a	a	*	c	a	*	b	a	*	a	*	a	*	b	*	Fair
Frencken et al.	1998b	a	*	c	a	*	b	a	*	a	*	a	*	b	*	Fair
Mallow et al.	1998	c		c	a	*	b	a	*	e		a	*	c		Poor
Frencken et al.	1994	a	*	c	a	*	b	a	*	a	*	a	*	c		Fair

S1, representativeness of the exposed cohort.
S2, selection of the non-exposed cohort.
S3, ascertainment of exposure.
S4, demonstration that outcome of interest was not present at start of study.
C1, comparability of cohorts on the basis of the design or analysis.
O1, assessment of outcome.
O2, was follow-up long enough for outcomes to occur.
O3, adequacy of follow up of cohorts.

Table A2
The estimated success rate of ART restorations based on the only available sample.

	6-month			12-month			24-month			36-month		
Study (year)	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight	ESR	95 % CI	% Weight
Menezes-Silva (2019)	0.99	(0.96–1.01)	4.57	0.96	(0.91–1.01)	2.56						
Olegário (2019)	0.90	(0.85–0.95)	4.48	0.85	(0.79–0.91)	2.54	0.72	(0.64–0.79)	4.34	0.69	(0.62–0.76)	9.09
Faustino-Silva (2019)				0.94	(0.89–0.99)	2.56	0.88	(0.80–0.95)	4.32			
de Franca Lopes (2018)	0.83	(0.69–0.97)	3.70	0.80	(0.65–0.95)	2.17						
Freitas (2018)	0.82	(0.73–0.92)	4.14	0.35	(0.22–0.47)	2.27						
Anna Luisa de Brito (2017)				0.43	(0.33–0.52)	2.42						
Duque (2017)				0.44	(0.34–0.54)	2.40						
Olegario (2017)				0.65	(0.57–0.73)	2.47						
Hesse (2016)	0.69	(0.64–0.74)	4.46	0.62	(0.56–0.67)	2.55	0.46	(0.41–0.52)	4.38			
Hilgert (2014)	0.92	(0.9–0.95)	4.56	0.85	(0.81–0.89)	2.58	0.70	(0.65–0.76)	4.39	0.60	(0.54–0.66)	9.14
Bonifacio (2013c)	0.58	(0.52–0.64)	4.39	0.46	(0.40–0.52)	2.53	0.25	(0.19–0.30)	4.38	0.24	(0.19–0.3)	9.16
Bonifacio (2013b)	0.78	(0.72–0.84)	4.41	0.72	(0.65–0.78)	2.52						
Bonifacio (2013a)	0.84	(0.73–0.96)	3.99	0.34	(0.18–0.50)	2.13						
Luengas-Quintero (2013)				0.83	(0.79–0.87)	2.58	0.78	(0.73–0.82)	4.41			
Roshan (2011)	0.86	(0.79–0.93)	4.36	0.80	(0.72–0.88)	2.47						
da Franca (2011)				0.33	(0.26–0.41)	2.48	0.46	(0.37–0.56)	4.25			
Ibiyemi (2011)				0.96	(0.93–0.99)	2.60	0.96	(0.93–0.99)	4.43			
Kemoli (2011)				0.44	(0.41–0.48)	2.59	0.30	(0.27–0.34)	4.42			
Carvalho (2010)	0.63	(0.56–0.70)	4.37	0.48	(0.39–0.57)	2.43	0.27	(0.13–0.41)	4.06			
Gurunathan (2010)				0.91	(0.85–0.97)	2.54						
Ercan (2009)	0.97	(0.93–1.01)	4.52	0.87	(0.80–0.94)	2.50	0.81	(0.73–0.90)	4.30			
Yassen (2009)	0.86	(0.79–0.94)	4.30	0.71	(0.60–0.81)	2.37						
Cefaly (2007)	0.98	(0.95–1.02)	4.54	0.97	(0.92–1.02)	2.56						
Van de Hoef (2007)	0.38	(0.31–0.46)	4.31									
Gemert-Schriks (2007)												
Frencken (2007)				0.94	(0.92–0.96)	2.61	0.88	(0.85–0.92)	4.43	0.83	(0.79–0.87)	9.20
Menezes (2006)	0.70	(0.64–0.77)	4.37	0.43	(0.36–0.51)	2.50						
Roeleveld (2006)	0.39	(0.26–0.52)	3.83	0.30	(0.17–0.42)	2.29						
Bresciani (2005)	0.97	(0.95–1.00)	4.56									
Wang (2004)	0.72	(0.62–0.81)	4.15							0.21	(0.10–0.32)	8.88
Yu (2004)	0.92	(0.85–0.98)	4.36	0.81	(0.71–0.90)	2.41	0.74	(0.63–0.84)	4.21			
de Souza (2003)	0.87	(0.84–0.91)	4.54									
Honkala (2003)				0.99	(0.96–1.01)	2.61	0.90	(0.82–0.97)	4.34			
Rahimtoola (2002)	0.99	(0.97–1.01)	4.59	0.97	(0.94–1.00)	2.60	0.94	(0.91–0.98)	4.42			
Louw (2002)				0.83	(0.78–0.88)	2.56						
Taifour (2002)				0.79	(0.76–0.81)	2.60	0.73	(0.70–0.76)	4.43	0.65	(0.62–0.68)	9.23
Ziraps (2002)							0.76	(0.65–0.88)	4.16			
Lo (2001b)							0.88	(0.83–0.93)	4.40			
Lo (2001a)				0.66	(0.59–0.74)	2.48						
Kikwilu (2001)				0.96	(0.94–0.99)	2.60						
Yee (2001)							0.73	(0.63–0.82)	4.25			
Holmgren (2000)				0.95	(0.93–0.98)	2.60	0.89	(0.85–0.93)	4.42	0.87	(0.83–0.92)	9.20
Mickenautsch (2000)				0.94	(0.89–0.98)	2.56						
Frencken (1998b)				0.96	(0.93–0.98)	2.61	0.96	(0.94–0.99)	4.44	0.93	(0.89–0.97)	9.21
Frencken (1998a)				0.99	(0.97–1.00)	2.61	0.93	(0.90–0.97)	4.42	0.88	(0.84–0.93)	9.19
Mallow (1998)				0.78	(0.66–0.89)	2.34				0.59	(0.43–0.75)	8.48
Frencken (1994)				0.78	(0.74–0.82)	2.58						
pooled ESR	0.79	(0.73–0.86)	100.00	0.74	(0.68–0.79)	100.00	0.71	(0.62–0.81)	100.00	0.61	(0.45–0.78)	100.00
p-value		<0.001			<0.001			<0.001			<0.001	
I^2		97.7%			98.5 %			99.0 %			99.2 %	

ESR, estimated success rate; CI, confidence interval; I^2, variation in estimations attributable to heterogeneity.

Table A3
Predicted confidence interval of estimated success rate of ART restorations at 12-month and 24-month follow-up using multiple meta-regression model based on only the available sample.

Surface	Operator	12-month		24-month	
		ESR	95 % CI	ESR	95 % CI
Single	Dentist	0.85	(0.78–0.92)	0.84	(0.77–0.91)
	Student/therapist	0.78	(0.70–0.86)	0.75	(0.62–0.87)
Multiple	Dentist	0.68	(0.58–0.77)	0.50	(0.40–0.60)
	Student/therapist	0.61	(0.54–0.68)	0.40	(0.31–0.49)

ESR, estimated success rate; CI, confidence interval.

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