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Clinical longevity of direct and indirect posterior resin composite restorations: An updated systematic review and meta-analysis

Uros Josic [a], Carlo D'Alessandro [a], Vesna Miletic [b], Tatjana Maravic [a], Claudia Mazzitelli [a], Jelena Jacimovic [c], Roberto Sorrentino [d], Fernando Zarone [d], Edoardo Mancuso [a], António HS Delgado [e,f], Lorenzo Breschi [a,*], Annalisa Mazzoni [a]

[a] Department for Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy
[b] Sydney Dental School, Faculty of Medicine and Health, University of Sydney, Sydney 2145, Australia
[c] Central Library, School of Dental Medicine, University of Belgrade, Serbia
[d] Department of Neurosciences, Reproductive and Odontostomatological Sciences, Division of Prosthodontics and Digital Dentistry, University "Federico II" of Naples, Italy
[e] Egas Moniz Center for Interdisciplinary Research (CiiEM), Monte de Caparica, Almada 2829–511, Portugal
[f] Division of Biomaterials and Tissue Engineering, UCL Eastman Dental Institute, London, UK

A R T I C L E I N F O

Keywords:
Longevity
Composite restoration
Systematic review

A B S T R A C T

Objectives: To answer the PICO(S) question: Is there a difference in clinical longevity between direct and indirect resin composite restorations placed on permanent posterior teeth?
Data: Randomized controlled clinical trials (RCTs) investigating direct and indirect resin composite restorations in posterior permanent teeth were considered.
Sources: Several electronic databases were searched, with no language or date restrictions. The revised Cochrane Collaboration's tool for assessing risk of bias (RoB-2) was used to analyze the studies; meta-analyses were run and the certainty of evidence was assessed by the GRADE tool. A subgroup meta-analysis was performed for resin composite restorations placed on posterior worn dentition.
Study selection: Twenty-three articles were included in qualitative synthesis, while 8 studies were used for meta-analyses. According to the RoB-2 tool, 5 studies were ranked as "low risk", 7 had "some concerns", while 11 papers were rated as "high risk" of bias. There were no statistically significant differences in short-term ($p = 0.27$; RR=1.54, 95% CI [0.72, 3.33]), medium-term ($p = 0.27$; RR=1.87, 95% CI [0.61, 5.72]) and long-term longevity ($p = 0.86$; RR=0.95, 95% CI [0.57, 1.59]). The choice of restorative technique had no influence on short-term survival of resin composite restorations placed on worn dentition ($p = 0.13$; RR=0.46, 95% CI [0.17, 1.25]). The certainty of evidence was rated as "very low".
Conclusions: Direct and indirect resin composite restorations may show similar clinical longevity in posterior region, regardless of the observation period or substrate (wear-affected and non-affected dentition). The very low quality of evidence suggests that more long-term RCTs are needed to confirm our results.

1. Introduction

Nowadays, resin composite restorations placed using a direct technique are usually the material of choice for posterior cavities due to their good mechanical and esthetical properties. Resin composite materials and bonding techniques have undergone major improvements since their launch to the dental market [1,2]. Indeed, if adhesive protocols are followed strictly and direct restorations are placed adequately, they can last up to 3 decades, showing clinically acceptable performance and annual failure rates of only 2.4% [3]. Nevertheless, resin composite restorations still fail, mainly due to secondary caries and fractures [4].

Annual failure rate of direct resin composite restorations increases after 65 years of age and in patients wearing removable dentures [5], in molar teeth, endodontically treated teeth and 4 + surface restorations [6]. Higher annual failure rate was seen in direct restorations placed by less experienced practitioners and those working in large group dental

* Correspondence to: Department for Biomedical and Neuromotor Sciences, DIBINEM, University of Bologna, Via San Vitale 59, 40125 Bologna, Italy.
E-mail address: lorenzo.breschi@unibo.it (L. Breschi).

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practices [5]. Interestingly, gender does not seem to be an important factor for direct restoration success [3,5]. Type of resin composite was not associated with restoration longevity [6], but "open sandwich" restorations combining resin composite with glass ionomer cements have shown proximal defects associated with dissolution of the material [7]. Fractures remain equally frequent for both amalgam and resin composites, though resin composites in adult patients seem to be more prone to secondary caries development [4].

The occurrence of secondary caries is usually attributed to polymerization shrinkage and polymerization stress at the material/tooth interface, while fracture can be explained by the limitations related to materials' mechanical properties, as well as tooth- and patient related factors, particularly evident in case of reconstruction of large cavities with cuspal involvement [8]. Another concern is proper polymerization of direct resin composite restorations, as depth of cure can be compromised by lack of frequent controls of quality of the light-curing units, as well as factors related to operator's technique [9].

Indirect resin composite restorations mitigate some of the drawbacks of the direct technique and, theoretically, should ensure longer life span of the restorations. They can be accomplished using prefabricated computer aided designed and manufacturing (CAD/CAM) resin composite blocks, or restorative resin composite crafted by the dental technician. These materials are subjected to longer polymerization times from different angles, which improves the degree of monomer conversion, undoubtedly improving the material's mechanical properties [10]. Besides, it is also possible to expose some resin composite materials to heat which further enhances degree of conversion and microhardness [11]. Higher degree of conversion of indirect resin composites offers another important benefit – improved biocompatibility as monomer elution from these materials tends to be inferior compared to direct resin composites since monomer leaching is limited merely to a thin resin cement layer between the restoration and tooth [12,13]. Lastly, it is easier to achieve stable occlusion control, as the dental technician has the possibility to faithfully reproduce the missing tooth morphology on stone casts and check the occlusal guidance in the articulator. However, elevated cost of the indirect technique, waiting time between two dental visits (which can be potentially avoided by CAD/CAM technology [14,15]), as well as greater tissue removal during tooth preparation for indirect restorations remain the biggest disadvantages of this technique [16,17].

Irrespective of the material used, failure reasons of indirect are similar to those for direct restorations mostly due to fractures and secondary caries, with fractures being more frequently associated with failure of ceramic and caries with cemented metal restorations [18]. Gold indirect restorations have been shown to perform superiorly to indirect resin composites in medium- to long-term, while lithium disilicate and leucite indirect restorations have shown similar short- to medium-term survival rates [19]. Survival or success of gold restorations was not associated with tooth- or patient-related factors (tooth type, shape of restorations, margin location, pulp capping, use of liners, presence of craniomandibular disease, patient age and gender and dental maintenance care) [20]. Associations between longevity of indirect resin composite restorations and tooth- or patient-related factors have not been reported [19,21,22]. As for manufacturing and cementation methods, CAD/CAM, pressable or stratified methods or selective enamel etching prior to application of self-adhesive resin cements do not affect longevity of indirect restorations, including indirect resin composites [23,24].

Previous systematic reviews have addressed the question of longevity of direct and indirect posterior resin composite restorations [25,26]. A meta-analysis revealed no differences in longevity between the two techniques up to 5 years of follow-up [25], while another systematic review reported inconclusive results [26]. Considering that new studies, including ones with a long-term follow-up have been published recently, we aimed to reassess the clinical longevity of direct and indirect resin composite restorations, discuss the failure modes associated with these restorations and answer the following PICOS question: Is there a difference in clinical longevity between direct and indirect resin composite restorations placed on permanent posterior teeth?

2. Materials and methods

2.1. Study protocol and registration

This systematic review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement [27] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database under the number CRD42021282801. The search process is also reported in accordance with the PRISMA-S guidelines 2021 [28].

2.2. Eligibility criteria and search strategy

The PICOS question [29] that guided the choice of the search strategy and inclusion criteria was as follows:

Population (P) - adult patients with Class I or Class II cavities (regardless of cusp involvement) that required restoration due to tooth decay and/or failing of pre-existing restoration, including patients with tooth wear;.

Intervention (I) – direct resin composite restoration;.

Comparison (C) – indirect resin composite restoration;.

Outcome (O) – clinical longevity of direct and indirect resin composite restorations for different follow-up periods;.

Study design (S): randomized controlled clinical trials (RCTs) with parallel-group study design, including split-mouth studies.

The literature search was performed without any limitations between 26 and 30 January 2023, using the following electronic databases: Clarivate Analytics' Web of Science (including Web of Science Core Collection—WoS, Korean Journal Database—KJD, Russian Science Citation Index—RSCI, SciELO Citation Index—SCIELO), Scopus, PubMed (including MEDLINE) and Cochrane Central Register of Controlled Trials (CENTRAL) [Cochrane Library]. Preliminary searches were conducted to identify the most common free keywords, synonyms for concepts of interest, and relevant controlled vocabulary (Medical Subject Headings—MeSH, https://www.ncbi.nlm.nih.gov/mesh/) and to evaluate various information retrieval strategies. The complete search strategy (Table S1), jointly developed by the experienced medical librarian (J.J.) and the review team, was peer-reviewed by a second information specialist using the PRESS guideline [30] whose feedback was incorporated before running the final database search. Furthermore, to locate relevant unpublished manuscripts, research reports, conference papers, doctoral dissertations, and other grey literature, complementary searches through OpenGrey (http://www.opengrey.eu), Google Scholar (first 100 returns) and other available digital repositories (e.g., Networked Digital Library of Theses and Dissertations (http://www.ndltd.org), Open Access Theses and Dissertations (https://oatd.org), DART-Europe E-theses Portal—DEEP (https://www.dart-europe.org/basic-search.php), Opening access to UK theses—EThOS (https://ethos.bl.uk) were completed. Finally, to ensure the reliability of the data collected and the inclusion of the relevant studies that may not have been identified through the database and grey literature searches, backward and forward snowballing was also performed using citation indexes (WoS, Scopus, and Google Scholar). Performed searches were rerun during the final drafting of the paper up to 15 May 2023, indicating no new relevant trials had been published after the conclusion of the literature search.

The exclusion criteria were: (1) laboratory studies; (2) case reports and case series; (3) review papers; (4) conference abstracts; (5) studies that did not employ a parallel group study design that compared direct and indirect posterior resin composite restorations; (6) studies conducted on deciduous teeth and pediatric patients; (7) studies conducted on endodontically treated teeth; (8) materials other than resin composite used for restorations. We established a 1-year minimum follow-up period threshold for this systematic review and meta-analysis.

2.3. Study selection and data extraction

All literature search results were imported into the Rayyan QCRI platform [31] for duplicate removal and subsequent screening. The study selection process was carried out in 2 stages. Two independent investigators (U.J. and C.D.A.) completed initial screening of titles and abstracts, as to select studies eligible for inclusion based on the previously stated criteria. Papers that did not meet the eligibility criteria were excluded, and full texts of initially selected studies were retrieved for full-text reading. In the next stage, the same two investigators independently assessed full texts of studies for the purpose of selecting the articles of interest. All disputes were resolved through a consensus or discussion with a senior investigator (T.M.).

The same two investigators (U.J. and C.D.A.) independently completed data extraction using custom-made extraction forms in MS Word. The following data were extracted (Table S2):

- Details of the study: author, year, location and study design;
- Participants: number and age range;
- Teeth involved in the study, reason for restoration placement, type of cavity, field isolation;
- Direct resin composite restoration details: number, type of adhesive system used during restorative procedures and direct resin composite material type;
- Indirect resin composite restoration details: number, cementation strategy and indirect resin composite material type;
- Methodology: evaluation criteria and follow-ups;
- Results: success and failure rates;
- Conclusions.

If data were missing, the corresponding author of the relevant paper was contacted by an e-mail in an attempt to retrieve the information of interest.

2.4. Risk of Bias Assessment

Quality and risk of bias of the included studies were assessed by 2 investigators (V.M. and U.J.), independently from each other. The revised Cochrane Collaboration's tool for assessing risk of bias in randomized clinical trials (RoB 2) was used [32]. The 2 authors compared and discussed the findings, and a third investigator (J.J.) was consulted in case of disagreements.

The RoB 2 tool [32] contains algorithms that map responses to signaling questions regarding a proposed risk of bias judgment for each outcome assessed in a given study. Therefore, assessment criteria were divided into five domains: D1 - risk of bias from randomization process; D2 - bias due to deviations from intended interventions; D3 - bias due to missing outcome data; D4 - bias in measurement of the outcome; and D5 - risk of bias in selection of the reported result. The risk of bias judgment for each of the five domains was classified as "low risk of bias," "some concerns," or "high risk of bias". The overall risk of bias on a study level was determined according to the classification of the assessment criteria domains, following guidelines from the RoB 2 tool. If at least one domain was rated as "some concerns" and all other domains "low risk", the overall risk of bias was rated to be "some concerns". If several domains were rated as "some concerns", the overall risk of bias could be judged as "some concerns". Only in cases where both D1 and D4 were rated as "some concerns", the overall risk of bias was rated as "high", since the authors of the current review considered these two domains crucial for adequate blinding. Lastly, if at least one domain was rated as "high risk of bias", the overall risk of bias had to be rated as "high".

2.5. Meta-analysis

In order to assess the differences between direct and indirect restorations' longevity, the data which had previously been extracted from the included studies were analyzed using Revman (Review Manager 5.4, The Cochrane Collaboration, Copenhagen, Denmark).

When multiple publications with different follow-up periods were detected, the data from the latest publication were used for conducting meta-analyses, unless stated otherwise. The data were dichotomous and were considered as "success" (no clinical or radiographic signs of retention loss/fracture) or "failure" (loss of retention or fracture, secondary caries and need for repair). Extractions due to periodontal reasons were not considered as failures and these data were censored. The risk ratio with a 95% confidence interval (CI) was calculated. Random-effects models were applied, and heterogeneity was tested using Cochran Q test and the I^2 index. Before choosing random-effects models, fixed effects analysis was carried out as a sensitivity analysis, which produced a very similar summary estimate. The follow-up periods were considered as short- (1–3 years), medium- (4–7 years) or long-term (8–11 years) [33,34].

2.6. Certainty of evidence assessment

Quality of evidence (certainty in the estimates of effect) was determined for the outcome longevity using the grading of recommendations assessment, development and evaluation (GRADE) approach [35]. Based on the mentioned indicators, the certainty of the estimated effect was rated as *high quality of evidence* (the true effect lies close to that of the effect estimate), *moderate quality of evidence* (the true effect is likely to be close to the effect estimate, but there is a possibility that it is substantially different), *low quality of evidence* (the true effect may be substantially different from the effect estimate), and *very low quality of evidence* (the true effect is likely to be substantially different from the effect estimate).

3. Results

3.1. Study selection

The information on the literature search, which resulted in 3946 articles across all the databases, is given in the PRISMA flowchart of Fig. 1. After the exclusion of 1772 duplicates, 2174 studies were left for review. Two more eligible studies were found through citation mining. Further screening by title and abstract led to another exclusion of 2146 studies. A total of 30 studies were retrieved for full-text evaluation. After reading full-texts, seven studies were excluded: due to missing direct resin composite group [36–38], endodontically treated teeth [39,40], and pediatric patients [41]. Finally, 23 studies [42–64] were included in the current systematic review.

3.2. Descriptive analysis of the selected studies

The extracted details from 23 studies included in the present review can be found in Table S1. The studies were published between 1994 and 2023, and most of them were carried out within a university clinical setting (excluding one study [46] which was conducted in a private dental practice). The studies were designed either as parallel-group [39,40,42,43,45,48,49,51–55,60–64] or split-mouth [46,47,50,56–59], and were performed in Brazil [52,57,58], The Netherlands [44,49,55], Turkey [48,50,59–62], Egypt [45], The United Kingdom [39,40,56], Italy [46], Denmark [47], Germany [54,63,64] and Sweden [43,51]. In total, 731 adult patients received 789 direct and 801 indirect restorations placed on posterior teeth. Modified United States Public Health Service (USPHS) were used in most clinical studies [39,45–48,51,54,56,60] when assessing the clinical outcomes of the restorations. FDI World Dental Federation criteria were also used in other studies [55,57–59].

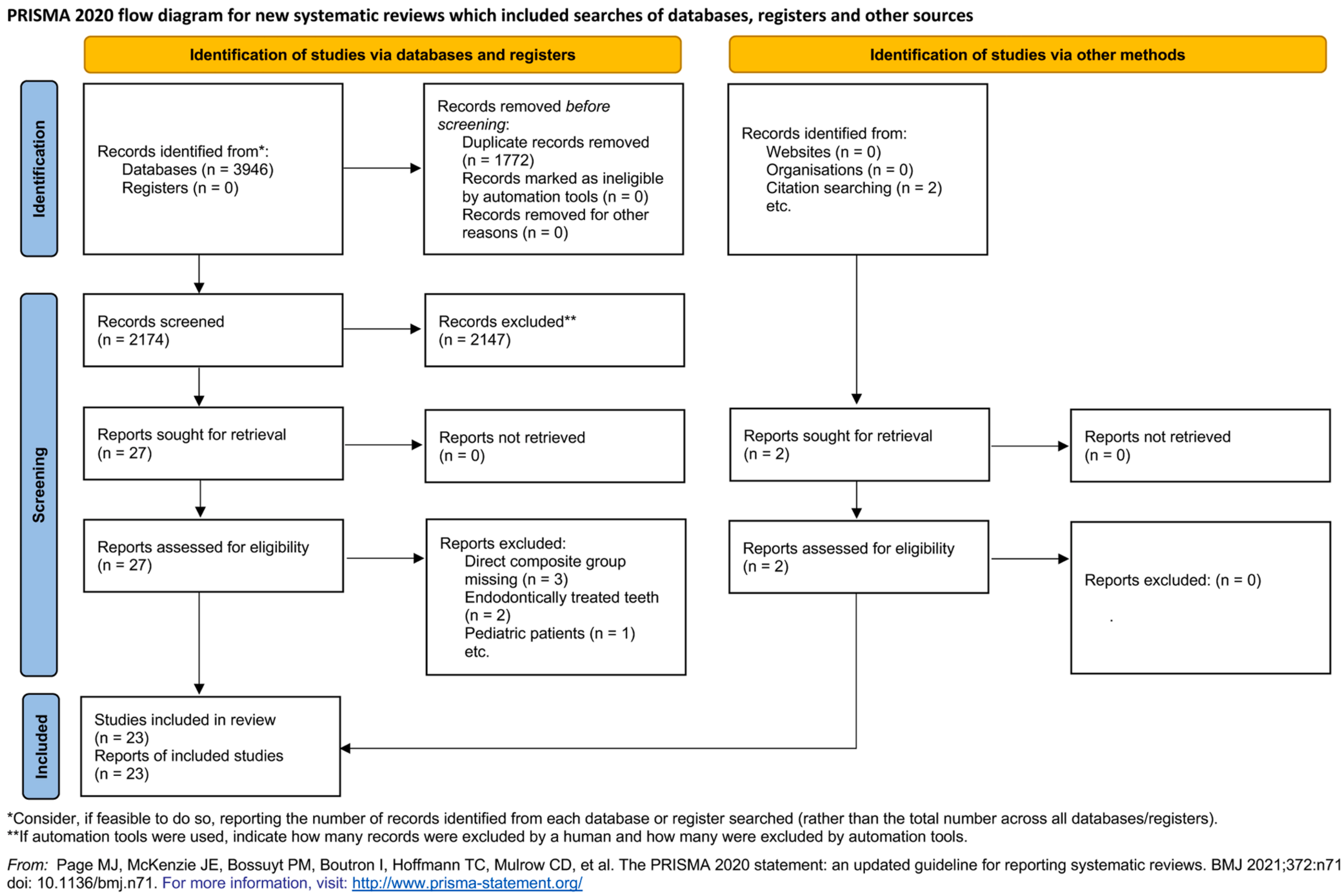

Fig. 1. PRISMA flowchart of study identifications. *Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers). * *If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. *From:* Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/.

The longest follow-up period available in the literature was 14 years (average) [55].

The posterior teeth restored with resin composites had to be in occlusion with good level of oral hygiene and absence of periodontal disease and parafunction, however, several RCTs did recruit patients with bruxism [42–44,47,51,55,56]. In regard to cavity configuration, resin composite restorations were placed on medium- and large size Class I and Class II, as well as on MOD cavities after removal of tooth decay or failing restorations, and some of the studies also included cusp-replacing restorations [42,44,55,58]. Rubber dam [43,45,46,48,51–54,58,59,63,64], cotton rolls and suction [44,47,55,60–62] and combination of both means [49,56] were used across the studies for moisture control and field isolation. For adhesive procedures in direct groups, etch-and-rinse [42–44,47–52,54,55,59,63,64], self-etch [45,46,53,60–62] and universal adhesives in selective-enamel etching mode [57,58] were employed, while indirect restorations were adhesively cemented [65,66] in all studies.

Two studies [49,56] compared the clinical longevity of direct and indirect posterior resin composites placed on severely worn dentition. In this case, the so-called "tabletop" indirect restorations were adhesively cemented to eroded teeth on which additional retention grooves or pits were prepared, while direct restorations were placed with a 3-step etch-and-rinse adhesive system where occlusal sharp edges were removed by means of course grid diamond chamfer bur.

The following methodologies were described for fabrication of indirect resin composite restorations: in numerous studies the same type of resin composite material was used in both direct and indirect technique [39,40,46,47,54,57,63,64], while CAD/CAM resin nano-composite blocks were utilized in two studies [58,59]. The inner surface of the indirect restorations received pre-treatment prior to luting procedure (i.e. orthophosphoric [53,60–62] or hydrofluoric acid etching [54,63,64], Al_2O_3 sandblasting with- or without silanization [42,44,47–49,52,55,57–59], only silanization [45], and mechanical roughening and application of a layer of adhesive system [46]), except in two studies [43,51] were no such attempt was made. Immediate dentin sealing, as means of improving clinical outcome of indirect restorations [67], was rarely applied [45,58]. Worn dentition was restored with indirect micro-filled and micro-hybrid light/heat cured resin composites, while direct restorations were placed with nanohybrid and micro-filled resin composites [49,56].

3.3. Risk of bias assessment

Fig. 2 summarizes the results of the risk of bias analysis for the studies included in this systematic review. Eleven studies [43,46,48,50–54,56,63,64] assessed by the RoB 2 tool were rated as "high risk of bias", 7 studies [42,44,47,49,55,60,62] received the rating "some concerns", while 5 studies were rated as "low risk" [45,57–59,61]. The raised concerns related to risk of bias arising from the randomization process (D1) were: operator's choice to restore the cavity with direct/indirect technique was influenced by the size of cavity [48,50,54,63,64]; substantial differences between the group sizes [43,51,53] and the lack of detailed description of the randomization process [46,52,56]. The problems associated with D2b were the disbalance in number of

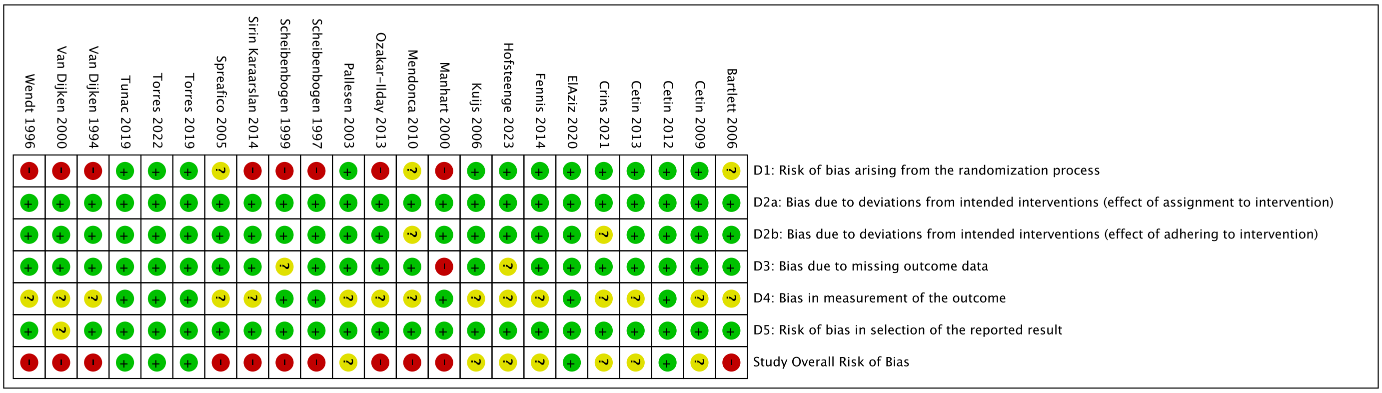

Fig. 2. Authors' Risk of bias assessment of the included studies.

repaired restorations between direct and indirect groups, as well as insufficient data on the number of repaired restorations [39,49,52]. Bias due to missing outcome data (D3) was suspected in three studies [39,55,63], while bias in measurement of outcome was problematic in 15 studies [42–44,46–53,55,56,60,62] where no detailed information of blinding of evaluators could be found throughout the text. One study [51] demonstrated concerns related to risk of bias in the selection of the reported results (D5) since it excluded restorations (the "open sandwich" technique) that were initially placed in the direct technique group [43] due to a large number of initial failures.

3.4. *Quantitative synthesis – meta analysis*

Following the data extraction process, 8 studies [47–49,54,55,57,58,60] presented suitable for running meta-analysis for the outcome of interest. Since 3 articles [42,44,55] were publications derived from the same cohort of patients at different follow-up periods, only data retrieved from the most recent study [55] were taken into consideration for the meta-analysis. Similarly, several authors reported clinical behaviour of resin composite restorations from the same group of patients, but at different follow-up periods [43,51,54,60–64]. We extracted data for the 6-year follow-up from the firstly published study from Van Dijken [43] which had more complete information compared to the author's subsequent publication [51]. The studies with no events in both arms were not considered for the meta-analysis, since they did not provide any indication of either the direction or magnitude of the relative treatment.

There were no statistically significant differences ($p > 0.05$) between direct and indirect resin composite restorations placed on posterior teeth after removal of tooth decay and/or failing restorations at short-, medium- and long-term follow-ups (Figs. 3, 4 and 5, respectively). The results for the mentioned time points were as follows: short-term longevity ($p = 0.27$; RR=1.54, 95% CI [0.72, 3.33]), medium-term longevity ($p = 0.27$; RR=1.87, 95% CI [0.61, 5.72]) and long-term longevity ($p = 0.86$; RR=0.95, 95% CI [0.57, 1.59]). No important heterogeneity was observed for short-term follow-up (I^2 =16%); the sensitivity analysis revealed moderate heterogeneity (I^2 =40%) when the data from the studies conducted on worn dentition were combined in the meta-analysis with the data from studies on non-eroded teeth. Considerable (I^2 =70%) and moderate (41%) heterogeneity were observed for medium- and long term follow-up, respectively.

Moreover, the results from the meta-analysis revealed that the choice of restorative technique had no influence on short-term longevity (Fig. 6) of resin composite restorations placed on worn dentition ($p = 0.13$; RR=0.46, 95% CI [0.17, 1.25]). The data showed substantial heterogeneity (I^2 =80%).

3.5. *Certainty of evidence assessment*

"Very low" certainty of evidence was observed for the outcome longevity for all observation periods (Table 1).

4. Discussion

The purpose of this paper was to systematically review the literature and assess the differences in clinical longevity between direct and indirect resin composite restorations placed on posterior permanent teeth. As far as we are aware, this is the most up-to-date and thorough systematic review which assessed differences in longevity for various follow-up periods, ranging from short- to long-term, while also implementing the GRADE tool to investigate the quality of evidence at each time point. Additionally, it was possible to perform a quantitative analysis of the potential differences in the lifespan of resin composite restorations placed on posterior worn dentition with direct and indirect

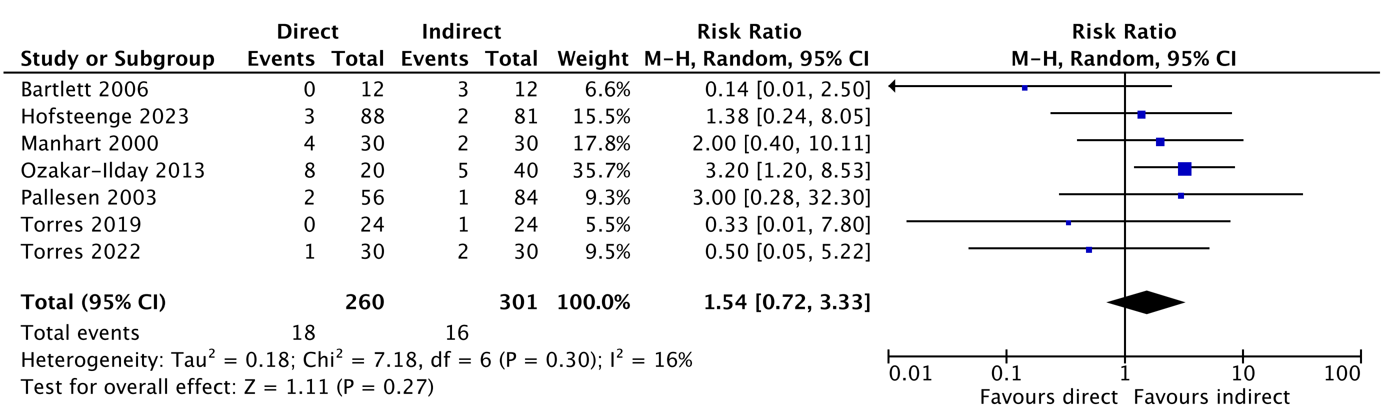

Fig. 3. Forest plot for Longevity at short-term (1/3 years) follow-up.

Study or Subgroup	Direct Events	Direct Total	Indirect Events	Indirect Total	Weight	Risk Ratio M–H, Random, 95% CI
Cetin 2013	1	67	0	41	9.6%	1.85 [0.08, 44.44]
Hofsteenge 2023	10	85	13	77	36.2%	0.70 [0.32, 1.50]
Pallesen 2003	3	54	1	84	15.9%	4.67 [0.50, 43.71]
Van Dijken 1994	20	50	12	98	38.3%	3.27 [1.74, 6.13]
Total (95% CI)		**256**		**300**	**100.0%**	**1.87 [0.61, 5.72]**
Total events	34		26			

Heterogeneity: $Tau^2 = 0.75$; $Chi^2 = 10.08$, df = 3 (P = 0.02); $I^2 = 70\%$
Test for overall effect: Z = 1.10 (P = 0.27)

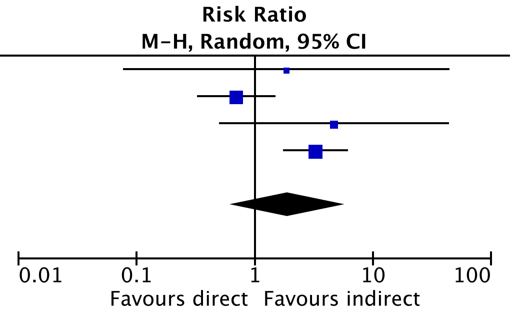

Fig. 4. Forest plot for Longevity at medium-term (4/7 years) follow-up.

Study or Subgroup	Direct Events	Direct Total	Indirect Events	Indirect Total	Weight	Risk Ratio M–H, Random, 95% CI
Hofsteenge 2023	20	75	22	60	45.6%	0.73 [0.44, 1.20]
Pallesen 2003	6	51	12	80	22.7%	0.78 [0.31, 1.96]
Van Dijken 2000	9	32	16	92	31.7%	1.62 [0.79, 3.29]
Total (95% CI)		**158**		**232**	**100.0%**	**0.95 [0.57, 1.59]**
Total events	35		50			

Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 3.38$, df = 2 (P = 0.18); $I^2 = 41\%$
Test for overall effect: Z = 0.18 (P = 0.86)

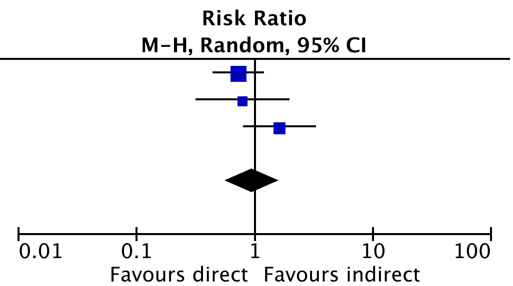

Fig. 5. Forest plot for Longevity at long-term (8/11 years) follow-up.

Study or Subgroup	Direct Events	Direct Total	Indirect Events	Indirect Total	Weight	Risk Ratio M–H, Random, 95% CI
Bartlett 2006	7	16	9	16	47.6%	0.78 [0.38, 1.57]
Crins 2021	13	88	39	76	52.4%	0.29 [0.17, 0.50]
Total (95% CI)		**104**		**92**	**100.0%**	**0.46 [0.17, 1.25]**
Total events	20		48			

Heterogeneity: $Tau^2 = 0.42$; $Chi^2 = 5.03$, df = 1 (P = 0.02); $I^2 = 80\%$
Test for overall effect: Z = 1.52 (P = 0.13)

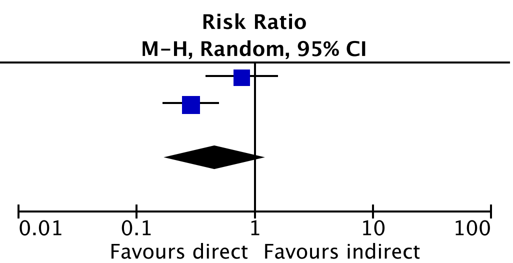

Fig. 6. Forest plot for Longevity worn dentition at short-term (1/3 years) follow-up.

technique.

The results from our meta-analyses revealed no differences in short-, medium- and long-term clinical longevity between direct and indirect resin composite restorations placed on permanent posterior teeth that were not affected by wear. The most common failure reasons in direct groups for short- and medium-term period were primarily restoration and tooth fractures, then secondary caries, while debonding, followed by restoration fractures, secondary caries and eventually tooth fractures were principal failures in indirect restorations. The quality of evidence according to GRADE for all investigated follow-up periods (1/3-, 4/7- and 8/11 years) was rated as very low, implying that we have very little confidence in the effect estimate.

Similar to our finding, a previous review [25] showed no differences in clinical longevity between direct and indirect restorations at 5 years, which we considered to be a medium-term follow-up period. Differently from our paper, the mentioned review did not report the quality of evidence and was not able to perform meta-analyses for observation periods shorter or longer than 5 years, most likely due to the insufficient number of studies with events of interest at the time when the last search strategy was carried out (August 18, 2015). It is, however, interesting to mention that a recent meta-analysis [33] found low quality evidence that suggested no difference in survival between direct and indirect resin composite restorations placed on endodontically treated posterior teeth at short-term follow-up, which is in line with our results. The lack of difference in longevity at short-term observation period may be explained by the fact that failure of resin composite restorations in the first 5 years of clinical service usually happens due to inadequate operator technique or incorrect material choice [68]. Since all analyzed clinical studies were carried out in a university setting where operators were calibrated before initiating restorative procedures, it is safe to assume that they closely followed adhesive protocols and manufacturer's instructions that led to good material performance and low number of premature failures within the first years of clinical service.

Although one might have expected to find differences in longevity after 8 years of clinical service (long-term period) in favor of indirect restorations, we found no such difference. Most of the events responsible for clinical failure that were included in the long-term meta-analysis were associated with secondary caries, followed by tooth and restoration fracture in the direct group. Secondary caries, restoration fracture, debonding of restorations and few tooth fractures accounted for majority of failures in the indirect group. Although the causes for clinical failure are similar in the direct and indirect group across all the assessed periods, it is interesting to note that tooth fracture was more frequently seen in the direct group, which could imply that indirect restorations could be a safer choice from the biomechanical point of view. The quality of evidence was downgraded and rated as very low due to problems related to risk of bias, as well as small number of events in the meta-analyzed studies. Furthermore, it should be stated that only one [55] out of three studies [47,51,55] comprehended in the long-term meta-analysis included cusp-replacing restorations.

Tooth wear is considered to be a complex phenomenon with a multifactorial etiology which includes erosion, abrasion and attrition [69],

Table 1
Certainty of evidence assessment according to GRADE tool for the outcome Longevity.

Certainty assessment							№ of restorations		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Indirect	Direct	Relative (95% CI)	Absolute (95% CI)	
Short-term longevity (1/3 years)											
7	randomised trials	very serious[a]	not serious	not serious	serious[b]	not suspected	18/260 (4.2%)	16/301 (4.3%)	**RR 1.54** (0.72–3.33)	**29 more per 1000** (from 15 fewer to 124 more)	⊕OOO VERY LOW
Medium-term longevity (4/7 years)											
5	randomised trials	very serious[c]	serious[d]	not serious	serious[e]	not suspected	38/323 (11.8%)	37/369 (10.0%)	**RR 1.30** (0.44–3.80)	**30 more per 1000** (from 56 fewer to 281 more)	⊕OOO VERY LOW
Long-term longevity (8/11 years)											
3	randomised trials	very serious[f]	serious[g]	not serious	serious[b]	n.a.	35/159 (22.0%)	51/236 (21.6%)	**RR 0.94** (0.58–1.51)	**13 fewer per 1000** (from 91 fewer to 110 more)	⊕OOO VERY LOW
Short-term (1/3 years) longevity for worn dentition											
2	randomised trials	very serious[h]	serious[d]	not serious	serious[b]	n.a.	22/104 (21.2%)	46/92 (50.0%)	**RR 0.60 (0.13–2.69)**	**200 fewer per 1000** (from 435 fewer to 845 more)	⊕OOO VERY LOW

CI: Confidence interval; RR: Risk ratio; n.a: not applicable
Explanations
a. Three of the included studies were ranked as High risk of bias, while two were ranked as Some concerns.
b. Small number of events.
c. One of the included studies was ranked as High risk of bias, while others were ranked as Some concerns.
d. Substantial heterogeneity; 95% CI do not entirely overlap.
e. Small number of events with rather wide 95% CI.
f. One included study was ranked as High risk of bias, while others were ranked as Some concerns.
g. Substantial heterogeneity.
h. One of the included studies was ranked as High risk, while the other was rated as Some concerns.

with consequent formation of sclerotic dentin. When wear reaches dentin and continues to progress, it leads not only to esthetical problems, but also functional deficiency as well as patient discomfort, often requiring a clinician to interfere [70]. Generally, it is widely accepted that sclerotic dentin observed in worn dentition can be seen as a challenging substrate for bonding procedures since it may impair the infiltration of the adhesive system and consequently result in creation of unstable hybrid layers [71]. It may also be argued that this type of dentin poses an equal adhesion problem for direct and indirect restorations as the bonding principle is the same (application of dental adhesive system required), thus resulting in similar durability of both types of restorations. During adhesive procedures, adequate surface pretreatment with 35% orthophosphoric acid and 5–10% sodium-hypochlorite was advocated as an appropriate method which allows obtaining bond-strength values that are comparable to sound dentin [72]. Nonetheless, even if the adhesive procedure has been performed properly, parafunctional habits that often persist in these patients are likely associated with different deteriorating effects on resin composite restorations. As such, highly destructive occlusal forces in bruxism [73] can be considered a risk factor for early failure of restorations placed on worn dentition in one of the studies [56] that was included in this quantitative synthesis.

Previous systematic reviews that assessed various methods for rehabilitation of severely worn dentition reported that no method can be considered superior in managing wear-affected teeth [74,75]. As far as we are aware, this is the first systematic review that additionally employed a meta-analysis to investigate potential differences in clinical longevity when posterior worn dentition is restored with direct and indirect resin composite restorations. According to the result of the meta-analysis, the choice of resin composite placement technique had no influence on the survival of restorations placed on worn dentition during the 3-year follow-up period. Again, this finding should be taken with caution, as GRADE assessment revealed very low certainty of evidence due to very serious problems related to risk of bias (one study rated as high risk, while the other was rated as some concerns), inconsistency and imprecision (Table 1). The rationale behind conducting a subgroup meta-analysis for the longevity of resin composite restorations placed on worn dentition was the fact that laboratory studies gave inconclusive results regarding coronal sclerotic dentin as a substrate used during bonding procedures [72,76] and that the authors of RCTs did not use sodium-hypochlorite to pretreat the eroded dentin. Moreover, extrapolation of results derived from laboratory studies to clinical scenarios is questionable, since many more variables are present in a complex clinical scenario compared to an in vitro setting [77]. Indeed, our decision to run a separate meta-analysis was additionally justified by the sensitivity analysis: when excluding studies conducted on worn dentition from the general meta-analysis at short-term follow-up (Fig. 6), the significant statistical heterogeneity (which is a direct consequence of clinical diversity) was eliminated.

One of the peculiar findings of this study concerns the quality of the reported data in the reviewed articles. According to the risk of bias analysis, only few studies were rated as "low risk" of bias, while the majority of them were scored either as having "some concerns" or being "high risk" of bias. There are a couple of possible explanations for such a result. Firstly, unlike in the previous review [25], the authors of this paper implemented revised Cochrane Collaboration's tool for assessing risk of bias in RCTs (RoB2) and did not attempt to contact the corresponding authors where no clear information on randomization or blinding could be found in the paper. This way, only the quality of the information reported in the papers was analyzed, without giving the possibility to the authors to provide the missing information, which eventually resulted in a rather strict assessment. Secondly, some of the papers included in this review had been published before the CONSORT 2010 Statement was introduced [78]. The implementation of the CONSORT statement in papers that report results of parallel group RCTs has undoubtedly contributed to higher data transparency, standardization and easier readability of the reported information. Indeed, we encountered less difficulties in extracting information of interest and finding relevant details we considered crucial for reducing bias from the most recently published articles [45,57–59], eventually resulting in rating D1 and D4 as "low risk".

To summarize, the results from our meta-analyses revealed no differences in clinical longevity between direct and indirect resin composite restorations placed on posterior teeth, regardless of the observation period or type of substrate (wear-affected and non-affected dentition). Therefore, it seems that the clinician's choice to restore posterior defects with a direct or indirect resin composite restoration does not play a crucial role in its longevity. A recent narrative review highlighted that, if adhesive technique and materials are handled appropriately, differences between the materials have a minor importance in clinical longevity [6]. On the other hand, patient-related factors such as caries risk, the amount of the residual sound coronal tissue and bad habits can significantly influence the lifespan of resin composite restorations [79,80]. According to the results of this systematic review, the decision whether to restore posterior teeth with a direct or indirect resin composite can be left to the dentist's preference and experience, taking into consideration the patient's individual characteristics and risks. Given the cost of indirect restorations and elevated technique sensitivity during cementation procedure, a clinician may consider giving an advantage to the direct technique, especially in cases where patients' socio-economic status has a central role in treatment planning.

It is, however, important to highlight a possible limitation of the current review: only few studies [55,58] included in our meta-analyses assessed the differences in clinical longevity between direct and indirect cusp-replacing resin composite restorations. Another potential limitation of the current review is the inclusion of studies rated as "high risk" of bias and "some concerns" in meta-analyses, which certainly downgraded the quality of evidence for the analyzed outcome. In order to provide more solid scientific evidence, it is necessary to conduct RCTs with adequate random sequence allocation where cavity size will not influence the choice of technique (direct or indirect) used for restoration of posterior defects with resin composites. Ideally, these RCTs should focus on comparing differences in clinical outcomes of direct and indirect restorations that are indicated to restore medium- to large-size posterior cavities with cusp involvement.

5. Conclusions

According to this systematic review and meta-analyses, very low certainty of evidence suggests that direct and indirect resin composite restorations show similar clinical longevity for short-, medium- and long-term observation periods. Additionally, it seems that the choice of restorative technique has no impact on short-term survival of resin composite materials placed on posterior worn teeth. The observed quality of evidence suggests that more long-term RCTs are needed to confirm the findings of the current systematic review.

Declaration of Competing Interest

The authors declare no conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dental.2023.10.009.

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