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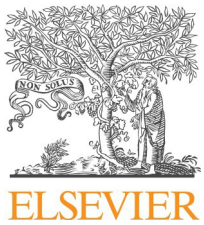

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Posterior ceramic versus metal restorations: A systematic review and meta-analysis

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ABSTRACT

Objectives: The goal of this systemic review and meta-analysis was to evaluate the longevity of indirect adhesively-luted ceramic compared to conventionally cemented metal single tooth restorations.

Data: Randomized controlled trials (RCT) investigating indirect adhesively-luted ceramic restorations compared to metal or metal-based cemented restorations in permanent posterior teeth.

Sources: Three electronic databases (PubMed, CENTRAL (Cochrane) and Embase) were screened. No language or time restrictions were applied. Study selection, data extraction and quality assessment were done in duplicate. Risk of Bias and level of evidence was graded using Risk of Bias 2.0 tool and Grade Profiler 3.6.

Results: A total of 3056 articles were found by electronic databases. Finally, four RCTs were selected. Overall, 443 restorations of which 212 were adhesively-luted ceramic restorations and 231 conventionally cemented metal restorations have been placed in 314 patients (age: 22-72 years). The highest annual failure rates were found for ceramic restorations ranging from 2.1% to 5.6%. Lower annual failure rates were found for metal (gold) restorations ranging from 0% to 2.1%. Meta-analysis could be performed for adhesively-luted ceramic vs. conventionally cemented metal restorations. Conventionally cemented metal restoration showed a significantly lower failure rate than adhesively-luted ceramic ones (visual-tactile assessment: Risk Ratio (RR)[95%CI]=0.31[0.16,0.57], low level of evidence). Furthermore, all studies showed a high risk of bias.

Conclusion: Conventionally cemented metal restorations revealed significantly lower failure rates compared to adhesively-luted ceramic ones, although the selected sample was small and with medium follow-up periods with high risks of bias.

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Contents

1. Introduction

Restoring decayed teeth with direct composite restorations allows to maintain a maximum of residual dental hard tissue. Indirect restorations have become a viable alternative to restore moderately and severely deteriorated posterior teeth [1]. The advance with respect to adhesive technology and to the mechanical characteristics of the different types of ceramics and resin composites allow dental practitioners to place restorations using a minimal invasive approach [2]. Composites provide high esthetics and adequate hardness for anterior and posterior restorations to maintain their physical properties regarding to wear resistance [3]. However, direct composite restorations show contraction of the composite material during polymerization through light curing using increment technique in in-situ studies [4,5]. Furthermore, the increments may polymerize incompletely due to poor access of the targeted region for polymerization and the contouring of large cavities and approximal regions of the teeth might be difficult in challenging cases. Besides polymerization shrinkage, limitations of large direct composite restorations were found to be increased marginal gap formation and fractures within the material [6]. Thus, indirect approaches using resin composites as well as additional restorative materials, e.g. ceramics and metals were developed to resolve these issues.

For moderately and severely deteriorated teeth indirect restorations, e.g. onlays, overlays and crowns were found to be favorable over large composite restorations [7–10]. Especially when cusps have to be reconstructed, indirect restorations may prevent cusp fracture by completely covering the occlusal surface of the tooth [8]. Generally, indirect restorations are either conventionally cemented or adhesively luted. When inserting all-ceramic restorations adhesively, less resin cement/composite is subjected to polymerization shrinkage compared to direct approaches [11]. Indirect ceramic restorations have further benefits, e.g. higher marginal integrity, higher color stability, a wear resistance similar to enamel, higher compressive strength, higher fracture resistance, higher elastic modulus, a more optimal interproximal design and, thus, an ideal anatomic morphology being superior over conventional direct resin composite restorations [12–14]. Furthermore, all-ceramic crowns showed good long-term prognosis and good biocompatibility concerning gingival adaptation [15–18]. However, the marginal adaptation of tooth-colored restorations together with fractures of the restoration (chipping) are considered to be the most critical parameters for clinical performance [19–21].

Even smaller indirect restorations, e.g. composite, ceramic or metal inlays, are supposed to show better marginal adaptation, better interproximal morphology, higher fracture and wear resistance due to better physical and mechanical properties than direct restorations and tend to have little to no polymerization shrinkages [22].

All-ceramic restorations have gained an increased popularity over the last decades due to the advances in ceramic materials and adhesive technologies and several predictors for the longevity of all-ceramic indirect restorations have already been analyzed in systematic reviews [18,23]. For instance, it could be shown that glass-ceramic crowns had a significant lower success rate than alumina crowns or reinforced glass-ceramic crowns [18] and that anterior all-ceramic crowns showed significantly lower failure rates than

posterior ones [18,23]. However, there is still a lack of information on the long-term success of all-ceramic indirect restorations [18,23] especially when compared to their metal-based pendants. Thus, the main goal of this systemic review and meta-analysis was to evaluate the longevity of adhesively-luted indirect ceramic restorations compared to cemented indirect metal restorations. We hypothesized that no difference in the longevity and failure rate between adhesively-luted indirect ceramic and (conventionally) cemented indirect metal restorations can be observed.

2. Material and methods

2.1. *Review design*

No study registration is necessary for this review.

This systematic review was based on the guidelines of PRISMA Statement [24] and the search was made based on the structure of the following PICOS [25]:

1. Population (P): permanent posterior single teeth (premolars and/or molars) in adults
2. Intervention (I): adhesively-luted indirect ceramic single tooth restorations
3. Comparison (C): (conventionally) cemented indirect metal or metal-based single tooth restorations
4. Outcome (O): longevity of all restorations
5. Study design (S): randomized clinical trial (RCTs) with at least two years follow-up

2.2. *Inclusion and exclusion criteria*

In addition to PICOS, the following inclusion criteria were adopted:

- Single tooth restorations
- Sufficient information extractable e.g.: number of restorations placed, outcome assessment, reason for failure

In addition to PICOS, the following exclusion criteria were adopted:

- Other studies than in-vivo studies (e.g.: in vitro, in situ, case report, reviews)
- Studies with less than 2 years follow

2.3. *Data sources*

Detailed search strategies were developed and appropriately revised for each database, considering the differences in controlled vocabulary and syntax rules by two authors (CT, HML). The electronic search was conducted through PubMed (Medline), CENTRAL (Cochrane) and Embase in November 2021. The search strategy for Medline/PubMed is shown in Fig. 1. The search strategies for CENTRAL and Embase were adapted from the strategy for Medline but revised appropriately for each database to take account of the differences in vocabulary and syntax rules.

Search Strategy PubMed

amalgam* OR ceramic* OR composite* OR crown* OR metal* OR bridge* AND

longevity* OR success* OR survival* OR performance* AND

restore* OR fill* OR prosthetic*

Filters: Clinical Trial

Fig. 1 – Search Strategy PubMed. Filters: Clinical Trial.

Two authors (LS, CT) independently reviewed titles and abstracts using these search strategies. The reviewers were not blinded to the identity of the journal names or article authors, their institutions, or the results of their research. No language or time restrictions were applied. A detailed sequence of filtering search results to include relevant articles can be found in the supplementary material. In order to further identify potential articles for inclusion, gray literature was searched in the register of clinical studies hosted by the US National Institutes of Health (www.clinicaltrials.gov), the multidisciplinary European database (www.opengrey.eu), the National Research Register, and Pro-Quest Dissertation Abstracts and Thesis databases. Agreement concerning study inclusion or data extraction was achieved by consultation and discussion with a third author (HML). Selected articles were screened full-text. Furthermore, gray literature was searched and cross-referencing was performed to identify further articles to be assessed.

2.4. *Data extraction*

Only available data given in the articles were used. If needed, the authors were contacted twice per e-mail for additional information.

Two authors performed data extraction independently and in duplicate (LS, CT). Following data were extracted in predefined structured excel sheets:

- Study name, year of publication and study type
- Setting and country
- Number of participants, sex, age, general health condition and caries risk assessment if available in the article
- Localization of the cavo-surface margin
- Cavity type and reason of the intervention/treatment
- Methods of treatments and materials
- Author of placement, evaluator and evaluation criteria
- Follow- up, primary and secondary outcomes

- Lesion activity at the moment of restoration placed or replacement of old restorations
- Lesion extension: surfaces of restoration
- Lesion margin: enamel or dentin
- Materials: restorative materials, adhesive technique, resin based luting agent or conventional cement, and base material if the information were available

- Technical issues: e.g., beveled cavity margins or use of rubber dam, etc.

2.5. Definition of failure

All studies reported if a reintervention was necessary. Therefore, in the present review the initially placed restoration was judged as successful if no clinical or radiographic signs of technical failures (e.g. loss of retention, root fracture or post fracture) was reported. In contrast, if the initially placed restoration was renewed, repaired or recemented due to fracture, restoration loss, secondary caries, and/or other reasons the restoration was considered as biological failure. However, endodontic intervention and extraction due to periodontal reasons as well as chipping, which did not lead to renewal, reparation or recementation, were not considered as biologically failed, but the observation period was censored.

2.6. Data analysis and grading

The statistical analyses were conducted in Review Manager (RevMan version 5.4 software, Cochrane Collaboration, Copenhagen, Denmark, 2014). Statistical significance was defined as a p-value ≤ 0.05 (Z test) and heterogeneity was assessed with I^2 [26]. Fixed or random-effects meta-analysis was performed depending on heterogeneity ($I^2 < 35\%$: fixed-effects; $I^2 > 35\%$: random-effect) [27,28]. The number of events was considered as the number of failures. To avoid unit-of-analysis errors the guidelines outlined by the Cochrane collaboration (chapter 9.3.4.) were followed [29]. Therefore, baseline data were compared with data of a single time point (mostly longest follow-up period). Forest plots were created to illustrate the meta-analysis. Grading of evidence was performed according to the GRADE network levels using Grade Profiler 3.6 [30].

2.7. Heterogenity

Clinical and methodological heterogeneity were assessed by examining the characteristics of the studies, the similarity between the types of participants, the interventions, and the outcomes as specified in the inclusion criteria for considering studies for this review.

Statistical heterogeneity would have been assessed using a Chi^2 test and the I^2 statistic, where I^2 values over 50% indicated substantial heterogeneity.

2.8. Assessment of reporting bias

In the presence of more than 10 studies in a meta-analysis, the possible presence of publication bias was investigated for the primary outcome. Publication bias was assessed by Funnel plots [31].

2.9. Sensitivity analysis

We explored whether or not the analysis of studies stratified by (1) risk of bias or (2) study design yielded similar or different results. For this (1) studies at high risk of bias or (2) studies using a split-mouth design were eliminated in a second/third analysis.

3. Results

A total of 3056 articles were found on PubMed (Medline), CENTRAL (Cochrane) and Embase (Fig. 2). A total of 146 records and additionally 21 records through cross-references and 19 found by hand-search were full-text screened. Of these, 114 articles were assessed for eligibility and finally, four randomized controlled clinical trials were selected [21,32–34]. Reasons for exclusion are given in Fig. 2. Of these, two studies were parallel-arm [33,34] and two with a split-mouth design [21,32].

The included studies were published between 2000 and 2013. Overall, 443 restorations of which 212 were adhesively-luted ceramic and 231 conventionally cemented metal/metal-based restorations have been placed in 314 patients (age: 22-72 years). Three studies gave information about the patients age, averaging 46 years [21,32,33]. One study did not record the age of the subjects [34].

In two RCT the distribution of restorations and teeth, jaw and number of restored surfaces were described and are represented in Table 1 [21,33]. Two studies only highlighted that restorations in posterior teeth were included, but gave no further information about the location of the restorations [32,34]. The observation periods ranged from 5/5.5 years [21,32,33] up to 7 years [34]. The dimensions of the restorations varied between the studies: Two studies compared the longevity of inlays [21,32], one study evaluated partial crowns (metal versus ceramic) [34], another study evaluated crowns (metal versus ceramic) [33]. Only one study provided information about the location of the cavo-surface. Passia et al. (2013) indicated, that the cavo-surfaces were at gingival level or not more than 1 mm subgingivally [33]. The other included studies didn`t specify the location of the cavo-surface [21,32,34]. Furthermore, the materials used for insertion of the indirect restorations varied between the studies. In three studies, gold inlays and gold partial crowns were inserted using Harvard cement, while ceramic restorations were inserted using different dual-cured composites [21,32,34]. In one study cerec restorations were inserted by using the total etch technique, Gluma and a two-component,dual-cured hybrid composit resin (Via Cerec-Etch, Vita) whereas IPS Empress restoration were inserted by using Syntac primer and adhesive in combination with the manufacturer`s specific cement IPS Empress cement Mirage FLC porcelain and Mirabond 1 and 2 [21]. In the second study cerec restorations were inserted by using a dual-cured composite system (Variolink II (high viscosity) and Excite (Vita Mark II)) (all Ivoclar Vivadent AG) [32]. No information about the etching technique was provided. In the third study IPS Empress I ceramic restorations (Ivoclar Vivadent AG) were inserted using different cements: Variolink II (high viscosity), Variolink ultra, Dual Zement (all Ivoclar Vivadent AG), Compolute (Espe), but no information about the etching technique as well as the dentin and enamel adhesives was provided [34]. In the fourth study ceramic and gold crowns were inserted using glass-ionomer cement [33].

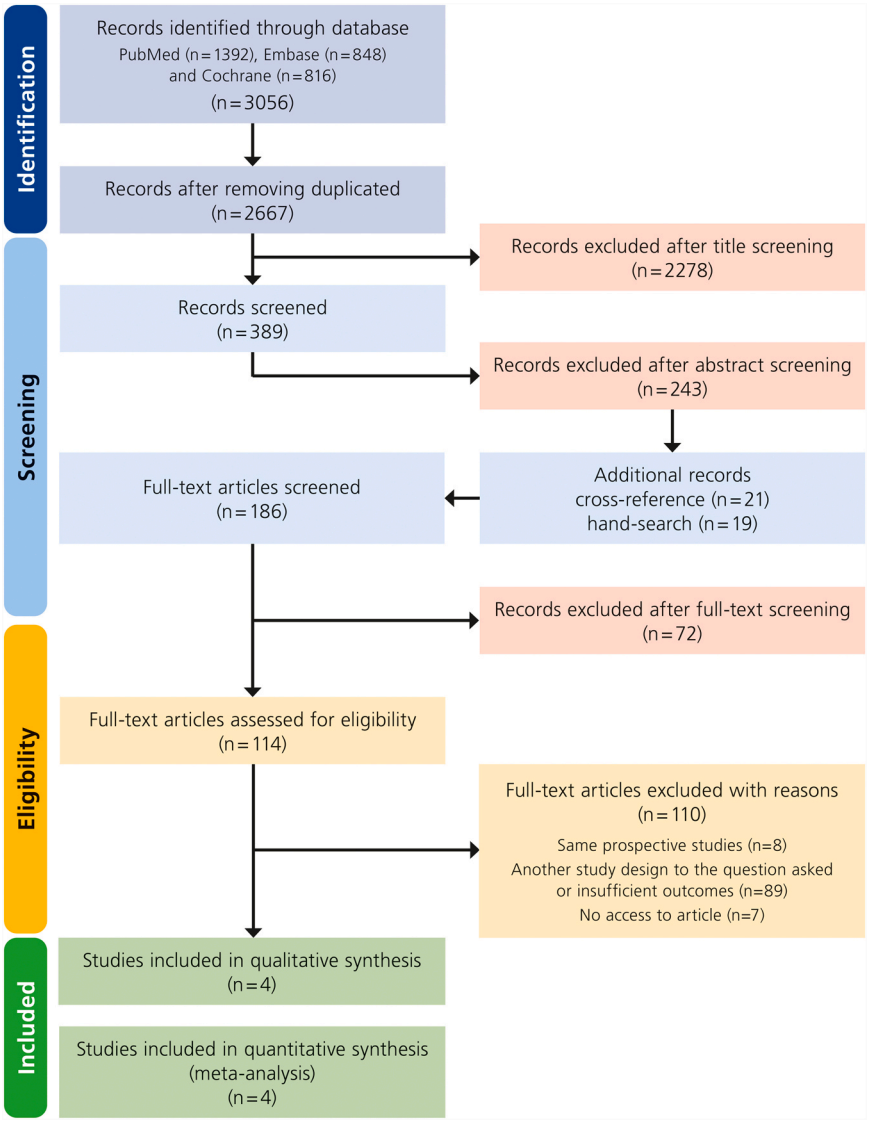

Fig. 2 – Prisma flow diagram.

The lowest failure rates were found for metal restorations (inlays, partial crowns and crowns) ranging from 0 to 11% after a maximum of 7 years of observation [21,32–34]. Two studies even observed a failure rate of 0% [21,34].The annual failure rates in these studies ranged from 0% to 2.1%. All metal restorations in these studies were gold restorations. The failure rates for ceramic restorations were in a roughly equally range between 7% and 9% for inlays and partial crowns after 5 to 7 years of observation in three studies [21,32,34]. However, the highest failure rates were found for ceramic crowns with 36% after 5 years of observation [33]. The annual failure rates for ceramic restorations ranged from 2.1% to 5.6% in the included studies. The most frequent reasons for failure for ceramics was found to be fracture of the restoration followed by caries, whereas caries was the most frequent reason for failure for cemented metal restorations [21,32–34].

Meta-analysis could only be performed for the following comparison: conventionally cemented metal vs. adhesively-luted ceramic restoration. It revealed that the relative risk to fail for conventionally cemented indirect restorations is significantly lower than for adhesively luted ones (visual-tactile assessment: Risk Ratio (RR)[95%CI]=0.31 [0.16, 0.57]). Grading of evidence for the meta-analysis showed a low level of evidence (Fig. 4 and Appendix Table 1).

3.1. *Risk of bias analysis*

Risk of bias was rated as high for all four trials (Fig. 3).

3.2. *Sensitivity analysis*

When excluding studies at high risk of bias no meta-analysis was possible. By excluding studies using a split-mouth design

[21,32] the RR [95%CI] changed from 0.31 [0.16, 0.57]) to 0.30 [0.15, 0.58]) (Appendix Fig. 1).

4. Discussion

The longevity of adhesively-luted ceramic restorations and cemented metal restorations of posterior teeth has been critically summarized. Based on a wide variety of restoration dimensions, such us inlays, partial crowns and crowns, and an overall small number of studies a significantly lower risk to fail could be observed for conventionally cemented indirect metal restoration compared to adhesively-luted ceramic ones. Thus, rejecting our hypothesis that no difference between both restoration types will be observed. Furthermore, for adhesively-luted ceramic restorations the most frequent reasons for failure were chipping and fracture of the ceramic. Nevertheless, metal and ceramic restorations can be recommended for restoration of posterior teeth.

The present meta-analysis revealed that the relative risk to fail for conventionally cemented indirect restorations is significantly lower than for adhesively-luted ones. This could also be seen in the survival rates. Two studies found a survival of 100% of gold inlays and partial crowns [21,34]. Only two studies observed failures for gold inlays (4.5%) and gold crowns (11%) at all [32,33]. However, when excluding ceramic crowns, ceramic inlays and partial crowns presented similar failure rates ranging from 7 to 9% [21,32,34]. This is in line with two single-arm studies on failure rates of ceramic inlays [35,36]. The authors found similar failure rates, 4% and 7%, after 6 years of observation [35,36]. Interestingly, in one of these studies all failures were attributed to caries [35], while in the other study caries was the reason for failure in only 1.7% [35,36].

Adhesively luted ceramic crowns showed a 3.2 higher risk to fail compared to conventional cemented crowns. Furthermore, they showed the highest risk when compared to inlays or partial crowns. However, this result is based on one single RCT reporting failure rates of 11% and 36% for gold and -ceramic crowns [33]. Interestingly, multiple single-arm trials found lower failure rates for ceramic crowns ranging from 1% after 9 years to 23% after 10 years of observation [1,16,17,37–39]. In four of these single-arm clinical trials, failures were only attributed to chipping or fracture of the restoration [1,16,37,38]. Caries as reason for failure was found in only two clinical trials with 1.4% and 3% after 10 years of observation [17,39]. Although Passia et al. had the lowest risk of bias and presumably the best study design compared to the other included studies. It would, thus, be interesting to see whether the present result remains the same when further studies on single ceramic vs. metal crowns will be published.

It has to be mentioned that slightly higher failure rates for adhesively-luted ceramic versus cemented metal restorations might be attributed to their insertion process. The insertion of ceramic restorations requires dentin and enamel adhesives, an adhesive to the ceramic and a dual-cured composite. This is a multi-step procedure and requires a precise handling by the operator and is more sensitive to contamination with saliva or other fluids when compared to

Table 1 – Overview over included studies.

Author/ Year	Subjects (male/ female)	Subjects Age (years)	Number of total restorations	Tooth type Premolars/ Molars	Type of resto-ration	max. follow up (years)	N Dropouts	N Restorations assessed (meterial)	N Restorations failed (material)	% Restorations failed (material)	% Annual failure rate
Molin et al. 2000	20 (11/9)	23-56	80	37/43	inlays	5	0	20 (gold) 60 (ceramic)	0 (gold) 5 (ceramic)	0 (gold) 8 (ceramic)	0 (gold) 2.11 (ceramic)
Wagner et al. 2003	42 (24/18)	NA	82	NA	Partial crowns	7	0	40 (gold) 42 (ceramic)	0 (gold) 3 (ceramic)	0 (gold) 7 (ceramic)	0 (gold) 0.47 (ceramic)
Federlin et al. 2010	29 (12/17)	25-54	58	NA	inlays	5.5	14	22 (gold) 22 (ceramic)	1 (gold) 2 (ceramic)	4.5 (gold) 9 (ceramic)	0.65 (gold) 2.61 (ceramic)
Passia et. al. 2013	223 (104/119)	22-72	223	18/205	crowns	5	65	81 (gold) 77 (ceramic)	9 (gold) 28 (ceramic)	11 (gold) 36 (ceramic)	2.14 (gold) 5.61 (ceramic)

Bias domain for RCTS	Source of bias	In vivo studies: Federlin et al. 2010	Molin et al. 2000	Passia et al. 2013	Wagner et al., 2003
Selection bias	Random sequence generation (clinical level)	−	?	+	−
	Allocation concealment	−	?	+	−
Performance bias	Blinding of participants and personnel	−	−	−	−
Detection bias	Blinding of outcome assessment	−	−	−	−
Attrition bias	Incomplete outcome data	+	+	+	+
Reporting bias	Selective reporting	+	+	+	+
Other bias	Anything else ideally prespecified	+	+	+	?
Overall bias		−	−	−	−

Fig. 3 – Risk of bias summary. Review authors' judgment about each risk of bias item for each included study. Red (-) corresponds to high risk, green (+) to low risk and yellow (?) to uncertain risk of bias.

conventional cementation [21,32]. Adhesively-luted ceramic restorations have also been found to show marginal deterioration of the luting space in earlier studies [10,36,40]. This may lead to a significant decrease in marginal integrity over time [10]. This can also be seen clinically. Unacceptable marginal gaps were found more frequently for ceramic restorations compared to metal restorations [21,32–34,41]. Furthermore, lack of adhesion of ceramic restorations might increase the risk of fracture of the restoration or marginal gap formation. Although, theoretically, the decrease of adhesion differs between enamel and dentin, until now no clinical study evaluated the influence of the proximal cervical cavity margins in enamel versus dentin.

Concerning clinical evaluation criteria, it should be taken into account that each study applied different evaluation criteria. Thus, there was no homogenous definition about failure in the included studies. One study used USPHS criteria [34], whereas another study used modified USPHS criteria

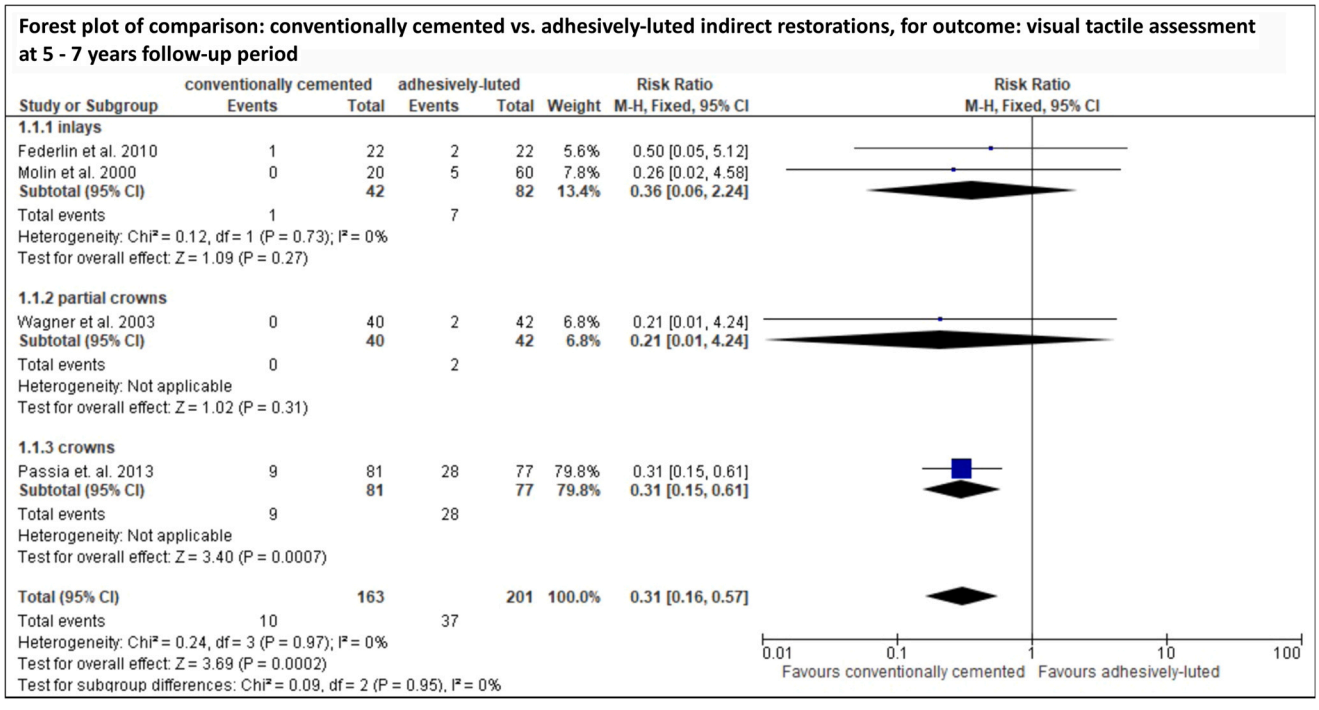

Fig. 4 – Forrest plot for meta-analysis of included studies of conventionally cemented metal or metal-based versus adhesively-luted indirect restorations in terms of failure of the restoration.

[32]. Two studies used own criteria or the California Dental Association`s system for quality assessment of dental care [21,33]. To make the results of the included studies comparable, in the present review the initially placed restorations were judged as successful if no clinical or radiographic signs of technical failures (e.g. loss of retention, root fracture or post fracture) were reported. In contrast, if the initially placed restoration was renewed, repaired or recemented due to fracture, restoration loss, secondary caries, endodontic intervention and/or other reasons the restoration was considered as biologically failed. However, in one study no distinction was made between catastrophic fracture/chipping and chipping, that did not result in repair or renewal [33]. Even after contacting the authors no distinction was possible. Thus, for the present meta-analysis all failures recorded as fracture/chipping were considered as biologically failed. Consequently, it might be speculated that the present meta-analysis overestimated the failure rate for ceramic crowns - at least in this study - and, that results would change if further studies with distinction between both types of failure could be included.

One of the most major limitations of the present is the overall low number of failures in the included studies. This might be explained by, firstly, the study design and, secondly, the included study population. Only in one study [34] subjects were not aware that they are being observed, graded, or measured, which results in changes in their behavior (Hawthorne effect) [42]. However, in the other three studies this could lead to positive (though transient) results. Furthermore, all RCTs included subjects with good oral hygiene and were free from periodontal diseases [32,33]. Subjects who are generally healthy with low caries activity, do not present a high number of failures due to secondary caries for both, ceramic and metal restorations. It might be speculated that the influence of the restoration type (ceramic vs. metal) would differ when a larger sample size, and hence more failures, was included.

In one study restorations were placed by one dentist in his dental clinic [34]. In contrast, in two studies, students, which were supervised by experienced dentists, placed the restorations [32,33] and in another study no information about the degree of experience of the clinicians and/or examiners was provided [21]. Since the clinicians' skills, the "clinician profiles" and the experience of the clinician may have an influence on the clinical outcome and long-term performance of restorations, differences in the survival rates between the included studies but not between the different materials within one study may be explained [43].

The most common failures for all-ceramic restorations have been attributed to the technical complication chipping in previous observations ranging from 8-25% [18,44–46]. The reasons for these ceramic fractures were not presented in the included studies and different factors have been discussed in in vitro studies: e.g. the thermal compatibility of the zirconia framework and the veneering ceramic [47], different surface treatments of the zirconia frameworks [48], the flexural strength of the veneering ceramic [49] and the bond strength between the veneering ceramic and the zirconia framework [50–52]. Incompatibilities of the veneering ceramic and the zirconia framework might increase the chance for fractures of the veneering ceramic in zirconia-based restorations. Additionally, the roughness of the ceramic surface might be an important factor inducing chipping. In a study evaluating fixed dental prostheses the authors found, that that chipping in almost all restorations had originated from a roughness at the occlusal region, where occlusal contacts or grinding were found [41].This was also found for ceramic inlays, partial crowns and crowns [21,33].

In conclusion, ceramic restorations can be recommended for large cavities in posterior teeth as well as metal restorations for single tooth restoration. Meta-analysis revealed that the relative risk to fail for conventionally cemented metal restorations is significantly lower than for adhesively-luted ceramic ones. The authors found the most frequent failures to be caused by chipping and fracture of the ceramic restorations followed by caries. To further confirm these findings, more long-term studies are needed in order to evaluate all-ceramic and metal-based restorations using standardized assessment criteria.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

CRediT authorship contribution statement

Christian Tennert: contributed to conception, design, acquisition, analysis and interpretation, drafted and critically revised the manuscript. **Lázaro Suárez Machado:** contributed to design, acquisition, analysis and interpretation and critically revised the manuscript. **Thomas Jaeggi:** contributed to acquisition and critically revised the manuscript. **Hendrik Meyer-Lueckel:** contributed to acquisition and interpretation, critically revised the manuscript. **Richard Johannes Wierichs:** contributed to analysis and interpretation, drafted and critically revised the manuscript. All authors gave their final approval and agree to be accountable for all aspects of the work.

Informed consent

For this type of study, formal consent is not required.

Data Availability

All data generated or analyzed during this study are included in this article [and/or] its supplementary material files. Further enquiries can be directed to the corresponding author.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dental.2022.08.002.

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