Mestrado Integrado Em Medicina Dentária

Clinical performance of partial indirect posterior restorations: systematic review

Review article

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Resumo

Introdução: As restaurações indiretas parciais, como inlays, onlays e overlays, garantem a conservação da estrutura dentária remanescente, aprimorando o reforço do dente comprometido e são indicadas em situações de grande destruição dentária.

Objetivo: Investigar de que forma é que as restaurações indiretas parciais (inlays, onlays ou overlays) de resina composta ou cerâmica afetam o desempenho clínico e os modos de falha dos dentes posteriores tratados.

Materiais e Métodos: Seguindo o protocolo dos Principais itens para relatar Revisões sistemáticas e Meta-análises (PRISMA-P), foi realizada uma pesquisa eletrónica em quatro bases de dados (PubMed- MEDLINE, Cochrane Library, EBSCOhost Research Platform, e LILACS), até 3 de maio de 2020. A pesquisa bibliográfica teve o objetivo de recuperar todos os ensaios clínicos randomizados relacionados com restaurações indiretas parciais (inlays, onlays ou overlays) de resina composta ou cerâmica, em dentes posteriores. Todos os títulos e resumos dos estudos selecionados foram avaliados por dois autores independentes. Foi realizada a extração dos dados e a avaliação do risco de viés dos estudos incluídos.

Resultados: Após a remoção dos duplicados, foram obtidos 1926 artigos, dos quais 13 cumpriram os critérios de inclusão e exclusão. Entre os 13 ensaios clínicos randomizados incluídos, 4 estudos avaliaram restaurações em resina composta e cerâmica, 2 estudos incluíram restaurações de resina composta e 7 avaliaram restaurações em cerâmica. Quase todos os estudos avaliaram inlays e nem todos avaliaram materiais com os mesmos métodos de fabricação. Existe alguma heterogeneidade entre os estudos relativamente aos procedimentos clínicos, 8 estudos apresentaram risco moderado de viés e 5 apresentaram alto risco. De acordo com as falhas relatadas pelos estudos, as restaurações de resina composta apresentaram mais falhas do que as restaurações cerâmicas apenas nos três primeiros anos de *follow-up*, portanto, aos cinco e dez anos de *follow-up*, as restaurações cerâmicas apresentaram valores mais altos de falhas. No entanto, as diferenças entre as restaurações de resina composta e cerâmica nesses períodos de *follow-up* atingem apenas 6,4%. Os principais motivos responsáveis pelas falhas encontradas nas restaurações de resina composta foram a fratura dentária e outras causas não relacionadas com a restauração. Em relação às restaurações cerâmicas, a maioria delas falharam devido à fratura da restauração e devido à fratura do dente.

Discussão e Conclusões: Dentro das limitações desta revisão sistemática, quer as restaurações indiretas parciais de cerâmica quer de resina composta exibiram resultados clínicos aceitáveis a curto e longo prazo. São necessários mais ensaios clínicos

randomizados bem projetados para fornecer evidência científica conclusiva sobre qual material apresenta melhor desempenho *in vivo*.

Palavras-chave: resinas compostas, cerâmica, desempenho clínico, falha de restauração dentária, revisão sistemática

Abstract

Introduction: Partial indirect restorations such as inlays, onlays and overlays, provide conservation of the remaining dental structure while enhancing the reinforcement of the compromised tooth and are indicated in situations with large tooth destruction.

Aim: To investigate how does indirect partial (inlays, onlays or overlays) ceramic or composite resin restorations affect the clinical performance and failure modes of posterior treated teeth.

Materials and Methods: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis protocol (PRISMA-P), an electronic search was conducted through four databases (PubMed- MEDLINE, Cochrane Library, EBSCOhost Research Platform, and LILACS), up to 3 May 2020. The literature search aimed to retrieve all the randomized controlled trials related to posterior restorations with ceramic or indirect composite inlays, onlays, or overlays. All titles and abstracts of the selected studies were assessed by two independent authors. Data extraction and risk of bias of the included studies were performed.

Results: After the removal of duplicates, a total of 1926 articles were obtained, of which 13 met the inclusion and exclusion criteria. Among the 13 RCTs included, 4 studies evaluated both composite resin and ceramic restorations, 2 studies included composite resin restorations and 7 studies were clinical trials concerning ceramic restorations. Almost all the studies evaluated inlays and not all of them evaluated materials with the same manufacturing methods. There is some heterogeneity between the studies concerning clinical procedures, 8 studies presented moderate risk of bias and 5 presented high risk. According to the failures reported by studies, composite resin restorations only showed more failures than ceramic restorations during the first three years of follow-up, so at five and ten years of follow-up were ceramic restorations that presented higher values of failures. However, differences between composite resin and ceramic restorations in these periods of follow-up only reached 6.4%. The main reasons behind the composite resin restorations failures found were tooth fracture and other causes not related to the restoration. Concerning ceramic restorations, most of them failed due to restoration fracture and due to tooth fracture.

Discussion and Conclusions: Within the limitations of this systematic review, both ceramic and composite resin indirect partial restorations exhibited acceptable clinical outcomes in short and long term. More well-design randomized clinical trials are necessary to provide conclusive evidence about which material perform better *in vivo* conditions.

Keywords: composite resins, ceramics, clinical performance, dental restoration failure, systematic review

Introduction

According to the World Health Organization (and the Global Burden of Disease 2017), untreated dental caries (tooth decay) in permanent teeth is the most common health problem in the world.[1] Certainly that prevention has an important role to reduce this high prevalence, but when loss of tooth substance is present, treatment becomes imperative. Furthermore, other non-carious lesions like erosion, abfraction, attrition and fracture may also conduct to breakdown of the hard tissues of the teeth.[2]

To replace the loss of tooth structure, gold and amalgam were for many decades the only available materials, but the need for more esthetic restorations led to the use of ceramic and composite resins in dentistry.[3] Among esthetic restorations direct or indirect treatment possibilities can usually be considered according to different clinical factors.[4] Relatively to posterior teeth (premolars and molars), direct restorations are indicated in situations of limited tooth decay and need of a conservative approach. On the other hand, partial indirect restorations such as inlays without cusp covering, onlays involving at least one covered cusp and overlays demanding all cusps covered provide conservation of the remaining dental structure while enhancing the reinforcement of the compromised tooth[5,6] and are indicated in situations with larger tooth destruction.

Indirect composites restorations are fabricated through composite resins submitted to polymerization processes by light cure, heat and/or pressure, or milling procedures from CAD/CAM blocks.[7,8] Although in general, these restorations have potentially lower polymerization shrinkage due to more in-depth curing, higher wear resistance and strength due to additional heat or light curing and improved occlusal and proximal contour, they are more expensive and more technique-sensitive than those accomplished with a direct approach.[3] Furthermore, a recent systematic review reported that there is insufficient evidence to make strict recommendations in favor of direct over indirect technique.[9] Thus, the choice for a direct or indirect restoration should be carefully taken.

Indirect ceramic restorations can be crystalline (alumina and zirconia) or vitreous (feldspathic porcelain and glass ceramic). Crystalline ceramics have minimal or no vitreous phase and are available in powder form (stratification and densely sintered) or in blocks (CAD/CAM). By contrast, feldspathic porcelain and glass ceramic have a vitreous and crystalline phase, in which a glassy matrix could be etched and are available in powder (stratification), ingots (heat-pressable, but just glass ceramics) or blocks (CAD/CAM).[10,11]

Many studies have compared these materials *in vitro*. Although ceramic materials are resistant to compressive forces, they are sensitive to tensile stresses and more susceptible to fracture than are composite materials.[12,13] Furthermore, although ceramics are more wear-resistant than composites, they can cause more wear than usual on the opposing tooth's

surface.[14] Another disadvantage of ceramics is that adhesive cementation is accomplished with composite materials, so interface degradation can be more extensive at adhesive interface impairing long-term marginal integrity.[15,16]

In vitro studies are important baseline predictability indicators of clinical performance materials behavior. Nevertheless, *in vivo* performance of indirect composite and ceramic posterior partial restorations can only be achieved from clinical studies. An earlier systematic review that compared ceramic and composite inlays, onlays and overlays[17] provided some evidence that indirect ceramic restorations performed better than indirect composite resin restorations in the short term. Nevertheless, it only included only two randomized controlled trials (RCTs) classified with high risk of bias. Once few RCTs comparing both techniques are available, other previous systematic reviews[8,18] attempted to include other type of study designs (prospective and retrospective cohort) in order to allow more robust conclusions. Those reviews concluded that in a follow-up period of 5 or more years, both ceramic and composite showed high survival rates, but no conclusive evidence is available about which presents better clinical behaviour.[8,18]

The objective of this systematic review was to provide an update of evidence through clinical outcomes reported in RCTs, answering the following problem, intervention, comparison and outcome (PICO) question: “How does indirect partial (inlays, onlays or overlays) ceramic or composite resin restorations affect the clinical performance and failure modes of posterior treated teeth?” PICO question is described in detail in **Table I**.

Table I. PICO question

P (Population)	Permanent posterior human teeth restored with partial indirect ceramic or composite resin restorations (inlays, onlays or overlays)
I (Intervention)	Partial indirect ceramic or composite resin restorations (inlays, onlays or overlays)
C (Comparison)	Not applicable in this study
O (Outcome)	Clinical performance and nature of failure

Materials and Methods

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis protocol (PRISMA-P: http://www.prisma-statement.org/).

2.1 Search strategy

The search for this systematic review was performed using four databases: MEDLINE (accessed through PubMed: www.pubmed.ncbi.nlm.nih.gov), Cochrane Library (www.cochranelibrary.com), EBSCOhost Research Platform (www.search.ebscohost.com) and LILACS (www.lilacs.bvsalud.org). The last search was conducted on 3 May 2020. The search strategy used for each database is shown in **Table II**.

The duplicate references were removed automatically using Mendeley (RELX Group, UK) and then manually by two authors.

All titles and abstracts of the selected studies were first assessed by two independent authors. Afterwards, the full text of each possible relevant study was evaluated, also by these two independent authors. A third author was consulted when necessary and a decision arrived at by consensus.

2.2 Inclusion and exclusion criteria

For this systematic review, only studies which met the following inclusion criteria were selected: (a) studies related to posterior restorations with ceramic or indirect composite inlays, onlays or overlays and (b) Randomized Controlled Trials.

Exclusion criteria were as follows: (a) studies not related to the topic; (b) reviews, guidelines, protocols, abstracts, comments, animal studies or *in vitro* studies; (c) series of cases or case reports (d) studies conducted in specific groups (bruxism, hypoplasia, hypomineralisation and others); (e) studies evaluating other type of cavity, cavities extending to the root surface, restorations of anterior teeth, deciduous teeth, non-vital teeth, teeth without antagonist and cracked teeth; (f) not partial indirect resin or ceramic inlay/onlay/overlay restorations, (g) survival not assessed, no follow-up, variable follow-up or follow-up lower than 3 years; (h) more than three operators; (i) not RCT; (j) studies with the same cohort (the most recent and/or with most complete data was considered); (k) article written in other language than Portuguese, English or Spanish, and (l) full-text not available.

2.3 Data extraction

The studies that accomplished the referred criteria were processed for the data extraction. The data were registered as follows: first author and year of publication; type of restoration; setting/number of operators; number of patients recruited; number of restorations placed; materials/methods; observation period (follow-up); evaluation criteria; number of reported failures/time of failure; and percentage of recall. Data extraction was performed independently and in duplicate by two authors.

2.4 Quality assessment

The assessment of the methodological quality of the included RCTs studies is fundamental for a better comprehension of the results. Each RCT was assessed using the bias risk assessment tool described in the Cochrane Handbook of Systematic Reviews of Interventions (Version 6, 2019)[19]. Briefly, seven domains were evaluated: random sequence generation; allocation concealment; blinding of participants and personnel; blinding of outcome assessment; incomplete outcome data; selective reporting; and risk of other potential sources of bias. Thus, studies were classified as: low risk (when all seven domains presented low risk); moderate risk (when one or more key domains presented unclear risk); and high risk (when one or more key domains presented high risk).

Table II. Research strategy used in each of the databases consulted

DATA BASE	SEARCH STRATEGY	
PubMed	((((((((((inlay*) OR onlay*) OR overlay*) OR coverage) OR inlays[MeSH Terms])) AND ((((((((((porcelain*) OR ceram*) OR dental porcelain[MeSH Terms]) OR resin*) OR composite) OR composite restoration*) OR composite resins[MeSH Terms]) OR ceromer*) OR CAD-CAM) OR CAD/CAM) OR computer aided design[MeSH Terms])) AND ((((((((((clinical evaluation) OR clinical study) OR comparative study) OR follow up studies[MeSH Terms]) OR clinical trial[MeSH Terms]) OR longevity) OR clinical performance) OR success) OR failure) OR survival rate[MeSH Terms])) AND Humans[Mesh])) NOT "Review" [Publication Type] Filters: Humans	
Cochrane Library	#1	inlay*
	#2	onlay*
	#3	overlay*
	#4	coverage
	#5	MeSH descriptor: [Inlays] explode all trees

	#6 #1 OR #2 OR #3 OR #4 OR #5
	#7 porcelain*
	#8 ceram*
	#9 MeSH descriptor: [Dental Porcelain] explode all trees
	#10 resin*
	#11 composite
	#12 composite restoration*
	#13 MeSH descriptor: [Composite Resins] explode all trees
	#14 ceromer*
	#15 CAD-CAM
	#16 CAD CAM
	#17 MeSH descriptor: [Computer-Aided Design] explode all trees
	#18 #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17
	#19 clinical evaluation
	#20 clinical study
	#21 comparative study
	#22 MeSH descriptor: [Follow-Up Studies] explode all trees
	#23 MeSH descriptor: [Clinical Trial] explode all trees
	#24 longevity
	#25 clinical performance
	#26 success
	#27 failure
	#28 MeSH descriptor: [Survival Rate] explode all trees
	#29 #19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26 OR #27 OR #28
	#30 #6 AND #18 AND #29
EBSCOhost	S1: TI inlay* OR TI onlay* OR TI overlay* OR TI coverage S2: TI porcelain* OR TI ceram* OR TI resin* OR TI composite OR TI composite restoration* OR TI ceromer* OR TI CAD-CAM OR TI CAD/CAM S3: TI clinical evaluation OR TI clinical study OR TI comparative study OR TI follow up OR TI clinical trial OR TI longevity OR TI clinical performance OR TI success OR TI failure OR TI survival rate S4: S1 AND S2 AND S3
LILACS	tw:((tw:((tw:(inlay*)) OR (tw:(onlay*)) OR (tw:(overlay*)) OR (tw:(coverage)) OR (mh:("inlay")))) AND (tw:((tw:(porcelain*)) OR (tw:(ceram*)) OR (mh:("porcelain, dental")) OR (tw:(resin*)) OR

(tw:(composite)) OR (tw:(composite restoration*)) OR (mh:("composite resins")) OR (tw:(ceromer*)) OR (tw:(cad-cam)) OR (tw:(cad/cam)) OR (mh:("cad-cam")))) AND (tw:((tw:(clinical evaluation)) OR (tw:(clinical study)) OR (tw:(comparative study)) OR (mh:("follow-up studies")) OR (mh:(clinical trial)) OR (tw:(longevity)) OR (tw:(clinical performance)) OR (tw:(success)) OR (tw:(failure)) OR (mh:("survival rate")))) NOT (mh:("review"))) AND (db:("LILACS") AND limit:("humans"))

Results

3.1 Study selection

The PRISMA flow diagram of the study selection is shown in **Fig. 1**.

A total of 2260 studies were identified through the search in the referred databases. After the removal of duplicates, a total of 1926 articles were obtained, of which 89 were selected after reading the titles and abstracts. The full-text reading led to the exclusion of 76 articles when submitted to the inclusion and exclusion criteria, and thus, 13 articles were considered for qualitative synthesis (**Table III**).

3.2 Study characteristics

3.2.1 Type of restorations

Among the 13 RCTs included in this review, 4 studies evaluated both composite resin and ceramic restorations, 2 studies included composite resin restorations and 7 studies were clinical trials concerning ceramic restorations. Regarding the manufacturing methods of indirect resin composite restorations, there are 4 studies in which they were fabricated by means of light cure, heat and/or pressure, and in 2 studies they were processed by CAD/CAM. In relation to manufacturing methods of ceramic restorations, there are 6 studies in which they were fabricated through CAD/CAM, 2 by pressable methods, 1 by both CAD/CAM and pressable methods, 1 by both CAD/CAM and stratification method, and in 1 study restorations were made by the three methods of manufacturing (CAD/CAM, pressable and stratification).

In relation to design of the cavity, ten studies evaluated inlays, two evaluated both inlays and onlays, and one evaluated onlays only.

3.2.2 Setting and number of operators

Concerning place of setting, one study was performed in a private practice and the other 12 were performed in Universities. Studies where treatments were carried out by more than three dentist were excluded, though in 5 studies there was 1 operator, in other 5 studies there were 2 operators, and in 2 studies there were 3 operators (1 study didn´t mentioned).

3.2.3 Clinical Procedures

Among the 13 included studies, most of them (8) referred that procedures were performed under rubber dam isolation, 4 studies didn´t use rubber dam, and 1 studied didn´t report which isolation type was applied.

Six studies performed the clinical procedures of each restoration in two medical appointments (first appointment for cavity preparation and impression; second appointment for cementation) implying a provisional phase. In those studies, no immediate dentin sealing (IDS) was performed. However, in some cases, a thin layer of calcium hydroxide liner was placed at the pulpal and axial walls, and a glass ionomer cement base was placed to eliminate undercuts in deep areas of the cavities and to replace lost dentin. In one study[20], a chemical curing composite filling material was used to eliminate undercuts, and to maintain a standardize preparation protocol.

Five studies used the chairside CAD/CAM technique, which allowed that all clinical procedures (cavity preparation, impression, and cementation of restoration) had been performed just in one appointment. In those cases, IDS were implemented. One study[21] performed the clinical procedures in one appointment to one type of material and in two appointments to the other two types of materials. One study[22] didn´t report if clinical procedures were performed over one or two appointments.

None of the included studies utilized a core build-up to replaced lost tooth structure. Regarding the cementation process, most studies used a dual-cure resin cement as luting agent. Detailed information can be further explored in **Table III**.

3.2.4 Evaluation criteria

In relation to the evaluation criteria selected by authors to assess quality of restorations during the follow-up period, in most of studies (10) the modified USPHS criteria was applied. Only two studies used CDA Quality Evaluation System and one other used a personalized index described by Vanherle et al.[23]

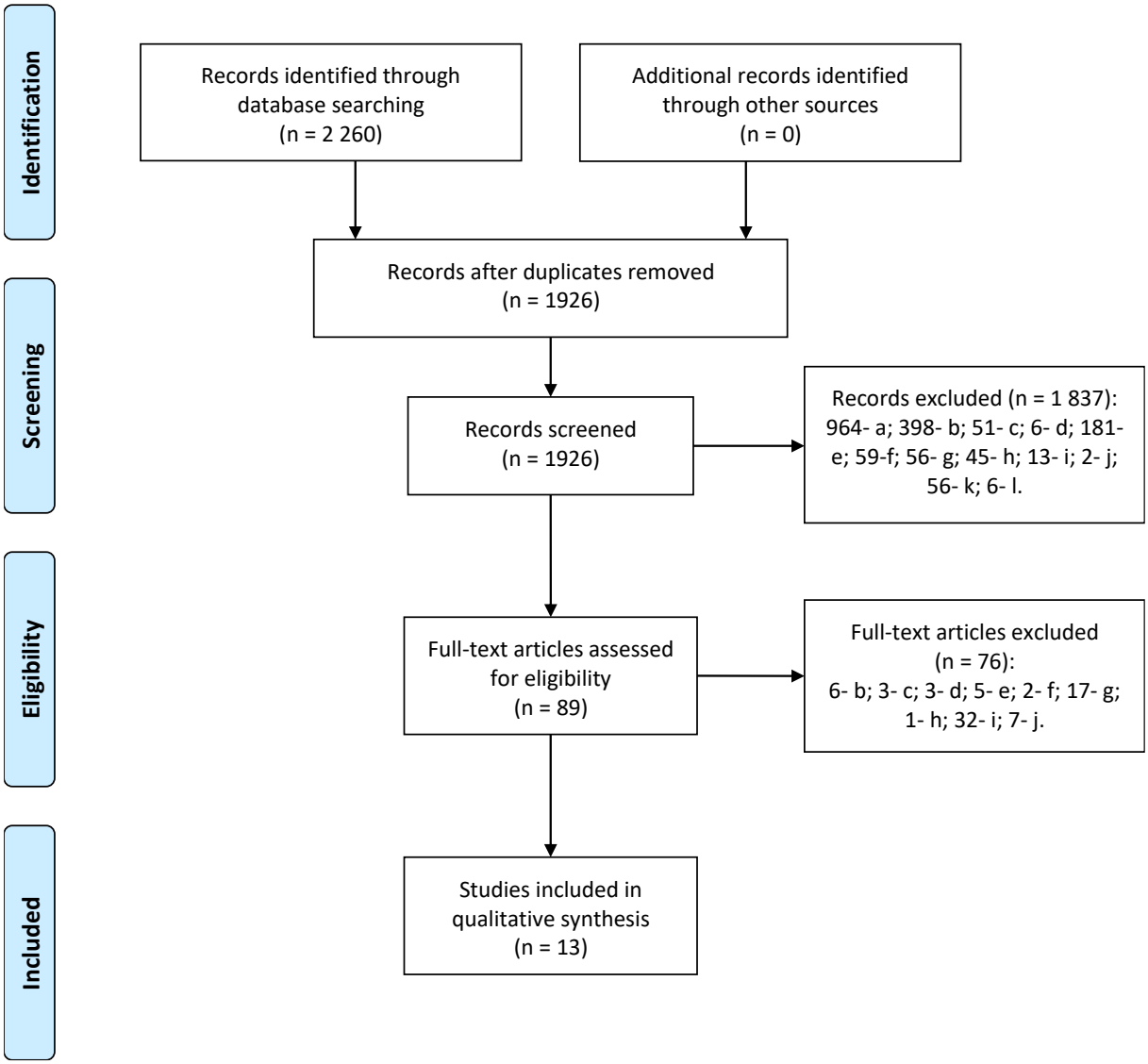

Fig. 1. PRISMA flow diagram of the study selection (a- studies not related to the topic; b- reviews, guidelines, protocols, abstracts, comments, animal studies or *in vitro* studies; c- series of cases or case reports; d- studies conducted in specific groups such as bruxism, hypoplasia, hypomineralisation and others; e- studies where was evaluated another type of cavity, cavities extending to the root surface, restorations of anterior teeth, deciduous teeth, non-vital teeth, teeth without antagonist and cracked teeth; f- not partial indirect resin or ceramic inlay/onlay/overlay restorations; g- survival not assessed, no follow-up, variable follow-up or follow-up lower than 3 years; h- more than three operators; i- not RCT; j- studies with the same cohort of which the most recent and/or with most complete data was considered; k- article written in other language than Portuguese, English or Spanish; l- full-text not available)

Table III. Summary of the included studies (13 RCTs)

Authors (year)	Type of rest.	Setting / N op.	N pat.	N rest.	Materials	Rubber dam	Cement	Follow -up	Evaluation criteria	% of failure	% of recall
Cetin et al. (2013)[24]	Direct + indirect (ph/th/pr) resin	Uv/1	54	108 (41 indirect)	21- Estenia [E] by Kuraray; 20- Tescera ATL [TATL] by Bisco	no	E- DC (Panavia, Kuraray); TATL- DC (Duo-Link, Bisco)	5y	Mod. USPHS (by 2 independent dentists)	3y: 2.4 5y: 2.4	100 (pat.)
Fasbinder et al. (2013)[25]	Resin + ceramic (both c/c)	Uv/2	43	80 (R-40; C-40)	40- Paradigm MZ100; 40- Vita Mark II	yes	DC (RelyX ARC, 3M ESPE)	10y	Mod. USPHS (by 2 independent evaluators)	3y: R= C- 2.5 5y: R=C-2.5 10y: R- 5; C-12.5	88 (rest.)
Fasbinder et al. (2019)[26]	Resin + ceramic (both c/c)	Uv/2	86	120 (R-60; C-60)	60- Lava Ultimate by 3M; 60- IPS EmpressCAD by Ivoclar	no	30 R + 30 C: DC (Variolink II, Ivoclar); 30 R + 30 C: DC (RelyX Ultimate, 3M ESPE)	5y	Mod. USPHS (by 2 independent evaluators)	3y: R- 1.7; C-3.3 5y: R- 5; C-6.6	nr
Frankenberger et al. (2009)[27]	Ceramic (pr)	Pv/2	39	98	Cergogold by Degussa Dental	yes	45- resin composite (Definite, Degudent); 53- DC (Variolink Ultra, Ivoclar Vivadent)	4y	Mod. USPHS (by 2 independent evaluators)	4y: 21.4	97 (rest.)

(Continues)

Table III (Continued)

Authors (year)	Type of rest.	Setting / N op.	N pat.	N rest.	Materials	Rubber dam	Cement	Follow -up	Evaluation criteria	% of failure	% of recall
Gladys et al. (1995)[15]	Ceramic (c/c) + indirect resin (ph/th/pr)	Uv/2	20	32 (R-8; C-24)	8- P50 indirect inlay system by 3M; 8- Dicor MGC [DIC] by Caulk-Dentsply; 16- Vita-Mark I [KUL + COL] by Vita Zahnfabrik;	yes	P50- exp. Luting Composite (3ML, 3M); DIC- DC (Dicor MGC Luting Composite, Caulk-Dentsply); KUL- DC (Microfill Pontic C, Kulzer); COL- DC (exp. Cerec-Coltene Duo Cement, Coltene)	3y	Color stability, translucency/ opacity and marginal adaptation/retention index, described by Vanherle et al. (1986) (by 2 independent clinicians)	3y: R=C- 0	100 (pat.)
Guess et al. (2013)[20]	Ceramic (pr + c/c)	Uv/nr	25	80	40 (pr)- IPS e.max Press by Ivoclar Vivadent; 40 (c/c)- ProCAD by Ivoclar Vivadent	yes	Hybrid composite resin material (Tetric/Syntac Classic, Ivoclar Vivadent)- preheated	7y	Mod. USPHS (by 2 independent investigators- 5 years)	3y: 1.25 5y: 1.25 7y: 1.25	56 (pat.); 60 (rest.)
Isenberg et al. (1992)[22]	Ceramic (both c/c)	Uv/3	nr	121	Dicor by Dentsply; Vita by Vita Zahnfabrik	yes	DC (Caulk, L.D. Caulk; Kulzer, Kulzer; Vivadent, Vivadent)	3y	USPHS (by 2 evaluators)	3y: 5.8	nr

(Continues)

Table III. (Continued)

Authors (year)	Type of rest.	Setting / N op.	N pat.	N rest.	Materials	Rubber dam	Cement	Follow -up	Evaluation criteria	% of failure	% of recall
Molin & Karlsson (2000)[28]	Ceramic (c/c + st + pr) + gold	Uv/1	20	80 (60 ceramic)	20 (c/c)- Vita Cerec by Vita 20 (st)- Mirage by Myron 20 (pr)- Empress by Ivoclar-Williams	nr	c/c- DC (Vita Cerec duo cement, Vita); st- DC (Mirage FLC, Chamelon); pr- DC (IPS Empress dual cement, Ivoclar-Williams)	5y	CDA_QES (by both authors independently)	3y: 5 5y: 10	100 (pat.)
Pallesen & van Dijken (2000)[29]	Ceramic (c/c)	Uv/1	16	32	16- Vita Mark II by Vita Zahnfabrik; 16- Dicor MGC by Dentsply/ DeTrey	yes	DC (Kulzer Cerec Cement)	8y	Mod. USPHS (by 1 evaluator - blind)	3y: 3.1 5y: 9.4 8y: 9.4	100 (pat.)
Pallesen & Qvist (2003)[30]	Resin (ph/th/pr)	Uv/1 (UP)	28	140 (84 indirect)	28 - Brilliant Dentin [BD] by Coltene; 28- Estilux Posterior [EP] by Kulzer 28- SR-Isosit [ISO] by Ivoclar	no	BD- (Coltene Duo Cement, Coltene) EP- (Microfil Pontic C, Heraeus/Kulzer) ISO- (Dual Cement, Vivadent)	11y	Mod. USPHS (by either UP or UP and VQ)	3y: 2.4 5y: 3.6 10y: 14.3 11y: 16.7	96.4 (pat.)
Peumans et al. (2013)[31]	Ceramic (pr)	Uv/2	31	62	IPS-Empress 2 by Ivoclar Vivadent	yes	SA- (RelyX Unicem, 3M ESPE)	4y	Mod. USPHS (by 2 independent investigators)	4y: 4.6	96.8 (pat. & rest.)

(Continues)

Table III. (Continued)

Authors (year)	Type of rest.	Setting / N op.	N pat.	N rest.	Materials	Rubber dam	Cement	Follow -up	Evaluation criteria	% of failure	% of recall
Sjogren et al. (2004)[32]	Ceramic (c/c)	Uv/3	27	66	Vita Mark II by Vita Zahnfabrik	yes	33- DC (Vita Cerec Duo Cement, Coltene); 33- CC (Cavex Clearfil F2, Cavex)	10y	Mod. USPHS (by the 3 authors)	3y: 3.0 5y: 6.1 10y: 10.6	92.6 (pat.); 92.4 (rest.)
Thordrup et al. (2006)[21]	Direct resin + indirect (ph/th/pr) resin + ceramic (c/c + st)	Uv/1	37	58 (14 indirect resin; 29 ceramic)	14- Estilux by Kulzer; 15- Cerec by Siemens; 14- Vita Dur N by Vita Zahnfabrik	no	DC (Cerec Dual Cement, Kuizer)	10y	CDA_QES	3y: R-7.1; C-3.4 5y: R- 7.1; C-10.3 10y: R- 14.3; C- 20.7	89.2 (pat.); 78.6 (R); 96.6 (C)

Abbreviations: R- resin; C- ceramic; ph/th/pr- photo/thermo/pressure; st- stratified; pr-pressed; c/c- cad/cam; Uv- University; Pv- Private; op.- operators; nr- not reported; DC/SA/CC - dual cured/self-adhesive/chemically cured resin cement; exp.- experimental; y-years; Mod. USPHS- Modified United States Public Health Service criteria; CDA_QES- California Dental Association Quality Evaluation System.

3.2.5 Follow-up time and percentage of recall

Since studies with a follow-up period shorter than 3 years were excluded, among the included studies there are 2 with 3 years of follow-up, 2 with 4 years of follow-up and 3 with 5 years of follow-up. There are 6 studies with a follow-up period larger than 5 years, of which 1 had 7 years, 1 had 8 years, 3 had 10 years and 1 had 11 years of follow-up.

At the last assessment of restorations in each study, percentage of recall is generically high, but some studies had significant dropouts such as Guess et al.[24], reaching values around 40%. Only two studies didn´t report the recall rate at the last assessment.

3.3 Assessment of risk of bias

Details of the assessment of the risk of bias for the included studies are displayed in **Fig. 2.** Thus, none of studies were classified as low risk, 8 studies were classified as moderate risk and 5 as high risk of bias.

3.4. Failure incidence

Among the included studies, ten reported the point period (years) of occurring failures. The other three (Frankenberger et al.[27], Isenberg et al.[22] and Peumans et al.[31]), only reported that failures occurred during the follow-up period. Frankenberger et al.[27] and Peumans et al.[31] evaluated restorations during a follow-up of 4 years, so we don´t know if restorations failed during first 3 years or between the 3rd and 4th year after placement. In Isenberg et al.[22], restorations failed during the 3 years of follow-up period.

3.4.1 Three years

Composite/ceramic studies (4): In Fasbinder et al. (2013)[25] study, 2.5% of both resin and ceramic baseline restorations failed during 3 years; Fasbinder et al. (2019)[26] reported 1.7% and 3.3% failed resin and ceramic restorations, respectively; Gladys et al.[15] didn´t report any failure of resin and ceramic restorations; and in Thordrup et al.[21] study, 7.1% of resin and 3.4% of ceramic restorations failed during first 3 years after placement.

Composite studies (2): Both Cetin et al.[24] and Pallesen & Qvist[30] reported that 2.4% of baseline resin restorations failed during 3 years after placement.

Ceramic studies (5): In Guess et al.[24] study, 1.25% of placed restorations failed during 3 years of follow-up; Isenberg et al.[22] reported 5.8%, Molin & Karlsson[28] reported 5%, Pallesen & van Dijken[29] reported 3.1% and Sjogren et al.[32] reported 3.0% of failures in this period of follow-up.

3.4.2 Five years

Composite/ceramic studies (3): In Fasbinder et al. (2013)[25] study, 2.5% of both resin and ceramic baseline restorations failed during 5 years; Fasbinder et al. (2019)[26] reported 5% and 6.6% failed resin and ceramic restorations, respectively; and in Thordrup et al.[21] study, 7.1% of resin and 10.3% of ceramic restorations failed during first 5 years after placement.

Composite resin studies (2): Cetin et al.[24] reported 2.4% of failures at 5 years of follow-up and Pallesen & Qvist[30] detected 3.6% of failed restorations.

Ceramic studies (4): In Guess et al.[24] study, 1.25% of placed restorations failed during 5 years of follow-up; Molin & Karlsson[28] reported 10%, Pallesen & van Dijken[29] reported 9.4% and Sjogren et al.[32] reported 10.6% of failures in this period of follow-up.

Furthermore, despite not knowing when failures happened in Frankenberger et al.[27] and Peumans et al.[31] studies, they identified over a follow-up period of 4 years, that 21.4% and 4.6% of baseline ceramic restorations failed, respectively.

3.4.3 Ten years

Composite/ceramic studies (2): In Fasbinder et al. (2013)[25] study, 5% of resin and 12.5% of ceramic baseline restorations failed during 10 years; Thordrup et al.[21] reported 14.3% and 20.7% failed resin and ceramic restorations, respectively.

Composite studies (1): Pallesen & Qvist[30] reported that 14.3% of baseline composite resin restorations failed during 10 years after placement.

Ceramic studies (1): In Sjogren et al.[32], 10.6% of placed restorations failed during 10 years of follow-up.

Moreover, although Guess et al.[24] didn´t evaluate restorations over 10 years of follow-up, they reported at 7 years the same percentage of failed ceramic restorations found at 3 and 5 years (1.25%); and Pallesen & van Dijken[29] also reported at 8 years the same percentage of ceramic failures found at 5 years (9.4%).

Additionally, Pallesen & Qvist[30] registered, at 11 years of follow-up, 16.7% of failures in relation to the number of baseline resin composite restorations.

3.4.4 Types of failures

Among the included studies, a total of 84 (22 resin and 62 ceramic) restorations were identified as failures during the different follow-up periods, as described in Table IV. Regarding the composite resin restorations, 36.4% (8) failed because of tooth fracture, 18.2% (4) by causes not related to the restoration (e.g. periodontitis, inclusion in a bridge, caries at a new surface), 13.6% (3) by restoration fracture, 13.6% (3) due to secondary

caries, 9.1% (2) due to endodontic problems, 4.5% (1) due to postoperative symptoms and 4.5% (1) due to loss of retention/debonding.

In relation to ceramic restorations, 67.7% (42) failed as a consequence of restoration fracture, 11.3% (7) due to tooth fracture, 6.5% (4) due to postoperative symptoms, 4.8% (3) due to marginal gap formation, 4.8% (3) due to loss of retention, 3.3% (2) due to secondary caries and 1.6% (1) due to endodontic problems.

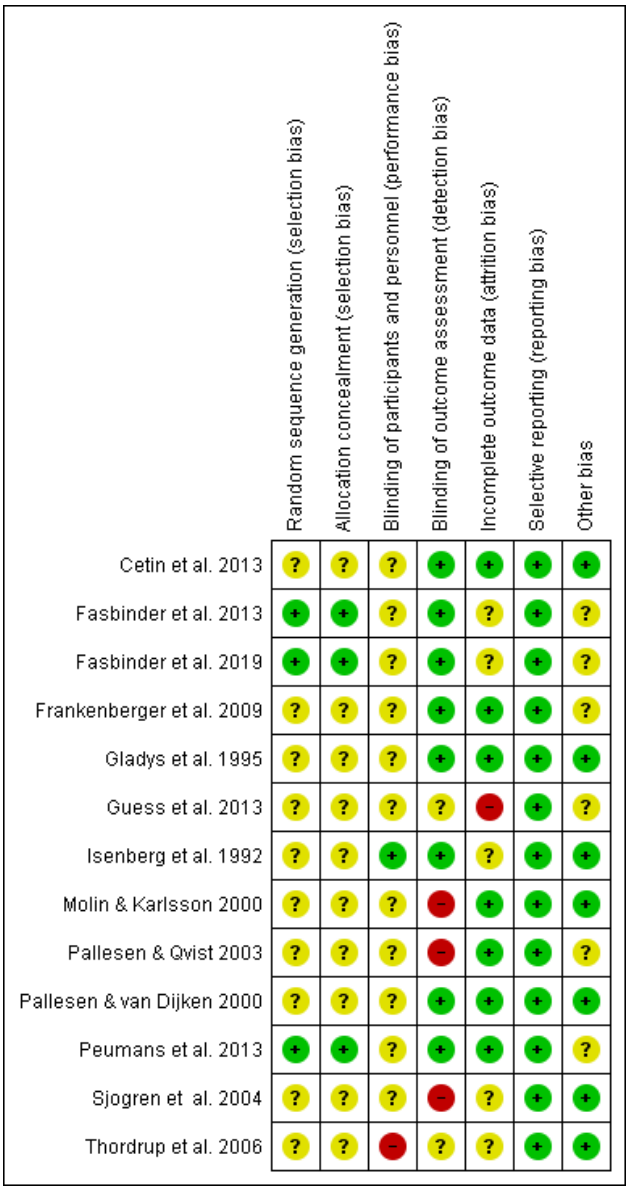

Fig. 2. Risk of bias of included studies

Table IV. Number and types of failures

	Authors (year)	Material type	Failure type								Total	N baseline
			Restoration fracture	Tooth fracture	Secondary caries	Postoperative symptoms (e.g. hypersensitivity)	Endodontic problems	Marginal gap formation	Lost retention/ Debonding	Not related to the restoration		
No. of failures (failure time - years)	Cetin et al. (2013)	Resin					1 (2)				1 (5y)	41
	Fasbinder et al. (2013)	Resin	1 (10)	1 (2)							2 (10y)	40
		Ceramic	2 (3,10)	2 (7,8)							4 (10y)	40
	Fasbinder et al. (2019)	Resin	1 (1.6)	2 (3.2, 3.6)							3 (5y)	60
		Ceramic	4 (0.8, 2.8, 3.1, 3.3)								4 (5y)	60
	Frankenberger et al. (2009)	Ceramic	11 (nr)	4 (nr)		3 (nr)		3 (nr)			21 (4y)*	98
	Gladys et al. (1995)	Resin									0 (3y)	8
		Ceramic									0 (3y)	24
	Guess et al. (2013)	Ceramic	1 (≈ 1)								1 (7y)	80
	Isenberg et al. (1992)	Ceramic	7 (nr)								7 (3y)*	121
	Molin & Karlsson (2000)	Ceramic	5 (0.08, 1.5, others between 3-5)						1 (0.25)		6 (5y)	60
	Pallesen & van Dijken (2000)	Ceramic	3 (3, 5, 5)								3 (11y)	32
	Pallesen & Qvist (2003)	Resin	1 (5)	5 (1.5, 7, 7, 8, 10.1)	3 (6, 8, 8.8)				1 (2.7)	4 (6.4, 7, 8, 10.4)	14 (4y)	84
	Peumans et al. (2013)	Ceramic	1- with tooth # (nr)						2 (nr)		3 (4y)*	62
	Sjogren et al. (2004)	Ceramic	4 (3, 4, 5, 7)	1 (2)		1 (10)	1 (7)				7 (10y)	66
	Thordrup et al. (2006)	Resin				1 (2)	1 (8)				2 (10y)	14
		Ceramic	4 (1,4,8.5,9.5)		2 (4.5,8.5)						6 (10y)	29

Abbreviations: #- fracture; nr/*- not reported when failure happened.

Discussion

The present systematic review aimed at answering the following question “How does indirect partial ceramic or composite resin restorations (inlays, onlays or overlays) affect the clinical performance and failure mode of posterior treated teeth?” by the analysis of randomized controlled trials dealing with the quality assessment of restorations followed up for at least 3 years.

Longevity have been established and considered in many clinical studies as an indicator for the performance of dental restorations and for the quality of care delivered. Concerning the performance of indirect posterior restorations, Anusavice[33] recommended the classification of success, when there were no intervention on the placed restoration; survival, when restoration is still in place and functioning, but it was repaired, recemented or the tooth endodontically treated; and failure when restoration was replaced or tooth extracted. Furthermore, recently (2019), Laske et al.[34] evaluated the “differences between three performance measures on dental restorations, clinical success, survival and failure” and stated that using these criteria “in future clinical studies would enable a better comparison of studies”.

Most of the included studies reported results through survival rates, number of failures and scores for the evaluation of criteria items, and only a few of them reported success rates. Moreover, success was not clearly defined among the included studies and to solve that, it may be defined as the percentage of highest criteria of the author´s standard (e.g. Alpha scores for the Modified USPHS criteria), like Abduo & Sambrook[35] suggested in their systematic review. However, Laske et al.[34] recommended that “only restorations that actually received an intervention should be considered as unsuccessful” because the lowest criteria as Charlie, Delta according to USPHS and score 4 and 5 in FDI definitions include items about discolorations, (…) that don´t mean that in all cases that restoration is not functioning satisfactorily”. So, since most of studies didn´t report success rates and didn´t clearly defined what success means, it is difficult to compare this parameter between them.

Regarding the survival rate, there are also several differences between the included studies because only five of them used the Kaplan-Meier algorithm to determine survival probability. The Kaplan-Meier method is a more sophisticated method of summarizing survival data, which utilizes all cases of the study, not only those followed up until the selected cut-off.[36] Thus, when a subject under study is lost to follow-up or when a restoration fail midway in the study, that information shouldn´t be ignored because it provide some data about survival.[37] However, in the other included studies that didn´t use this method to calculate survival rate, this information were not reflected in the results, so it is difficult to compare survival rate among studies.

In relation to failure incidence, it was calculated through the quotient of the number of failures reported on studies during follow-up periods of three, five and ten years (or the last year of follow-up if it didn´t coincide with these) by the total number of restorations placed when study started. Despite most of the studies didn´t report high percentage of dropouts, there were some restorations that studies didn´t access, so there was no way to known if they failed or not. Consequently, the real percentage of failures may be higher than the one that was calculated in this review.

After three years of follow-up, composite resin restorations presented more failures than ceramic restorations. It is valid among studies that compared resin composite with ceramic (resin- 7.1%; ceramic- 3.4%) and when all studies are included in this comparison (resin- 7.1%; ceramic- 5.8%). After five years of follow-up, ceramic restorations showed more failures than composite resin restorations. It is valid not only among studies that compared resin composite with ceramic (resin- 7.1%; ceramic- 10.3%) but also among all studies (resin- 7.1%; ceramic- 10.6%). After ten years of follow-up, ceramic restorations also failed more than composite resin restorations. And in this case, it is also valid among studies that compared resin composite with ceramic (resin- 14.3%; ceramic- 20.7%) and among all studies (resin- 14.3%; ceramic- 20.7%). Therefore, it turns out that composite resin restorations only showed more failures than ceramic restorations during the first three years of follow-up and at five and ten years of follow-up ceramic restorations presented higher values of failures. Differences between composite resin and ceramic restorations in those periods of follow-up only reached 6.4%.

Regarding the lower percentages of failures reported among all the included studies, at three years they were the same either for composite resin restorations or for ceramic restorations (0%). At five years of follow-up, ceramic restorations presented the lower value (resin- 2.4%; ceramic- 1.25%) and at ten years of follow-up were composite resin restorations that showed the lower value among included studies (resin- 5%; ceramic- 10.6%).

Manhart et al.[38] reviewed the clinical survival of direct and indirect restorations in posterior permanent teeth (class I and II) and evaluated the causes that might have contributed to the success or failure of those restorations. They calculated an annual failure rate of 2.9% for composite inlays/onlays, which corresponds to 8.7%, 14.5% and 29% after three, five and ten years, respectively. Manhart et al.[38] also calculated an annual failure rate of 1.9% for ceramic inlays/onlays and 1.7% for CAD/CAM inlays/onlays, which corresponds to 5.7%/5.1% after 3 years, 9.5%/8.5% after five years and 19%/17% after ten years, respectively. Though, the results of failure incidence found in this current review aren´t completely in line with the literature, especially concerning composite resin indirect

restorations that present 29% of failure incidence at 10 years, in contrast to 14.3% (higher value among the studies) found in this current review. Differences found between this review and the literature may be justified by the fact that exclusion criteria used in this review were possibly more restrictive since only RCTs were included, and studies with non-vital teeth or studies which restorations were placed by more than 3 operators were excluded.

A systematic review and meta-analysis made by Morimoto et al.8 reported that survival rate for the indirect partial ceramic restorations (glass-ceramics and feldspathic porcelain) was 92-95% (failure rate: 5-8%) at 5 years and 91% (failure rate: 9%) at 10 years. Furthermore, a systematic review by Abduo & Sambrook[35] that evaluated longevity of ceramic onlays, reported survival rate of 91-100% (failure rate: 0-9%) among the medium-term studies (2-5 years) and survival rate of 71-98.5% (failure rate: 1.5-29%) among the long-term studies (more than 5 years). Though, this may differ slightly from those found in this current review.

However, previous systematic reviews, Fron Chabouis et al.[17], Grivas et al.[3], Mangani et al.[39] and Sampaio et al.[18], were inconclusive as to whether partial indirect composite resin restorations survive longer than ceramics, or vice versa. Two of them were not able to perform meta-analysis (Grivas et al.[3]; Mangani et al.[39]), one performed meta-analysis just for ceramics because only included one resin composite study (Fron Chabouis et al.[17]), and the other one that conducted meta-analysis (Fron Chabouis et al.[17]) only compared two RCTs and 138 restorations.

The main reasons behind the indirect composite resin restoration failures found in this review were tooth fracture and causes not related to the restoration (e.g. periodontitis, inclusion in a bridge, caries at a new surface). Concerning ceramic restorations, most of them failed due to restoration fracture and due to tooth fracture.

These findings seem to be in line with the literature. Manhart et al.[38] reported inlays fracture, marginal opening, secondary caries and postoperative sensitivity as the main reasons for composite failure. Restorations fracture, tooth fracture, postoperative symptoms, and recurrent caries were reported as the main reasons for ceramic failure. Fron Chabouis et al.[17] stated that inlay fracture was the most frequent type of failure, especially for ceramic inlays. Morimoto et al.[8], Abduo et al.[35] and Sampaio et al.[18] indicated that fractures remain the most frequent type of ceramic restoration failure (no results for composite resin restorations). Regarding the ceramic fractures, it can be justified by ceramic vulnerability to fatigue and crack propagation from internal or external surfaces.[40]

A few limitations can be pointed out to this study. Included studies present heterogeneity concerning fabrication process of composite resin restorations since both CAD/CAM and conventional (light cure, heat and/or pressure) methods are present.

Regarding the ceramic materials, CAD/CAM, pressable and stratification methods are present. Despite that, Sampaio et al.[18] concluded that regardless of the manufacturing methods, vitreous ceramic (feldspathic porcelain and glass ceramic) inlays, onlays, and overlays showed a high survival, being an advised treatment. However, they didn´t report conclusive evidence about indirect composite or crystalline ceramic inlays, onlays, and overlays.

Additionally, in relation cavity design, ten studies evaluated inlays, two evaluated both inlays and onlays, and one evaluated only onlays. Nevertheless, most of the reviews found in the literature also didn´t distinguish these types of cavities. In terms of clinical procedures, none of the studies used a core build-up, not all of them employed absolute isolation with rubber dam, some of them utilized a provisional phase with no immediate dentin sealing, and others performed all restoration procedures just in one appointment, benefiting from IDS. Thus, these all differences might have led to inhomogeneous results.

Bias risk analysis may also help to understand differences in methodological protocols among studies. Most of studies presented an unclear risk of bias regarding the random sequence generation and allocation concealment, which means that similarity of groups was not ensured. Another important aspect is that sometimes blinding of participants and personnel is difficult because an experienced dentist´s eye can easily distinguish ceramic and composite inlays, so most of studies revealed an unclear risk in this item. Relatively to the detection bias (blinding of outcome assessment), evaluations of restorations in some studies were performed by the operator, which might have led to differences in results. One study[20] revealed high values of incomplete outcome data (just 60% of baseline restorations were assessed at the last period of follow-up: 7 years) and other studies[20,25–27,30,31] were supported by industries in restorative dentistry, so this bias cannot be excluded.

Despite RCTs evaluated these materials in an extremely controlled environment which may not correspond to day by day of clinical practice, it seems to be consensual that indirect partial composite resin or ceramic restorations show high survival rate in short and long term. However, there is a long way to go through in order to improve these materials, and technologies like CAD/CAM will certainly held to do that.

Finally, we recommend that in future clinical studies, researchers should conduct well-design randomized controlled trials focusing on the comparison of manufacturing methods and materials, as well as, type of cavity preparations. Moreover, we recommend that all future studies should use FDI consensus criteria to assess quality of restorations[41], clearly describe dropouts and failure types and undergo a clear separation of the survival and success rates, Thus, for the purpose of produce well-design RCTs with low risk of bias, CONSORT guidelines[42] must be followed by authors.

Conclusions

Within the limitations of this systematic review, the following conclusions can be drawn:

1. Regardless of the follow-up duration (three, five or ten years), both ceramic and composite resin indirect partial restorations exhibited acceptable clinical outcomes;
2. There is insufficient evidence to make strict recommendations in favour of ceramic over composite resin indirect partial restorations;
3. The most common types of failures were restoration and/or tooth fracture;
4. More well-designed randomized clinical trials are necessary to provide conclusive evidence about which material perform better *in vivo* conditions; thus, the quality of care delivered might be improved.

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