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Literature Review

Long-term Clinical Performance of Composite Resin or Ceramic Inlays, Onlays, and Overlays: A Systematic Review and Meta-analysis

J Fan • Y Xu • L Si • X Li • B Fu • M Hannig

Clinical Relevance

Composite resin or ceramic inlays, onlays, and overlays can achieve high long-term survival and success rates.

SUMMARY

Objective: This study evaluated the long-term clinical performance and complications of composite resin or ceramic inlays, onlays, and overlays, as well as identified the factors that might influence the clinical outcome of the restorations.

Method: A systematic literature search was conducted in the Pubmed, Embase, Cochrane Central Register of Controlled Trials, and Web of Science databases until April 30, 2019, without language restrictions. Randomized clinical trials, clinical retrospective, and prospective cohort studies with a mean follow-up period of five years were included. Two reviewers extracted the study data independently. Newcastle-Ottawa Scale was applied for quality assessment. Meta-analysis was performed by the random-effects model and fixed-effects model.

Results: After removal of duplicates, 2818 studies were identified. Finally, 13 observational studies were included in the meta-analysis based on retrospective and prospective cohort studies. The cumulative survival rate and success rate of composite resin inlays, onlays, and overlays were 91% and 84% after five years of follow-up, respectively. The survival rates of ceramic inlays and onlays were 90% at 5 years, 89% at 8 years

Jiayan Fan, Master, Stomatology Hospital affiliated to Zhejiang University School of Medicine, Department of Prosthodontics, Hangzhou, China

Yuedan Xu, BDS, postgraduate, Stomatology Hospital affiliated to Zhejiang University School of Medicine, Hangzhou, China

Lujie Si, BDS, postgraduate, Stomatology Hospital affiliated to Zhejiang University School of Medicine, Hangzhou, China

Xiuyang Li, PhD, Zhejiang University School of Medicine, Hangzhou, China

*Baiping Fu, DMD, Stomatology Hospital affiliated to Zhejiang University School of Medicine, Department of Prosthodontics, Hangzhou, China

Matthias Hannig, Professor, Saarland University, Clinic of Operative Dentistry, Periodontology and Preventive Dentistry, Homburg, Germany

*Corresponding author: Yan'an Rd 395, Hangzhou, Zhejiang 310006, China; e-mail fbp@zju.edu.cn

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and 85% at 10 years, while the success rates of ceramic inlays and onlays were 88% at 5 years and 77% at 10 years. Secondary caries and endodontic complications were the predominant failures for composite resin inlays, onlays, and overlays, while restoration fractures and endodontic complications were the main failures for ceramic inlays and onlays. No direct association between parafuntional habits and bruxism and the fractures of restorations was found. Nonvital teeth and multiple-surface restorations tended to increase the risk of failure. Regarding other factors influencing the clinical outcome, no definite conclusion could be drawn due to inconsistent results.

Conclusions: The long-term clinical outcomes have been demonstrated to achieve high survival and success rates based on 10-year data for ceramic inlays and onlays, as well as 5-year data for resin inlays, onlays, and overlays.

INTRODUCTION

With the rapid development of the dental bonding technology by means of micro- and nanomechanical interlocking, indirect adhesive restorations for posterior teeth have been widely used in contemporary restorative dentistry.[1] Most commom types of posterior indirect adhesive restorations include inlays, onlays, and overlays.[2-4] Numerous clinical trials have demonstrated that the preservation of sound tooth structure is an important factor for the durability of the restorations.[5-10]

An inlay is a dental restoration without cusp coverage and made outside of the oral cavity to correspond to the form of the prepared cavity and tooth morphology, which is cemented or adhesively bonded into the tooth (Figure 1A).[11] Inlays could be used for restorations of teeth having medium- to large-size class-II cavities with well-preserved buccal and lingual walls.[12] Christensen[13] recommended the application of inlays when the width of the isthmus is confined within one-third to half of the distance between the buccal cusp tip and lingual cusp tip. An onlay is a partial coverage restoration of a tooth that restores one or more cusps as well as the partial or entire occlusal surface, which is retained by conventional and resin cements (Figure 1B and 1C).[11] Christensen[13] suggested the use of onlays when the width of the isthmus is larger than half the distance from buccal cusp tip to lingual cusp tip and/or when a weak cusp exists. An overlay, a special type of an onlay with entire cusp coverage, is an adhesively bonded restoration (Figure 1C and 1D).[14] Ferraris[1] suggested the main indications of onlays and overlays are as follows: (1) medium- to large-size cavities with one or more cusps missing; (2) morphological modification of the occlusal surface and/or an increase of the occlusal vertical dimension for full-mouth oral rehabilitations rather than aggressive interventions such as full-crown restorations; and (3) seeking preservation of pulp vitality and miminal invasive intervention of the cracked tooth. Besides traditional restorations such as inlays, onlays, and overlays, newer adhesive restorations such as additional overlays, occlusal veneers, overlay veneers, long-wrap overlays, and adhesive crowns are being increasingly applied with the development of adhesive dentistry.[12]

Compared with direct filling restorations, indirect restorations possess the advantages of easily restoring occlusal morphology and proximal contacts as well as reducing polymerization shrinkage.[15] Although crown or post-and-core crown restorations have achieved reliable results, crown preparations need to remove a large amount of sound tooth structure.[16] Recently, Vagropoulou and others[17] reported that the five-year survival rates for crowns, inlays, and onlays were more than 90%. Li and others[18] reported that the success and survival rates of the mildly defective endodontically treated premolars were 96.3% and 98.1%, respectively (after three years of restorations with quartz fiber posts and crowns), while the success and survival rates of severely defective nonvital premolars were 88.5% and 96.2%, respectively. However, the success and survival rates of the mildly defective nonvital premolars were both 96.6% after three years of restorations with ceramic onlays, while those of the severely defective nonvital premolars were 94.1% and 100%.[18] Though no significant difference was found, the ceramic onlays seemed to reveal higher success rates to restore medium or severe defects of endodontically treated premolars as a result of fewer debonding failures.[18]

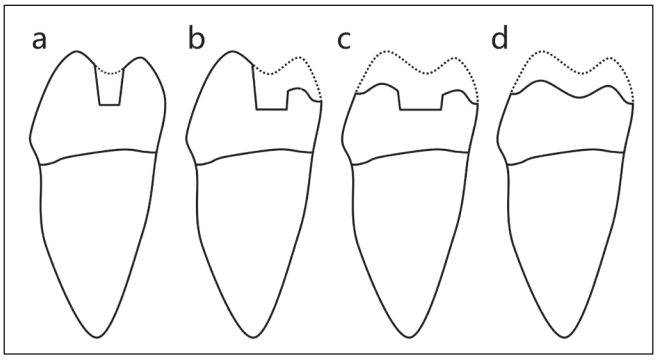

Figure 1. *Types of restorations: inlay (A), onlay (B, C), overlay (C, D). Conventional cement and resin cement can be used for inlays and onlays. Overlays should be adhesively bonded.*

Considering the esthetic demand, inlays, onlays, and overlays are often made of tooth-colored materials such as composite resins and ceramics.[19] Composite resins are composed of a resinous matrix and reinforced fillers with different sizes of particles.[20] Great improvements of the mechanical properties of tooth-colored composite resins enable their applications to restore large-size cavities using indirect restorations.[21] Compared with composite resins, ceramic restorations possess higher wear resistance and compressive forces.[22, 23] Nevertheless, ceramics are brittle and more prone to fracture under tensile stresses than composite resins. Based on the data of two randomized clinical trials (RCTs), Fron Chabouis and others[24] concluded that indirect ceramic restorations performed better than indirect composite resin restorations within the first six months, but this may not be valid in long-term clinical service. Furthermore, composite resin inlay restorations reveal survival rates of 79.3% to 92.0% after 5 to 10 years in clinical service,[25-30] while the survival rates of ceramic inlay restorations have been reported in a wide range from 51.4% to 96.0% after 5 to 15 years of follow-up periods.[10,28,31-38] Mangani et al[39] reported that the weighted average success rate of composite resin inlays was 92.8% after 2.6 years of the mean observation period, while the success rate of ceramic restorations reached 96.3% after 5.9 years of the mean observation period. This data demonstrated that indirect restorations functioned excellently in the treatment of both Class I and II cavities in posterior teeth.[39] Recently, Morimoto and others[40] reported that ceramic inlays, onlays, and overlays performed very well after long-term clinical service, although data greater than five years on composite inlays, onlays, and overlays is lacking.

With the increasing use of indirect aesthetic restorations, the systematic review of the long-term clinical performance of composite resin and ceramic restorations such as inlays, onlays, and overlays needs to be updated. The aim of the present review and meta-analysis was to (1) systematically evaluate the cumulative survival and success rates of composite resin or ceramic inlays, onlays, and overlays after 5-, 8-, and 10-year follow-up periods; (2) analyze the main complications of failures; and (3) identify the factors that may influence the clinical outcome of restorations based on RCTs and observational studies with five years of a mean follow-up period.

METHODS AND MATERIALS

The systematic review protocol was registered at the PROSPERO database under #CRD42018100783 and carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement protocol.[41] Survival indicates that restorations are considered to be clinically acceptable according to the clinical criteria during the follow-up period. Once the restoration is debonded, it is considered as a failure, regardless of whether the restorations can be rebonded or not. Success indicates that restorations function well without any complications and don't need any clinical interventions during the follow-up period.

Eligibility Criteria

The search strategy conducted for the systematic review and meta-analysis was based on the following elements:

- P (population): Population included permanent posterior teeth restored with ceramic or composite resin inlays, onlays, and overlays.
- I (intervention): Intervention indicated that patients received the treatments of ceramic or composite resin inlays, onlays, and overlays.
- O (outcome): Outcome included the survival and success rates of ceramic or composite resin inlays, onlays, and overlays, analysis of the biological and mechanical complications, as well as identification of the factors that may influence the survival rates of composite resin or ceramic restorations.
- S (study): Study designs included RCTs, clinical retrospective and prospective cohort studies.

Follow-up period: The period of mean clinical observation was at least five years.

Exclusion Criteria

1. Case reports, reviews, protocols, letters, laboratory studies, animal studies, and meeting abstracts.
2. Studies that did not report dropout rate, survival rate, and complete data or incongruous data for analysis.
3. Studies that had dropout rates of restorations higher than 30% during 5 years of follow-up.
4. Studies that had sample sizes either less than 30 restorations or less than 15 patients.
5. Studies that did not define the clinical evaluation criteria.
6. In the case that two or more studies involved the same population, only the most recent one or complete one was included.

Information Sources and Sarch Strategy

The electronic databases including Pubmed, Embase, Cochrane Central Register of Controlled Trials and

Web of Science were searched until April 30, 2019. We also manually identified unpublished and ongoing clinical trials related to the topic of review on the website ClinicalTrials.gov (www.clinicaltrial.gov). The literature search strategy was employed using Mesh terms and keywords. Details are summarized in Supplementary Table 1.

The relevant articles were imported into Endnote X7 software to eliminate duplicates. Two reviewers independently assessed all titles and abstracts. The potential articles and abstracts without sufficient information were screened via reading full-text.

Data Extraction and Data Items

Two reviewers independently extracted the necessary data from the selected papers. For each identified study, the following items were obtained by two reviewers: authors, materials, country, evaluation criteria, follow-up period, setting/operator, ages (means), number of patients, number of restorations, dropout rate, study type, survival rate, success rate and score. Any disagreements were resolved by discussion and data rechecking. A third examiner was invited to check the process and settle discrepancies when the two reviewers did not agree.

Quality Assessment

The quality analysis of the identified observational study was conducted independently by two reviewers using the Newcastle-Ottawa Scale (NOS).[42] The studies were dichotomized into high quality and low quality according to the aspects of the quality of selection, comparability and outcome. A study scoring no less than 6 was considered to be of high methodological quality, while a study scoring less than 6 was considered to be low quality. Any disagreement between two reviewers was resolved by discussion.

Measures and Statistical Analysis

The data concerning the clinical performance of composite resin or ceramic inlays, onlays and overlays with a mean follow−up period ranging from 5 to 10 years were assessed. Descriptive and statistical analyses were performed to estimate survival rates, success rates and complication rates. Survival rates, success rates and complication rates were calculated through logit transformation. Heterogeneity was analyzed with inconsistency index (I^2) statistic and Q statistic. The random-effects model was adopted when heterogeneity of the eligible studies was obvious ($I^2 > 50\%$); the fixed-effects model was used when heterogeneity was not significant ($I^2 < 50\%$). Subgroup analysis was employed to explain the source of heterogeneity. Funnel plots were used to explore the bias of publication. All analysis was performed using R software version 3.4.0 and the Meta package (R Foundation, Vienna, Austria).

RESULTS

Literature Search

Initial searches using Mesh terms and keywords obtained a total of 4757 articles in the aforementioned databases. No additional study was added by manual search, and 1939 studies were eliminated due to duplicates. After the titles and abstracts were screened, 2640 articles were excluded and 178 were considered for full-text evaluation. Finally, 165 studies were ruled out, and 13 studies[28-31,33,36,43-49] were adopted for meta-analysis in this study. The screening process of the literature is summarized in Figure 2.

Characteristics of the Studies

The main characteristics of the included studies are presented in Table 1. Thirteen studies adopted in this study were retrospective or prospective cohort studies with 5 to 10 years of follow-up. Nine studies investigated ceramic restorations, and three studies investigated composite resin restorations. Only one study involved both ceramic and composite resin restorations. The earliest data in this study were published in 2000,[31,43,44] and the most recent one was in 2015.[49]

Some studies[25,27,37,50-52] were excluded in this study due to incongruous statistical data. In addition, one study investigated overlays on average after 93 months, and the dropout of patients/restorations and the failures of restorations at different years were not reported[53]. Therefore, the data were not extracted for statistical analysis in the present study. Another two studies[54,55] were excluded, because the numbers of dropout patients were higher than those of the dropout restorations.

Quality Assessment

Of 13 studies, 11 studies with NOS scores ≥ 6 were considered as high quality; only two studies[28,46] with NOS scores = 5 were considered to have a high risk of bias. The mean value of quality for the 13 observational studies was score 6.77. (Supplementary Figure 1)

Survival Rate

Composite Resin Inlays, Onlays, and Overlays − The cumulative survival rate of the composite resin inlays, onlays and overlays in the included 4 studies was 91%

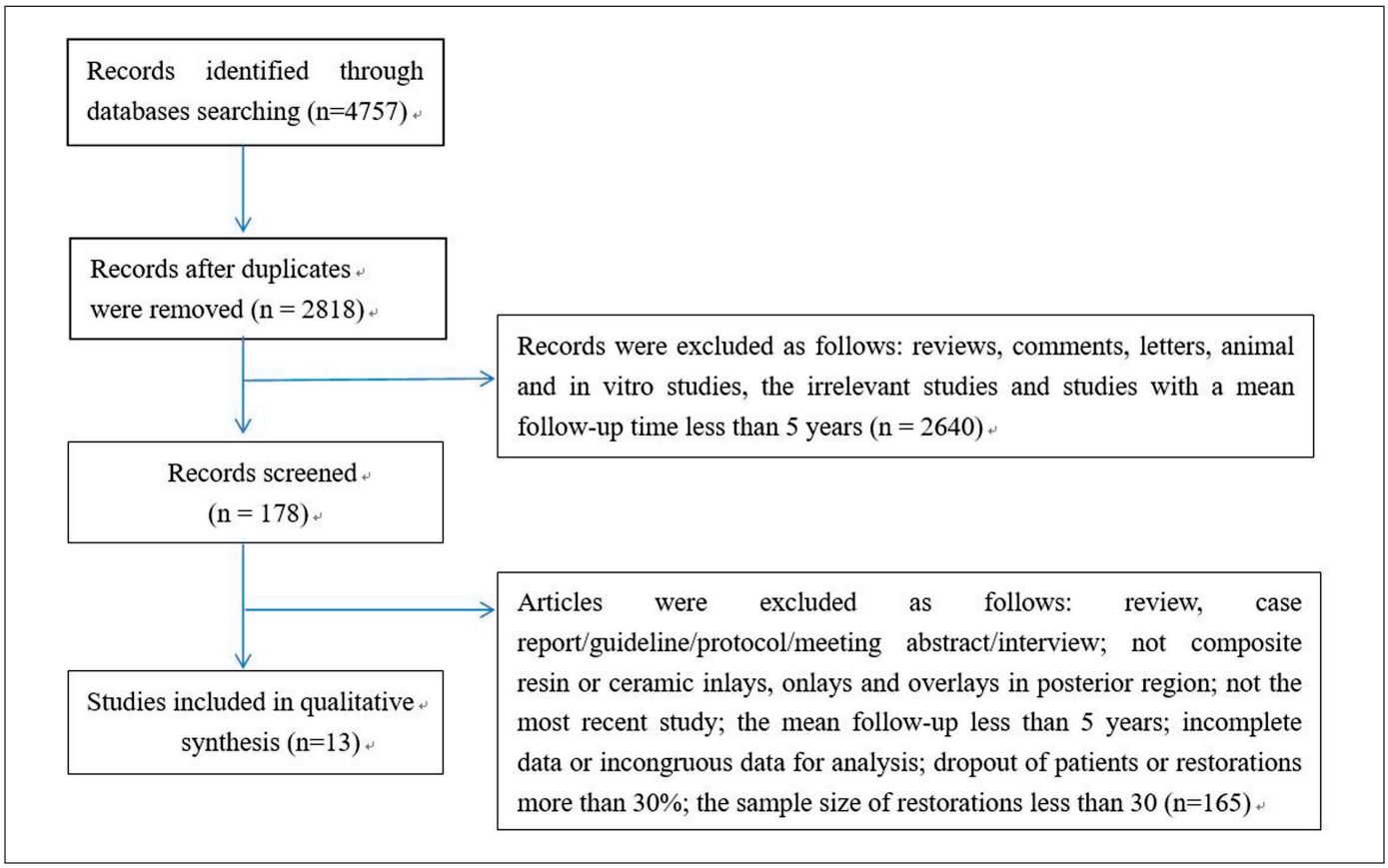

Figure 2. *Flowchart of the search strategy.*

(95% CI: 86~94%, I^2=47%, p=0.13) after 5 years of follow-up (Figure 3A). Only one study reported that the 10-year survival rate of indirect composite resin restorations was 79.2%.[28]

Ceramic Inlays and Onlays – Nine studies reported on the survival rate of ceramic inlays and onlays. The 5-year cumulative survival rate reached 90% (95% CI: 86-93%, I^2=51%, p=0.04) (Figure 4A). According to subgroup analysis, the survival rate of feldpathic porcelain inlays and onlays was 90% (95% CI: 86-93%, I^2=0%, p=0.57) and that of glass ceramic restorations was 86% (95% CI: 73-94%, I^2=78%, p=0.01) after 5 years of clinical service (Figure 5A). Dropouts of patients and restorations may be the main reason for the heterogeneity of the 5-year cumulative survival rate of the ceramic restorations (Supplementary Figure 2).

The 8-year survival rate of ceramic inlays and onlays was 87%-91% according to three studies.[31,43,48] Based on the fixed effect model, the pooled survival rate of the ceramic restorations was 89% (95% CI: 83-93%, I^2=0, p=0.80) (Figure 4B), in which the 8-year survival rates of feldpathic procelain and glass ceramic restorations were 88% (95% CI: 77-94%, I^2=0, p=0.46) and 90% (95% CI: 81-95%, I^2=0, p=0.74), respectively (Figure 5B).

The 10-year survival rate of the ceramic restorations was 85% (95% CI: 76-91%, I^2=32%, p=0.22) (Figure 4C).

Success Rate

Composite Resin Inlays, Onlays, and Overlays – Based on data from 3 studies,[29,30,47] the cumulative 5-year success rate of composite resin inlays, onlays and overlays ranged from 83.6-88.0% and the pooled success rate was 84% (95% CI: 78-89%, I^2=34%, p=0.22) (Figure 3B). Whereas, Thordrup and others[28] reported that the 10-year success rate of composite resin restorations was 66.7%.

Ceramic Inlays and Onlays – The 5-year cumulative success rate of ceramic inlays and onlays was 88% (95% CI: 82-92% I^2=24%, p=0.27) (Figure 6A). One study reported that the 8-year success rate of ceramic inlays was 80%.[43] The 10-year success rate of ceramic inlays and onlays ranged from 67.96% to 83.6% and the pooled estimate for the 10-year success rate was 77% (95% CI: 59-89% I^2=64%, p=0.10) (Figure 6B).[28,33]

Table 1: *Characteristics of the Studies*

No.	Author (year)	Materials	Country	Investigation Period	"Evaluation Criteria"	"Follow-up Period (y)"
1	Sjogren et al. (2004) [32]	Vita Mark	Sweden	NR	Modified USPHS	10
2	Schulz et al. (2003) [44]	Mirage ceramic	Sweden	1988-1997	CDA	6.3
3	Hayashi et al. (2000) [42]	G-cera Cosmoteh	Japan	1990.10-1991.3	Modified USPHS	8
4	"Pallesen & van Dijken (2000) [30]"	"Vita Mark Dicor MGC"	Denmark	NR	Modified USPHS	8
5	"Molin & Karlsson (2000) [43]"	"Cerec Mirage Empress"	Sweden	NR	CDA	5
6	Najatidanesh et al. (2015) [48]	"CEREC blocks Empress CAD blocks"	Iran	2009.3-2009.9	CDA	5
7	Cetin et al. (2013) [28]	"Estenia Tescera ATL"	Turkey	2005-2006	Modified USPHS	5
8	Zhang et al. (2008) [46]	3M Vitremer	China	2001.3-2001.10	Modified USPHS	5
9	D' Arcangelo et al. (2014) [29]	Enamel Plus HFO	Italy	2005.4-2007.1	Modified USPHS	5
10	Thordrup et al. (2006) [27]	"Cerec.cos2.0 Brilliant DI Vita Dur N Estilux Kulzer"	Denmark	NR	CDA	10
11	van Dijken (2003) [45]	IPS Empress	Sweden	NR	Modified USPHS	5
12	Kramer et al. (2008) [47]	IPS Empress	Germany	NR	Modified USPHS	8
13	Santos et al. (2013) [35]	"Duceram IPS Empress"	Brazil	NR	Modified USPHS	5.5

Abbreviations: CDA, California Dental Association; NR, not reported; PC, prospective cohort; RC, retrospective cohort; Score, the value of the Newcastle-Ottawa Scale (NOS); USPHS, United States Public Health Service.

Setting/ Operator	"Age Range (mean)"	"No. of Patients"	"No of Restorations"	"Dropout (%) (Patient/ Restoration)"	Study Type	"Survival Rate (%)"	"Success Rate (%)"	Score
University / NR	26-73 (48)	27	66	8% / 7%	PC	88.5	83.6	6
"Private Practice / 1"	28-79 (54)	52	109	1.9% / 1.8%	RC	84.1	65.4	7
University / NR	NR	25	45	0	RC	86.7	80	6
NR / 1	24-58 (40)	16	32	0	RC	90.6	NR	7
NR / 1	23-56	20	60	0	PC	86.7	NR	7
"Private Practice / 1"	18-70 (45.5)	109	159	5.5% / 3.8%	RC	95.4	NR	8
University / 1	20-28 (23)	54	41	0	RC	97.6	NR	8
University / 1	20-60	NR	100	9%	RC	95.6	87.9	8
University / 1	18-51	47	79	9.7% / 7.5%	RC	87.7	83.6	8
NR / 1	23-69	37	58	10.8% / 10.3%	PC	78.8	67.3	5
University / NR	22-68 (45.5)	29	79	10.3% / 11.3%	RC	88.7	81.7	5
University / 6	NR	31	94	25.8% / 27.7%	PC	89.7	NR	6
NR / 1	25-44 (33)	35	86	25.7% / 27.9%	RC	79	NR	7

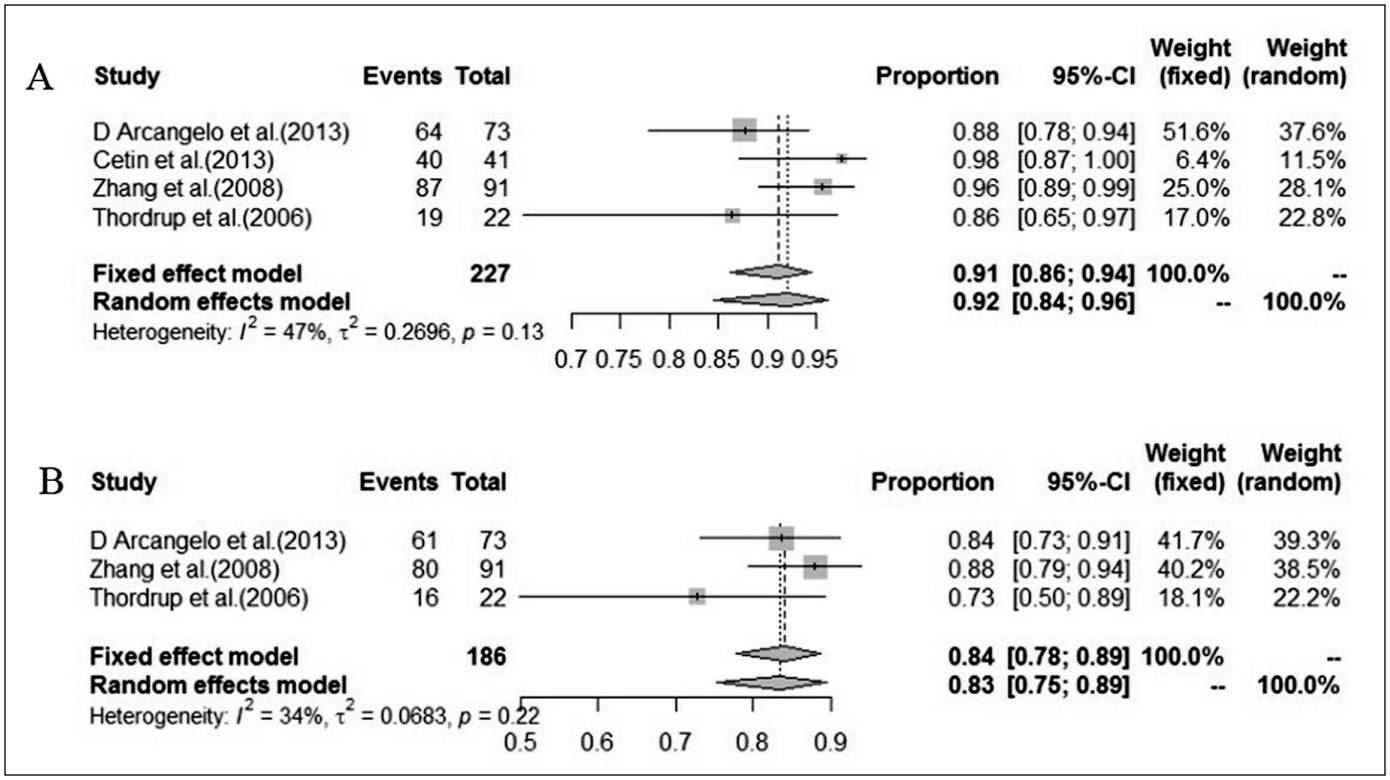

Figure 3. *Five-year cumulative survival rate (A) and success rate (B) of composite resin inlays, onlays, and overlays.*

Publication Bias Analysis

The shape of funnel plots does not reveal any obvious asymmetry (Supplementary Figure 3). Moreover, there was no publication bias on the basis of Egger's test ($p > 0.05$) in the composite resin and ceramic groups.

Complications

According to the identified studies of composite resin inlays, onlays, and overlays, the reasons for failures included endodontic complications such as post-operative sensitivity, pulpitis, and pulp necrosis, secondary caries, fracture of restorations, debonding and severe restoration discolorations. Secondary caries and endodontic complications were the most frequent reasons leading to failures, with the pooled proportions of 47% (95% CI: 26 - 70%) and 27% (95% CI: 11 - 54%) (Figs. 7A, B).

For the ceramic restorations, fracture of restorations, endodontic complications and secondary caries were the main reasons of failures. During 5 years of follow-up, a total of 34 fracture failures among 62 failures occurred with a pooled proportion of 54% (95% CI: 40-67%) (Figure 8A). Five studies revealed that 20% (95% CI: 11-33%) of failure cases were caused by endodontic complications including post-sensitivity, pulpitis and pulp necrosis (Figure 8B). The overall estimated proportion of secondary caries was 14% (95% CI: 7-26 %) (Figure 8C). In addition, marginal defects, open contacts, dull surfaces, and tooth fractures were also reported as failures. After 8 years of follow-up, the proportions of the fractures of restorations and the endodontic complications were 54% (95% CI: 28-78%) and 34% (95% CI: 7-78%), respectively (Figs. 9A-B). In addition, the pooled proportion of fracture of restorations among failures increased to 61% (95% CI: 34-83%) after 10 years of follow-up (Figure 10). All the data of complications are summarized in Table 2.

Factors Influencing the Survival Rate of Restorations

Molar and Premolar Regions – Five studies[33,36,43,45,49] investgated the clinical performance of restorations in molar and premolar regions. Schulz and others[45] reported that inlays in the molar region were three times more likely to be fractured than those in premolar region. Furthermore, three studies[33,36,49] demonstrated that fracture of restorations occurred only in the molar region. Contrarily, Hayashi and others[43] reported that restorations in premolars were 2 times more prone to fracture than those in molars.

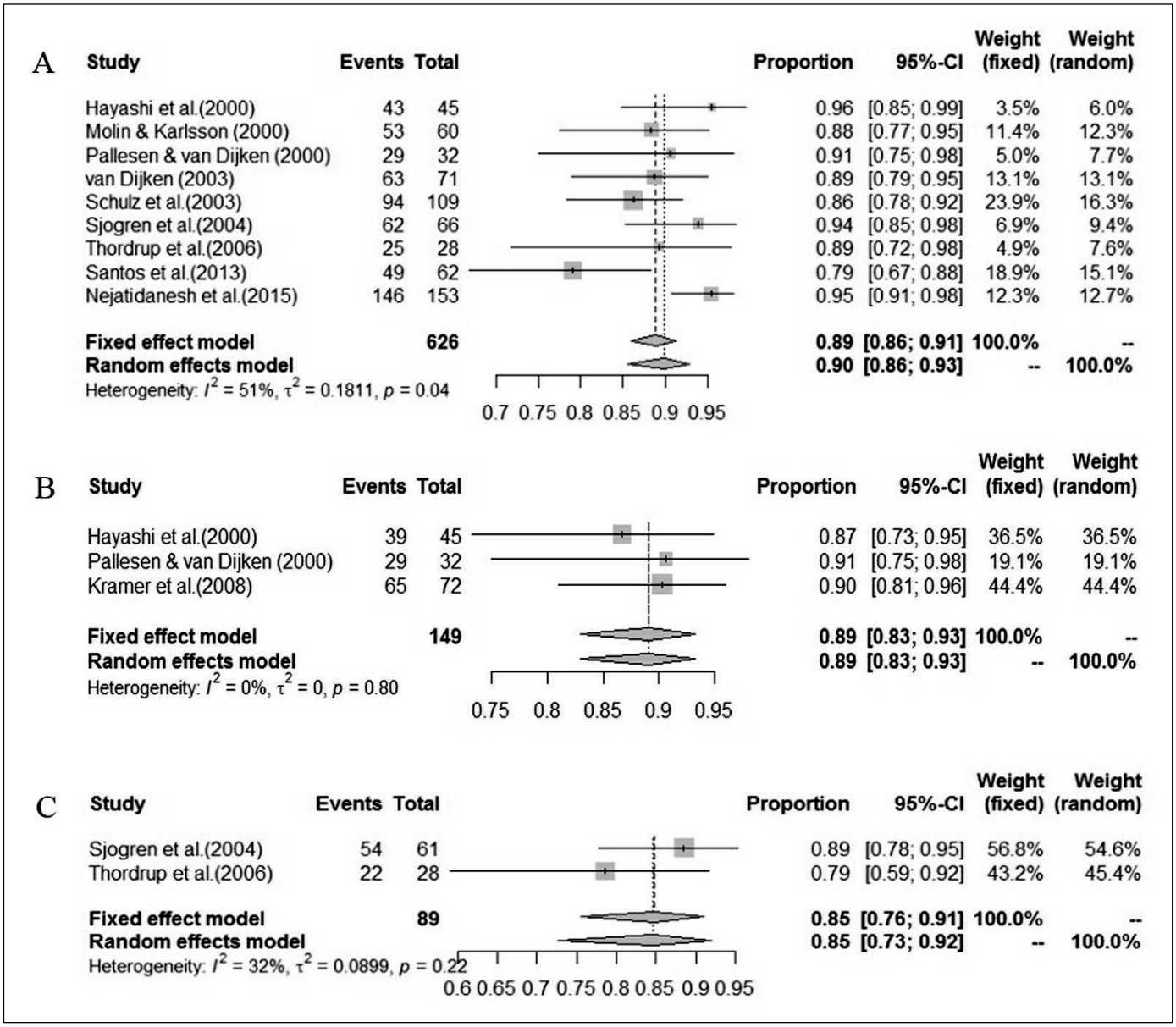

Figure 4. *Cumulative five year (A), eight-year (B), and ten-year (C) survival rate of ceramic inlays and onlays.*

Types of Restorations – Hayashi and others[43] placed 43 inlays and 2 onlays in 25 patients. They reported that 4 inlays fractured while the two onlays functioned well after 8 years of follow-up. However, Santos and others[36] concluded that the fracture rate of onlays was 1.6 times larger than that of inlays when they investigated 53 inlays and 33 onlays after 5 years in service, and two of them were fractured in each type of restoration. In addition, Sjogren and others[33] reported that three-surface inlays were 2.88 times more susceptible to fracture than two-surface inlays. Nejatidanesh and others[49] reported that no failure occurred in two-surface inlays, 1.72% of three-surface restorations failed as a result of dentin hypersensitivity, 8.16% of four-surface restorations failed due to fracture, retention loss and hypersensitivity, and 5.26% of more than four-surface restorations failed owing to fracture and hypersensitivity. All the fractures occurred in four- or more-surface restorations.[49]

Luting Cements – Three studies[33,46,48] reported the implementation of different adhesives and luting cements for inlays made by the same restorative materials. Two studies reported that no different clinical outcomes of 5-8 years in service were found (p>0.05) after resin-modified glass ionomer cement (Fuji Plus, GC Dental Industrial Corp., Tokyo, Japan) and self-cure composite resin cement (Panavia 21, Kuraray-Noritake, Tokyo, Japan) were compared,[46]

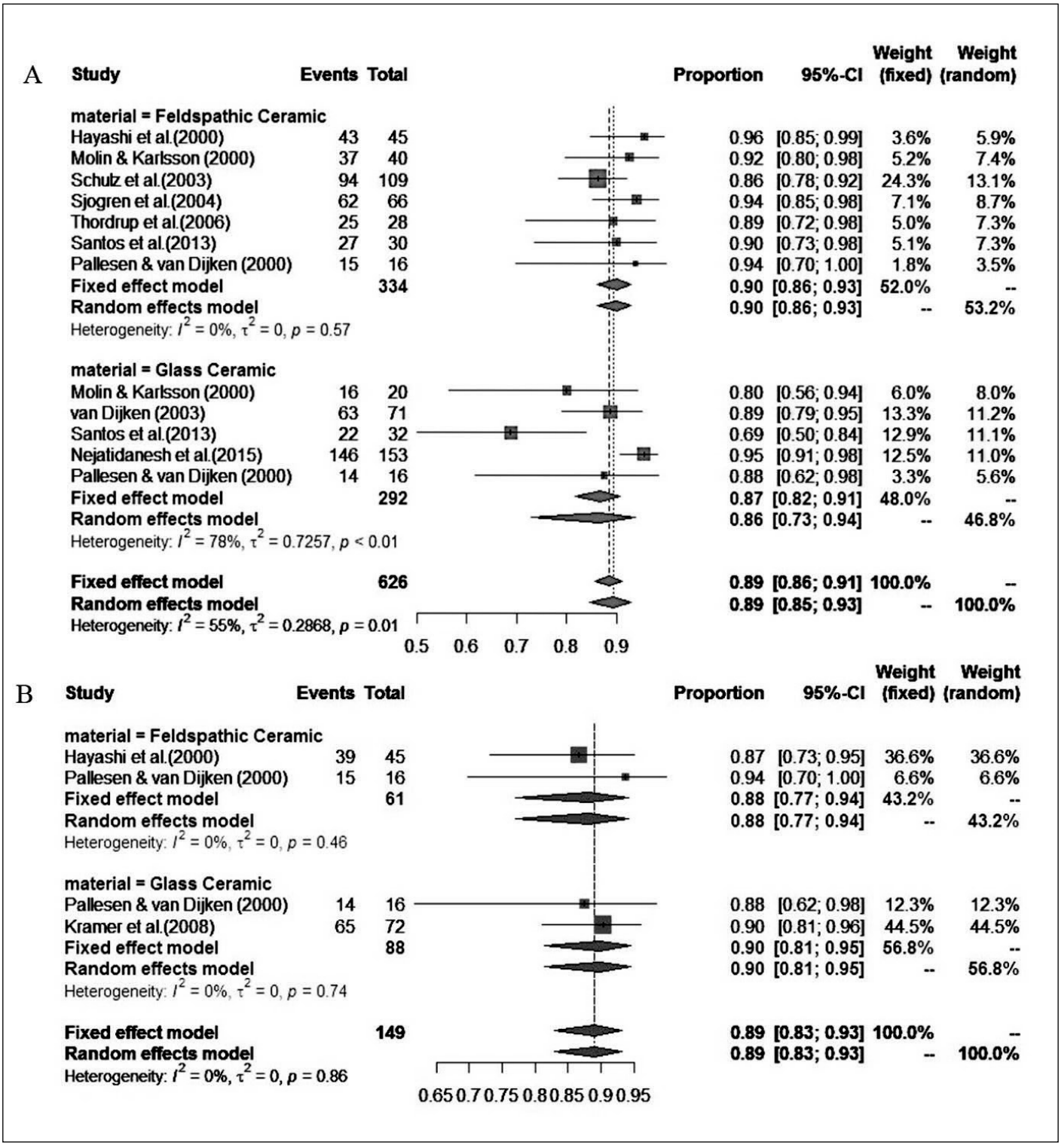

Figure 5. *Five-year (A) and eight-year (B) cumulative survival rate of feldspathic and glass ceramic inlays and onlays.*

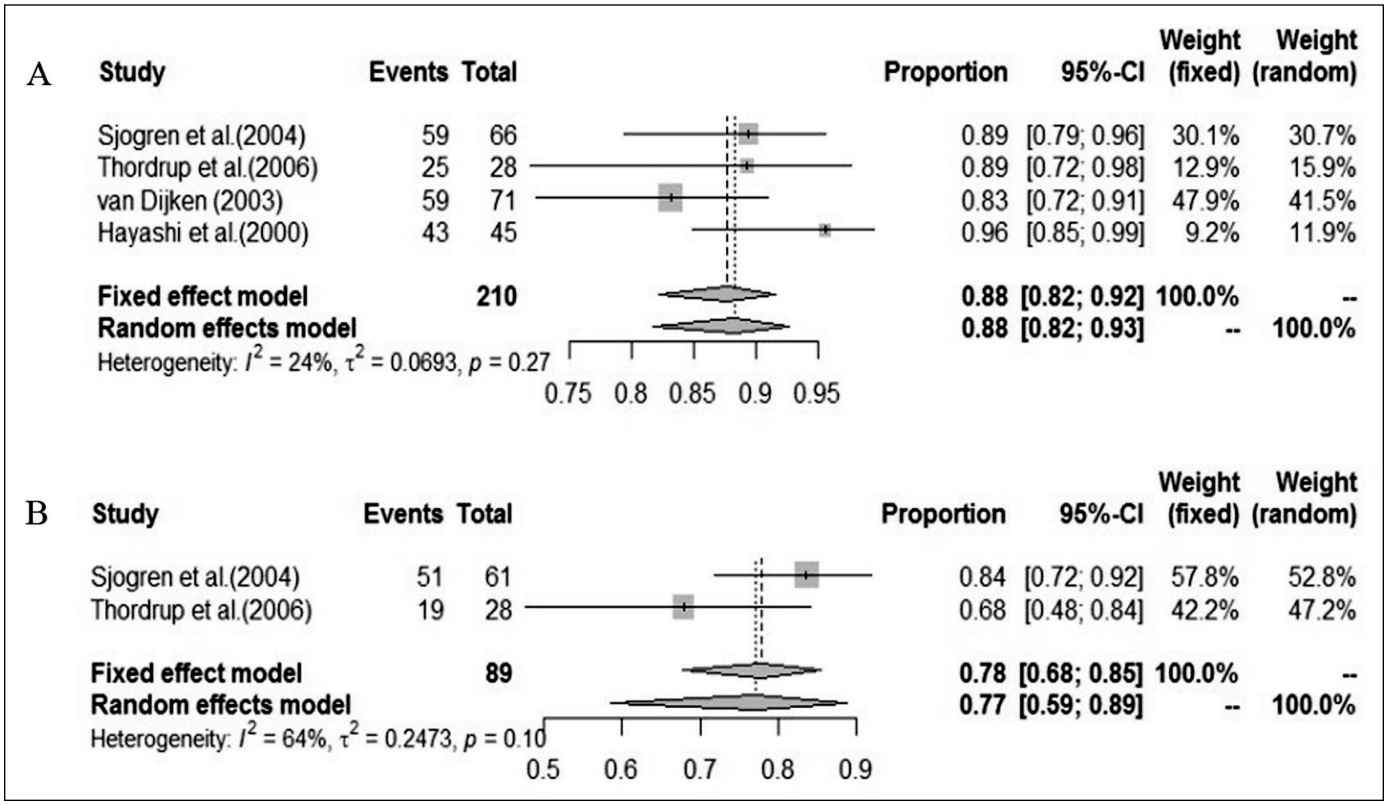

Figure 6. *Five-year (A) and ten-year (B) cumulative success rate of ceramic inlays and onlays.*

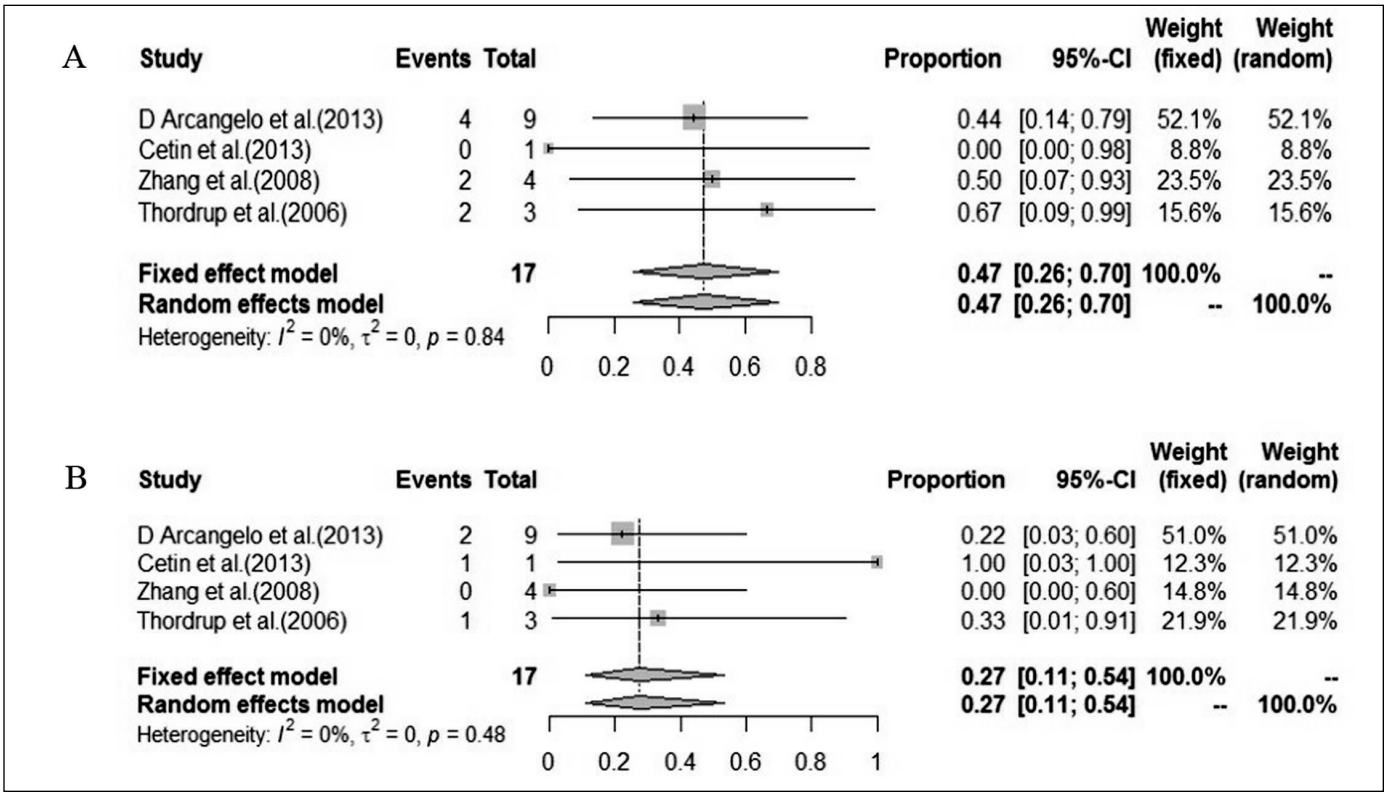

Figure 7. *Five-year pooled proportion of complications of composite resin inlays, onlays and overlays. (A): secondary caries; (B): endodontic complications.*

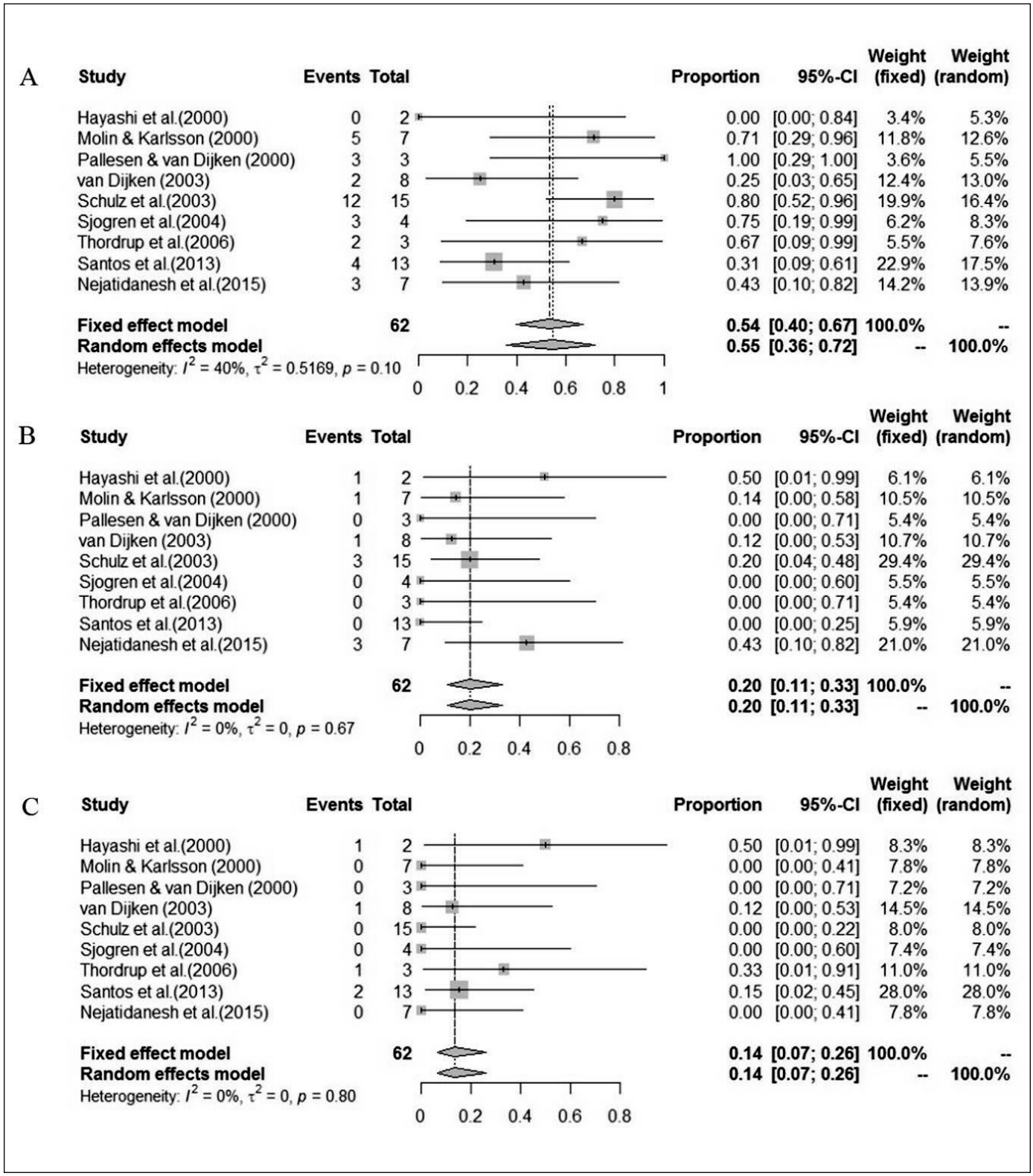

Figure 8. *Five-year pooled proportion of complications of ceramic inlays and onlays. (A): Restoration fractures; (B): Endodontic complications; (C): Secondary caries.*

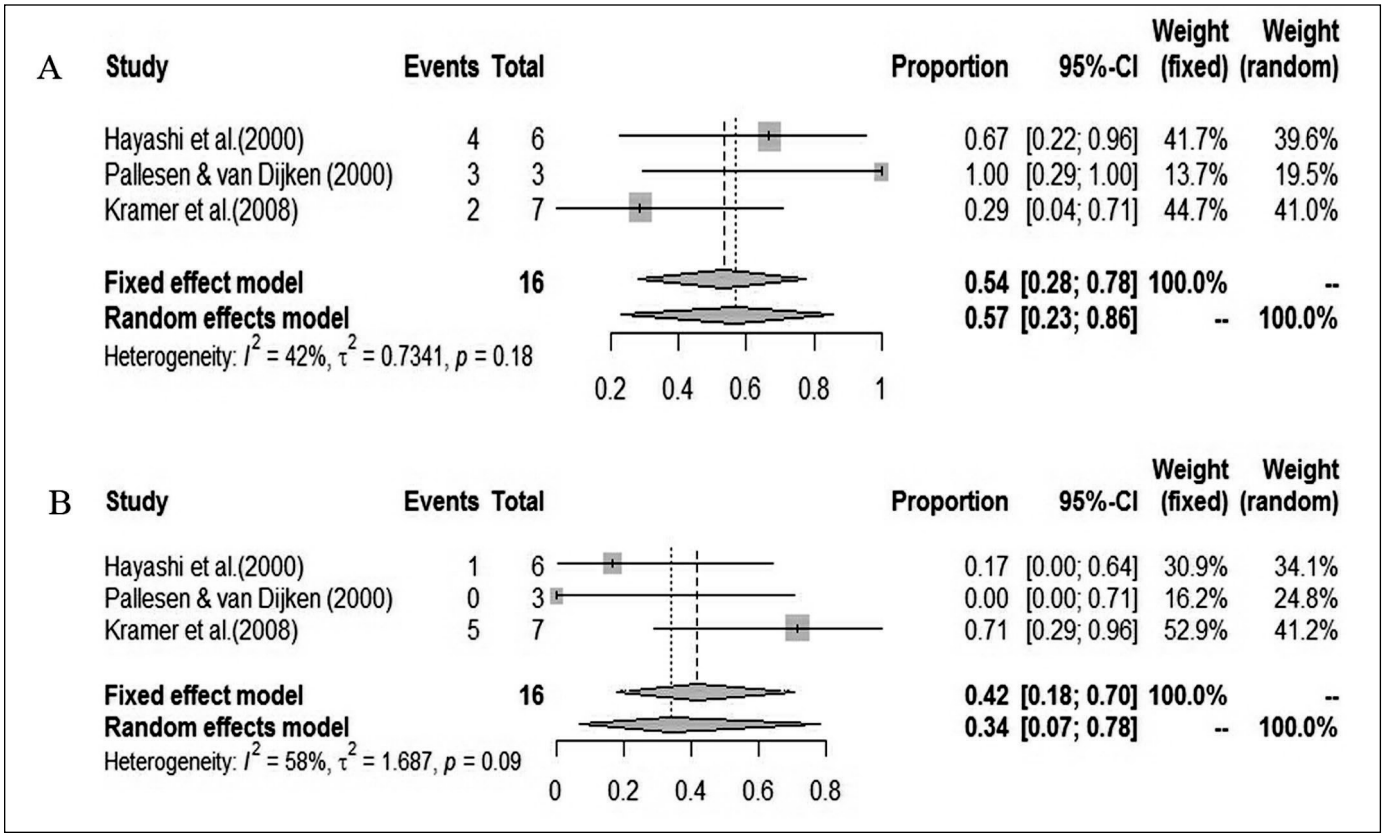

Figure 9. *Eight-year pooled proportion of complications of ceramic inlays and onlays. A: Restoration fractures; B: Endodontic complications.*

as well as two light-cure resin cements (EBS Multi + Compolute, 3M ESPE, Seefeld, Germany; Syntac + Variolink II, Ivoclar Vivadent, Schaan, Liechtenstein) were investigated.[48] Sjogren and others[33] reported that the estimated survival rate of Vita Mark II (Vita Zahnfabrik, Bad Säckingen, Germany) inlays fabricated by CAD/CAM after 10 years was 89%. The survival rate (77%) of the dual-cure composite resin (Vita Cerec Duo Cement, Coltene-Whaledent, Altstetten, Switzerland) was significantly lower than that (100%) of the chemically cure composite resin (Cavex Clearfil F2, Cavex, Haarlem, the Netherlands) ($p<0.05$).[33]

Materials and Fabrication Methodology – Pallesen & van Dijken[31] reported that the fracture rate of machinable Dicor MGC (Dentsply, Konstanz, Germany) inlays was 12.5% after 8 years of follow-up, while that of sintered Vita Mark II was 6.25%. Molin & Karlsson[44] indicated that the 5-year failure rate of Cerec (Vita Cerec, Vita Zahnfabrik, Bad Säckingen, Germany) inlays fabricated by CAD/CAM was 10% as a result of restoration fracture and debonding, and that of pressed IPS Empress (Ivoclar Vivadent, Schaan, Liechtenstein) inlays was 20%. On the contrary, 5% of sintered Mirage (Chameleon Dental Products, Kansas City, USA) inlays failed because of endodontic complications. In a study by Santos and others,[36] 18.75% of pressed Empress inlays and 10% of sintered Duceram (Dentsply-Degussa, Dentsply International Inc., PA, USA) inlays failed due to mechanical and biological complications after 5 years of follow-up. Based on these studies, it is difficult to reveal which material or fabrication method is superior to the others.

Tooth Vitality – Six of the included studies investigated the clinical outcome of inlay and onlay restorations for vital teeth,[30,31,33,36,46,47] while the other six studies[28,29,43-45,48] did not mention the vitality of teeth. Only Nejatidanesh and others[49] investigated the effect of tooth vitality on the clinical outcome of ceramic inlays and onlays. They reported that no fracture of ceramic inlays or partial coverage occurred in 92 vital teeth after 5 years of follow-up, while three restorations were fractured in 67 nonvital teeth. Nonvital teeth had a significantly higher risk of fracture ($p<0.05$). Vital teeth tend to achieve better clinical performance with ceramic rastorations.

Tooth Preparation – Clinical performance associated with the tooth preparation or different thickness of restorations was not involved in this study.

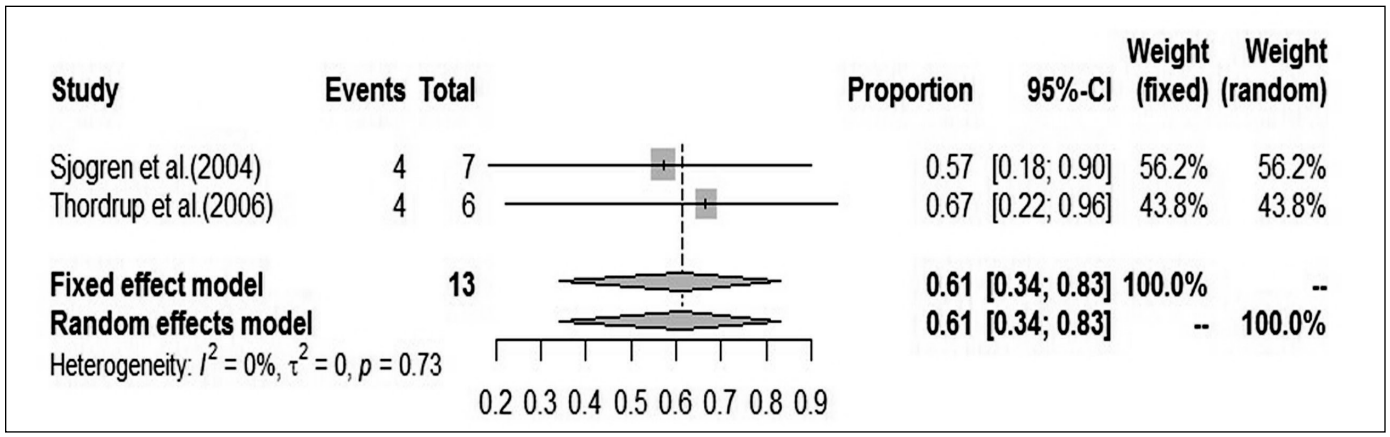

Figure 10. *Ten-year pooled proportion of restoration fractures of ceramic inlays and onlays.*

Parafunctional Habits and Bruxism – Parafuntional habits and bruxism were not mentioned in the majority of the previous publications.[29,31,43-46,48] Four studies[28,30,36,47] clearly stated patients who suffered from temporomandibular disorders or had signs of bruxism or clenching habits were excluded. Two studies included the patients with parafunctional habits and bruxism.[33,49] Sjogren and others[33] and Nejatidanesh and others[49] indicated that no association between the parafuntional habits and fractures of restorations was found.

DISCUSSION

The present study evaluated the long-term clinical survival and success rates of composite resin and ceramic inlays, onlays, and overlays, as well as the main failure reasons of restorations and the factors influencing the survival rate of restorations.

Several systematic reviews concerning composite resin and ceramic inlays, onlays, and overlays have been published.[24,39,56,57] Recently, Morimoto and others[40] reported that the survival rate of ceramic inlays, onlays and overlays was 95 % at 5 years and 91% at 10 years. More recently, Abduo & Sambrook[58] systematically evaluated the longevity of ceramic onlay restorations for at least 2 years of clinical follow-up and identified the factors that influence the survival of a ceramic onlay. They reported that the survival rate of the ceramic onlay restorations was 71%-98.5% after more than 5 years of observation. They also indicated that tooth preparation, tooth vitality and occlusal force tended to influence the clinical outcome of ceramic onlays while different materials, manufacturing techniques and luting cements had minimal effects on the survival of ceramic onlays.[58] Compared to their meta-analysis results, data in the present meta-analysis appeared to be ultra-conservative due to the long clinical evaluation (at least 5 years) and low restoration dropout (less than 30%). Besides the ceramic restorations, this meta-analysis covered the long-term survival and success rates of indirect composite resin restorations as well. According to the data in this review, we hold the view that the multiple-surface restorations and nonvital teeth may have a negative effect on the longevity of restorations. With respect to the other factors potentially influencing the clinical outcome, no definite conclusion could be drawn owing to lacking consistent data.

Survival Rate of Composite Resin Inlays, Onlays, and Overlays

With the advance of esthetic and mechanical properties of composite resins, these materials have been

Table 2: *Summary of Data of Complications*

Complications	Estimated Pooled Proportions			
	5-yr		8-yr	10-yr
	Composite resin	Ceramic	Ceramic	Ceramic
Fracture	24% (9-51%)	54% (40-67%)	54% (28-78%)	61% (34-83%)
Endodontic complications	27% (11-54%)	20% (11-33%)	34% (7-78%)	-

recommended to be used for inlays or onlays even in large cavities.[21,59,60] The 5-year cumulative survival rate of composite resin inlays, onlays and overlays in this review was 91%, indicating an excellent clinical outcome. Pallesen & Qvist[27] reported that 88% of the composite resin inlays performed clinically acceptable even after 11 years in service. This is in agreement with the study performed by Barabanti and others[37] They stated that approximately 90% of indirect composite resin inlays and onlays used for restoring large tooth defects still functioned well after 10 years of clinical service.[37] However, Thordrup and others[28] reported that the 10-year cumulative survival rate of composite resin inlays decreased to 79.2% due to secondary caries and endodontic complications. Furthermore, van Dijken and others[25] reported that the cumulative survival rate of direct composite resin inlays and onlays was 82.3% after 11 years of clinical service. Most recently, Derchi and others[61] reported that the failure rate of the composite resin inlays was 12% at 12 years. However, these data were excluded in the present meta-analysis due to inconsistent results in respect to the number of failures[25] and high dropout rate.[61] This disparity might be attributable to the limited number of RCTs and the high dropout rate. In the meanwhile, Ravasini and others[62] revealed that the survival rate of indirect posterior composite restorations was 81% at 10 years according to the Kaplan-Meier plot. This is completely in accordance with the previous report.[28] They also reported that the probability of survival rate will rapidly decrease to 57% after 20 years in service.[62] In contrast to the mechanical failure of ceramic restorations, the main failures of composite resin restorations were biological complications, including secondary caries and endodontic complications.

Survival Rate of Ceramic Inlays, Onlays, and Overlays

In this study, the cumulative survival rate of ceramic inlays and onlays reached 90% at 5 years, and slightly decreased over time, 89% at 8 years and 85% at 10 years. These findings are in agreement with the previous studies.[63-65] Arnelund and others[63] indicated that the overall survival rate of ceramic inlays and onlays was 92% after a 60 month follow-up period. Federlin and others[65] reported that 88.8% of the ceramic inlay and onlay restorations were judged as clinically acceptable after 5.5 years of follow-up. Zimmer and others[64] reported that Class I and II CAD/CAM ceramic inlays/onlays fabricated with feldspathic porcelain (Vita Mark II) and glass ceramic blocks (Dicor, Corning Dentsply, Konstanz, Germany) had a survival rate of 85.7% at 10 years. This is in line with the cumulative survival rate in this study. To date, there are not sufficient RCT data concerning inlays and onlays for more than 10 years of clinical follow-up. Santos and others[38] evaluated the 12-year clinical performance of sintered (Duceram) and pressable (IPS Empress) ceramic inlays and onlays with a total cumulative survival rate of 47.92%. Contrarily, Frankenberger and others[35] reported that 84% of IPS Empress inlays and onlays functioned well over 12 years. This is attributable to the high restoration dropout rates of 44.19%[38] and 39.59%[35] in both studies. Reiss and others[66] reported that the success rate of 1011 Cerec inlays was 84.4% after 16.7 years in service according to the Kaplan-Meier plot. These data were excluded in this study due to the unreported failures and dropout rates. However, Arnetzl[53] reported that the estimated survival rate of nonretentive ceramic overlays was 96.5% after 93 months in average. Most recently, Edelhoff and others[67] reported that occlusal onlays made of monolithic lithium disilicate for full-mouth oral rehabiliation presented a 100% survival rate in seven patients with severe toothwear up to 11 years.

Which Restoration Is the Best Among Inlays, Onlays, and Overlays?

Inlay, onlay, and overlay restorations can function well even in the case that the tooth hard structures suffer from extensive loss.[10] However, it has not been clarified whether onlay or overlay restorations could perform better than inlays.[36,43,54,55,68-70] Recently, several in vitro studies investigated the fracture resistance of indirect restorations related to different cavity designs of posterior teeth.[68-70] However, their results were not always consistent. For example, Cubas and others[68] reported that MOD inlays presented fracture resistance similar to sound teeth while the restorations with partial or complete coverage (onlays and overlays) exhibited significantly lower fracture resistance than inlays and sound teeth. Therefore, they concluded that less invasive preparation of inlays should be preferred.[68] Contrarily, Alshiddi & Aljinbaz[69] reported that the endodontically treated teeth restored with composite resin inlays had a significant increase in fracture resistance when compared to the teeth restored with onlays. Therefore, they pointed out that tooth fracture up to the root was prone to occur in teeth with inlay restorations, whereas, most of the fractures are confined to the restorations when onlays are placed.[69] Furthermore, Harsha and others[70] reported that the fracture resistance of partial coverage (onlays) seemed to be higher than MOD inlays, but both were not significantly different, and complete coverage (overlays) could reinforce the tooth structure at maximum. There were some conflicting results in previous clinical studies concerning inlays

and onlays. Otto and others[54,55] reported that the fracture rates of inlay and onlay restorations were 4.1% and 6.7% at 10 years, and 7.2% and 6.7% at 15 years, respectively. Hayashi and others[43] reported that the fracture rate of inlay restorations was higher than that of onlay restorations, since four of 43 inlays and none of a total of 2 onlays fractured during 8 years of follow-up. Contrarily, Santos and others[36] reported that the fracture rate of onlays was 1.6 times larger than that of inlays after 5 years. Therefore, further RCTs investigating the influence of different cavity designs on the clinical success rate should be performed.

Feldspathic Porcelain versus Glass Ceramic

Usually, flexural strength of glass ceramic is much stronger than that of feldspathic porcelain.[71,72] Based on the flexural strengths, the failure rate of glass ceramic restorations might be lower than that of feldspathic porcelain restorations. However, in the present study, the cumulative survival rates of feldspathic porcelain and glass ceramic inlays were recorded as 90% and 86%, respectively. Santos and others[36] reported a comparatively low survival rate of glass ceramic restorations due to the severe restoration discolorations.[36]

Tooth Preparation and Stronger Materials

Regarding ceramic restorations, fractures occurred as a principal complication with the pooled proportion of 54% at 5 years, 54% at 8 years and 61% at 10 years, indicating that the more hard tooth structure lost due to cavity preparation, the stronger material needed. In order to resist the mastication force in posterior teeth, the thickness of ceramics has been suggested to be at least 1.5 to 2 mm for functional cusps and 1-1.5 mm for non-functional cusp.[73-75] Concerning the thickness of ceramic restorations, the results of laboratory research and clinical trials were entirely inconsistent.[10,19,76-78] Laboratory studies indicated that the thickness of inlays and onlays may not be an important factor influencing the fracture risk of restorations.[77,78] Holberg and others[77] analyzed a finite element model of inlays and reported that the thinner inlay would not significantly increase the risk of fracture. This is in agreement with a laboratory report,[78] indicating that cusp coverages of 1.5 and 2.5 mm had similar fracture rates when endodontically treated teeth were restored with composite resin onlays.[78] In contrast, clinical trials draw the opposite conclusion and suggest at least 2 mm thickness for feldspathic porcelain and leucite-reinforced ceramics.[10,19,76] Murgueitio and others[19] discovered that the thickness of the occlusal surface of the failed restorations was less than 2 mm in their clinical research. Based on two clinical trials, van Dijken and others[10,76] also insisted that the cusp fracture of IPS Empress restorations can be effectively prevented when the thickness of the ceramic reached 2 mm. IPS e.Max (Ivoclar Vivadent, Schaan, Liechtenstein) ceramic made of lithium disilicate has been widely used for its high flexural strength (up to 400 MPa).[79] High short-term survival rates of IPS e.Max inlay and onlay restorations have been reported.[75,80,81] Moreover, the long-term performance of IPS e.max Press partial and entire coverage restorations demonstrated no failures after 7-11 years of follow-up.[67,82]

Vital Teeth Versus Nonvital Teeth

In this analysis, only one study[49] indicated that ceramic fracture more frequently occurred in nonvital teeth than in vital teeth. Generally, a large amount of dentin removal by root canal therapy leads to lower fracture resistance of the residual tooth. Removal of pulp tissues may also increase the brittleness of dentin.[83] Several studies revealed that posterior indirect adhesive restorations in nonvital teeth functioned well after 2-4 years of clinical service.[15,84,85] Nevertheless, two previous publications showed that the vital tooth had a more favorable outcome and were less likely to fail than the nonvital teeth.[19,76] After 3 years of IPS Empress onlays and partial coverage restorations, 85.7% of failures took place in the restorations of nonvital teeth.[19]

Molar Versus Premolar

The restorations in molar regions are subjected to larger masticatory forces than those in premolars. They are presumed to be more prone to be fractured. Numerous previous publications revealed a significantly higher rate of failure of restoration in molars than that in premolars.[19,21,40,86] Contrarily, Collares and others[3] reported that no differences of the success and survival rates were found between inlays and onlays, as well as between molars and premolars after they analyzed 5791 ceramc inlays and onlays.

Parafunctional Habits

Numerous previous reports showed that composite resin and ceramic inlay and onlay restorations were more prone to be fractured when subjects had parafunctional habits.[7,55,87,88] It might be attributed to parafunctional habits playing a significant role in material fatigue leading to fracture after long-term clinical service.[87] Contrarily, some researchers insist that direct evidence between parafunctional habits and the fracture of composite resin and ceramic restorations had not been found.[58,89]

Limitation of This Systematic Review and Meta-analysis

Most of the data in the included studies reveal homogeneity. Neverthless, when the 5-year survival rate of ceramic inlays was calculated, the included studies showed moderate heterogeneity (I^2=51%). After a subgroup analysis was carried out to explain the origin of heterogeneity, the heterogeneity was obviously associated with dropout of patients and restorations, which may lead to a high risk of bias. Thirteen observational studies included in this study were prospective or retrospective cohort studies with their evidence levels being lower than that of RCTs. Hence, further RCTs are needed to investigate the long-term performance of composite resin or ceramic inlays, onlays, and overlays.

CONCLUSION

The cumulative survival and success rates of composite resin inlays, onlays and overlays were 91% and 84% at 5 years, respectively. The survival rates of ceramic inlays and onlays were 90% at 5 years, 89% at 8 years and 85% at 10 years, while the success rates of ceramic inlays and onlays were 88% at 5 years and 77% at 10 years. Biological complications, including secondary caries and endodontic complications with the respective pooled proportion of 47% and 27%, were the main reasons leading to the failure of composite resin restorations. In contrast, mechanical complications were the principal issue of ceramic restorations, accounting for 54% of the restoration failures. Nonvital teeth and multiple-surface restorations had negative effects on the longevity of the inlay and onlay restorations. Based on the data in this study, no direct association between parafuntional habits and bruxism and the fracture of restorations was found. Due to inconsistent data or lack of sufficiently evident data in this study, a definite conclusion could not be drawn regarding factors influencing the clinical outcome, such as restorations in premolar and molar regions, luting cements, fabrication method of the restorations, tooth perapation and parafunctional habits. Hence, further RCTs should be conducted to investigate clinical performance of composite resin and ceramic inlays, onlays and overlays for tooth restorations.

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Conflict of Interest

The authors have no financial interest in any of the companies or products mentioned in this article.

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