Survival Rate of Resin and Ceramic Inlays, Onlays, and Overlays: A Systematic Review and Meta-analysis

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Abstract: This systematic review and meta-analysis aimed to evaluate the survival rate of ceramic and resin inlays, onlays, and overlays and to identify the complication types associated with the main clinical outcomes. Two reviewers searched PubMed, EMBASE, and the Cochrane Central Register of Controlled Trials for articles published between 1983 through April 2015, conforming to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines for systematic reviews. Clinical studies meeting the following criteria were included: 1) studies related to resin and ceramic inlays, onlays, and overlays; 2) prospective, retrospective, or randomized controlled trials conducted in humans; 3) studies with a dropout rate of less than 30%; and 4) studies with a follow-up longer than 5 y. Of 1,389 articles, 14 met the inclusion criteria. The meta-regression indicated that the type of ceramic material (feldspathic porcelain vs. glass-ceramic), study design (retrospective vs. prospective), follow-up time (5 vs. 10 y), and study setting (university vs. private clinic) did not affect the survival rate. Estimated survival rates for glass-ceramics and feldspathic porcelain were between 92% and 95% at 5 y (n = 5,811 restorations) and were 91% at 10 y (n = 2,154 restorations). Failures were related to fractures/chipping (4%), followed by endodontic complications (3%), secondary caries (1%), debonding (1%), and severe marginal staining (0%). Odds ratios (95% confidence intervals) were 0.19 (0.04 to 0.96) and 0.54 (0.17 to 1.69) for pulp vitality and type of tooth involved (premolars vs. molars), respectively. Ceramic inlays, onlays, and overlays showed high survival rates at 5 y and 10 y, and fractures were the most frequent cause of failure.

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Survival and Complication Rates of Resin and Ceramic Inlays, Onlays and Overlays: A Systematic Review and Meta-analysis

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Abstract

The aim of this systematic review was to evaluate the survival rate of ceramic and resin inlays, onlays e overlays, as well as the rate of complications of the main clinical outcomes and possible associated factors.. Two reviewers searched PubMed, Embase and Cochrane Central Register of Controlled Trials (Central)through 1983 to April 2015. Clinical studies were included 1) related to resin and ceramic inlays, onlays and overlays; 2) prospective, retrospective or randomized controlled trials conducted in humans; 3) drop-out less than 30%; 4) follow-up time longer than 5 years. A total of 14 articles from 1389 articles initially identified, met the inclusion criteria. Meta-regression indicated no influence of the type of ceramic material (feldspathic porcelain versus glass-ceramic), study design (retrospective versus prospective), follow up time (5 versus 10 years) or study settings (university versus private clinic) on the survival rate. For glass-ceramics and feldspathic porcelain, the estimated survival rates ranged between 95 to 92%, and 91%, for 5 (N=5811 restorations) and 10 years (N=2154 restorations), respectively. Failures were related to fracture/chipping (4%), followed by endodontic complications (3%), secondary caries (1%) and debonding (1%) and severe marginal staining (0%). Pulp vitality and type of tooth involved (premolars versus molars) presented Odds Ratio of 0.19 (0.04-0.96) and 0.54 (0.17-1.69), respectively. No conclusive evidence was available on the survival of resin or crystalline ceramic materials., evaluation of color, wear, marginal integrity, post-operative sensitivity and patient satisfaction due to lack and/or standardization of criteria. Meta-analysis for the duration of 15 years, influence of cusp coverage, manufacturing method, cementation technique and location (maxilla or mandible) could not be performed with the available data. Ceramic Inlays, onlays and overlays showed high survival rates in 5 and 10 years, with the most frequent failure being fractures, providing evidence that these restorations are a safe treatment.

Introduction

The improvement in adhesive dentistry and the increase in esthetic requirements have driven the indication of ceramic and resin inlays, onlays and overlays, however, investigation into the survival of these restorations is still a frequent question in primary studies (Fabianelli et al. 2006; Guess et al. 2009; Hayashi et al. 2003). Partial indirect restorations in posterior teeth may be classified as inlays (without covering the cusps), onlays (covering at least one cusp) and overlays (covering all cusps) (Felden et al. 1998; Fuzzi and Rappelli 1998; Schulz et al. 2003).These partial restorations enable conservation of the remaining dental structure, promoting reinforcement of the compromised tooth, and re-establishment of masticatory function, phonetics, and esthetics as far as possible (Fuzzi and Rappelli 1998; Fabianelli et al. 2006; Guess et al. 2009).

At present, there are numerous resin or ceramic materials available for fabricating indirect partial restorations (Thordrup et al. 2006; Pol and Kalk 2011). For laboratory resin composites, the ultimate strength depends on the degree of conversion of the monomers (organic phase) and the quantity of inorganic phase. Their fabrication methods involve chemical, heat or photo-polymerization and they could be milled from pre-fabricated CAD/CAM blocks (Kildal and Ruyter 1994). Partial reconstructions could also be made of feldspathic porcelain, glass or crystalline ceramics. Feldspathic porcelain and glass-ceramics, available in powder (stratification) or blocks (CAD/CAM), comprise a vitreous and crystalline phase, where glassy matrix could be etched (Conrad et al. 2007; McLaren and Whiteman 2010). Crystalline ceramics, alumina or zirconia, have minimal or practically no vitreous phase (up to 85 to 99.5% of crystals), and are available in powder form for stratification or densely sintered CAD/CAM blocks (McLaren and Whiteman 2010). The approach by systematic reviews to the clinical efficacy of ceramic and resin inlays, onlays e overlays. Nevertheless, they have reported that there is no conclusive evidence about the performance of ceramic inlays, onlays and overlays over the course of time, and it is not possible to perform a meta-analysis in these studies (Martin and Jedynakiewicz 1999; Hayashi et al. 2003; Pol and Kalk 2011; Fran Chabouis et al. 2013; Grivas et al. 2014). Fron Chabouis et al. (2013) review about ceramic inlays, onlays

and overlays *versus* resin, concluding that there is very limited evidence that ceramics perform better than composite materials for inlays in the short term. Grivas et al. (2014) affirmed that there is insufficient evidence to answer whether any differences in longevity exist between direct and indirect composite inlays on one side and ceramic and gold inlays on the other side. Previous systematic reviews (Martin and Jedynakiewicz 1999; Hayashi et al. 2003; Pol and Kalk 2011; Fran Chabouis et al. 2013) attempted to include only RCT studies, and they reported that the exclusion criteria became very strict, and consequently, they were unable to gather strong evidences about the subject. When evaluating the foregoing considerations, our study sought in RCTs, prospective and retrospective studies the elucidation of numerous factors, or additionally, to evaluate the trends that needed to be investigated about ceramic and resin inlays, onlays and overlays, which could guide new primary studies.

There is a gap in the information, justifying the elaboration of a systematic review that is broad in scope, and seeks to detail the different materials, techniques, preparations and associated failures, in order to bring forward integrated scientific evidence.

The aim of this systematic review was to evaluate the survival rate of ceramic and resin inlays, onlays e overlays, as well as the rate of complications and possible associated factors.

Materials and Methods

The PRISMA guidelines (Moher et al. 2009) were followed to report this review.

Information Sources

Articles that reported survival of resin and ceramic inlay, onlay and overlay restorations published from 1983 until 2014 were searched in MEDLINE (Pubmed) (until April 2, 2015), Cochrane Central Register of Controlled Trials (Central) (until April 2, 2015) and EMBASE (until August 01, 2014) databases. References of included articles were checked manually. Search started from the year 1983 as adhesive

procedures for ceramics with the use of hydrofluoric acid and silanization were first standardized that year (Horn 1983; Simonsen and Calamia 1983).

Search Strategy

Initially PICOS question (Population (P), Intervention (I), Comparison (C), Outcomes and Study Design (O), Study type (S)) defined the search strategy, where P=Patients who received resin or ceramic inlays, onlays and overlays; I=Inlays, onlays and overlays made of resin or ceramic; C=Not applicable in this study; O=Survival rate; S=Randomized controlled clinical trials (RCT) and clinical follow-up studies.

Following MeSH terms, search terms and their combinations were used for this search in MEDLINE: *((((((inlay*) OR onlay*) OR overlay*) OR coverage)) AND ((((((porcelain*) OR ceram*) OR resin) OR ceromer) OR CAD/CAM) OR CEREC)) AND ((((((((((clinical evaluation) OR clinical trial[MeSH Terms]) OR longevity) OR success) OR failure) OR survival rate[MeSH Terms]) OR clinical performance) OR follow up study[MeSH Terms]) OR clinical study) OR comparative study))*. For the search in EMBASE, the following terms were used: *'ceramics'/exp OR 'porcelain' OR 'porcelain tooth'/exp OR 'resin'/exp OR 'ceromer' AND ('dental inlay'/exp OR 'inlay' OR 'onlay' OR 'overlay') AND ('clinical trial'/exp OR 'clinical study'/exp OR 'intervention study'/exp OR 'prospective study'/exp OR 'retrospective study'/exp OR 'follow up'/exp) NOT [medline]/lim AND [embase]/lim AND [1983-2014]/py.* As for the search in “Central”, the search terms were as follows: ((inlay or onlay or overlay) and (ceramic or resin) and (dental or tooth or teeth) and (clinical and trial or clinical)).

Study Selection and Eligibility Criteria

All titles and abstracts of the selected studies were first assessed for the inclusion criteria: 1) studies related to resin and ceramic inlays, onlays and overlays and 2) with clinical follow-up (prospective or retrospective) or randomized controlled trials (RCT), conducted in humans in posterior teeth. Articles without abstract or abstracts with insufficient description to enable decision were included for evaluation of the complete text.

Eligibility was determined after evaluation of the full text according to the previously defined exclusion criteria: 1) articles without description of the procedure, or in which uncommon preparations had been performed such as bridge abutments, splinting, uncommon bonding procedures, occlusal coverage of posterior teeth without preparation, implant abutments or restorations including metal; 2) case reports; 3) literature or systematic review, protocols, interviews, *in vitro* studies; 4) studies conducted in isolated groups (bruxism, hypoplasia, others); 5) studies with the same sample (the most recent and/or most complete was considered); 6) studies without survival analysis, incomplete data for the analysis; 7) drop-out higher than 30% and 8) follow-up time shorter than 5 years. No restriction in languages was made for eligibility.

Data Collection Process

Two calibrated reviewers (FBWRS, SM) collected the data from selected papers onto structured tables. Cohen`s Kappa values between examiners ranged from 0.8 to 0.9 for the stage of inclusion and stage of eligibility respectively.. Discrepancies were resolved by consensus and a third examiner (NS) was consulted.

Two calibrated examiners (FBWRS, SM), using the quality assessment (Hayashi et al. 2003; Morimoto et al. 2016) assessed the risk of bias in the included studies (Appendix1).

Measures and statistical analysis

Descriptive statistics, meta-regression and meta-analysis were performed, based on the estimated survival rates. Cochran Q test was performed ($p<0.001$, CI 95%) to evaluate the heterogeneity among the studies and the presence of heterogeneity was analyzed using inconsistency test ($I^2 \geq 50\%$) (Higgins and Thompson 2002). The inverse variance method was used with the *DerSimonian-Laird* estimator for the I^2. Data were transformed and the individual CI of the studies was calculated by the *Clopper-Pearson* method (Software program R 3.1.0, R Core Team, 2014) with the aid of the Meta package (Schwarzer 2013). The meta-regression was performed (Stata 13.1, StataCorp, Texas, USA) considering the type of material

used, highest survival rate, study design (retrospective vs prospective) and study settings (university vs private clinic).

The meta-analysis of the survival rates was primarily performed for the ceramic types during the intervals of 5 and 10 years. Analyses of survival in the subgroups were performed, separating the feldspathic porcelain and glass-ceramics. When the study did not present variance or standard deviation, it was calculated based on the analysis of the number of failures and censorship during the time of follow-up. The data collected from the text was calculated using the Kaplan-Meier graphics for some articles (Roulet 1997; Felden et al. 1998; Fuzzi and Rapelli 1998; Hayashi et al. 2000; Posselt and Kerschbaum 2003; Sjögren et al. 2004; Schulte et al. 2005; Reiss 2006; Frankenberger et al. 2008; Kramer et al. 2008; Otto and Schneider 2008; Beier et al. 2012) / life tables (Schulz et al. 2003; Smales and Etemadi 2004). The *Greenwood* formula was used to calculate the variance, assuming that the censorships occurred uniformly over time, together with the failures. Failure rates were collected for the subgroups: fracture/chipping, endodontic problems, secondary caries, debonding, severe marginal staining. For the analysis of marginal staining, although different evaluation criteria were used such as modified UPSHS (Roulet 1997; Felden et al. 1998; Fuzzi and Rapelli 1998; Hayashi et al. 2000; Sjögren et al. 2004; Frankenberger et al. 2008; Kramer et al. 2008; Otto and Schneider 2008) or CDA/Ryge (Beier et al. 2012; Schulz et al. 2003; Reiss 2006), the worst criteria (Charlie or Score 3) was selected. The influence of vitality of teeth (vital vs endodontically treated), the tooth involved (premolar vs molar), covering of cusps (inlay vs onlay vs overlay) and location (maxilla vs mandible), the Odds Ratio (OR) was calculated.

Results

Study Selection

The search strategies employed yielded 1389 studies (Fig. 1). After evaluating the titles and abstracts, and eliminating duplicates, 261 studies were identified, from which 247 were excluded after review of the titles and abstracts. Finally, 14 papers were included for quantitative and risk of bias analysis (Appendix 2).).

Study Characteristics

Publication year of included studies ranged from 1987 to 2012. Information and characteristics of each study are provided in Table 1. From the studies with the same sample (Reiss and Walther 2000; Otto and Reiss 2001; De Nisco 2002; Lohbauer et al. 2008), the most recent one was considered with the exception of one study (Fuzzi and Rappelli 1999) where the oldest study was included (Fuzzi and Rappelli 1998) as the most recent study presented incongruous data with respect to distribution and number of failures per patient and incidence of secondary caries lesions.

Measures and statistical analysis

Resin group- No study of resin inlays, onlays and overlays could be selected in the data collection process; hence meta-analysis could not be performed for this material. One study (Thordrup et al. 2006) evaluated the survival rate of ceramics and resins, fulfilling various inclusion criteria but they did not present the number of patients per material.

Ceramics group- Six of the selected studies used feldspathic porcelain and five of them used glass-ceramics (Table 1). In three studies, the sample included both materials. Meta-regression showed no association between ceramic types and the survival rate for 5 years (p=0.12) and 10 years (p=0.55) (Test of Moderators-coefficient 2.3).

Funnel plot and Standardized Residual graphs for 5 years (Appendix 3), allowed evaluation of the homogeneous distribution of all 14 articles included, with the exception of two outliers (Roulet 1997; Smales and Etemadi 2004) where lower survival rates were reported than the other studies. A sensitivity analysis revealed that removal of these two studies would not influence the interpretation of the results. Funnel plot and Standardized Residual graphs for 10 years (Appendix 4) allowed evaluation of the homogeneous distribution of the 8 articles included. Likewise, no association was found between survival rate and study design (retrospective vs prospective) (p=0.927), follow-up time (p=0.837) or study setting (university vs private clinic) (p=0.914).

Since the maximum follow-up time of the included studies ranged between 6 to 20 years, all studies with 5 years reports were included but for 10 years, only seven studies were included. An attempt was made to advance the evaluation to 15 years, however, only two studies (Otto and Schneider 2008; Reiss 2006) could be included, but the data did not allow performing meta-analysis. For studies where the estimated survival was not explicit at the time point of follow-up, the value of survival was stipulated from analysis of the survival curves in the texts, supporting this assumption up to 5 years.

The survival rate of the total pooled sample including feldspathic porcelain and glass-ceramic for 5 year follow-up (N=5811 restorations) was 95% (95% CI: 91-97%; I^2=93.6%; p <0.0001) (Fig. 2a).. In the 10-year follow-up, survival rate of the sample (N=2154) was 91% (95% CI: 88-94%; I^2=74.5%; p<0.0003) (Fig. 3a).. One study presented separate data for the inlay and onlay restorations (Beier et al. 2012).

For feldspathic porcelains, for the follow-up time of 5 years (N=661), the survival rate was 92% (95% CI: 80-97%; I^2= 90.9%; p<0.0001) (Fig. 2b). For the clinical follow-up time of 10 years (N=538), the survival rate was 91% (95% CI: 83%- 95%; I^2=77.4%; p<0.0041) (Fig. 3b). As for glass-ceramics, while for the follow-up time of 5 years (N=1579), the survival rate was 96% (95% CI: 89-98%; I^2=91%; p<0.0001) (Fig. 2c), for the clinical follow-up time of 10 years (N=605), it was 93% (95% CI: 86-96%; I^2=75.8%; p<0.016) (Fig. 3c).

Meta-regression and Analysis of Subgroups

The fracture/chipping rate of teeth and/or inlay, onlay and overlay restorations was 4% (95% CI: 2-9%), according to 13 included studies (n=106 failures out of 4800 restorations).The incidence of endodontic problems was 3% (95% CI: 3-4%) (n=117 failures out of 3785) involving 11 studies , due to I^2 being lower than 50% (I^2=37.7%; p=0.098), the data presented were those obtained by the fixed effect, with no difference in incidence for both models. The incidence of secondary caries 1% (95% CI: 1-3%) (n=48 out of 4644) involving 10 studies. The incidence of debonding was 1% (95% CI: 0-3%) according to 6 studies (n= 24 out of 4854) (Figs. 4a-d). The frequency of severe marginal staining was 0% according to 3 studies (n=0 out of 338). The pulp vitality (vital teeth vs endodontically treated teeth) presented OR of 0.19 (95%

CI: 0.04-0.96; p=0.0063) according to 3 studies (n=142 out of 2236 in vital teeth; n=34 out of 132 in non vital teeth) (Fig. 5a). The type of tooth involved (premolar vs molar) presented OR of 0.54 (95% CI: 0.17-1.69, p=0.0001), including 5 studies (n=39 out of 710 in premolars; n=64 out of 997 in molars) (Fig. 5b). The OR for the influence of cusp coverage and location, could not be established. Only two studies presented complete and conclusive data on these items (Posselt and Kerschbaum 2003; Schulte et al. 2005) and 4 studies compared the types of preparation, yet not in a standardized manner (Posselt and Kerschbaum 2003; Sjögren et al. 2004; Schulte et al. 2005; Beier et al. 2012). Evaluation of color, wear, marginal integrity, post-operative sensitivity and patient satisfaction in particular could not be included due to either the lack and/or standardization of the criteria and/or data.

Risk of Bias within Studies

None of the retrospective studies were able to fulfill all the requisites, since item no. 9,10,11,12 and 25 were better suited for prospective studies and/or RCTs. Therefore, a retrospective study was expected to attain a maximum value of 80.77%. Nevertheless, the stipulated items may be sources of bias and heterogeneity, and were therefore tabulated, in order to help understanding the statistical data afterwards. The percentage of articles included in our analysis of risk of bias ranged from 46.1 to 76.9% (Appendix 2).

Discussion

Previous systematic reviews on the survival rate of resin and ceramic inlays, onlays and overlays as the main outcome were unable to perform meta-analysis (Martin and Jedynakiewicz 1999; Hayashi et al. 2003; Pol and Kalk 2011; Fran Chabouis et al. 2013; Grivas et al. 2014).

Accordingly, since meta-regression did not show significant differences between survival rate and study design, retrospective studies were included, this allows some advantages, as such studies include a large number of patients, a wide variety of materials and various operators . Frequently, such studies are able to follow the evolution of materials and techniques; hence the sample is continuously updated (Felden et al. 1998).

Heterogeneity tests showed higher levels than 50% (Cochran Q and I^2), thus, the random effect model was used in all analyses, with the exception of endodontically treated teeth (I^2=37.7%). In order to assist the evaluation of possible sources of this heterogeneity, visual inspection was performed, also to the data of the meta-regression considering funnel plots and standardized residuals graphs (Appendix 3-4). The meta-regression and analysis of the material subgroups discarded the hypothesis that the type of ceramic would be the cause of heterogeneity. When evaluating the heterogeneity of the studies included, with the exception of 2 outliers for the follow-up time of 5 years, the funnel plot and standardized residuals indicated homogeneous distribution of the remaining studies involved (Appendix 3). Nevertheless, the sensitivity test indicated that removal of the outliers would not influence the interpretation of the results. Bruxists (Smales and Etemadi 2004) or replacement of cusps and wide inlays (Roulet 1997) were considered as determinants for low survival rates in these studies.

No study with resin inlays, onlays and overlays could be selected in this study, therefore it was not possible to perform meta-analysis. Previous review (Fron Chabouis et al. 2013; Grivas et al. 2014) was also inconclusive as to whether resins are better than ceramics.

In the present study, the pooled estimated survival rate for 5 years of follow-up was 95%, and after 10 years follow-up, survival rate decreased to 91% (glass-ceramics: 93%; feldspathic porcelain: 91%), yet presenting no significant difference. One explanation for similar performance of glass-ceramics and feldspathic porcelain could be the adhesive cementation that probably compensated for the mechanical differences between the two ceramic materials. Another factor is that many glass-ceramic frameworks were stratified from vitreous ceramics. The veneering ceramics are less resistant than the ceramic coping, being generally, the main cause for chipping or fracture (Conrad et al. 2007; Pol and Kalk 2011).

The meta-analysis indicated low complication rates. Apparently, strong and durable adhesion of resin cements to both the ceramics, most probably increased the survival rate. The tooth-ceramic bond guarantees re-establishment of the tooth strength, reduction in deflection of the cusps (Cobakara et al. 2008; Morimoto 2009) reflected in low rates of failures.

The chance of failures was 80% less (OR=0.2) in vital teeth compared to endodontically treated teeth implying that there is a trend towards vitality of teeth being a significant factor. There was no significant association between the incidences of failures in premolars compared to molars. Two studies (Schult et al. 2004; Beier et al. 2012) presented high number of failures for inlays and onlays but did not report statistical difference for the type of preparation. Similarly, Sjögren et al. (2004) concluded that there was no relationship between fractures and the type of preparation. On the contrary, one study (Posselt and Kerschbaum 2003) related the decreased survival rate to the increased number of surfaces involved in the preparation, but did not specify the number of failures for each preparation type. Thus, effect of preparation type on the survival could not be involved in the meta-analysis. As for the effect of location of the restoration, while, one study (Schulte et al. 2005) presented higher survival rate in the maxilla than in the mandible, contradictory results were reported in another (Posselt and Kerschbaum 2003).

A positive aspect observed in the present study was the improvement in the methodological delineation, namely description of data and using more robust statistics in recent clinical studies. During the eligibility stage, among 261 full-text articles, still 247 of them were excluded, as they did not present the survival rate, or complete data for the analysis. Based on this review and on other previous systematic reviews that approached the subject, there is a lapse of clinical evidence for survival on the best fabrication technique, performance of indirect resin restorations or crystalline ceramics, covering the cusps, and location of the restoration. Information on the survival of inlays, onlays and overlays performing up to 15 years could also not be retrieved from the reviewed material.

With regard to the implications for future clinical researches, it is necessary to conduct randomized clinical studies with the comparison of techniques, cavity preparations and materials, with detailed samples, description of censorship in survival graphs, drop outs, detailed description of failures classified as acceptable or unacceptable, better standardization of the evaluation criteria, and separation of the survival and success rates.

Implications for Clinical Practice

This meta-analysis indicated that the survival rate of inlays, onlays and overlays remained high, irrespective of the follow-up time, 5 and 10 years, regardless of the ceramic material, study design and study setting, providing that the most frequent failures remains to be fractures. The type of tooth seems not to affect the survival rate but endodontic treatment are no longer related to the outcome of failures. Clinicians should note that there exists gap in the clinical evidence for justifying resin composites versus ceramics as well as material choice, when restoring teeth with inlays, onlays and overlays.

Author Contributions

S. Morimoto, F.B.W. Rebello de Sampaio, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; M.M. Braga, contributed to data acquisition, critically revised the manuscript; N. Sesma, contributed to conception, design, data acquisition, and interpretation, critically revised the manuscript; M. Özcan, contributed to conception and data interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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References

Barone A, Derchi G, Rossi A, Marconcini S, Covani U. 2008. Longitudinal clinical evaluation of bonded composite inlays: a 3-year study. Quintessence Int. 39(1):65-71.

Beier US, Kapferer I, Burtscher D, Giesinger JM, Dumfahrt H. 2012. Clinical performance of all-ceramic inlay and onlay restorations in posterior teeth. Int J Prosthodont. 25(4):395-402.

Cobankara FK, Unlu N, Cetin AR, Ozkan HB. 2008. The effect of different restoration techniques on the fracture resistance of endodontically-treated molars. Oper Dent. 33(5):526-533.

Conrad HJ, Seong WJ, Pesun IJ. 2007. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent. 98(5):389-404.

Fabianelli A, Goracci C, Bertelli E, Davidson CL, Ferrari M. 2006. A clinical trial of Empress II porcelain inlays luted to vital teeth with a dual-curing adhesive system and a self-curing resin cement. J Adhes Dent. 8(6):427-431.

Felden A, Schmalz G, Federlin M, Hiller KA. 1998. Retrospective clinical investigation and survival analysis on ceramic inlays and partial ceramic crowns: results up to 7 years. Clin Oral Investig. 2(4):161-167.

Frankenberger R, Taschner M, Garcia-Godoy F, Petschelt A, Kramer N. 2008. Leucite-reinforced glass ceramic inlays and onlays after 12 years. J Adhes Dent. 10(5):393-398.

Fron Chabouis H, Smail Faugeron V, Attal JP. 2013. Clinical efficacy of composite versus ceramic inlays and onlays: a systematic review. Dent Mater. 29(12):1209-1218.

Fuzzi M, Rappelli G. 1998. Survival rate of ceramic inlays. J Dent. 26(7):623-626.

Fuzzi M, Rappelli G. 1999. Ceramic inlays: clinical assessment and survival rate. J Adhes Dent. 1(1):71-79.

Grivas E, Roudsari RV, Satterthwaite JD. 2014. Composite inlays: a systematic review. Eur J Prosthodont Restor Dent. 22(3):117-24.

Guess PC, Strub JR, Steinhart N, Wolkewitz M, Stappert CF. 2009. All-ceramic partial coverage restorations--midterm results of a 5-year prospective clinical splitmouth study. J Dent. 37(8):627-637.

Hayashi M, Tsuchitani Y, Kawamura Y, Miura M, Takeshige F, Ebisu S. 2000. Eight-year clinical evaluation of fired ceramic inlays. Oper Dent. 25(6):473-481.

Hayashi M, Wilson NH, Yeung CA, Worthington HV. 2003. Systematic review of ceramic inlays. Clin Oral Investig. 7(1):8-19.

Higgins JP, Thompson SG. 2002. Quantifying heterogeneity in a meta-analysis. Stat Med. 15;21(11):1539-1558.

Horn HR. 1983. Porcelain laminate veneers bonded to etched enamel. Dent Clin North Am. 27(4):671-684.

Kramer N, Taschner M, Lohbauer U, Petschelt A, Frankenberger R. 2008. Totally bonded ceramic inlays and onlays after eight years. J Adhes Dent. 10(4):307-314.

Kildal KK, Ruyter IE. 1994. How different curing methods affect the degree of conversion of resin-based inlay/onlay materials. Acta Odontol Scand. Oct;52(5):315-22.

Lohbauer U, Kramer N, Petschelt A, Frankenberger R. 2008. Correlation of in vitro fatigue data and in vivo clinical performance of a glassceramic material. Dent Mater. 24(1):39-44.

Martin N, Jedynakiewicz NM. 1999. Clinical performance of CEREC ceramic inlays: a systematic review. Dent Mater. 15(1):54-61.

McLaren EA, Whiteman YY. 2010. Ceramics: rationale for material selection. Compend Contin Educ Dent. 31(9):666-668, 670, 672.

Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 6(7):e1000097.

Morimoto S, Vieira GF, Agra CM, Sesma N, Gil C. 2009. Fracture strength of teeth restored with ceramic inlays and overlays. Braz Dent J. 20(2):143-148.

Morimoto S, Albanesi RB, Sesma N, Agra CM, Braga MM. 2016. Main clinical outcomes of feldsphathic porcelain and glass-ceramic laminate veneers: a systematic review and meta-analysis of survival and complication rates. Int J Prosthodont. 29(1):38-49.

Otto T, De Nisco S. 2002. Computer-aided direct ceramic restorations: a 10-year prospective clinical study of Cerec CAD/CAM inlays and onlays. Int J Prosthodont. 15(2):122-128.

Otto T, Schneider D. 2008. Long-term clinical results of chairside Cerec CAD/CAM inlays and onlays: a case series. Int J Prosthodont. 21(1):53-59.

Pol CW, Kalk W. 2011. A systematic review of ceramic inlays in posterior teeth: an update. Int J Prosthodont. 24(6):566-575.

Posselt A, Kerschbaum T. 2003. Longevity of 2328 chairside Cerec inlays and onlays. Int J Comput Dent. 6(3):231-248.

Reiss B, Walther W. 2000. Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations. Int J Comput Dent. 3(1):9-23.

Reiss B. 2001. Long-term clinical performance of CEREC restorations and the variables affecting treatment success. Compend Contin Educ Dent. 22(6):14-18.

Reiss B. 2006. Clinical results of Cerec inlays in a dental practice over a period of 18 years. Int J Comput Dent. 9(1):11-22.

Roulet JF. 1997. Longevity of glass ceramic inlays and amalgam--results up to 6 years. Clin Oral Investig. 1:40-46.

Schulte AG, Vockler A, Reinhardt R. 2005. Longevity of ceramic inlays and onlays luted with a solely light-curing composite resin. J Dent. 33(5):433-442.

Schulz P, Johansson A, Arvidson K. 2003. A retrospective study of Mirage ceramic inlays over up to 9 years. Int. J Prosthodont. 16(5):510-514.

Schwarzer G. 2013. Book Package ‘meta’: Meta-Analysis with R. City: The R Foundation for Statistical Computing; Package ‘meta’: Meta-Analysis with R. p.69-87

Simonsen RJ, Calamia JR. 1983. Tensile bond strength of etched porcelain [abstract 1154]. J Dent Res. 62:297.

Sjogren G, Molin M, van Dijken JW. 2004. A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite. Int J Prosthodont. 17(2):241-246.

Smales RJ, Etemadi S. 2004. Survival of ceramic onlays placed with and without metal reinforcement. J Prosthet Dent. 91(6):548-553.

Thordrup M, Isidor F, Horsted-Bindslev P. 2006. A prospective clinical study of indirect and direct composite and ceramic inlays: ten-year results. Quintessence Int. 37(2):139-144.

Legends to figures and tables:

Figures:

Figure 1. Flow diagram with the information through the phases of study selection based on PRISMA (Moher et al. 2009).

Figures 2a-c. Forest plot of pooled studies at 5 years for **a.** feldspathic porcelain and glass-ceramic (n=14) with cumulative survival rate of 95% (95% CI: 91-97%); **b.** feldspathic porcelain (n=6) with cumulative survival rate of 92% (95% CI: 80-97%); **c.** glass-ceramic (n=5) with cumulative survival rate of 96% (95% CI: 89-98%). (A- Beier et al. 2012=inlay, B- Beier et al. 2012=onlay).

Figures 3a-c. Forest plot of pooled studies at 10 years for **a.** feldspathic porcelain and glass-ceramic (n=7) with cumulative survival rate of 91% (95% CI: 88-94%); **b.** feldspathic porcelain (n=4) with cumulative survival rate of 91% (95% CI: 83-95%); **c.** glass-ceramic (n=2) with cumulative survival rate of 93% (95% CI: 86-96%). (A- Beier et al. 2012=inlay, B- Beier et al. 2012=onlay).

Figures 4a-d. Forest plot of subgroup for **a.** outcome on fractures (n=13) with a rate of 4% (95% CI: 2-9%) **b.** outcome on endodontic problems (n=11) with a rate of 3% (95% CI: 2-4%); **c.** outcome on caries (n=10) with a rate of 1% (95% CI: 1-3%); **d.** outcome on debonding (n=6) with a rate of 1% (95% CI: 0-3%).

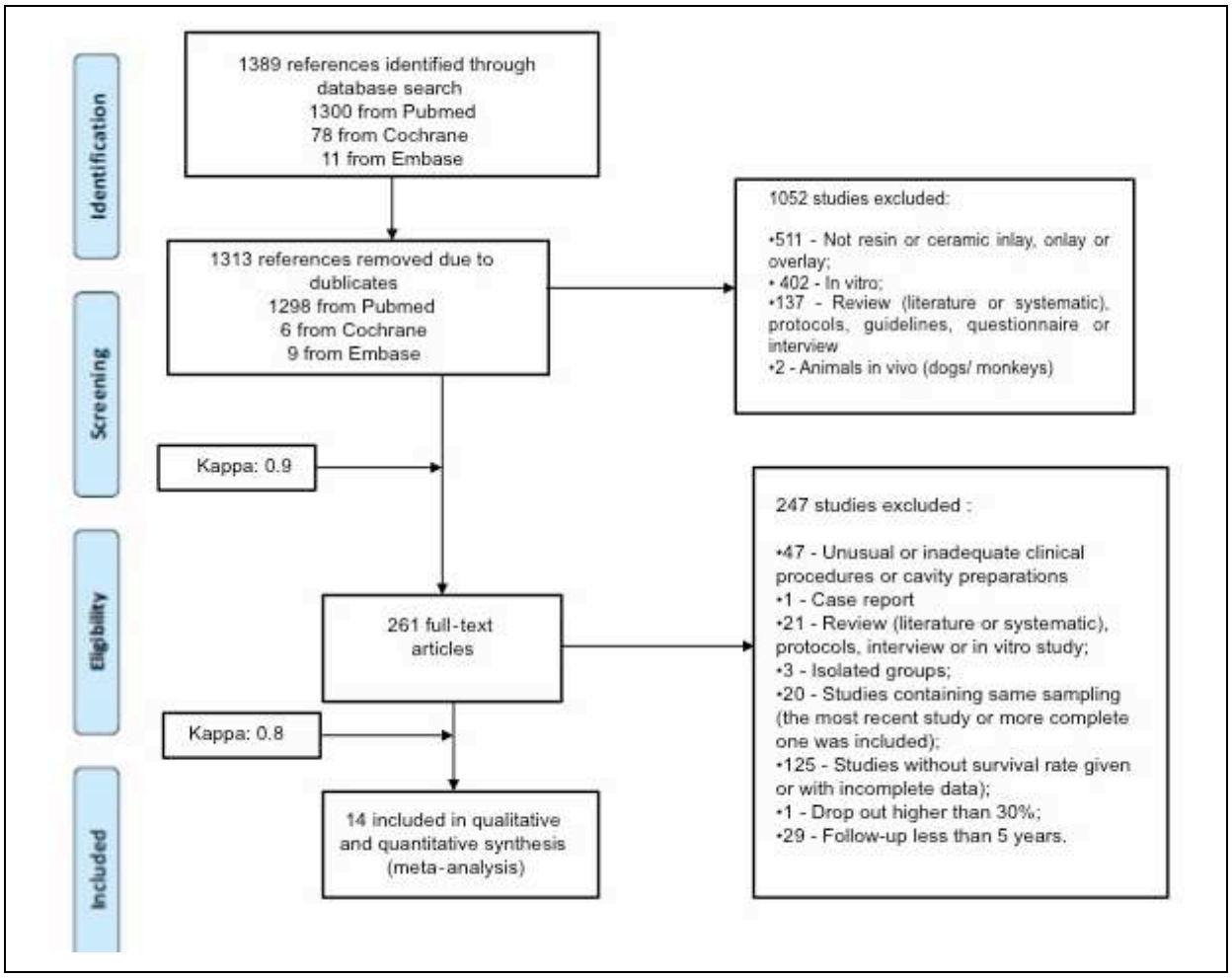
Figures 5a-b. a. Outcome on subgroup for comparison between vital and endodontically treated teeth (n=3) regarding the failures with Odds Ratio (OR): 0.19 (95% CI: 0.04-0.96%); **b.** outcome on subgroup for comparison between premolars and molars (n=5) regarding the failures with OR: 0.54 (95% CI: 0.17-1.69%).

Table:

Table 1. Study characteristics of 14 studies included. ns= not specified; y= year; m= months; w= week; N= number; ns op= not specified operator; RC= retrospective cohort; PC= prospective cohort; *= same sample; **= average; [a]=onlay; [b]=inlay

Appendix 1-4 (in other file)

Figures:



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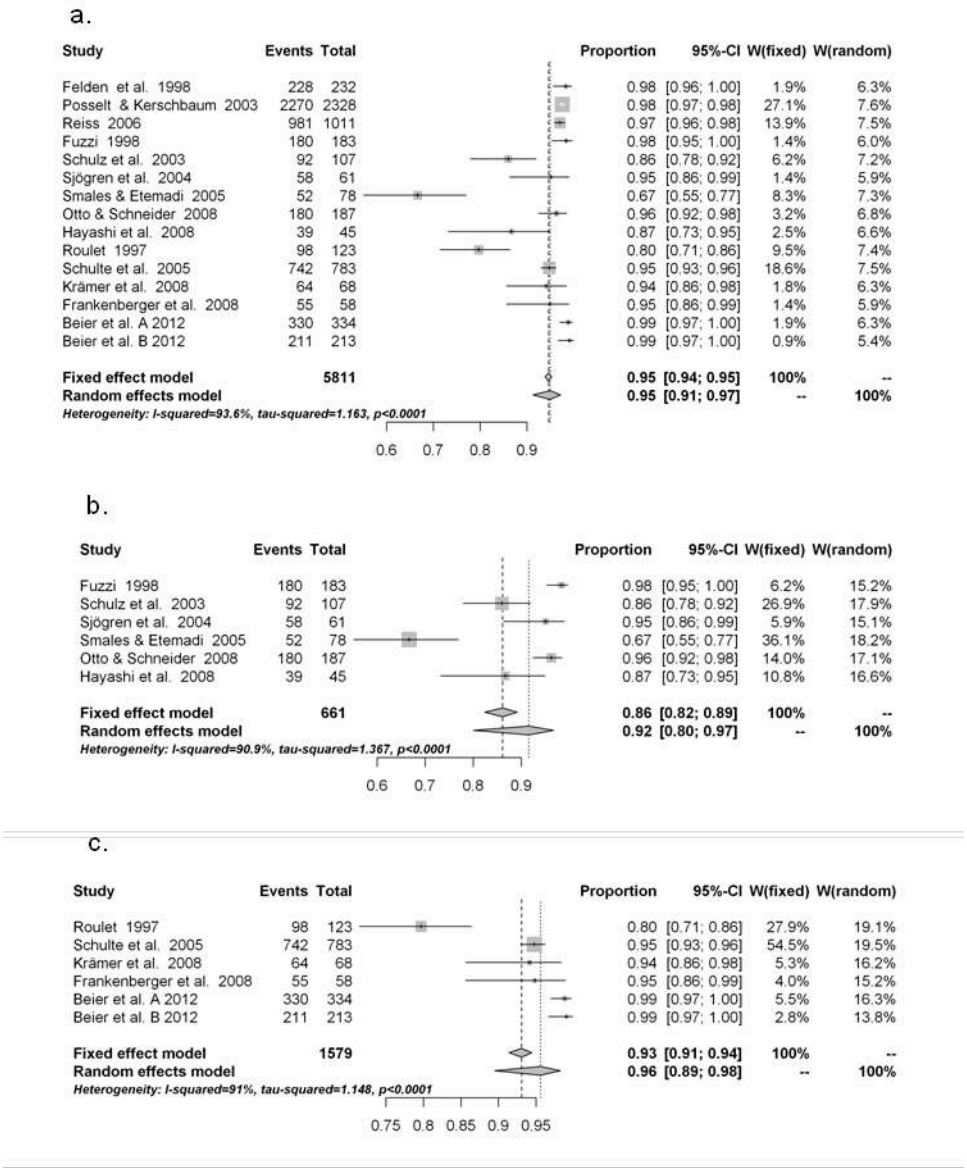

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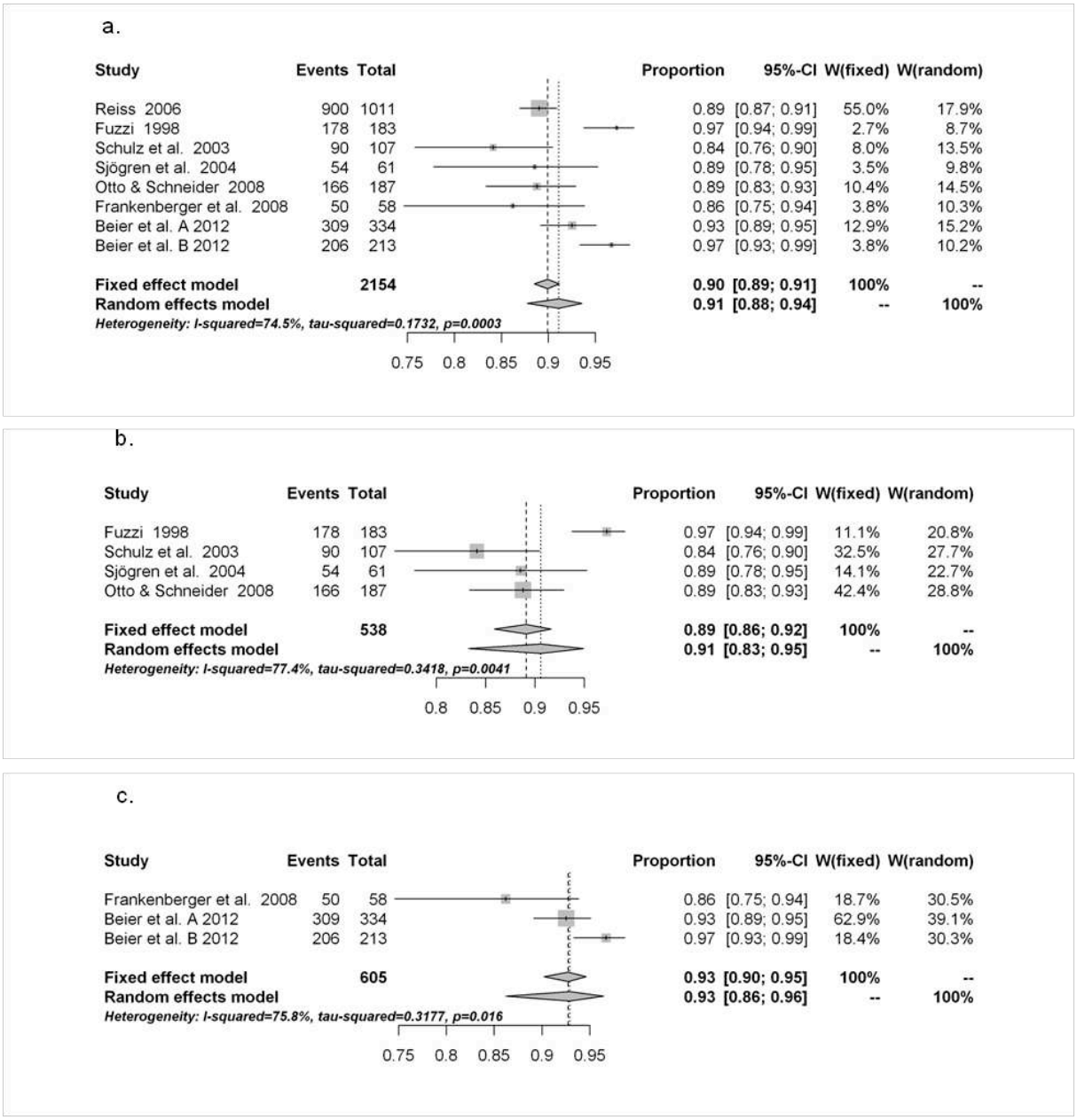

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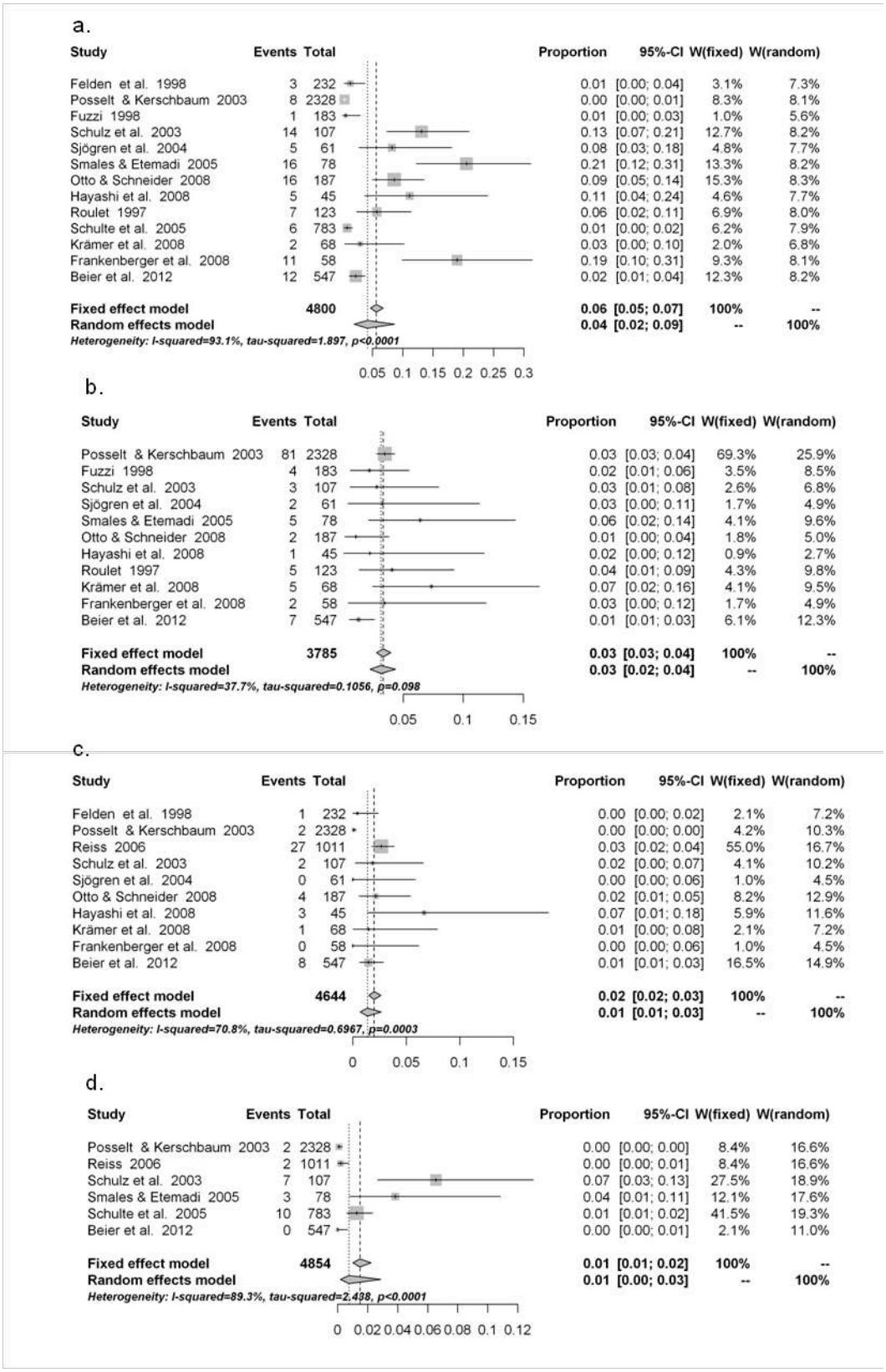

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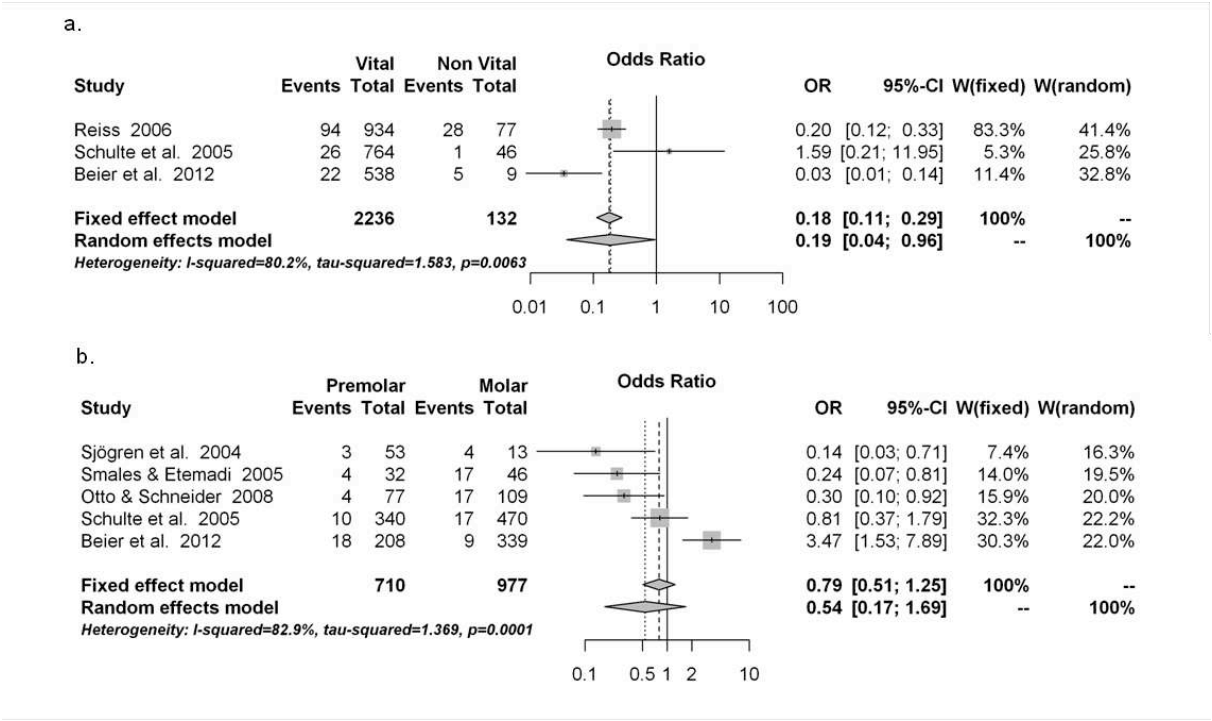

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Author	Year	Material	Language	Country	Inclusion period	Evaluation criteria	Follow up period (y)	Setting/ operator	Age range (y)	N patients	Drop out (%)	Study	N inlays/onlays/ overlays	Survival (%)
Beier et al.	2012	Glass-ceramic	English	Austria	1987-2009	CDA/Ryge	12y[a] 20y[b]	University / 2 op	14 - 72	120	0	RC	213[a]/334[B]	92.4[a]/81.5[b]
Frankenberger et al.	2008	Glass-ceramic	English	Germany	ns	modified USPHS	12y	University / 6 op	20-57	34/26	23.5	PC	96/58	86
Krämer et al.	2008	Glass-ceramic	English	Germany	ns	modified USPHS	8y	University / 6 op	24-54	31/ 23	25.8	PC	94/68	90
Otto & Schneider	2008	Feldspathic porcelain	English	Switzerland	1989-1991	modified USPHS	17 (16 y 11 m)	Private / 1 op	17-75	108/89	17.59	RC	200/187	88.7
Reiss	2006	Feldspathic porcelain / Glass-ceramic	English	Germany	1987-1990	CDA/Ryge	18.3 y	Private / ns op	12-70	299	0	RC	1011	89
Schulte et al.	2005	Glass-ceramic	English	Germany	1993-2002	ns	9.6 y	University / 244 op	17-64	434/390	10.13	RC	810/783	90
Smales & Etemadi	2004	Feldspathic porcelain	English	Australia	1988-1995	ns	6 y	Private / 2 op	15->50	50	0	RC	78	60.5 +- 6.3
Sjögren et al.	2004	Feldspathic porcelain	English	Sweden	ns	modified USPHS	10 y	University / 3 op	26-73	27/25	7.4	RCT	66/61	89
Schulz et al.	2003	Feldspathic porcelain	English	Sweden	1988-1997	CDA/Ryge	9 y	Private / 1 op	28-79	52/51	1.92	RC	109/107	84
Posselt & Kerschbaum	2003	Ceramics (ns)	English	Germany	1990-1999	ns	9.1 y	Particular ns op	17-75.7	794	ns	RC	2328	95.5
Hayashi et al.	2000	Feldspathic porcelain	English	Japan	1990-1991	modified USPHS	8 y	University / ns op	ns	29/25	13.79	RC	49/45	80
Felden et al.	1998	Feldspathic porcelain / Glass-ceramic	English	Germany	1988-1994	modified USPHS	6.5 y	University / 5 op	17-66	92	0	RC	287	98
Fuzzi & Rappelli.	1998	Feldspathic porcelain	English	Italy	1986-1996	modified USPHS	10 y	Private / 1 op	21-58	67	0	RC	183	97
Roulet	1997	Glass-ceramic	English	Germany	ns	modified	6 y	University	ns	30/29	3.33	RC	137/123	76