Review Article

Dental Composite Restorations Repair: a systematic review and meta-analysis

Abstract

Background: Controversy exists in the literature regarding the most optimal repair procedure for improving the adhesion between the repair resin and the existing resin composite materials. Hence the aim of the present study was to do a systematic review and to analyze the adhesion potential of resin-based composites to similar and dissimilar composites and aimed to determine the possible dominant factors affecting the bond strength results.

Materials & Methods: Randomized clinical trials (RCTs) and prospective cohort design were searched through electronic databases including MEDLINE, PubMed, Web of Science, and the Cochrane Central Register of Controlled Trials for randomized clinical trials (RCTs) until July 2020 that compared different methods of composite restoration repair and a minimum mean follow-up time of 1 year. There were no restrictions on a particular treatment indication or outcome measures. Two authors independently conducted screening, risk of bias assessment, and data extraction of eligible trials in duplicate. We applied the Cochrane risk of bias assessment tool to consider the risk of bias.

Results: We identified 10 articles; two of them were RCTs, and eight prospective cohort studies. There were 530 participants, with 990 teeth, dealing with resin-based composite (RBC) restorations. The intervention of defective restorations ranged from minimal intervention to total restoration replacement. The evaluation criteria were also varied with different evaluation protocols. The low number and heterogeneity of RCTs did not allow for meta-analyses.

Conclusions: Although different repair protocols are mentioned in the literature according to the included studies, an appropriate and definitive conclusion can't be drawn. However, it seems repairs versus replacements should be considered as the first line of treatment when all factors lead to repair rather than replacement. Further randomized controlled trials with high methodological quality need to be conducted in order to establish evidence-based recommendations, particularly for RBC repair.

Keywords: Resin-based composites, clinical protocols, repair, alternative treatments, replacement, randomized clinical trial, prospective cohorts studies, restorative dentistry.

1. Introduction:

In the last decade, increasing demands by patients for mercury-free and esthetic restorations have markedly increased the use of direct, light-activated resin composites in restorative dentistry [1,2]. Nonetheless, despite the ongoing development of resin composites with improved properties, discoloration, color mismatch, wear, chipping, or bulk fracture may still be issues [3-5].As a result, when esthetics or function are compromised, an operative treatment is needed, and the clinician must decide whether to replace or simply repair these restorations [3-5]. A: Prospective randomized controlled trials (RCTs) and systematic reviews have highlighted that even though the overall survival rates were satisfactory, there were high annual failure rates associated with composites [6,7]. Accordingly, failures of composite restorations are still being reported in clinical studies, with failure rates ranging between 5% and 45% during an observation period of up to five years. Furthermore, annual failure rates for composite restorations range from 0.9% to 9.4%, with 1% to 3% being the most representative rate [8-11]. Evidence from a prospective dental practice-based research (DPBR) cohort study in the United States shows that out of over 6000 restorations followed for 2 years, 6% were recorded as failed [12]. The majority of failures were caused by caries or restorations (61%), with the remainder being endodontic origin (7%), extraction (6%), pain or sensitivity (6%), and miscellaneous (19%) [12].Factors such as tooth type and location, operator skills, socioeconomic, demographic, and behavioral conditions strongly affect these rates [13]. The annual failure rates of anterior and posterior composite restorations have been reported to vary between 1% and 4% [14]. Moreover, ageing of such materials is often a consequence of mechanical/physical degradation mechanisms such as wear, abrasion, and fatigue or is due to chemical degradation mechanisms such as enzymatic, hydrolytic, acidic, or temperature-related breakdown [15]. Furthermore, 70% of clinicians' chair-side time is spent replacing restorations [3,16-20].Complete removal of the restoration and replacement is the traditional approach to managing a failed composite. However, each time this is done, the cavity becomes larger, the tooth weaker, more complex restorations may result, and pulpal symptoms may ensue [3,21]. Whereas previous studies found no advantages of replaced restorations over repaired restorations [22].Also, it has been shown that it is difficult to remove existing direct and indirect resin composite restorations without significantly increasing the size and shape of the cavity [22]. This would suggest that the repair of an existing restoration should be considered where possible. Moreover, complete removal of the restoration inevitably results in weakening of the tooth, unnecessary removal of intact dental tissue, and repeated injuries to the pulp [22]. Furthermore, such treatment involves difficulties such as recognizing the composite-tooth interface and the need to remove previously etched enamel to enable a new bonded restoration to be made [23,24]. Repair is defined as the removal of part of the restoration together with the localized defect, followed by restoration of the prepared defect [22]. Nowadays, there is accumulating evidence that suggests composite repair can be a viable and long-term clinical procedure. Moreover, a minimally invasive operative philosophy has prevailed, and selective composite repair has been proposed and emphasized as a more conservative, cost-effective, and time-saving option, reducing dental tissue loss and pulpal trauma [18]. In addition, replacement costs represent an enormous annual expense in the United States, considering that the annual cost for tooth cavity restorations in the United States was $46 billion in 2005 [18]. According to recent studies, the repair of an existing restoration has been considered a viable and less costly alternative to complete replacement [26,27]. However, several changes occur to resin-based composites during the aging process, which could influence the success of the repair procedure, such as water sorption, chemical degradation, and leaching out of some of their constituents [28-30]. A high degree of controversy was observed in most of the clinical evidence studies regarding the protocols of composite restoration repair and replacement. Despite the variability of materials, techniques and investigation methods, the aim of this review is to establish an evidence-based reference for composite repair by involving the highest quality clinical evidence studies for a dentist to use during their clinical practices. Moreover, this systematic review will analyze the adhesion potential of resin-based composites to similar and dissimilar composites and aims to determine the possible dominant factors affecting the bond strength result.

Materials and Methods:

1. **Protocol and registration:**

The study protocol of this systematic review and meta-analysis was registered at the National Institute for Health Research PROSPERO, International Prospective Register of Systematic Reviews (registration number CRD42020219970). The text was structured in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines. [31]

The research also has the approval of the KING ABDULLAH INTERNATIONAL MEDICAL RESEARCH CENTER (Protocol Number: NRC21R/168/04).

2. **Information source:**

Two independent reviewers (A.A. and A.A.) conducted an electronic literature search of several databases, including MEDLINE through PubMed, Web of Science, and the Cochrane Central Register of Controlled Trials for randomized clinical trials (RCT) written in English up to July 2020.

The four parts of the question to be asked are: participants/problem, intervention, comparison, and outcome (PICO):

- Participants/Problem: Defective Composite Restoration.
- Intervention: repair of restorations.
- None/replacement
- The end result is minimally invasive dentistry that preserves tooth structure.

3. **Screening process:**

Three major electronic databases were screened. For the PubMed library, combinations of controlled terms (MeSH and EMTREE) and keywords were used whenever possible. In the search terms used, "[mh]" represented the MeSH terms and "[tiab]" represented the title and/or abstract. Other terms were not indexed as MeSH and filters were also applied. As such, the key terms used were: (Composite restoration repair [MeSH terms]) OR composite repair, partially [MeSH terms]) OR defective composite [MeSH terms]) AND resin composite repair, bond strength [MeSH terms]) OR dental composite [MeSH terms]) OR composite replacement, sealing [MeSH terms]) AND refurbishment [MeSH terms]) OR resin composite restoration [all terms] Humans; Clinical Trial; English

4. **Eligibility Criteria:**

The screening process had to be broad because of the dearth of studies with proper randomization and prospective evaluations. Articles were included in this systematic review if they met the following inclusion criteria: Randomized clinical trials (RCTs) and prospective cohort studies Accordingly, several factors, such as study design, number of patients included at the last follow-up, number of repaired composite restorations and/or any other interventions, evaluating criteria, and/or other conditions that might alter the outcome, type of intervention, and type of repairing material, were recorded and extracted from the selected studies for further evaluation. On the other hand, case reports, case series, systematic reviews, animal studies, and in vitro studies were excluded.

5. **Data Items:**

Data extracted from the individual studies included items 18–20 in the PRISMA checklist (Appendix S1), that is, (i) characteristics of the individual studies, (ii) risk of bias within the individual studies, and (iii) the results of individual studies. The individual studies included identification of the lead author and a description of the study participants' condition; the years when the restorations were placed; and whether the study was conducted in a single or multiple university, public health, or private practice settings. The number of study participants and composite restorations placed, as well as the average follow-up time, was supplemented with a description of the restoration type(s) and details on the taper design. Details of the actual intervention included the following: (i) evaluation criteria, (ii) type of restoration that must be repaired, (iii) type of repaired material, and (iv) type of intervention.

6. **Risk of bias in individual studies:**

Elements that possibly could limit the study's internal and external validity include an assessment of the stated study objective versus its conclusions, the choice and quality of statistical tests, and the source of funding of the study. The Cochrane risk of bias assessment tool (Higgins et al., 2011) [32] was applied to estimate the risk of bias of individual trials.

7. **Summary measures:**

   The primary outcomes were complications associated with the repaired/replaced composite restorations, restoration success and survival, maintenance needs, patient-reported function, satisfaction, quality of life, and aesthetics; all outcomes were measured at 1 year or greater after interventions. Secondary outcomes were failure of interventions at 1 year or greater after repair or replacement took place.

8. **Synthesis of results and risk of bias across studies:**

   The pre-hoc objective was to undertake meta-analyses and estimate risk ratios and differences in means. As the review progressed, it became clear that the evidence base was too weak for such statistical analyses. Hence, this SR does not include summary measures or formal statistics to examine possible publication bias or selective reporting.

Results:

1. **Study selection:**
   We initially identified approximately 721 reports (Figure 1). After screening the abstracts, the great majority (n = 665) were considered not eligible according to the inclusion criteria. The predominant reasons were that there was not an RCT trial or prospective cohort studies (n = 554) or that the term "composite repair" was not considered in the studies (n = 100). A third reason for ineligibility was that the study did not include human study participants (n = 11). The remaining 56 articles were read in full. Ten of these articles were selected for data extraction. The major reasons for non-inclusion were a lack of a full description of repair methods (n = 39) and/or evaluation criteria not mentioned in the studies (n = 7). It was planned initially to estimate by the use of kappa statistics the strength of agreement between the two reviewers on abstract screening, full-text screening, and methodological quality assessment. However, the low yield of n = 4 RCTs that both raters agreed to include, hence inferring a = 1, rendered other formal calculations of kappa statistics inconsequential (Table 1).
2. **Study characteristics:**

The reports of the four randomized clinical trials described the outcomes after 10 years (Fernández et al., 2015), 1 year (Estay et al., 2018), 12 years (Estay et al., 2018), and 5 years (Dennison et al., 2019) (Table 1). The first trial evaluated the repair versus replacement of defective composite restorations using Filtek Supreme (3M ESPE) as the material of choice on the posterior teeth (Fernández et al., 2015). The second trial use only sealing by either fissure sealant material (Clinpro Sealant, 3M Oral Care) or nanofilled flowable composite material (Filtek Flow Z350 XT, 3M Oral Care) along with control group, third RCT evaluate repaired versus replacement with control group using (Filtek Supreme; 3M ESPE) as material (Estay et al, 2018), and the fourth trail repaired or sealed defective composite restorations comparing them with control group and using (Revolution, Kerr Mfg Co) as a repairing material (Dennison et al, 2019). The other prospective clinical trail (Gordan et al 2006 and 2009, Moncada et al 2008 and 2009, Fernández et al, and Martin et al) used different protocol methods of repairing and different materials (Table 1).

3. **Risk of bias within studies:**

According to the Cochrane bias tool, all the RCTs were deemed to have a moderate risk of selection and performance bias (Table 3). A power calculation was described satisfactorily in all RCTs. Detection bias was considered moderate as no precautions were described regarding masking of the photographs to distinguish between the repair quality, except in two studies with low bias (Dennison et al., 2019 and Moncada et al., 2008). The relatively high dropout rates in two trials (Estay et al., 2018; Dennison et al., 2019) imply a possible defect bias and may raise concern about the representativeness of the findings. The risk of reporting bias was considered moderate for three RCTs and low for one RCT. Three prospective trials (Moncada et al., 2008; Moncada et al., 2009; Martin et al., 2013) were funded by the manufacturer of the composites that were tested. None of the trials reported any details about financial arrangements with the patients, that is, whether they received free professional care and/or components or paid full fees. Three of the studies did not report the number of dropped patients at the follow-up (Moncada et al., 2009, Gordan et al., 2009, and Dennison et al., 2019). In sum, all four RCTs were considered to have moderate bias. Regarding the prospective studies, one of them is considered to have low bias (Gordan et al., 2009), moderate bias (Gordan et al., 2006), Moncada et al.2008, Moncada et al.2009, Fernández et al. 2011) and one with high bias (Martin et al.2013).

4. **Results of individual studies:**

The clinical performance of repairing composite restoration in all studies is good, viable, minimally invasive treatment. Similar to replacement (Fernández et al 2015, Estay et al 2018, Dennison et al 2019, Martin et al, 2013), improving restoration longevity (Estay et al 2018, Moncada et al 2008, Moncada et al 20119, Fernández et al 2015), superior to replacement (Gordan et al 2006, Gordan et al 2009).None of the RCTs reported any patient-reported outcome measurements (PROMs). The variable experimental clinical variables in the identified studies preclude making any strong conclusions about the potential influence of these factors on the reported clinical outcomes. The modified USPHS criteria [33] have 10 evaluating criteria. The only two studies that use all the criteria are (Gordan et al., 2006 and 2009). However, the authors acknowledge that the USPHS criteria may have limited application, as the information they provide for the range of acceptability may be too broad, and certain characteristics of a restoration may fall between categories. The remaining studies use some of the criteria, with at least four criteria. Only one study uses World Dental Federation criteria for restoration evaluation (Estay et al., 2018). However, the Ryge/USPHS and FDI World Dental Federation criteria [34] do not consider the evaluation of the restoration–repair interface; this could be an interesting point to analyze because it could be the cause of the Charlie values in parameters such as surface roughness and luster. Except for one study (Dennison et al. 2019), all of the studies used rubber dam isolation during composite repair. Caries risk assessments are very important and may play a major role in the finding. The studies that used caries risk assessment with cariogram [35] are (Martin et al. 2013, Fernández et al. 2015, Estay et al. 2018). The remaining studies do not use a caries risk assessment program. Additionally, some studies excluded high-caries-risk patients from their studies, which impacted the overall result of all the studies when trying to draw clear conclusions.

5. **Risk of bias across studies:**

The risk of bias across studies appears to be low. All three RCTs reported clinically relevant outcomes, although a lack of patient-reported outcomes was identified.

Discussion:

The main finding of this SR is that the evidence basis is currently insufficient to conclude whether repaired composites have any benefits compared to replace dental composites in terms of survival or success rates. The limited evidence of long-term clinical outcomes signifies that the question of whether repaired dental composites have any merits compared to replaced composites remains uncertain for a range of potential clinical indications. However, the results of the majority of included studies show that repairing the defective restorations outperforms the traditional methods, i.e., replacement [36,37], for a variety of reasons:1) repair is a less invasive and minimally invasive dentistry approach [20], 2) replacement causes increased the size of the previous restoration and may cause trauma to the pulp and more complex consequences [3,13,21,24,26,38-49], and 3) more time and cost-saving [26,27].Based on the amount of resin composite sold, it is estimated that around 800 million resin composite restorations were placed worldwide in 2015 alone, with about 80% placed in the posterior region and 20% in the anterior region [50,51].

A meta-analysis of resin composite restorations in posterior teeth has shown that at least 5% of them failed due to fracture of the material and about 12% showed noticeable wear over an observation period of 10 years. In other words, almost 77 million resin composite restorations in posterior teeth are likely to show noticeable wear, and about 32 million resin composite restorations placed in posterior teeth in 2015 will need to be repaired or replaced due to fracturing by 2025 [51,52]. Therefore, repairing should be considered as the first line of treatment unless the opposite replacement factors appear. Repair, defined as the removal of part of the restoration together with the localized defect, followed by restoration of the prepared defect, sealing, defined as the application of a sealant in the non-carious marginal gap, and refurbishing, defined as the removal of excess and reshaping of the anatomic form or removal of a surface stain by polishing [53-56]. Due to aging of the composite resin surface in the dynamic oral environment, the adhesive strength of composite-to-composite restorations decreases by 25% to 80% compared to their original strength [8,13,23,37,57-67]. There is now accumulating evidence that repair of composite can be a viable, long-term, clinical procedure [3,8,36,68-75].

Factors for repairing defective restorations mentioned on the literature:

1. **Material compositions and related factors:**

a) Silorane-based composite versus dimethacrylate-based composite: In 2007, a silorane-based composite was introduced. Due to its modified matrix consisting of siloxane and oxirane components, silorane-based composite (SBC) exhibits a reduced shrinkage of approximately 1% by volume per ring-opening cationic polymerisation [76]. On the basis of the differing chemical composition of the matrices of dimethacrylate-based composites (MBC) and SBC, it is highly probable that the compatibility of both is problematic. Because silorane was only recently introduced, little is known about its bonding properties.Tezvergil-Multuay et al. [77] found that the bond strength between a silorane and a dimethacrylate-based composite without any intermediate resin showed the lowest values compared to silorane–silorane and dimethacrylate–dimethacrylate combinations without an intermediate layer.

b) Direct Versus Indirect composite restorations: It has been reported that proper bonding between laboratory composite and newly added direct composite can be achieved by combining mechanical surface treatment of the preexisting composite with the use of intermediate bonding agents and silanes, which can improve repair bond strength [78,79].Studies on the bond strengths between CAD/CAM materials and resin composites have shown that, besides surface roughening, an additional application of adhesive systems is required [80-83].

c) Presence or absence of oxygen inhibition layer: When the clinician places composite restorations in increments, he or she relies on the oxygen-inhibited layer to make the bonding of subsequent increments possible [38, 39, 84-94]. However, controversial opinions exist on the function of the oxygen-inhibited layer on the adhesion between two composite resin layers [93,95,96]. Some studies have shown that composite resin layers could bond even in the absence of an oxygen-inhibited layer [95,96], but it is also speculated that the amount of the remaining active free radicals that are available for reacting with resin composite monomers is a crucial factor in direct composite repair [95].

d) Composite restoration brand: One of the clinical problems faced during the accomplishment of repair procedures is the lack of knowledge of the composite resin type and brand employed for the particular restoration. Since commercial products present different chemical compositions, the repair strength at the restoration/repair interface may be affected [97-101]. Studies comparing the repair for the same and different bands also measured the bonding strength and found the best results were accomplished with similar material [22,90,102].

e) Difficulty in recognize old restoration: Such treatment involves difficulties such as recognizing the composite-tooth interface and the need for removing previously etched enamel to enable a new bonded restoration to be made[23,24,42].
f) Composite restoration physical properties: Repair situations occur regardless of the type of resin or technique used, whether macrofill, hybrid, microfill, chemical cure, light cure, heat cure, direct or indirect [57].
g) Time after repair: Bonding between the aged composite resin and added fresh composite resin is affected by various factors, namely, surface roughness, intermediary material used, repair material used, and time after repair [23].
h) Restorative cycle: Each restoration has its own cycle and longevity. Therefore, whenever it's possible to avoid restoration placement by preventive measure, it can prevent a restoration cycle [58,103-106].
2. Technique for repairing old defective restorations: The surface treatment of an aged resin composite has two purposes: to remove the superficial layer altered by the saliva, exposing a clean, higher energy composite surface, and to increase the surface area through the creation of surface irregularities. [107] Union between the old and the new composite in a repair situation may occur by three distinct mechanisms: (1) through a chemical bonding with the organic matrix; (2) through a chemical bonding with the exposed filler particles, and (3) through micromechanical retention to the treated surface. Bonding to the resin matrix relies on the unconverted C-C double bonds remaining in the surface of the aged composite [101].Many techniques are described in the literature. Using only mechanical methods [23,24,44,57,101,102,108-110], mechanical and chemical [92,101,111-117], using aluminum oxide sandblasting [23,43,44,57,92,99,101,108,109,118,119-132],using phosphoric acid etch [44,99,121,124,128,130,134,3135], using self-etching system [110,136-138], roughening with diamonds burs [44,99,123,124,128,130-132], roughening with silicon carbide paper or diamond stones[101,120,122,123,128,139,140],etching with hydrofluoric acid [99,101,117,118,122,124,125,131,134,141,142],using acidulated phosphate fluoride [143,144], using bonding agent [19,23,38,43,57,88,90,101,102,109,112,117,120,122,123,139,141,145-150] , Combined use of silane primer and unfilled resin [38,43,87,90,101,122,129,141,146-148,152-154], coating with flowable composite [43,69,124,155-158], tribochemical coating [159-161], and surface treatment with laser technology [162-168
However, controversy between techniques exists in the literature [57,120,122,169]. Unfortunately, there is no standard protocol for composite restoration repair [99,110,170–173].
3. In vitro studies: There are many in vitro studies that focus on composite restoration repair with different tests and storage medium. Some studies measure tensile bond strength [23,79,88,115,149,174], bond strength [147], shear bond strength [23,44,87,90,101,117,122,134,141,147,148,175-178], flexure strength [23,24,132,149,179-182], fatigue strength [43], microtensile test [153,183-186], diametral tensile strength [186], microleakage tests [150], and scanning electron microscopy [23,102,122].
4. Repair versus replacement: The clinical diagnosis of secondary caries is the main reason for the replacement of all types of directly placed restorations [74,75,186]. For years, the traditional management consisted of replacing the entire restoration, even in the presence of only minor imperfections [75]. A systematic review did not reveal any advantages of repaired restorations compared to replaced restorations [22], while many advocate repairing versus replacement [3,17,36,53,55,58,59,63,69,188-191].
5. Surveys on composite restorations repair: Most recently, it has been reported in a survey of North American, Scandinavian, British, Irish, and German dental schools that at least 50% of the surveyed schools confirmed the teaching of composite resin repair in

their curricula. Further, the report noted that there was diversity in approach as regards surface preparation of existing composite resin in the protocol for repair [17,21,37,64,68,70,94,192-205].

6. Limitations: The results of the present study have to be interpreted with caution because of its limitations. First of all, all confounding factors may have affected the long-term outcomes. The included studies have a considerable number of confounding factors, and most of the studies, if not all, did not include high-caries-risk patients or patients with bruxism. Moreover, several professionals were involved in the treatment of these patients, and there was a considerable variability in the restorative approaches applied by these different professionals. Therefore, the influence of different dentists on the composite repair failure rate must be taken into account. The lack of control of the confounding factors, therefore, limited the potential for drawing robust conclusions. Second, most of the included studies had a prospective design, and the nature of a prospective study varied according to the protocols of repair methods.

Third, much of the field's research is constrained by small cohort sizes and high heterogeneity rates. This might have led to an underestimation of actual failures in some studies.

Conclusions:

Although different repair protocols are mentioned in the literature according to the included studies, an appropriate and definitive conclusion can't be drawn. However, within the limitations of the present systematic review, it can be concluded:

1. It seems repairs versus replacements should be considered as the first line of treatment when all factors lead to repair rather than replacement.
2. There is a need for consensus statements on the best evaluation method for defective composite restorations and the best repair protocol method, and the inclusion of these methods for undergrad curricula.
3. Further randomized controlled trials with high methodological quality need to be conducted in order to establish evidence-based recommendations, particularly for RBC repair.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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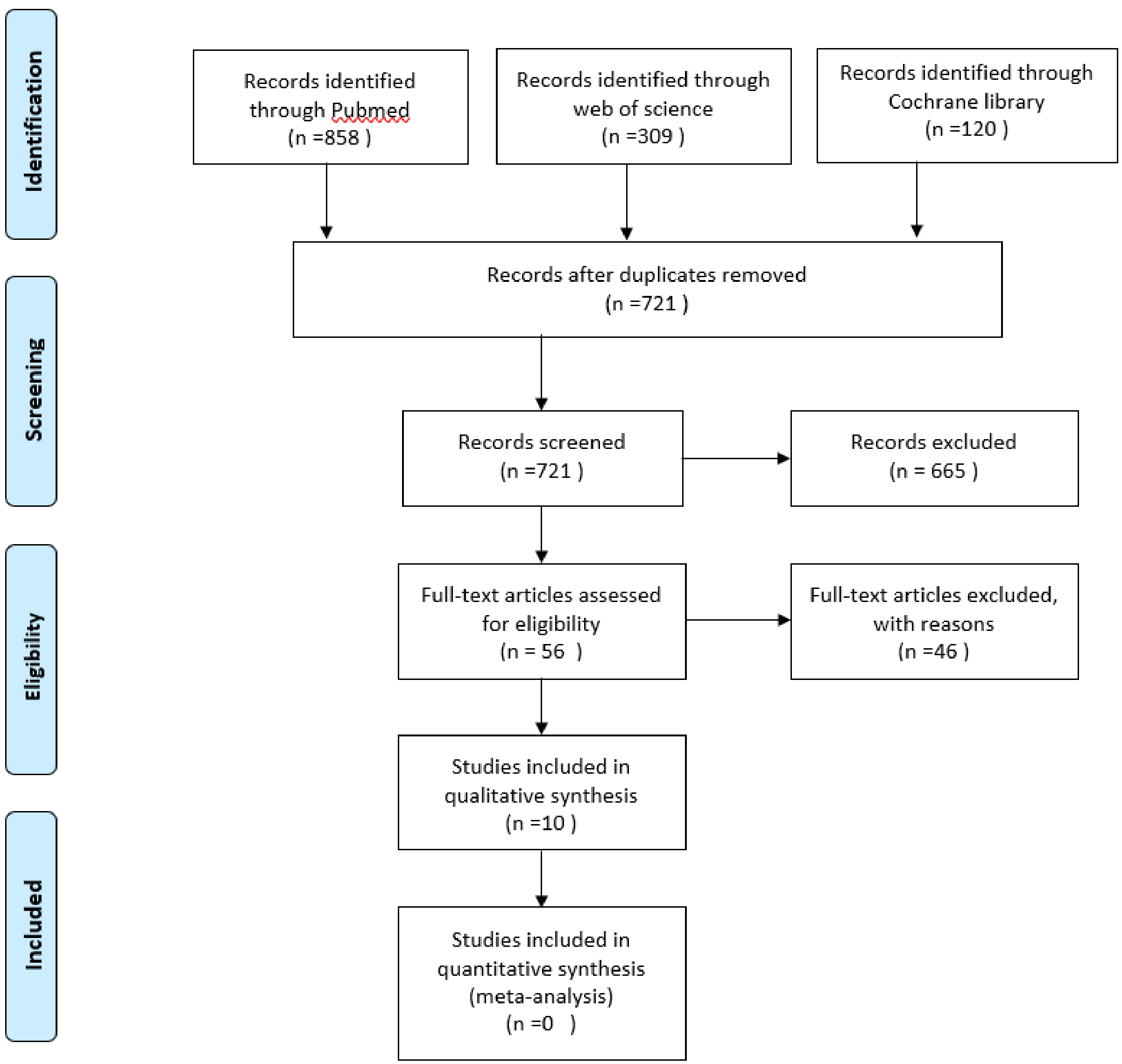

Figure 1: PRISMA format for the Systematic Review

Table 1: Identified RCT trials (*n* = 4) from identified reports (*n* = 10)

RCTs #4	
1. Fernández et al (2015)	**10 years data**
2. Estay et al (2018)	**1 years data**
3. Estay et al (2018)	**12 years data**
4. Dennison et al (2019)	**5 years data**
Prospective cohort studies #8	
1. Gordan et al (2006)	**2 years data**
2. Moncada et al (2008)	**2 years data**
3. Moncada et al (2009)	**3 years data**
4. Gordan et al (2009)	**7 years data**
5. Fernández et al (2011)	**4 years data**
6. Martin et al (2013)	**5 years data**

References [8,36,55,61,63,69,71,206-208]

Table 2: Study characteristics

RCT/Prospective	Setting	Patient situation	N orig.	Time (years)	N exam.	Intervention methods
Fernández et al (2015) [71]	Operative Dentistry Clinic at the Dental School of the University of Chile	Class I,26 teeth Class II, 24 teeth	28 patient 50 Defective composite restorations.	10	24 patient 50 restorations repaired or replaced	Repair, and replacement
Estay et al (2018) [206]	Operative Dentistry Clinic, Dental School, University of Chile, Santiago, Chile	Premolars and molars	35 patient 105 Defective composite restorations.	1	32 patient 96 sealed with nanofilled flowable RC, sealed with resin-based sealant, or control group	Sealed with nanofilled flowable RC, sealed with resin-based sealant, and control without intervention
Estay et al	Operative	Posterior	34 patient	12	29 patient	Repair,

(2018) [207]	Dentistry Clinic at the Dental School of the University of Chile	teeth Class I, and Class II	67 Defective composite restorations (repair 15, replace 22, + control 22, - control 8)		66: (repaired 14, replaced 22, + control 22, - control 8)	replacement, and controlled group.
Dennison et al (2019) [208]	University of Michigan School of Dentistry, Cariology, Restorative Sciences and Endodontics, Ann Arbor, MI, USA	Not mentioned	152 patients 360 defective composite restorations	5	Patients? 339 restorations at one year, 308 at 3years, and 271 at five years.	Repair/resealed or control group
Gordan et al (2006) [53]	Operative Dentistry Clinic, College of Dentistry at the University of Florida	Class III (*N* = 40), Class IV (*N* = 19), and Class V (*N* = 29)	40 patient 88 Defective composite restorations (repair 25, sealing with sealant 13, resurfacing 18, replacement	2	58 repaired, sealed, resurfaced, replaced, or no treatment	Repair, sealing, resurfacing, replacement, or no treatment

			16, and no treatment 16			
Moncada et al (2008) [69]	Operative Dentistry Clinic at the Dental School, University of Chile.	Not mention	66 patient 78 Defective composite restorations.	2	66 patient 78 repaired composites, or untreated	Repair, sealing of margins, refurbishing, replacement of restorations, and untreated
Moncada et al (2009) [63]	Operative Dentistry Clinic, Faculty of Dentistry, University of Chile, Santiago.	Class I and class II restorations	66 patient 78 defective composite restorations.	3	Patient? 73 sealed, refurbished, repaired, replaced, and untreated	Sealing, refurbishment, repair, replacement, or untreated
Gordan et al (2009) [36]	University of Florida College of Dentistry	Class II and V of posterior teeth, Class III and IV for anterior teeth.	37 patient 88 defective composite restorations (25 repair, sealing 12, refinishing 19, replacement 16, and no treatment 16)	7	Patient? 69 at six months, 68 at one year, 62 at two years, and 53 at seven years.	Repair, sealing, refinishing, replacement, or no-treatment
Fernández et al (2011) [8]	Operative Dentistry	Class I and class II	66 patient	4	52 patient	Sealing, refurbishment,

	Clinic at the Dental School, University of Chile, Santiago, Chile.	restorations	78 defective composite restorations		58 (sealed, refurbished, repaired, replaced, or untreated	repair, replacement, or untreated
Martin et al (2013) [61]	Operative Dentistry Clinic at the Dental School, University of Chile, Santiago, Chile	Class I and class II restorations	32 patient 57 defective composite restorations	5	23 patients 37 (sealed, replaced, or untreated)	Sealing, replacement, or untreated

TABLE 3 Bias assessment

RCT/Prospective studies	Study design	Study objective (sic)	Statistics	REB	Funding	Seq. generate	Allocate conceal	Blinding pat	Blinding outcome	Incomplete data	Select reporting	Other	Sum
Fernández et al (2015) [71]	Repair VS replacement	To assess the longevity of repairs to localized clinical defects in composite resin restorations that were initially planned to be treated with a restoration	Wilcoxon tests Friedman tests	Approved by the Institu-tional Research Ethics Committee of the Dental School at the University of Chile	Non funded	Low	Low	High	High	Moderate	Moderate	Moderate	Moderate

		replacement.											
Estay et al (2018)[206]	Sealing with nanofilled flowable composite Vs sealing with fissure sealant	To evaluate the 6-and 12-month performance of microrepairs of marginal occlusal microdefects of resin composite restorations in a group of patients with high caries risk.	• Wilcoxon tests • Mann-Whitney tests	This research was conducted in full accordance with the World Medical Association Declaration of Helsinki, and was independently reviewed and approved by a local	Non funded	Moderate	Low	High	High	Moderate	Low	Moderate	Moderate

				ethics committee/institutional review board									
Estay et al (2018) [207]	Repair, replacement, and controlled group.	To clinically evaluate repaired posterior amalgam and composite restorations over a 12 year period, investigate the influence of repair in the survival of restorations, and compare	Wilcoxon test Mann-Whitney test	The study protocol was approved by the Institutional Research Ethics Committee of the Dental School at the University of Chile	Non funded	Low	Moderate	High	High	High	Moderate	Moderate	Moderate

		their behavior with respect to controls.											
Dennison et al (2019) [208]	Repair/ resealed or control group	To assess the effectiveness of repair/ resealing of stained composite margins as an alternative to controlled observation without treatment in a randomized clinical trial after five years.	Chi-square test	The study protocol and consent form were approved by the Health Sciences Institutional Review Board at the university of Michigan School of	This study was supported by USPHS from the National Institute of Dental and Craniofacial Research.	Low	Low	High	High	Moderate	Moderate	Moderate	Moderate

				Dentistry, Cariology, Restorative Sciences and Endodontics, Ann Arbor, MI, USA									
Gordan et al (2006) [53]	Repair, sealing, resurfacing, replacement, or no treatment	To investigate the effectiveness of alternative treatments to the replacement of resinbased composite (RBC) restoration	Kruskal - Wallis Test	The study was approved by the Institutional Review Board (IRB) at the University of Florida	supported by the University of Florida Division of Sponsored Research	Moderate	Low	Moderate	Low	Low	Moderate	Moderate	Moderate

		s.											
Moncada et al (2008) [69]	Repair, sealing of margins, refurbishing, replacement of restorations, and untreated	This investigation assessed the effectiveness of alternative treatments for the replacement of amalgam and resin-based composite restorations.	Paired *t*-test	Approved by the Ethics Committee of the Research Office of the Dental School at the University of Chile.	3M ESPE	Low	Low	Moderate	Moderate	High	Low	Moderate	Moderate
Moncada et al (2009) [63]	Sealing, refurbishment, repair, replacement, or untreat	To examine the effectiveness of treatments other than replacement for	Nonparametric Pairwise test	This research was supported by the Faculty of Dentistr	3M ESPE, St. Paul, Minn., supplied the 3M ESPE	Low	Low	High	High	Moderate	Low	Moderate	Moderate

	ed	defective Class I and Class II resinbased composite (RBC) and amalgam (AM) restorations.		y, University of Chile	products for this study.								
Gordan et al (2009) [36]	Repair, sealing, refinishing, replacement, or no-treatment	The authors assessed the longevity of defective resin-based composite (RBC) restorations that were not treated or were	Fisher exact test LIFETEST procedure in SAS	The institutional review board (IRB) at the University of Florida approved the study	Division of Sponsored Research, University of Florida, Gainesville.	Low	Low	Low	Low	Low	Moderate	Moderate	Low

		treated by means of repair, sealing, refinishing or total replacement. They also aimed to identify and quantify the main reasons clinicians diagnosed restorations as defective.											
Fernández et al (2011) [8]	Sealing, refurbishment, repair, replacement, or	To estimate the median survival time (MST) of marginal	Kaplan Meier test Chi-square nonpara	Operative Dentistry Clinic at the Dental School, Univers	Non funded	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate

	untreated	sealing, repair and refurbishment of amalgam and resin-based composite restorations with localized defects as a treatment to increase the restoration longevity.	metric pairwise comparisons test	ity of Chile, Santiago, Chile. The protocol was approved by the local Research Ethics Committee									
Martin et al (2013) [61]	Sealing, replacement, or untreated	To assess sealed defects at the margins of Class I and Class II amalgam	Wilcoxon test Kruskal-Wallis test Mann-Whitney post	The Institutional Research Board and Ethical Board of the Dental	This study was supported by Universidad of Chile and	Low	Moderate	High	High	Moderate	High	Moderate	High

		and resin-based composite (RBC) restorations and to follow-up the results after five years.	hoc tests	School at the University of Chile approved the study	3M-ESPE.							

Table 4 Study results

RCT/Prospective studies	Pre-operative evaluation of composite restoration	Repair protocol	Composite product	Isolation methods	PROMs	Evaluation of composite restorations at follow-up	Major finding
Fernández et al (2015)	Modified USPHS [33] (Marginal adaptation, Secondary caries, Anatomic form, and Colour)	Exploratory cavity, removal of any demineralized and soft tooth tissue, a self-priming resin bonding system was used (Adper Prompt L-Pop; 3M ESPE, St. Paul, MN, USA), followed by a restoration.	Filtek Supreme; 3M ESPE	Rubber dam	None	Modified USPHS	Over the 10 years, the performance of the repaired restorations was similar to that of the resin composites that were replaced.

Estay et al (2018)	World Dental Federation (FDI) criteria [34] (Marginal adaptation, surface staining and recurrent caries, erosion and abfraction)	The restoration was initially cleaned using water and a hard brush at low speed, Following the protocol, the surface was conditioned with 35% orthophosphoric acid for 15 s, then the tooth was rinsed with water for 30 s and dried with compressed air from a syringe for 15 s. The adhesive (Single Bond Universal, 3M Oral Care) was actively applied using a brush	Filtek Flow Z350 XT, 3M Oral Care, Clinpro Sealant, 3M Oral Care	Rubber dam	None	World Dental Federation (FDI) criteria	Occlusal RC restorations that were sealed using either a resin-based sealant or a nanofilled flowable RC benefited from improved clinical status after 12 months. Use of the latter presented the better clinical performance of the two by providing a higher rate of total retention of sealing materials.

		(Microbrush International; West Chester, PA, USA) for 20 s, then the bonding agent was air dried for 5 s and photopolymerised for 10 s using a light-curing unit (2500 Curing light, 3M Oral Care). Lamp potency was verified before each session using a light-emitting diode (LED) radiometer (LED Radiometer, SDI; Bayswater, Victoria, Australia).					

Estay et al (2018)	Modified USPHS (Marginal adaptation, Surface roughness, Secondary caries, Marginal stain, Teeth sensitivity, Anatomic form, Luster)	Exploratory cavity, removal of any demineralized and soft tooth tissue, For composite restorations, a one-step, self-etch adhesive was used (Adper Prompt L-Pop, 3M ESPE, St Paul, MN, USA) according to the manufacturer's instructions, followed by a restoration.	Nanofill composite resin restorative Material Filtek Supreme, 3M ESPE	Rubber dam	None	Modified USPHS	Given that most clinical parameters investigated were similar between all groups during the follow-up, the repair of RC and AM restorations is a good clinical option because it is minimally invasive and can consistently increase the longevity of restorations.
Dennison et al (2019)	Modified USPHS (color	The discolored margin was exposed with a	Revolution, Kerr Mfg Co (repaired and resealed	Cotton roll	None	Modified USPHS	Resealing of restorations with margin

	match, margin discoloration, margin adaptation, and recurrent caries)	¼ or ½ round bur, removing all stain from the interface and exposing sound adjacent tooth structure on one side of the margin. All of the marginal interface was then etched with 37% phosphoric acid for 30 seconds and rinsed thoroughly for 15 seconds. A dentin bonding agent (Optibond Solo Plus, Kerr Mfg Co, Orange, CA, USA) was then applied in a thin coat and	group)				discoloration reduced the occurrence of penetrating stain from 81% in controls to 46% in resealed margins and crevicing from 21% to 11% after five years. Both controlled observation and resealing of margins resulted in a similar very low incidence (<6%) of recurrent caries.

		photocured for 10 seconds using a standard halogen light (650 mwatts/cm2 intensity).					
Gordan et al (2006)	Modified USPHS (Color match, Marginal adaptation, Anatomic form, Surface roughness, Marginal staining, Interfacial staining/Bulk discoloration, Contact, Post-operative sensitivity,	The RBC at the defective site was removed with a round carbide bur (Brasseler USA, Dental Rotary Instruments, Savannah, GA, USA) to allow a proper diagnosis and extent of the defect. The preparation margins were acid etched with	Filtek Z250, 3M/ESPE (repair and replacement), Delton, Denstply/Caulk, Milford, DE, USA (sealant)	Rubber dam	None	Modified USPHS	RBC restorations that present less-than-ideal marginal adaptation and stained margins are better off being repaired.

	Secondary caries, and Luster of restoration)	35% phosphoric acid and bonded with a resin-based bonding system (Single Bond, 3M/ESPE, St. Paul, MN, USA).					
Moncada et al (2008)	USPHS (United State Public Health Service)/Ryge criteria (Marginal adaptation, Anatomic form, Surface roughness, Marginal staining, Occlusal contact, Secondary	Carbide burs were used to explore the defective margins of the restorations, beginning with the removal of part of the restorative material adjacent to the defect. Once this material was removed, the exploratory cavity	Filtek Supreme, 3M ESPE	Rubber dam	None	USPHS (United State Public Health Service)/Ryge criteria	The two-year recall examination showed that sealant, repair and refurbishing treatments improved the clinical properties of defective amalgam and resin-based composite restorations by increasing the longevity

	caries, and Luster of restoration)	preparation then included any stained or soft tooth tissues. For Am restorations, a dispersed phase amalgam (original D: Wykle Research, Inc, Carson City, NV, USA) was used to repair the preparation. Mechanical retention was created inside the existing restoration. For RBC restorations, a self-priming bonding system was used (Adper					of the restorations with minimal intervention.

		Promp L-Pop, 3M ESPE, St Paul, MN, USA), followed by restoration					
Moncada et al (2009)	Modified U.S. Public Health Service/Ryge Criteria (Marginal adaptation, Anatomic form, Surface roughness, Secondary caries, and Luster of restoration)	The clinicians explored the defects in both RBC and AM restorations by using carbide burs (no. 330-010, Brasseler USA), starting with the restorative material adjacent to the defect. After removing the restorative material in the area of the defect, the clinicians removed any	Clinpro Sealant, 3M ESPE, St. Paul, Minn (sealing material) Filtek Supreme Plus Universal Restorative, 3M ESPE (repairing or replacement material)	Rubber dam	None	Modified U.S. Public Health Service/Ryge Criteria	Marginal sealing or repair or refurbishment of anatomical form and roughness are conservative and simple procedures that increase the longevity of RBC and AM restorations with minimal intervention.

		stained and soft tooth tissues present at the exploratory cavity preparation. The defect rarely involved demineralized or soft dentin. For RBC restorations, the dentists used a self-priming resin bonding system (Adper Prompt LPop Self-Etch Adhesive, 3M ESPE), followed by restoration.					
Gordan et al (2009)	Modified U.S. Public Health	The dental student removed the	Filtek Z250, 3M ESPE (repair and	Rubber dam	None	Modified U.S. Public Health	Restorations degraded to varying

	Service criteria ((Color match, Marginal adaptation, Anatomic form, Surface roughness, Marginal staining, Interfacial staining/Bulk discoloration, Contact, Post-operative sensitivity, Secondary caries, and Luster of restoration)	defective portion of the RBC by using a round carbide bur (Brasseler USA, Savannah, Ga.). The prepared margins were partly in enamel and dentin, as well as in the original restoration. The student acid etched the preparation and the remaining composite with 35 percent phosphoric acid and bonded them with a resin-based bonding system (Single Bond, 3M ESPE, St. Paul, Minn.),	replacement material), Delton, Denstply Caulk, Milford, Del. (sealant material)			Service criteria	degrees in all criteria, and the survival of restorations differed among treatment approaches. Longitudinal data collected across seven years support the viability of all nonreplacement restoration treatment strategies.

		then placement of restoration.					
Fernández et al (2011)	Modified U.S. Public Health Service criteria (Marginal adaptation, Anatomic Form, Surface Roughness, Secondary Caries, and Restoration Luster)	Repair was defined as the removal of part of the restoration, along with the localized defect and restoration of the prepared site. For repair, carbide burs (330-010) were used to explore the defective margins of the restorations, beginning with the removal of restorative material adjacent to the defect. Once this material was removed, an	Clinpro Sealant, 3M ESPE, St. Paul, MN, USA (sealant material) Filtek Supreme; 3M ESPE (repair and replacement material)	Rubber dam	None	Modified U.S. Public Health Service criteria	Defective amalgam and resin-based composite restorations treated by sealing of marginal gaps, refurbishment of anatomic form, luster or roughness, and repair of secondary caries lesions, had their longevity increased.

		exploratory cavity preparation included any demineralized and soft tooth tissue. A dispersed phased AM (Original D; Wykle Research, Inc Carson City, NV, USA) was used to repair the AM restoration. Mechanical retentions were created inside the existing restoration. For RBC restorations, a self priming resin bonding system was used (Adper Promp					

		L-Pop; 3M ESPE) followed by restoration.					
Martin et al (2013)	Modified U.S. Public Health Service criteria (Marginal adaptation, Surface roughness, Secondary caries, Marginal stain, Teeth sensitivity)	Defective areas were acid etched with 35% phosphoric acid for 15 seconds. A resin-based sealant (Clinpro Sealant, 3M ESPE) was applied over the defective area. The sealant was polymerized with a photocuring unit (Curing Light 2500, 3M ESPE) for 40 seconds.	Clinpro Sealant, 3M ESPE (sealant material) Filtek Supreme, 3M ESPE (replacement material)	Rubber dam	None	Modified U.S. Public Health Service criteria	This study demonstrated that marginal sealing of restorations is a minimally invasive treatment that may be used instead of the replacement of restorations with localized marginal defects.