

The influence of indirect bonded restorations on clinical prognosis of endodontically treated teeth: A systematic review and meta-analysis

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ABSTRACT

Objective: The loss of the dental coronal portion following carious lesions or fractures leads to endodontic treatment with subsequent restoration to ensure correct anatomy and function. Recently, partial adhesive restorations have been widely proposed to increase the survival rate of endodontically treated teeth. The primary purpose of this review is to assess the failure rate of indirect partial adhesive restorations on endodontically treated teeth (ETT), considering the follow-up period.

Methods: The indications reported in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) were used to draft the present review. The study was constructed on PICO questions: population (patients who need indirect adhesive restorative treatment on endodontically treated teeth with onlay and overlay), intervention (onlay and overlay), control (patients with onlay and overlay on endodontically treated teeth) and outcome (failure rate and types of failure for onlay and overlay). The asked scientific question was: what are the failure rate and types of failure for adhesive indirect partial restorations on ETT?

Results: The overall failure rate that emerges is 0.087 with a ratio of 121/1254, I^2 80 % p-value < 0.001. Moreover, by meta-regression with covariates the follow-up period reports a coefficient of 0.013 with a P-value < 0.001. In conclusion, the indirect partial restorations on endodontically treated teeth displayed overall acceptable outcomes in terms of success from 2 to 4 years after their placement with only 4.32 % of failure. Failures increase after 7

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years up to 12–30 years with failure rates of approximately 10.65 % and 20.94 %. The analysis of the included articles reporting the causes of restorations failures showed that 15.51 % of cases were related to the loss of dental element.

Significance: Besides the survival rates of indirect adhesive restorations on endodontically treated posterior teeth, it was highlighted that the majority of failures appeared restorable. Thus, partial restorations seemed able to prevent the ETT tooth loss.

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Contents

1. Introduction	204
2. Materials and methods	205
2.1. Eligibility criteria	205
2.2. Research methodology	205
2.3. Screening methodology	205
2.4. Risk of bias	205
2.5. Statistical analysis protocol	205
3. Results	208
3.1. Study characteristics and data extraction	208
3.2. Risk of bias	211
3.3. Metanalysis	211
3.3.1. Primary outcome	211
3.3.2. Secondary outcome	211
3.3.3. Tertiary outcome	211
3.3.4. Quaternary outcome, subgroup-analysis and meta-regression	211
4. Risk of bias across study	213
5. Discussion	213
CRediT authorship contribution statement	218
References	218

1. Introduction

A tooth can undergo a considerable loss of tissue due to a carious lesion and a direct composite restoration could not be able to restore the correct function and morphology. Moreover, its pulp may appear necrotic or affected by pulpitis with the need for endodontic treatment, resulting in a considerable reduction of structural resistance towards occlusal stresses. Therefore, the conservative approach could not be sufficient in preventing tooth fracture and, thus, a cuspal coverage restoration could be indicated [1].

In the past, there was the opinion that endodontically treated teeth (ETT) needed a root canal post and full coverage crown rehabilitation [2,3]. Aquilino and Caplan showed that cuspal coverage could increase up to six times the survival rate of non-vital posterior teeth [4]. Therefore, for years, the full crown has been considered the gold standard therapeutic approach for large cavities in posterior ETT [5]. However, full crown preparations tend to remove a large amount of healthy dental tissue from teeth that have already lost a massive quantity of sound tooth structure due to pathology and endodontic procedures [6]. Hence, many recent studies focused on bonded restorations, which ensure higher sound tissue preservation than traditional fixed full crowns [7,8]. Because

of this paradigm shift, indirect bonded partial restorations, such as inlays, onlays, overlays and, more recently, endocrowns have been proposed for ETT rehabilitation as valid therapeutic alternatives to conventional prosthetic solutions [9–13]. They are defined as partial coverage restorations that restore one or more cusps and adjoining occlusal surfaces on the entire occlusal surface and are retained by adhesive means [14,15].

According to Bresser et al., 2019 [1] the failure rate of partial restorations on non-vital teeth is around 3 out of 45 (non-vital teeth: $n = 45$, events $n = 3$, survival 93 %, $p > 0.05$) with a follow-up of 12 years. Reiss et al. [13] reported a failure rate of 28 out of 77 inlays on non-vital teeth with a longer follow-up (16.7 years). Moreover, Otto et al. [15] stated 3 failures out of 25 endocrowns with 12-years observations. These studies showed high heterogeneity, partially explained by differences in the follow-up period, restoration type, and material used. More recently, focusing on non-vital teeth, Chrepa et al. [16] showed a restoration survival of 96.8 % and a tooth survival of 100 % with a mid-term follow-up when indirect composite onlays and overlays were employed. Consequently, considering recent improvements of materials such as composites and ceramics, the use of partial restorations instead of 360-degree tooth preparation used in full

crown rehabilitation could be suggested to increase the survival rate of endodontically treated teeth [16].

Previous systematic reviews did not investigate the survival rate of partial indirect restorations exclusively on endodontically treated teeth. Morimoto et al. [17] reported a survival rate of 92–95 % at 5 years and 91 % at 10 years, while Sampaio et al. [18] showed an overall survival rate of 97 % after 5 years and 89 % after 10 years, making no distinction whether on vital or non-vital teeth. However, from recent studies the survival rate of bonded partial restorations on ETT appeared shorter, with a failure rate of about 10 % in the first 3 years [1]. The correct knowledge of the survival rates of partial restorations and the type of failure encountered on ETT can be helpful for proper treatment planning [19,20]. Therefore, this review with meta-analysis aimed to investigate the different failure rates and types of failure of adhesive restorations on endodontically treated teeth and the consequent tooth survival rate through a meta-regression analysis divided for the tooth preparation design and restoration extension.

2. Materials and methods

The following systematic review was conducted based on the indications of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [21] and was registered in PROSPERO: CRD42021268060.

The study was constructed on the population, intervention, control, and outcome (PICO) questions: patient (patients who need restorative treatment with inlay, onlay, overlay and endocrowns on ETT), intervention (inlay, onlay, overlay and endocrowns), control (patients with inlay, onlay, overlay and endocrowns on endodontically treated teeth), and outcome (failure rate and types of failures for inlay, onlay, overlay and endocrowns on ETT); A scientific question was asked: What are the failure rate and the types of failures of indirect adhesive restorations on ETT?

2.1. Eligibility criteria

By reading the title and abstract, all in vivo studies that dealt with indirect adhesive restorations on endodontically treated teeth were investigated and the causes of failure were considered potentially eligible.

Case reports, reviews, and in vitro studies were excluded from this systematic review. The reviews were considered sources of bibliographic information, studied, and analyzed at a preliminary stage not to repeat a systematic review already performed by previous authors.

The articles deemed eligible were read and analyzed to include them in qualitative and quantitative analysis.

The exclusion criteria applied to the studies were as follows:

- exclude all those studies: who did not report a follow-up period, who provided data on indirect adhesive restorations only on vital teeth.

The inclusion criteria applied to the studies were as follows:

- include all in vivo studies reporting data regarding the survival or failure rate of indirect adhesive restorations performed on endodontically treated teeth.

2.2. Research methodology

The articles were identified using electronic databases such as PubMed, Scopus and Ebsco; the search was conducted between 1 and 09–2021 and 30–09–2021 and the last survey was conducted on 25–11–2021.

All keywords and related details on database searching methods are reported in Table 1.

2.3. Screening methodology

The research methodology took place in a series of phases. The first involved the identification of keywords, databases on which to search, inclusion and exclusion criteria, and data to be extracted, agreed by the two appointed experts before the search and screening. (M.D and M.A.) with a third expert (A.C.) who decided in doubtful situations. The second phase involved identifying records on the databases (the overlaps were removed using the EndNote 9 software) and screening potentially eligible articles (through an analysis of the title and abstract) and the choice of articles to be included in the full-text reading. The third phase involved the comparison of the studies identified by the two experts and the choice of articles to be included in the meta-analysis (the k-agreement between the two experts was 0.87). The fourth phase involved the extraction of data by the two experts separately with subsequent comparison of the extracted data. The outcome sought by the two experts was the following: the relative and total failure rate of indirect adhesive restorations on endodontically treated teeth.

2.4. Risk of bias

Risk of bias was assessed using the checklist described in the Handbook of Cochrane Reviews in dentistry for epidemiological studies (cohort, cross-sectional and case-control studies), modified by the authors to adapt it to studies in restorative dentistry, as already done in previous systematic reviews with meta-analyses [22–26].

2.5. Statistical analysis protocol

The meta-analysis protocol was based on the indications written by the Cochrane Handbook for systematic reviews of interventions. The program used was Open Meta-Analyst version 10 (Tufts University, Medford, MA, USA). The pooled failure rate was measured as the ratio between the number of indirect partial restorations and the number of failures. A meta-regression was also conducted based on the years of follow-up and the type of material/method used for the restoration, and the pooled failure rate was calculated for each subgroup. The presence of heterogeneity was measured with

Table 1 – Complete overview of the search methodology. Records identified by databases:1969; records selected for quantitative analysis: 20. The search was conducted between 1 and 09–2021 and 30.09.2021 and the last survey was performed on 25–11–2021.

Database -- Provider	Keywords	Search details	Number of records	Articles after removing overlapping articles	Number of records) after restriction by year of publication (last 40 years)	Number of remaining articles related to partial restoration	number of articles reporting data on the survival/failure of partial restoration (included in metanalysis)
Pub-med	inlay AND onlay AND overlay	Search: inlay AND onlay AND overlay Sort by Most Recent (((("inlays"[MeSH Terms] OR "inlays"[All Fields] OR "inlay"[All Fields] AND (((("inlays"[MeSH Terms] OR "inlays"[All Fields] OR "onlays"[All Fields] OR "onlay"[All Fields] OR "onlays"[All Fields]) AND ("onlay"[All Fields] OR "onlayed"[All Fields]) AND (((("overlay"[All Fields] OR "overlying"[All Fields] OR "overlays"[All Fields] OR "overlays" [All Fields]	70				
Pub-med	inlay OR onlay OR overlay AND endodontic	Search: inlay OR onlay OR Overlay AND endodontic Sort by: Most Recent (((("inlays"[MeSH Terms] OR "inlays"[All Fields] OR "inlay"[All Fields] OR (((("inlays"[MeSH Terms] OR "inlays"[All Fields] OR "onlays"[All Fields] OR "onlay"[All Fields] OR "onlays"[All Fields]) OR "onlayed"[All Fields] OR (((("overlay"[All Fields] OR "overlying"[All Fields] OR "overlays"[All Fields] OR "overlays" [All Fields]	407				

(continued on next page)

Table 1 – (continued)

Database --- Provider	Keywords	Search details	Number of records	Articles after removing overlapping articles	Number of records after restriction by year of publication (last 40 years)	Number of remaining articles related to partial restoration	number of articles reporting data on the survival/failure of partial restoration (included in metanalysis)
Pub-med	partial Crown OR endo crown AND endodontic	Search: partial Crown OR endo crown AND endodontic Sort by: Most Recent (((("partial"[All Fields] OR "partials"[All Fields]) AND (((("crown s"[All Fields] OR "crowned"[All Fields]) OR "crowns"[MeSH Terms]) OR "crowns"[All Fields]) OR "crown"[All Fields])) OR ("endo"[All Fields] AND (((("crown s"[All Fields] OR "crowned"[All Fields]) OR "crowns"[MeSH Terms]) OR "crowns"[All Fields]) OR "crown"[All Fields])) AND (((("endodontal"[All Fields] OR "endodontic"[All Fields]) OR "endodontical"[All Fields]) OR "endodontically"[All Fields]) OR "endodontics"[MeSH Terms]) OR "endodontics"[All Fields])	531				
Scopus	inlay AND onlay AND overlay	TITLE-ABS-KEY	31				
Scopus	inlay OR onlay OR Overlay AND endodontic	TITLE-ABS-KEY	140				
Scopus	partial Crown OR endo crown AND endodontic	TITLE-ABS-KEY	178				
EBSCO	inlay AND onlay AND overlay	Boolean/Phrase:	57				
EBSCO	partial Crown AND endodontic	Boolean/Phrase:	81				
EBSCO	endocrown	Boolean/Phrase:	208				
Other Bibliographic sources (literature reviews)	"Systematic reviews"	Sampaio et al. [17], Morimoto et al. [16], Vagropoulou et al. [18], Abdou et al. [19]	266				
tot			1969	1137	1022	460	20

Higgins Index (I^2): values above 50 % were considered heterogeneous. The risk of bias within the studies was evaluated following the guidelines reported in PRISMA for assessing the quality of studies in meta-analyses [21].

3. Results

From searches in the PubMed, Scopus, EBSCO databases and the analysis of bibliographic references present in previous systematic reviews, 1969 records were identified. With the use of the End-Note software (EndNote 20–2021, Clarivate), the overlaps were removed, resulting in 1137 records. After the elimination of articles before 1980, a record number of 1022 was reached. With the application of the eligibility criteria (all studies that investigated indirect partial restorations), a total of 460 articles were reached. After the application of the inclusion and exclusion criteria 20 studies were included. (Figs. 1–4).

The following PRISMA flow chart describes the whole selection process.

3.1. Study characteristics and data extraction

The studies included in the quantitative analysis are reported in Table 2.

The extraction of the data and the way it was reported followed the indications of the Cochrane Handbook for Systematic Reviews of Interventions, chapter 7 (selection of studies and data collection); in particular, from pages 156–182 [43].

The extracted data concerned the first author, the publication date of the study, the type of study, the average follow-up duration, the material used for the restoration and type of partial restoration, the number of total restorations and the number of failures.

The extracted data are shown in Table 2.

The main outcome studied was the failure rate of indirect bonded restorations on ETT. Given the high heterogeneity of the materials and the impossibility of aggregating the results of failures in a single meta-analysis, it was decided to subdivide the main outcome in different secondary outcomes and to perform a meta-analysis for each individual outcome.

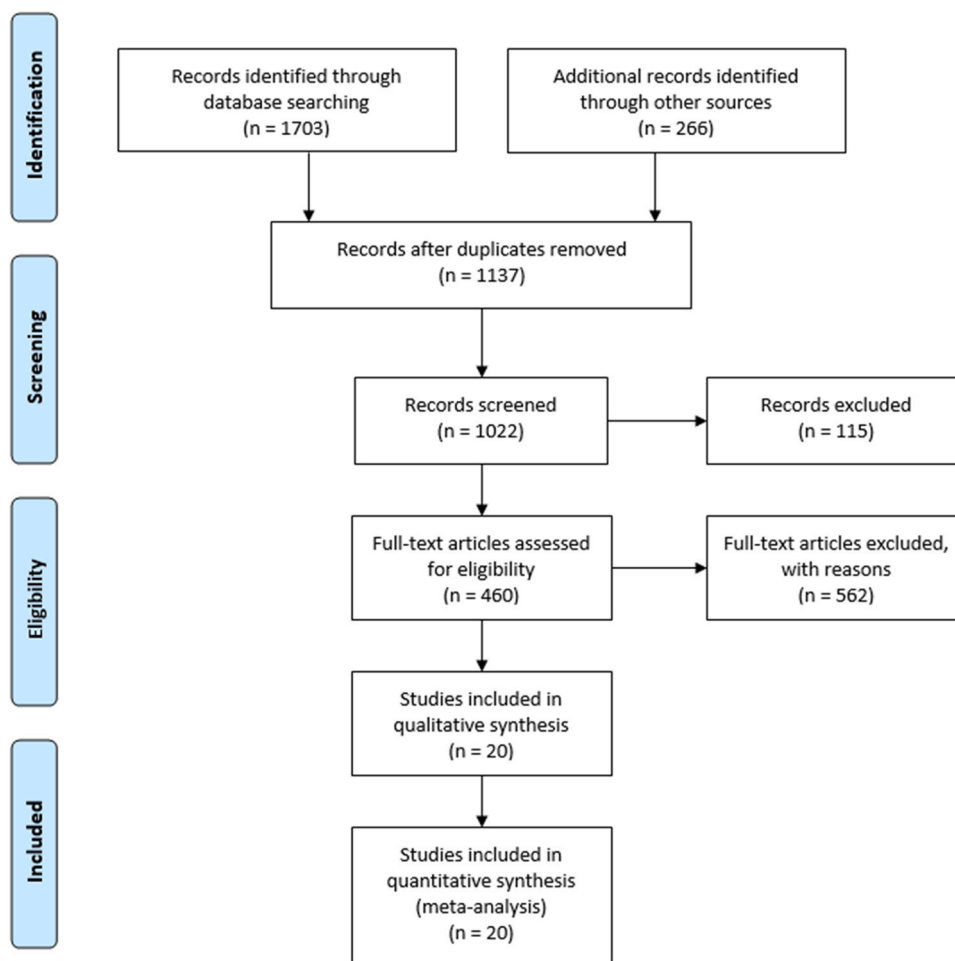


Fig. 1 – Flow chart of the different phases of the systematic review.

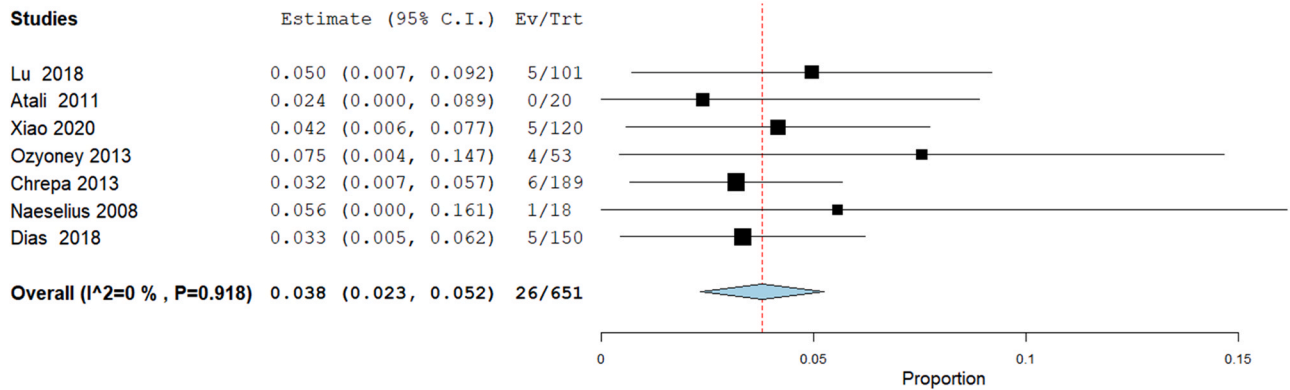


Fig. 2 – The random effect meta-analysis (Q 2.02, df 6, I² 0 %, p = 0.918) pooled failure rate 0.038 (95 % CI: 0.023 0.052), standard error (SE) = 0.007, p < 0.001. Legend: Q = Q statistic (measure of weighted squared deviations); df = degrees of freedom; I² (I²) = Higgins heterogeneity index, I² < 50 %, heterogeneity irrelevant; I² > 75 %, significant heterogeneity; C.I. = confidence intervals; P = p-value. The graph for each study shows the first author, the date of publication, and the ratio between failed indirect partial restorations and the number of restorations placed with the relative confidence interval. The final value is expressed in bold with the relative confidence intervals. The red line shows the position of the average value and the rhombus in light blue shows the measure of the average effect.

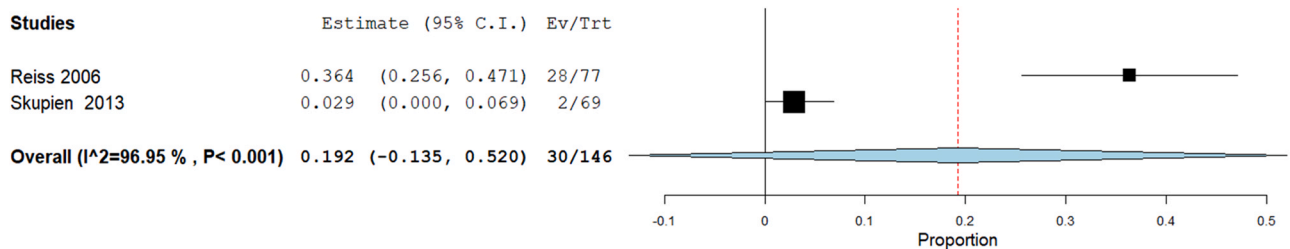


Fig. 3 – Forest plot of the secondary outcome.

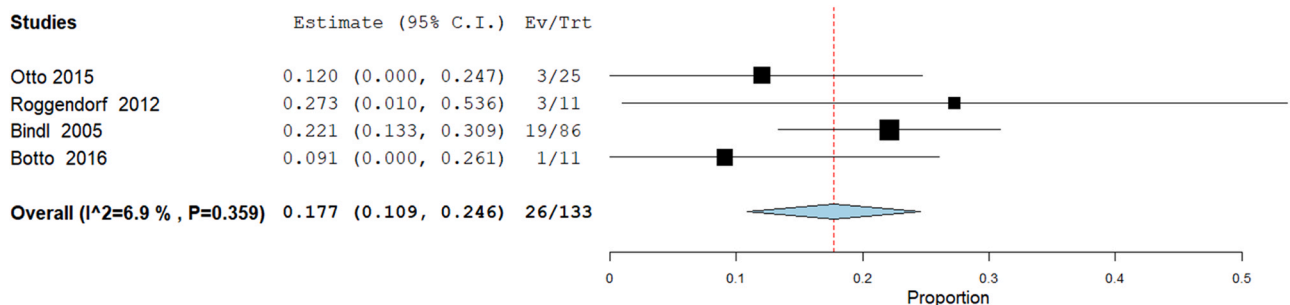


Fig. 4 – Forest plot of the tertiary outcome.

This protocol was selected to minimize the possibility to involve studies that lack statistical significance with the impossibility of including them in meta-analysis. The outcomes were then divided into:

1. Primary outcome: failure rate of onlays on ETT;
2. Secondary outcome: failure rate of inlays on ETT;
3. Tertiary outcome: Failure rate of endocrowns on ETT;
4. Quaternary outcome: failure rate of indirect bonded restorations (inlays, onlays, endocrowns or unspecified partial restoration) on ETT

Table 2 – Primary outcome: the data reported concern the characteristics of the included studies, with the related data on the number of failures of indirect restorations; the number of the subgroup to which they belong based on covariant (type of partial restoration) is also indicated: 1 = Endocrown, 2 = Inlay, 3 = Onlay, 4 = partial restoration (inlay, and onlay, or unspecified):

First Author, Data	Type of study	Material	Period of follow-up (years)	Total number of partial restorations	Failures	Subgroup (covariant: type of partial restoration)
van Dijken et al. 2010 [26]	Clinical prospective study	Dentin-bonded ceramic partial and complete coverages	15	41	16	4
Schulte et al. 2005 [27]	Clinical retrospective study	Glass-ceramic	9,6	46	1	4
Stoll et al. 2010 [28]	Clinical observational study	Glass-ceramic	10	36	7	4
Bresseret al. 2019 [1]	Clinical study	Indirect ceramic restorations	12	45	3	4
Reiset al. 2006 [13]	Clinical long-term study	Glass-ceramic	16,7	77	28	2
Beier et al. 2012 [29]	Clinical retrospective study	Glass-ceramic	12	9	5	4
Skupien et al. 2013 [30]	Clinical retrospective study	Porcelain inlay	12	69	2	2
Otto et al. 2015 [14]	Clinical prospective observational longitudinal	Endocrown(Feldspathic porcelain CAD-CAM)	12	25	3	1
Roggendorf et al. 2012 [31]	Clinical prospective observational longitudinal	Endocrown(Feldspathic porcelain CAD-CAM)	7	11	3	1
Bindl et al. 2005 [32]	Clinical prospective study	Endocrown(Feldspathic porcelain CAD-CAM)	7	86	19	1
Botto et al. 2016 [41]	Clinical retrospective study	Endocrown	19	11	1	1
Ferrari et al. 2019 [33]	Clinical randomized controlled trial	Lithium disilicate partial crowns	3	120	7	4
Lu et al. 2018 [34]	Clinical research	Onlay restorations (feldspar ceramic, hybrid ceramic)	3	101	5	3
Atali et al. 2011 [35]	Clinical research	IPS Empress ceramic onlays luted with two dual-cured adhesive resin cements	3	20	0	3
Xiao et al. 2020 [36]	Clinical research	Lithium Disilicate Glass-Ceramic Onlays	2	120	5	3
Ozyoney et al. 2013 [37]	Clinical research	Glass-ceramic onlays	4	53	4	3
Homsy et al. 2015 [38]	Clinical research	Ceramic class II inlays/onlays	2	27	0	4
Chrepa et al. 2014 [15]	Clinical retrospective study	Onlay	2	189	6	3
Naeselius et al. 2008 [39]	Clinical retrospective Study	Onlay	4	18	1	3
Dias et al. 2018 [40]	Clinical prospective Study	Onlay	5	150	5	3

3.2. Risk of bias

The results of the risk of bias analysis are detailed in [Table 3](#). Each category was assigned a value from 1 to 5 (where one = low and five = high). The questions that the experts answered by assigning the score were the following:

- I. Non-response rate: Is the participation on/follow-up rate stated? Do the authors describe the effort to increase the participant/follow-up rate?
- II. Representativeness of sample to target population: Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
- III. Validity and reliability of outcome measurement: Were the main outcome measures used accurate (valid and reliable)?
- IV. Amount of loss to follow-up: Are the non-participants/subjects lost to follow-up described? Do the authors describe the effort to increase the participation/ follow-up rate?
- V. Appropriate statistical tests: Are the statistical methods described?

Studies presenting a high risk of bias were not included in the meta-analysis. Items with a high risk of bias were excluded from the scale and eliminated during the inclusion phase. Other articles were excluded because they presented the same data and samples for the investigated results. The assessment of the risk of bias of the 19 included articles was conducted by the first expert (M.D.).

3.3. Metanalysis

3.3.1. Primary outcome

The statistical analysis of the data was performed using Open Meta-Analyst version 10 (Tufts University, Medford, MA, USA). The results were represented by forest plots.

For the primary outcome (onlays, with 7 studies included, Lu et al. [35], Atali et al. [36], Xiao et al. [37], Ozyoney et al. [38], Naeselius et al. [40], Dias et al. [41] and Chrepa et al. [16]) the pooled failure rate was 0.038 (C.I. 0.23 0.052) with 26 failures out of 651 onlays $I^2 = 0\%$ and p-value 0.918.

3.3.2. Secondary outcome

For the secondary outcome (inlays, with only 2 studies included Skupien et al. [31] and Reiss et al. [13]), the pooled failure rate was 0.192 (C.I. 0.135 0.520) with 30 failures out of 146 placed inlays, $I^2 = 96.95\%$, p-value < 0.001 and SE = 0.167, p = 0.250.

3.3.3. Tertiary outcome

For the tertiary outcome (endocrowns, with 4 studies included Otto et al. [15], Roggendorf et al. [32], Bindl et al. [33] and Botto et al. [42]), the meta-analysis reported a pooled failure rate result of 0.177 (C.I. 0.109 0.246) on 26 failures out of 133 endocrowns with $I^2 = 6.9\%$, p-value 0.359 and SE=0.035, p < 0.001.

3.3.4. Quaternary outcome, subgroup-analysis and meta-regression

The meta-analysis of the quaternary outcome (indirect bonded partial restorations, 20 study included van Dijken et al. [27], Schulte et al. [28], Stoll et al. [29], Bresser et al. [1], Reiss et al. [13], Beier et al. [30], Skupien et al. [31], Otto et al. [15], Roggendorf et al. [32], Bindl et al. [33], Chrepa et al. [16], Ferrari et al. [34], Lu et al. [35], Atali et al. [36], Xiao et al. [37], Ozyoney et al. [38], Homsy et al. [39], Naeselius et al. [40], Dias et al. [41], Botto et al. [42]) was conducted by applying random-effects models given the high heterogeneity (80 % with a P-value < 0.001); the pooled failure rate measured was 0.087, confidence interval (CI) was 0.057–0.117, standard error 0.015 < 0.001 with a ratio of 121 failures out of 1254 indirect bonded partial restorations. The forest plot and the weight of every single study are shown in [Fig. 5](#) and [Table 4](#).

The meta-analysis of the quaternary outcome shows high levels of heterogeneity since it included studies investigating different types of indirect bonded partial restorations, whose data could not be extracted and included in the other outcomes, the decision to include these data in a single outcome to minimize the effects of the publication bias as described in the Cochrane Handbook (Chapter 10, [Section 2](#)) [43].

To reduce the high heterogeneity of the quaternary outcome, it was decided to perform a subgroup analysis using the follow-up period as a covariant and to subsequently perform a Meta-regression according to the follow-up period for the data extracted from the 20 included studies.

When the years of follow-up were used as covariant, a pooled failure rate equal to 0.040 with 28 failures out of a total of 648 indirect bonded restorations inserted ($I^2 = 0\%$, p-value 0.844) was observed for the follow-up period between 2 and 4 years; a ratio of 0.112 with 35 failures out of 329 indirect bonded restorations ($I^2 = 84.1\%$, p-value 0.000) was measured for the period between 5 and 7 years, while the 12–30 year subgroup had a pooled failure rate of 58 indirect bonded restorations t out of 277 ($I^2 = 89.67\%$, p-value 0.000) ([Fig. 6](#)).

Since the follow-up period is a variant that affects the duration and therefore the failure of the indirect bonded restorations, the analysis passed from a pooled failure rate 0.04 (28/648) for the 2–4 years subgroup to a pooled failure rate 0.112 (35\ 329) for the subgroup 5–7 years up to a ratio 0.201 (58\277) for the subgroup 12–30 years. It was decided to perform a meta-regression according to the years of follow-up to investigate more analytically how covariant time affects indirect bonded restorations of ETT, [Fig. 7](#), [Table 5](#).

The calculated regression coefficient was 0.013 with a p-value < 0.001, the covariant "follow-up years" had a significant effect on the failures of indirect bonded restorations.

Not all restoration failures lead to the tooth loss. The analysis of the included articles that report the causes of restorations failures attributable to ETT (11 Studies) showed that on a total of 58 failures out of 931 indirect restorations, only 9 cases related to the tooth loss, 6 of which were attributable to root fractures and 2 to periodontal problems ([Table 6](#)). Nevertheless, for the failures of indirect bonded restorations, the main causes were loss of adhesion/retention (25 restorations); tooth fractures/restoration (17 restorations, sometimes secondary to caries); periodontal/periapical lesion (7 restorations).

Table 3 – Assessment of the risk of bias within the studies, with scores 7–12 = low quality, 13–20 = intermediate quality, and 21–25 = high quality.

Reference	Selection		Outcome		Loss to follow-up		Analysis		Score
	Non-response rate	Representativeness of sample to population	Validity and reliability of outcome measurement	Amount of loss to follow-up	Appropriate statistical tests	Appropriate statistical tests			
Beier et al. 2012 [29]	4	2	4	4	4	4	4	4	18
Van Dijken et al. 2010 [26]	4	4	4	4	5	5	5	5	22
Reiss et al. 2006 [13]	4	4	4	4	5	5	4	4	21
Bresser et al. 2019 [1]	4	4	4	4	5	5	4	4	21
Stoll et al. 2010 [28]	4	4	4	4	4	4	4	4	20
Schulte et al. 2005 [27]	4	4	4	4	4	4	4	4	20
Skupien et al. 2013 [30]	4	4	5	5	5	5	5	5	23
Ferrari et al. 2019 [33]	5	4	5	5	5	5	5	5	24
Lu et al. 2018 [34]	5	5	5	5	5	5	4	4	24
Atali et al. 2011 [35]	4	3	5	5	4	4	3	3	19
Xiao et al. 2020 [36]	4	5	5	5	4	4	4	4	22
Ozyoney et al. 2013 [37]	4	5	5	5	4	4	5	5	23
Homsy et al. 2015 [38]	3	3	5	5	4	4	3	3	18
Otto et al. 2015 [14]	4	4	4	4	4	4	4	4	20
Roggendorf et al. 2012 [31]	4	3	4	4	4	4	3	3	18
Bindl et al. 2005 [32]	4	4	4	4	4	4	4	4	20
Chrepa et al. 2014 [15]	4	4	5	5	5	5	4	4	22
Naeselius et al. 2008 [39]	5	3	5	5	4	4	4	4	21
Dias et al. 2018 [40]	4	4	4	4	4	4	4	4	20
Botto et al. 2016 [41]	3	2	4	4	4	4	2	2	15

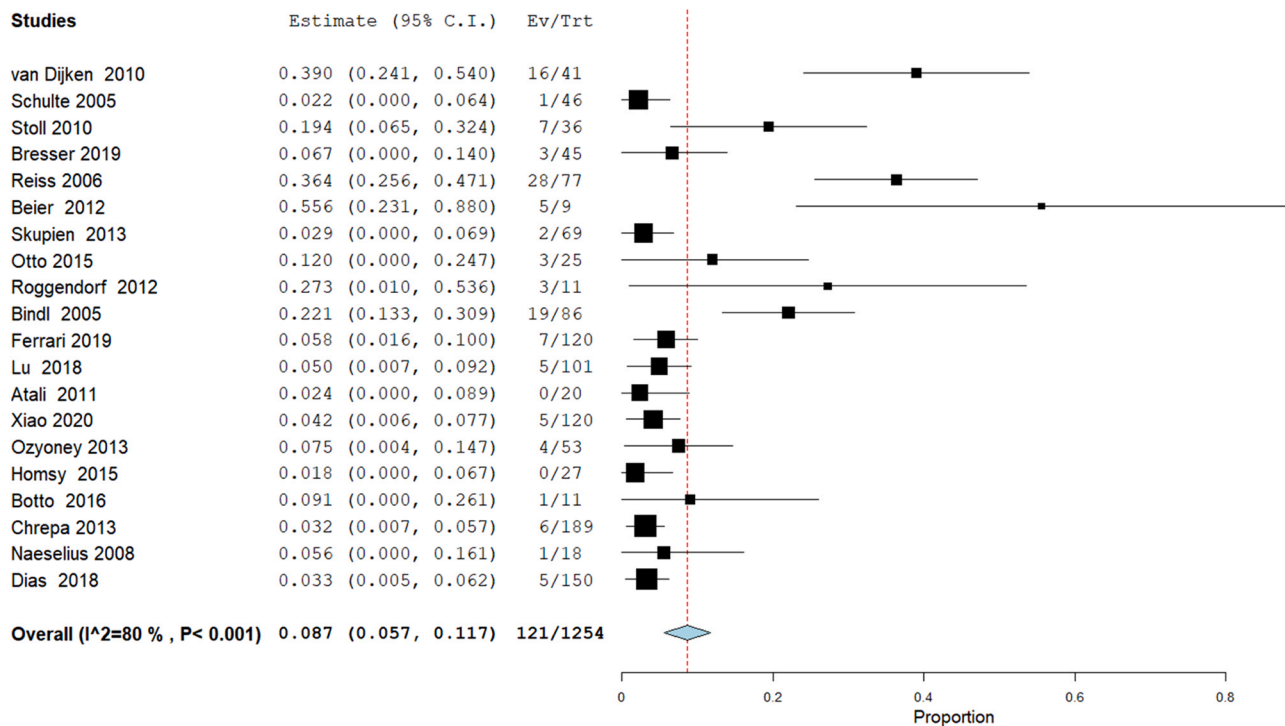


Fig. 5 – The random effect meta-analysis (Q 94.998, df 19, I² 80%, p < 0.001) pooled failure rate 0.087 (95% CI: 0.057 0.117), standard error (SE) = 0.015, p < 0.001. Legend: Q = Q statistic (measure of weighted squared deviations); df = degrees of freedom; I² (I²) = Higgins heterogeneity index, I² < 50 %, heterogeneity irrelevant; I² > 75 %, significant heterogeneity; C.I. = confidence intervals; P = p-value.

4. Risk of bias across study

The risk of bias between studies was considered low for primary outcome (Onlay) with I² equal to 0 % with a p-value = 0.918. and tertiary outcome (endocrowns) with I² equal to 6.9 % with a p-value 0.359 and for the remaining secondary and quaternary outcome, the heterogeneity was I² 96.95 % and 80 %, respectively with a p-value < 0.001 in both outcomes.

For the quaternary outcome it was decided to perform a subgroup analysis using the follow up period as a covariant. Analyzing the data according to follow-up period (2–4 years, 5–7 years, 12–30 years) the subgroup 2–4 years showed an I² of 0 % with a p-value of 0.844, thus low heterogeneity. For the subgroup 5–7 years, I² was 84.1 % with p-value = 0.000 and for the subgroup 12–30 years I² = 89.67 % with a p-value = 0.000. The heterogeneity analysis showed that primary outcome (onlay), tertiary outcome (endocrowns) and 2–4 years subgroups had a low heterogeneity both with I² 0 %, 6.9 %, and 0 % respectively, therefore with a low risk of bias between the studies in these subgroups.

Confirmations of the low heterogeneity could be identified from the graphical evaluation of the confidence intervals of the single studies (forest plot), which showed good overlap for the primary outcome (onlay), tertiary outcome (endocrowns) and 2–4-year subgroups and little overlap for the remaining outcome and subgroups for the lack of homogeneity [43].

5. Discussion

The prognosis of a posterior non-vital tooth not only depends on endodontic variables, but also on adequate tooth rehabilitation [12,18,44,45]. This systematic review aimed to evaluate the failure rate of indirect partial adhesive restorations in endodontically treated posterior teeth, analyzing a possible relationship between the type of failures obtained during the follow-up period and the kind of restorations placed.

It should be considered that indirect partial adhesive restorations are a heterogeneous group that could involve different materials and techniques: for this reason, it was decided to divide this heterogeneous group into different outcomes according to the type of indirect bonded restoration (inlay, onlay, overlay and endocrowns). The most homogeneous data came from primary outcome (onlay) with 7 studies included and a heterogeneity index of 0% (I²). The cumulative failure rate was 0.046 (26\651) with a follow-up period that ranged from 2 to 4 years. These data confirmed the optimal clinical behavior of adhesive onlays on ETT in the short-term period [18–20]. Among the studies which reported an excellent performance on ceramic onlays, Atali et al. (2011) encountered any clinical failure out of 20 onlays placed in a 3-year follow-up period [36]. These data agree with Xiao et al. (2020), which showed 5 failures out of 120 glass-ceramic onlays in 24 months [37].

Table 4 – A random-effects meta-analysis was performed with the DerSimonian-Laird method; the table shows the weight expressed as a percentage of each single study.

study names	Schulte	van Dijken	Stoll	Bresser	Reiss	Beier	Skupien	Otto	Rogge-ndorf	Bindl	Ferrari	Lu	Atali	Xiao	Ozyoney	Homsy	Chrepa	Botto	Naeslius	Dias
weights	6.940 %	2.719 %	3.258 %	5.475 %	3.991 %	0.785 %	7.052 %	3.315 %	1.136 %	4.795 %	6.950 %	6.933 %	5.845 %	7.212 %	5.560 %	6.624 %	7.603 %	2.276 %	4.052 %	7.478 %

Following previous reviews performed on partial restorations [1,27–30,34,39], the total failure rate that emerges in the present study for indirect bonded partial restorations is 0.087, with a ratio of 121/1254. However, this rate does not consider the different follow-up periods, which appear to be non-homogeneous. Some studies showed the highest failure rates jointly with the most prolonged follow-up period Dijken et al. [27], Beier et al. [30] and Reiss et al. [13] Therefore, to understand the efficacy of indirect bonded partial restorations on ETT, the follow-up was used as a covariant to perform a meta-regression analysis. Over a 2–4 years follow-up, 28 out of 648 placed restorations failed, in accordance with a previous systematic review [17], which reported 5580 successes over 5811 placed inlays and onlay after 5 years of clinical function without distinguishing between vital and non-vital teeth. The failure rate tends to increase when the follow-up period is extended to 5–7 years, with a failure ratio on placed restorations of 35\329 and a failure rate of 10.64 %. Moreover, if the follow-up considered is between 12 and 30 years, the ratio between failures and indirect restorations becomes 0.201, with failure rates of 20.94 %. Therefore, the regression coefficient resulting from the meta-regression is +0.013 with a p-value < 0.001: it means that for every follow-up year, the ratio between failures and total restorations placed significantly increases, with a failure rate that increases by a percentage of just over 1% each year.

Based on the present metanalysis, indirect adhesive restorations still show some limits in providing a high success rate for the long period. However, the continuous evolution of the restorative materials reduces the possibility to achieve information on the long-term prognosis of these ETT rehabilitations. Moreover, it is essential to consider the type of failures evaluated during the clinical studies more than the failure rate itself. Within the minimal intervention dentistry concept, a partial adhesive restoration represents the less invasive indirect solution that could cover tooth cusps without an extensive reduction of the oral and buccal surfaces. It is fundamental to distinguish between reversible failures, which allow the clinician to repair or replace the restoration, and irreversible ones, which brings to tooth extraction. Thus, in accordance with Dias et al. [41], the tooth survival rate has a much more critical role than the restoration failure rate and it should be expressed by all clinical studies when evaluating the clinical performances of teeth restorations. This aspect is nowadays crucial since it shifts the failure meaning to a different and more conservative concept, where importance is only given to tooth preservation and not only to the permanence of the restoration in the oral cavity.

The vertical root fracture, which inevitably led to extraction, was observed in only 6 cases: 4 of them were restored with endocrowns and failed between 45 and 84 months of clinical functions, while the remaining 2 cases had a partial restoration and failed after 24 months. The other irreversible failures reported were not directly related to the post-endodontic restoration. It could be speculated that most of the partial adhesive restoration failures were repairable or, eventually, replaceable without affecting the tooth survival.

The limits of this review could be found in the variety of studies investigated (retrospective, observational and clinical

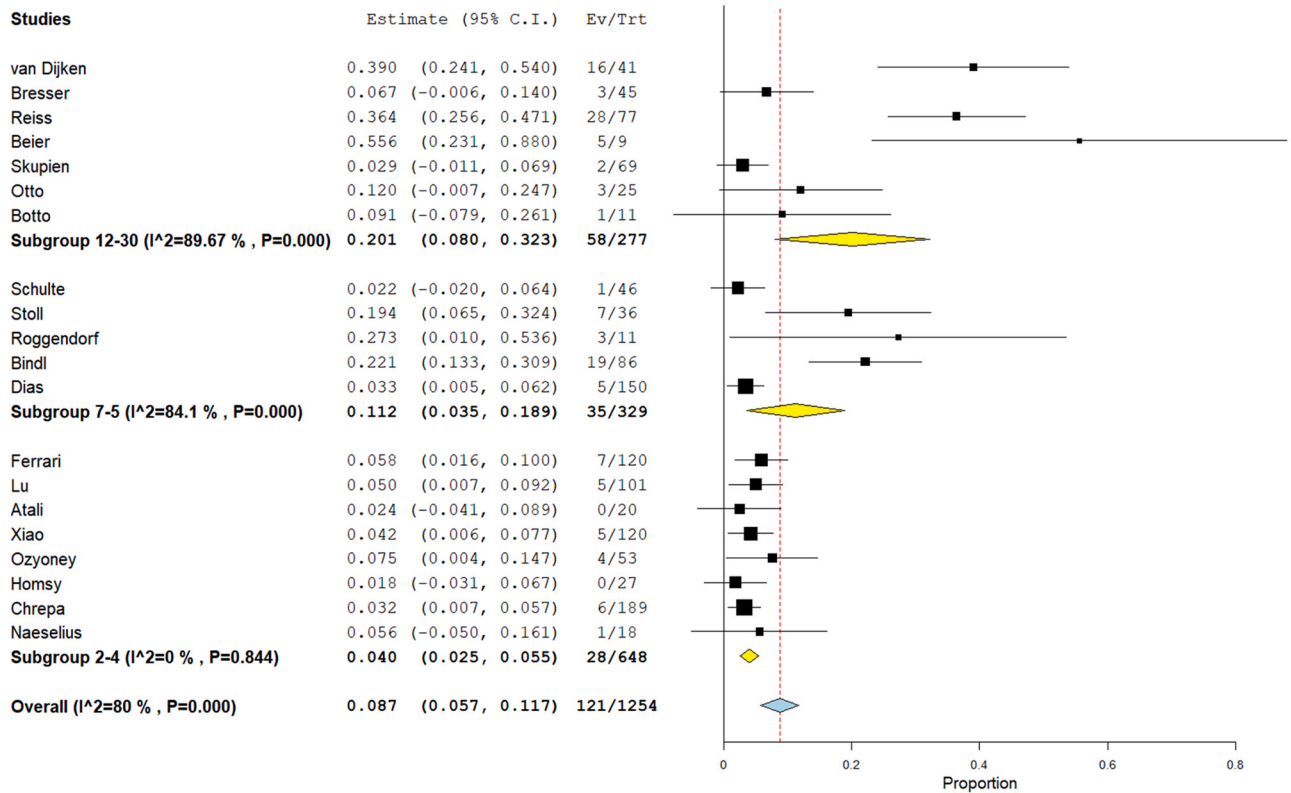


Fig. 6 – Forest plot of the 3 Subgroups Covariant (years of follow-up). Subgroup (2–4 years) ratio: 0.04 (C.I. 0.025 0.055); Subgroup (5–7 years) ratio: 0.112 (C.I. 0.035 0.189); Subgroup (12–30 years) ratio: 0.201 (C.I. 0.08 0.323). The results of the meta-analysis for each subgroup are highlighted in bold. Yellow rhombuses in the forest plot indicate the average effect for each subgroup investigated. The red line shows the position of the average value and the rhombus in light blue shows the measure of the average effect.

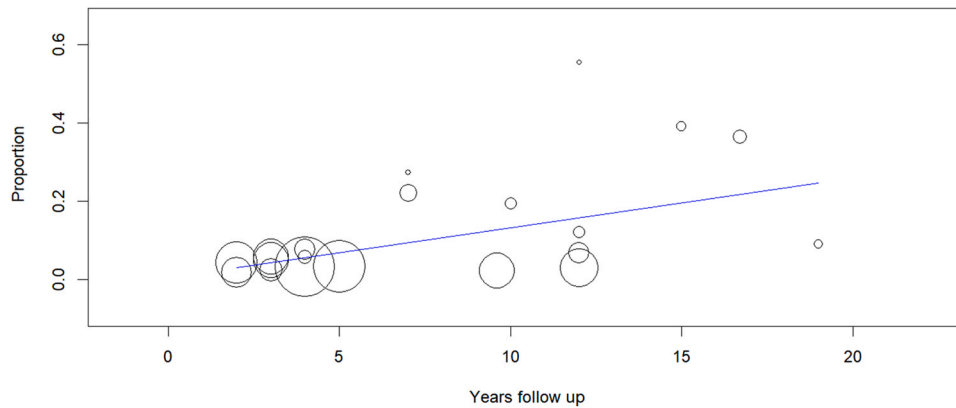


Fig. 7 – Meta-regression plot; the failure rate increases when the follow-up increases with a regression coefficient equal to 0.013 per year and a p-value of 0.001.

Table 5 – Random-effects model: regression results for the covariant.

Covariant	Coefficients	Lower bound	Upper bound	Std. error	Z-value	p-value
Intercept	0.004	-0.059	0.067	0.032	0.125	0.905
Years of follow-up	0.013	0.005	0.020	0.004	3.25	< 0.001

trials), the heterogeneity of the materials (glass-ceramic, lithium disilicate) the cementation strategies (adhesive treatment of the prepared tooth, cleaning/preparation of the indirect material, luting cement employed). Even though the employed restoration designs (onlay and overlay) were carefully selected, these limits were only partially solved through the subgroups analysis. Some studies reported a distinction between survival, success and failure; others did not adopt the same evaluation criteria for restoration. However, all possible sources of bias were carefully evaluated and scored.

In conclusion, indirect partial restorations on endodontically treated teeth showed an optimal clinical performance in a medium follow-up period. However, after 12–30 years of function the restoration failure rates rose considerably. However, further clinical trials with modern adhesive techniques and materials employed for partial preparation of the ETT should be conducted to understand if they could represent a valid and long-lasting alternative to the full crown restoration in maintaining the tooth in the patient mouth.

CRedit authorship contribution statement

h, i: Coordinator of the research project and manuscript supervisor, b, c, d: Data Analysis, e, f, g, i: Manuscript revision, a, b: Manuscript writer.

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