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REVIEW

Atraumatic restorative treatment versus amalgam restoration longevity: a systematic review

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Abstract The aim was to report on the longevity of restorations placed using the atraumatic restorative treatment (ART) approach compared with that of equivalent placed amalgam restorations. Five databases were systematically searched for articles up to 16 March 2009. Inclusion criteria: (1) titles/abstracts relevant to the topic; (2) published in English; (3) reporting on 2-arm longitudinal in vivo trials; (4) minimum follow-up period of 12 months. Exclusion criteria: (1) insufficient random or quasi-random allocation of study subjects; (2) not all entered subjects accounted for at trial conclusion; (3) subjects of both groups not followed up in the same way. Fourteen from the initial search of 164 articles complied with these criteria and were selected for review. From these, seven were rejected and seven articles reporting on 27 separate datasets, accepted. Only identified homogeneous datasets were combined for meta-analysis. From the 27 separate computable dichotomous datasets, four yielded a statistically significant improvement of longevity of ART versus amalgam restorations: posterior class V, 28% over 6.3 years; posterior class I, 6% after 2.3 years and 9% after 4.3 years; posterior class II, 61% after 2.3 years. Studies investigating restorations placed in the primary dentition showed no significant differences between the groups after 12 and 24 months. In the permanent dentition, the longevity of ART restorations is equal to or greater than that of equivalent amalgam restorations for up to 6.3 years and is site-dependent. No difference was observed in primary teeth. More trials are needed in order to confirm these results.

Keywords Atraumatic restorative treatment · Amalgam · Longevity · Systematic review · Meta-analysis · Glass ionomer cement

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Introduction

Atraumatic restorative treatment (ART) is a minimally invasive procedure that involves removing markedly softened carious enamel and dentine using only hand instruments and then restoring the resulting cavity with an adhesive restorative material [1]. Although developed for use in the less industrialized parts of the world, ART has now been accepted as part of the minimum intervention philosophy in developed countries [2–7]. At present, the restorative material of choice for ART is high-viscosity glass ionomer cement (GIC) [8]. GIC is ideally suited to managing dental caries according to the principles of minimally invasive dentistry as it can be applied in the very early stages of caries development or in the larger cavity. Additionally, it simplifies the restorative process and enables the dentine–pulp complex to react against the carious process [9]. During the ART procedure, the histological zone of caries-infected dentine is removed with hand instruments, and, upon application of GIC, a seal is created between the GIC and the remaining enamel margin, and caries-affected dentine lining the cavity surfaces. The glass ionomer adheres to this enamel and dentine primarily via calcium bonds to the mineral content of the tooth structure [10]. This adherence provides an adaptive seal, and, as the material slowly leaches fluoride ions into the adjacent tooth tissue, GICs are capable of halting or slowing the progression of carious lesions [11]. Amalgam has been used successfully as an universal posterior restorative material for over a century [12]. However, much controversy still exists regarding the use of amalgam in dentistry mainly because of its mercury content [13]. The search for a suitable replacement for this material continues. Its operative advantages of being relatively simple to place, its intrinsic strength, and the longevity of the final restoration has led to amalgam being considered the "gold standard" against which all new materials are measured for outcomes such as the effectiveness and durability of the restoration.

To date, only one meta-analysis comparing the success rate of ART and amalgam restorations has been published [14]. This focused on single-surface restorations in permanent teeth only and is based on a systematic literature search in PubMed/Medline up to 1 of September 2003. The meta-analysis found no difference in the survival results between both types of restoration over the first 3 years. No systematic review has been published in the literature comparing the longevity of single- and multiple-surface ART versus amalgam restorations in permanent and primary dentition over longer time periods than 3 years. This systematic review sought to answer the question as to whether, in tooth cavities of the same size, type of dentition, and follow-up period, ART restorations are as successful as conventional amalgam fillings. Therefore, the aim of this quantitative systematic review was to analyze trials comparing the longevity of ART versus amalgam fillings in the permanent or primary dentition in single- or multisurface cavities with follow–up periods of more than 1 to exceeding 3 years.

Materials and methods

Data collection

Five databases: Biomed Central, Cochrane Library, Directory of Open Access Journals, PubMed, and ScienceDirect were systematically searched for articles reporting on clinical trials up to 16 March 2009. The terms "ART", "ART approach", and "ART technique" yielded 43,111; 3,282; and 2,147 articles, respectively, in PubMed. In order to optimize the search breadth and specificity of the databases, excluding many 1-arm longitudinal studies not involving amalgam and non-ART studies using GIC, the final text search term "atraumatic restorative treatment" was used. Articles were selected for review from the search results on the basis of their compliance with the inclusion criteria:

1. Titles/abstracts relevant to topic;
2. Published in English;
3. 2-arm longitudinal in vivo trial;
4. Minimum follow-up period of 12 months.

Where only a relevant title without a listed abstract was available, a full copy of the article was assessed for inclusion. The references of included articles were checked for additional studies suitable for inclusion.

Article review

Only articles that complied with the inclusion criteria were reviewed further. Full copies of articles were reviewed independently by two reviewers (V.Y. and S.M.) for compliance with the exclusion criteria [15]:

1. No random or quasi-random allocation of study subjects;
2. Not all entered subjects accounted for at the end of the trial;
3. Subjects of both groups not followed up in the same way.

For the purpose of this review, atraumatic restorative treatment (ART) was defined as a tooth restoration procedure including caries removal by hand instruments, using spoon excavators, and cavity restoration with a high-viscosity GIC. Therefore, articles reporting on treatment procedures, which differed from this definition, were excluded. Articles were also excluded if no computable data were reported for both the control and the test groups. Where several articles had reported on the same trial over similar time periods, the one covering the trial most comprehensively in accordance with the inclusion/exclusion criteria was accepted. Disagreements between reviewers were resolved by discussion and consensus.

Data extraction from accepted trials

The outcome measure was restoration longevity measured according to the dichotomous success/failure rates of tooth restorations. Two reviewers (V.Y. and S.M.) independently extracted data from the accepted articles. Individual dichotomous datasets for the control and test group were extracted from each article, including the number of successful restorations (n) and total number of evaluated restorations (N). Where possible, missing data were calculated from information given in the text or tables. In addition, authors of articles were contacted in order to obtain missing information. Disagreements between reviewers during data extraction were resolved through discussion and consensus. It was anticipated that some of the studies eligible for inclusion would be split-mouth in design (quasi-randomized trials). The split-mouth study design is commonly used in dentistry to test interventions and has the advantage of enabling an individual to serve as both subject and control. In this study design one or more pairs of teeth (e.g. primary molars) form the unit of randomization. These pairs are, strictly speaking, not independent and should be analyzed as “paired data” on a per-patient basis. However, as in other similar reviews [16], in order to prevent exclusion of data, split-mouth trials were included and the pairs were analyzed independently.

Quality of studies

The quality assessment of the accepted trials was undertaken independently by two reviewers (V.Y. and S.M.) following Cochrane guidelines [17]. Trials not included in this review were used to pilot the process. Subsequently, quality assessment rating scored by both reviewers was derived by consensus. The following quality criteria were examined:

1. Generation of randomization sequence (allocation), recorded as:
   (a) Adequate, e.g. computer-generated random numbers, table of random numbers;
   (b) Unclear, unclear or not reported;
   (c) Inadequate, e.g. case record number, date of birth, date of administration, alternation not reported.
2. Allocation concealment, recorded as:
   (a) Adequate, e.g. central randomization, sequentially numbered sealed opaque envelopes;
   (b) Unclear, unclear or not reported;
   (c) Inadequate, e.g. open allocation schedule, unsealed or nonopaque (envelopes).
3. Blind outcome assessment, recorded:
   (a) Yes;
   (b) Unclear;
   (c) No;
   (d) Not possible.

Statistical analysis

A fixed effects model in RevMan Version 4.2 statistical software by the Nordic Cochrane Centre, the Cochrane Collaboration (Copenhagen; 2003), was used. Differences in treatment groups were computed on the basis of relative risk (RR) with 95% confidence intervals (CI). From the accepted articles, datasets were extracted and assessed for their clinical and methodological heterogeneity, following Cochrane guidelines [18]. Datasets were considered to be heterogeneous if they did differ in type of dentition (primary or permanent), assessment criteria (ART [19] or USPHS [20]), cavity type, and follow-up period. Chi squared, degree of freedom (df), and the percentage of total variations across datasets (I^2) were used in assessing statistical heterogeneity [21]. Only identified datasets without clinical and methodological heterogeneity were pooled for meta-analysis. Pooled datasets for meta-analysis were assigned a Mantel–Haenszel weight directly proportionate to their sample size.

Results

An initial search of PubMed resulted in 164 articles of which 14 articles [4, 22–34] complied with the inclusion criteria and were selected for review. A subsequent search of the other four databases generated no additional results. From the selected articles, seven were excluded: one article lacked random allocation of subjects [28]; one did not report on loss-to-follow-up of subjects per treatment group and thus, did not enable computing of data [29]; two reported on trials using caries removal by hand excavation combined with chemomechanical caries removal, followed by cavity restoration with a low-viscosity GIC [26, 27]; one article reported on a trial using Cermet (Chelon Silver) compared with a mix of GIC (Chelon Fil) with amalgam as restorative materials [25]; one did not report results as computable (dichotomous or continuous) data [33], and one article [31] reported on 12- month data that was also reported in the accepted article by Frencken et al. (2007) [23]. Seven articles reporting on randomized and quasi-randomized control trials were accepted [4, 22–24, 30, 32, 34]. Table 1 provides information about quality aspects assessed for the accepted articles. Random allocation of subjects was rated A (Adequate) in one trial [4], and B (Unclear) in all other trials [22–24, 30, 32, 34]. The concealment of random allocation was rated as B in all trials. All B ratings were based on the lack of information describing how random allocation was made and whether the allocation was concealed. Owing to the visible material characteristics of the compared materials (GIC and amalgam), blinding of outcome assessment was rated D (Not possible) in all trials.

From the accepted seven articles, 27 separate computable dichotomous datasets with relevance to the review objective were extracted. It has to be noted that both articles by Frencken et al. (2006 and 2007) reported on different datasets from the same trial [22, 23]. The articles by Gao et al. (2003) and Yip et al. (2002) also presented the results of different datasets from the same trial [24, 32]. The main characteristics of the datasets are described in Table 2. The RR with 95% CI of most datasets showed no statistically significant difference ($p>0.05$) between the success rates of ART and amalgam

Table 1 Quality assessment of randomized/quasi-randomized control trials

Article	Selection bias		Detection bias
	Random allocation	Allocation concealment	Evaluator blinding
Frencken et al. (2007) [23]	B	B	D
Frencken et al. (2006) [22]	B	B	D
Gao et al. (2003) [24]	B	B	D
Yip et al. (2002) [32]	B	B	D
Yu et al. (2004) [34]	B	B	D
Honkala et al. (2003) [4]	A	B	D
Taifour et al. (2002) [30]	B	B	D

restorations (Table 3). The results of four datasets: #02 [23] and #06, #08, #12 [22] indicate a higher success rate of ART in comparison with conventional amalgam restorations. The relative risk calculated for dataset #02 (RR 1.28; 95%CI 1.08–1.51; p=0.004) indicates that ART restorations in posterior class V cavities of permanent teeth have a 28% higher chance of being rated successful than amalgam restorations after 6.3 years [23]. The relative risk calculated for dataset #06 (RR 1.06; 95%CI 1.01–1.10; p=0.02) and #08 (RR 1.09; 95%CI 1.03–1.15; p=0.004) indicates that ART restorations in posterior class I cavities of permanent teeth have a 6% higher chance after 2.3 years and a 9% higher chance after 4.3 years, respectively, of being rated more successful than amalgam restorations. The relative risk calculated for dataset #12 (RR 1.61; 95%CI 1.11–2.34; p=0.01) indicates that ART restorations in posterior class II cavities of permanent teeth have a 61% higher chance of being rated more successful than amalgam restorations after 2.3 years [22]. Only two homogeneous datasets for class I cavities in primary teeth after 12 months [34] and three datasets for the follow-up period of 24 months [4, 34] were identified as suitable for meta-analysis (Table 4). No statistical heterogeneity (I^2=0%) was found in both pooled datasets. The relative risks after 12 and 24 months (RR 0.93; 95%CI 0.83–1.06; p=0.26 and RR 1.07; 95%CI 0.91–1.27; p=0.39, respectively) indicated no statistically significant difference in the success rates of class I ART and amalgam restorations in primary teeth.

Discussions

Quantitative systematic reviews with or without meta-analysis have value over narrative synthesis in providing the chance for detecting a statistically significant (p<0.05) treatment effect and for improving estimation of such effect by quantifying its outcome [35]. In quantitatively collating clinical information from separate trials carried out for a particular treatment approach, such as ART, in comparison with others, a more objective assessment of a systematic analysis of the currently available evidence is given. In this case, the longevity of GIC ART restorations and equivalent amalgams were compared. Often, owing to the heterogeneity of such trials, the outcome data are not directly comparable, and therefore, restrictive inclusion criteria are used to limit the variation and so strengthen the value of the post meta-analysis results. There is a risk, however, that some useful trial data will be excluded from the review as they may fall outside the inclusion criteria, thus weakening the overall clinical value of the systematic review. In this study, in order to increase the inclusion envelope, split-mouth quasi-random study designs and their data [4, 24, 32, 34] were included and analyzed independently. The reviewed data included the results of 27 datasets, the main characteristics of which are outlined in Table 2. Other aspects in the methodology of this review might have contributed to limitations in its results: (1) not all relevant publications were listed in the selected databases; and (2) not all relevant publications were published in English. Thus, some relevant studies may not have been identified. Despite these considerations, in PubMed, only 8.5% of the initially identified 164 articles were randomized/quasi-randomized control trials reporting on the comparison of ART with amalgam as control. Most other studies constituted nonrandomized longitudinal ART trials without control groups. Moreover, no further eligible articles were identified in the other databases. Therefore, the inclusion of further data sources might not have resulted in the selection of more articles. From the initial 14 included articles, three were excluded because they did not comply with the chosen definition of ART [25–27]. This definition was based on the consideration that ART constitutes a synthesis of the concepts of: (1) the retention of remineralizable affected dentine after caries removal by hand excavation [1] and (2) the promotion of remineralization of such affected dentine through the placement of a biomimetic restorative material [1]. Originally, ART was developed for use in underdeveloped regions [1] to address the need for inexpensive instrumentation. Other excavation techniques relying on specialized hand instruments in connection with a chemical agent [36] do not fulfill this criterion. In regard to the material of choice

Table 2 Main characteristics of datasets from randomized and quasi-randomized control trials

Article	Dataset number	Study design	Evaluation criteria	Age (years)	Type of dentition	Cavity conditioning before GIC placement during ART	Type of cavity	Follow-up period (months / years)	Glass ionomer cement
Frencken et al.[a] (2007) [23]	01	Parallel group	ART criteria	7.5	Permanent	Yes	Posterior class I	6.3	Fuji IXGP / Ketac Molar
	02						Posterior class V		
	03						Small class I		
	04						Large class I		
Frencken et al.[a] (2006) [22]	05	Parallel group	ART criteria	7.5			Class I	1.3	Fuji IXGP / Ketac Molar
	06							2.3	
	07							3.3	
	08							4.3	
	09							5.3	
	10							6.3	
	11						Class II	1.3	
	12							2.3	
	13							3.3	
	14							4.3	
	15							5.3	
	16							6.3	
Gao et al. (2003)[b] [24] Yip et al. (2002)[b]	17	Splitmouth	USPHS criteria	7-9			Class I	30	Fuji IXGP / Ketac Molar
[32]	18	Splitmouth	USPHS criteria	7-9			Class I	12	Fuji IXGP
	19								Ketac Molar
Yu et al. (2004) [34]	20	Splitmouth	ART criteria	7.4	Primary	Not reported	Class I	12	Fuji IXGP
	21								Ketac Molar
	22							24	Fuji IXGP
	23								Ketac Molar
Honkala et al. (2003) [4]	24	Splitmouth	ART criteria	5.7			Class I	22	ChemFlex
	25						Class II		
Taifour et al. (2002) [30]	26	Parallel group	ART criteria	6–7		Yes	Class I	36	Fuji IXGP / Ketac Molar
	27						Class II		

[a] /[b] Articles reporting on different datasets from the same trials. *GIC* glass ionomer cement, *ART* atraumatic restorative treatment

for ART, only GICs have been shown to have a (hyper-) remineralizing effect on hard tooth tissue [37–39]. GIC can therefore be considered as the only material currently proven to be capable of effectively remineralizing the retained affected dentine. A previous meta-analysis reported higher restoration longevity with high-viscosity GIC than with low-viscosity GIC for ART [14]. For these reasons, the ART definition chosen was considered to be correct and its use as the criterion for exclusion of articles in this review, justified.

The quality of the clinical control trials related to internal validity was assessed using a structured checklist. The assessment outcome indicated that the results of the trials might be limited by selection bias (Table 1). Such bias or systematic error may affect studies by causing either an over- or under-estimation of the treatment effect of an investigated clinical procedure. The overestimation of such effect has been observed to be the most common [40]. Schulz et al. (1995) reported a 41% treatment effect overestimation due to selection bias caused by lack of allocation concealment during the randomization process alone [41]. As all trials accepted in this review did not report on allocation concealment, their results need to be interpreted with caution.

Quantitative assessment, through calculation of the RR with 95% confidence interval of the 27 dichotomous datasets, indicated that all but four datasets in the permanent dentition [22, 23] showed no statistical differences between the success rates of ART GICs and amalgam restorations ($p>0.05$). Although this current review differed in aspects of methodology and included articles, its findings are in line

Table 3 Comparison of success rates between ART and amalgam restorations per dataset

Article	Dataset number	ART n	ART N	Amalgam n	Amalgam N	RR	95% CI
Permanent dentition							
Frencken et al. (2007) [23]	01	230	355	173	295	1.10	0.98–1.25
	02	106	132	68	108	1.28[a]	1.08–1.51[a]
	03	154	222	74	116	1.09	0.92–1.28
	04	39	70	57	108	1.06	0.80–1.39
Frencken et al. (2006) [22]	05	454	487	370	403	1.02	0.98–1.05
	06	375	397	289	323	1.06[a]	1.01–1.10[a]
	07	334	348	258	267	0.99	0.96–1.02
	08	274	288	191	218	1.09[a]	1.03–1.15[a]
	09	153	161	108	113	0.99	0.94–1.05
	10	138	153	97	108	1.00	0.92–1.09
	11	41	52	26	33	1.00	0.80–1.25
	12	31	34	13	23	1.61[a]	1.11–2.34[a]
	13	25	29	9	12	1.15	0.80–1.64
	14	18	21	7	9	1.10	0.75–1.63
	15	12	12	2	2	1.00	–
	16	9	12	2	2	0.88	0.48–1.60
Gao et al. (2003) [24]	17	16	17	6	6	0.99	0.77–1.27
Yip et al. (2002) [32]	18	21	21	22	22	1.00	–
	19	17	17	22	22	1.00	–
Primary dentition							
Yu et al. (2004) [34]	20	17	18	17	17	0.95	0.81–1.10
	21	12	13	17	17	0.92	0.75–1.12
	22	5	6	5	7	1.17	0.65–2.10
	23	5	5	5	7	1.33	0.79–2.26
Honkala et al. (2003) [4]	24	24	26	23	25	1.00	0.85–1.18
	25	8	9	10	10	0.89	0.67–1.19
Taifour et al. (2002) [30]	26	322	376	316	380	1.03	0.97–1.09
	27	360	610	224	425	1.12	1.00–1.25

[a] Significant difference in favor of ART ($p<0.05$); *RR* relative risk, *CI* confidence interval, *n* number of successful restorations, *N* total number of evaluated restorations

Table 4 Meta-analysis results of homogeneous datasets reporting on the success rates of ART and amalgam restorations (class I) in primary teeth

Evaluation period (Numbers of combined datasets)	Dataset	Weight (%)[a]	Chi²	df	I^2	RR	95% CI	Statistical difference (*P* value)
12 months	020	54.0	0.06	1	0%	0.93	0.83–1.06	0.28
	021	46.0						
24 months	022	14.1	1.42	2	0%	1.07	0.91–1.27	0.39
	023	14.4						
	024	71.5						

RR relative risk, *CI* confidence interval, *df* degree of freedom, I^2 percentage of total variations across datasets due to heterogeneity

[a] Mantel–Haenszel weight directly proportionate to sample size

with the results of a previous meta-analysis [14]. The four datasets with a significant difference in success in favor of the ART GICs ($p<0.05$) were spread over the three classes of posterior restorations: I, II, and V. The relative risks (improvement in favor of ART) for class I occlusal restorations varied from 6–9% over a follow-up period of 2.3–4.3 years ($p<0.05$); class V restorations, 28% after 6.3 years; and class II restorations, 61% after 2.3 years ($p<0.05$). It has been reported that nonexposure to occlusion and smaller cavity size are factors supporting the survival duration of tooth restorations [27]. The maximum length of the follow-up period for class II (=2−surface restoration with exposure to occlusion), class I (=1−surface restoration with exposure to occlusion), and class V (=1−surface restoration with no exposure to occlusion) restorations at which ART had a higher success rate than similar amalgam fillings (at 2.3; 4.2, and 6.3 years, respectively) confirms this. Why these four datasets showed a higher success rate than amalgam is not clear. Additional clinical procedures that enhance ART longevity, such as cavity conditioning before GIC placement have also been reported for datasets, but these have been found to make no difference to the survival rate between both types of restoration in this review (Table 2). However, not material or technique factors but operator factors related particularly to operator diligence, especially in the area of clinical indication, caries removal, moisture control, cavity conditioning, material mix, and material insertion, have been reported to affect the success of ART restorations most [42, 43]. As it has been suggested that these are the main causes of clinical ART failures, it can be assumed that they may be potential confounders that could increase or decrease the success rates of the analyzed datasets. Thus, further high-quality randomized control trials are needed to confirm these results. Reporting of such trials should follow the CONSORT statement and, particularly, include a clear description of how the randomized allocation of study subjects was conducted and report on details of any restrictions and state who generated the allocation sequence, who enrolled the subjects, and who assigned subjects to their groups. Reporting should further include information about whether such allocation was concealed from the clinical operators until interventions were assigned and if it was, about how this was done [44].

Conclusions

The systematic literature search identified seven randomized/quasi-randomized control trials including 27 separate datasets with relevance to the review question. None of the datasets found tooth restorations placed using conventional drilling and amalgam to be a treatment option superior to ART. Regardless of the type of cavity, dentition, or length of follow-up, there was no difference in longevity between GIC and amalgam except for four datasets where GIC performed better. These datasets compared restorations in class I, II, and V cavities of permanent teeth. No differences could be found in the primary dentition studies over a 2-year follow-up period. The answer to the review question was that, in comparison with conventional fillings with amalgam of the same size, type of dentition, and follow-up period, ART restorations with high-viscosity GIC appear to be equally successful, and their survival rate may even exceed that of amalgam fillings. However, these findings have to be regarded with caution, and a conclusive statement about the superiority of either type of procedure above the other cannot yet be made as all the included studies had limited internal validity due to unclear randomized sequence allocation and/or allocation concealment. Further high-quality randomized control trials are therefore needed. It is recommended that reporting of such future trials should follow the CONSORT statement.

Conflict of interest The authors declare that they have no conflict of interest.

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