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SYSTEMATIC REVIEW

Clinical performance of direct composite resin versus indirect restorations on endodontically treated posterior teeth: A systematic review and meta-analysis

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ABSTRACT

Statement of problem. High-level evidence concerning the restoration of endodontically treated posterior teeth by means of direct composite resin or indirect restorations is lacking.

Purpose. The purpose of this systematic review and meta-analysis was to analyze the current literature on the direct and indirect restoration of endodontically treated posterior teeth.

Material and methods. Databases MEDLINE, CENTRAL, and EMBASE were screened. Risk of bias was assessed by using the ROB2 tool for RCTs and the ROBINS-I tool for prospective and retrospective clinical studies. Randomized clinical trials (RCTs) and prospective and retrospective studies comparing direct composite resin and indirect restorations on endodontically treated posterior teeth were included. Outcomes were tooth and restoration survival. A meta-analysis was conducted for tooth retention and restorative success.

Results. Twenty-two studies were included (2 RCTs, 3 prospective, and 17 retrospective). Over the short term (2.5 to 3 years), low-quality evidence suggested no difference in tooth survival. For the prospective and retrospective clinical trials, the overall risk of bias was serious to critical from the risk of confounding because of a difference in restorative indication: Direct restorations were fabricated when one marginal ridge remained or when tooth prognosis was unfavorable. For short-term restorative success, low-quality evidence suggested no difference between the direct and indirect restorations.

Conclusions. For the short term (2.5 to 3 years), low-quality evidence suggests no difference in tooth survival or restoration quality. To assess the influence of the type of restoration on the survival and restorative success of endodontically treated posterior teeth, clinical trials that control for the amount of coronal tooth tissue and other baseline characteristics are needed. (J Prosthet Dent 2023;130:295-306)

High-level clinical evidence concerning the restoration of endodontically treated teeth is scarce.[1,2] Several operator-, patient-, tooth-, and technique-related variables affect the survival of endodontically treated posterior teeth, with the type of restoration reported to be an important determinant.[1-3] Endodontically treated posterior teeth can be restored by using either a direct composite resin or an indirect restoration, each with advantages and disadvantages. A direct composite resin restoration can be fabricated in a single appointment, with no to minimal removal of tooth tissue and is a less expensive option. An indirect restoration can be made from a material that is more rigid and can be fabricated outside the oral cavity and therefore with greater control over anatomy.[3]

Previous systematic reviews have compared direct and indirect restorations on endodontically treated

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Clinical Implications

For the short term (2.5 to 3 years), low-quality evidence suggests no difference in tooth survival or restoration quality for direct composite resin or indirect restorations on endodontically treated posterior teeth.

teeth[1,2,4]; however, these systematic reviews clustered amalgam and composite resin restorations. More recently, endodontically treated teeth have typically been restored by using adhesive as opposed to nonadhesive restorations,[3,5-7] and endodontically treated posterior teeth seem more prone to complications resulting in loss of the restoration or the tooth.[8-10] However, tooth types are often clustered in clinical studies, which hinders a valid comparison between direct composite resin and indirect restorations.[1,2]

Therefore, the objective of this systematic review and meta-analysis was to analyze the current literature on the direct and indirect restoration of endodontically treated posterior teeth. The null hypotheses were that no difference in tooth survival would be found between direct composite resin and indirect restorations on endodontically treated posterior teeth and that no difference would be found in restorative success between the 2 treatment options.

MATERIAL AND METHODS

To compare direct and indirect restorations on endodontically treated teeth, the search strategy was based on the following patient, intervention, comparison, outcome (PICO) question: What is the difference in clinical performance (O) between direct (C) and indirect restorations (I) for the restoration of endodontically treated teeth (P)? Databases MEDLINE/PubMed, CENTRAL, and EMBASE were searched by using search strings to identify relevant literature (Table 1).

Inclusion criteria were randomized, prospective, and retrospective clinical trials comparing both direct composite resin and indirect restorations, published since 2000. References from systematic reviews were assessed for eligibility and used to identify relevant literature that was not included via the search string. Case reports, comparisons not between direct and indirect restorations, survey studies, in vitro studies, studies about anterior teeth, and articles in languages other than English, German, or Dutch or published before 2000 were excluded. Transparent reporting of systematic reviews and meta-analyses (PRISMA) guidelines was followed (Supplementary Table 1, available online).

Table 1. Search strings

Database	Search String
MEDLINE	*("Composite Resins"[Mesh] OR "direct"[tiab]) AND ("indirect"[tiab] OR "Computer-Aided Design"[Mesh] OR "computer-aided design/ manufacturing" OR "Crowns"[Mesh] OR "Inlays"[Mesh] OR "Dental Porcelain"[Mesh] OR "adhesive restoration"[tiab] OR "bonded"[tiab] OR "endocrown"[tiab] OR "partial") AND ("Tooth, Nonvital"[Mesh] OR "pulpless t*"[tiab] OR "root-filled"[tiab]). Run data search: December 6,2020 (546 results)*
EMBASE	*('pulpless teeth' OR 'nonvital tooth' OR 'nonvital teeth' OR 'endodontically treated' OR 'root canal treated') AND ('composite restoration*' OR 'direct restoration*' OR 'resin'/exp) AND ('tooth crown'/ exp OR 'indirect restoration*' OR 'partial restoration*' OR 'dental inlay'/ exp OR 'computer aided design/computer aided manufacturing'/exp OR "endocrown*' OR 'dental porcelain'/exp). Run data search: December 6, 2020 (701 results)*
CENTRAL	*#1 'direct restoration:ti,ab,kw', #2 'indirect restoration:ti,ab,kw', #3 'Tooth, Nonvital', #4 '#1 AND #2 AND #3'. Run data search: December 6, 2020 (10 results).*

Two reviewers (M.C.F.M.d.K., M.M.G.) independently screened the titles and abstracts for eligible articles. If eligible aspects were present in the title, the article was selected for further reading. If not, the abstract and keywords were read in detail. After selection, the 2 reviewers read the full text of the articles in detail. Any disagreement was resolved by additional discussion. If disagreement persisted, the judgment of a third reviewer (M.S.C.) was decisive. The articles that fulfilled all selection criteria were processed for data extraction. Data considering the number of extractions and restorative failures were extracted by using a predefined format by an author (M.C.F.M.d.K.). If possible, only data for posterior composite resin and indirect restorations were collected. For those articles that provided insufficient data to be included in the analysis, the first and/or corresponding author was contacted to obtain additional data.

For randomized clinical trials, risk of bias was assessed by using the ROB2 tool.[11] Because of the different nature of the type of restoration (direct or indirect), blinding of personnel and patients was not considered to lower the quality of the study in RCTs. The randomization process, however, was assessed. Performance bias was assessed as low, when a researcher other than the clinician was responsible for the randomization. If the clinician was responsible for this, it was scored as "some concerns." When no randomization procedure was described, it was scored as "high risk." When a researcher other than the clinician evaluated the restoration, detection bias was scored as "low risk." Otherwise, the detection bias was scored as "high risk." For prospective and retrospective cohort studies, risk of bias was evaluated by using the ROBINS-I tool.[12] A target RCT was specified to assess whether the included observational studies could be related to the target RCT. The PICO for the target RCT was the same as that specified previously. Bias because of confounding,

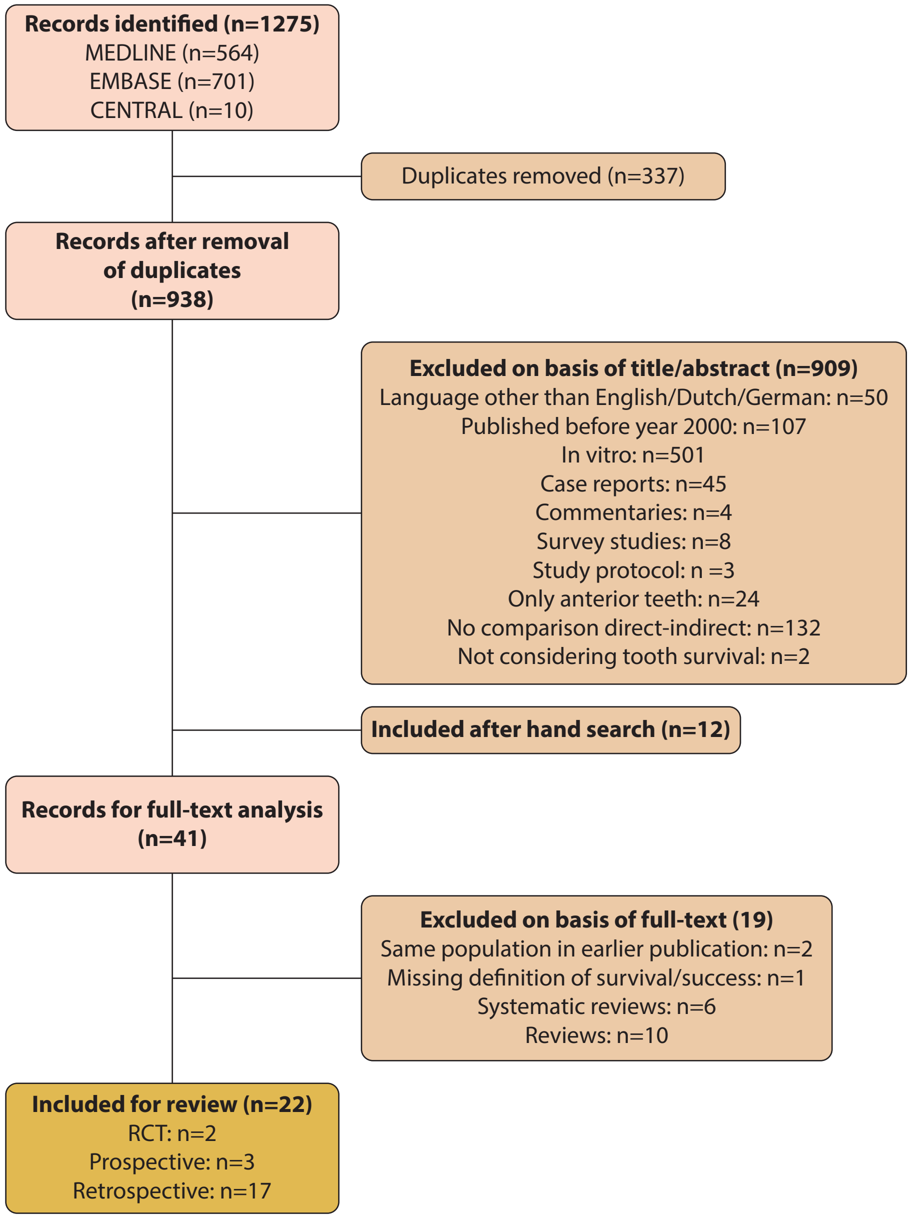

Figure 1. Flow chart inclusion process for literature concerning direct versus indirect restoration of endodontically treated posterior teeth. RCT, randomized clinical trial.

selection of the participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported results was assessed (from low to critical risk). A relevant confounder was the indication for an indirect or direct restoration from the amount of coronal structure or tooth prognosis. When no statement was made about the indication, the study was assessed as "critical risk." When it was described, the risk was scored as "serious" when there was a clear difference in coronal structure. Otherwise, the risk was scored as "moderate" or "low," according to the balance of cointerventions. The presence of a post was considered a relevant cointervention. When the type of direct restoratives included materials other than composite resin (such as amalgam or glass ionomer) and it was not possible to extract data only for the composite resin groups, bias due to classification of interventions was considered "serious." For the short-term studies (up to 5 years follow-up), risk of nonadherence to the intended intervention (direct or indirect restoration) was considered "low." For example, when a tooth was restored with a direct restoration after endodontic treatment, the chance of receiving an indirect restoration because of further coronal destruction will probably increase in time. For medium-term studies (≥7 years), this risk was therefore

Table 2. Characteristics of included studies comparing direct/indirect restorations

Study	Study Population	No. of Teeth	No. of Patients	Tooth Type (%)	Loss to Follow-up	No. of Extractions	ETx	Use of Post (%)	Follow-up (y)
RCT	—	—	—	—	—	—	—	—	—
—	ET premolar teeth with class II defect	117	117	P: 117 (100%)	12 (10%)	0 (0%)	1st	No: 0 (0%) Yes: 117 (100%) Type: carbon fiber	3
Skupien et al, 2016[17]	ET treated teeth in university setting 2009-2014	57	47	A: 14 (25%) P: 21 (37%) M: 22 (38%)	0 (0%)	1 (2%)	-	No: 0 (0%) Yes: 57 (100%) Type: glass fiber	Mean 2.5 (range 1-4)
Prospective	—	—	—	—	—	—	—	—	—
Salvi et al, 2007[18]	ET teeth with or without post-core specialist practice	325	183	A: 48 (15%) P: 81 (25%) M: 179 (55%)	17 (5%)	19 (6%)	1st 2nd	No: 60 (19%) Yes: 248 (81%) Type: prefabricated titanium, cast post-and-core	Mean 5.2 (SD 1.9; range 2-11.5)
Cagidiaco et al, 2007[19]	ET treated teeth university setting 2003	162	150	A: 57 (35%) P/M: 105 (65%)	0 (0%)	0 (0%)	1st 2nd	No: 0 (0%) Yes: 162 (100%) Glass fiber	2 y
Ng et al, 2011[20]	ET treated and retreated by postgraduate students 1997-2005	1617	1617	A: 509 (31%) P: 286 (18%) M: 821 (51%)	-	76 (5%)	1st: 47% 2nd: 53%	No: 1426 (88%) Yes: 191 (12%) Type: -	4
Retrospective	—	—	—	—	—	—	—	—	—
Lazarski et al, 2001[21]	ET teeth in dental plan Washington Dental Service 1993-1998	44 613	33 002	A: 8087 (18%) P: 12 355 (28%) M: 24 171 (54%)	-	2484 (6%)	1st	No. of treatments not clearly defined Type: -	Mean 3.5 (range 2-6)
Aquilino et al, 2002[22]	ET teeth in University of Iowa College of Dentistry 1985-1987	203	156	A: 58 (29%) P: 72 (35%) M: 73 (36%)	-	42 (21%)	1st	No: 108 (53%) Yes: 95 (47%) Type: cast post-and-core, prefabricated metal	10
Lynch et al, 2004[28]	ET teeth in university setting 1993-1996	176	166	A: 86 (49%) P: 52 (30%) M: 38 (21%)	-	40 (23%)	-	-	Mean 3 (range 1-5)
Salehrabi et al, 2004[8]	ET teeth in insurance database 1995-2002	1 462 936	-	A: 309 979 (21%) P: 390 343 (27%) M: 762 614 (52%)	-	42 190 (3%)	1st 2nd	-	8
Tickle et al, 2008[29]	ET molars insurance database 1998-2003	174	174	M: 174 (100%)	-	15 (9%)	-	-	Mean 3.5 (SD 3.5; range 0-7.7)
Dammaschke et al, 2013[30]	ET treated posterior teeth in university setting 1991-2000	676	676	P: 321 (47%) M: 355 (53%)	-	93 (14%)	-	No: 374 (55%) Yes: 302 (45%) Type: cast post-and-cores, prefabricated metal	Mean 9.7 (SD 2.8; range 5-13)
Lucarotti et al, 2014[31]	ET treated teeth insurance database 1991-2001	30 073	-	A: 8506 (28%) P: 10 725 (36%) M: 10 842 (36%)	-	Event first new treatment, no number extractions specified	-	-	11
Skupien et al, 2013[32]	ET treated teeth in private practice 2000-2011	795	458	A: 163 (21%) P: 255 (32%) M: 377 (47%)	-	45 (6%)	-	No: 686 (86%) Yes: 109 (14%) Type: -	Mean 4.5 (range 0-9.6)
Pratt et al, 2016[36]	ET treated (pre)molars in university setting 2008-2016	882	880	P: 116 (26%) M: 325 (74%)	-	105 (12%)	-	No: 139 (32%) Yes: 302 (68%) Type: fiber post	8
Dawson et al, 2017[33]	ET treated teeth insurance database 2009	248 299	217 047	A: 51 493 (21%) P: 70 484 (28%) M: 126 323 (51%)	-	22 939 (9%)	1st	-	5
Guldener et al, 2017[34]	ET treated teeth in specialist practice	144	100	A: 38 (26%) P: 40 (28%) M: 66 (46%)	18 (13%)	15 (10%)	1st 2nd	No: 106 (74%) Yes: 38 (26%) Type: glass fiber	Mean 8.8 (SD 2.3; range 5-15)
Pirani et al, 2018[23]	ET treated teeth in university setting 2008-2010	213	94	A: 40 (19%) P: 65 (31%) M: 108 (50%)	-	26 (12%)	1st 2nd	No: 166 (78%) Yes: 47 (22%)	5
Pirani et al-2, 2018[35]	ET retreated teeth in university setting 2009-2011	132	81	A: 11 (8%) P: 49 (37%) M: 72 (55%)	-	27 (20%)	2nd	No: 99 (75%) Yes: 33 (25%) Type: prefabricated metal, glass fiber	5
Jirathanyanatt et al, 2019[24]	ET treated (pre)molars in university clinic 2012-2016	226	226	P: 122 (54%) M: 104 (46%)	-	12 (5%)	-	No: 141 (62%) Yes: 85 (38%)	3-5

(*continued on next page*)

Table 2. (*Continued*) Characteristics of included studies comparing direct/indirect restorations

Study	Study Population	No. of Teeth	No. of Patients	Tooth Type (%)	Loss to Follow-up	No. of Extractions	ETx	Use of Post (%)	Follow-up (y)
								*Only posts in indirect restorations. Type: cast post, glass fiber	
Pirani et al, 2019[25]	ET treated teeth in university setting 2006-2008	206	89	A: 41 (20%) P: 59 (29%) M: 106 (51%)	-	27 (13%)	1st: 71% 2nd: 29%	No: 147 (71%) Yes: 59 (29%)	10
Stenhagen et al, 2020[26]	ET treated (pre)molars in university clinic 2007-2010	347	87	P: 60 (17%) M: 67 (19%)	220 (64%)	4 (3%)	1st	-	Mean: 7.3 (range 3.5-8.7)
Sadaf et al, 2020[27]	ET treated by students 2010-2018	4012	3863	A: 1309 (33%) P: 1055 (26%) M: 1648 (41%)	-	2800 (70%)	1st	-	8

*Based on baseline risk. -, missing data; A, anterior; ET, endodontically treated; M, molars; P, premolars; SC, single crown; SD, standard deviation.

considered "moderate." Risk of bias was assessed the same for the outcome tooth survival and restorative success. The grading of recommendations assessment, development, and evaluation (GRADE) system was used to appraise the evidence emerging from this review.[13] Three reviewers (M.C.F.M.d.K., M.M.G., M.S.C.) rated the body of evidence; any disagreement was resolved by discussion.

Characteristics and extracted data of the included studies were presented. For the meta-analysis, a software program (Review Manager, v5.4.1; The Cochrane Collaboration)[14] was used to estimate the odds ratio (OR; Mantel-Haenszel method[15]; random-effects model) and 95% confidence intervals (CI). To assess the validity of pooling the studies in the meta-analysis, heterogeneity between studies was expressed by using the I2 statistic, by using the thresholds as stated in the Cochrane handbook: 0% to 40% might not be important, 30% to 60% moderate, 50% to 90% substantial, and 75% to 100% considerable heterogeneity. When specified, only data concerning posterior teeth were extracted, and only studies with a clear description of posterior composite resin and indirect restorations were included in the meta-analysis (α=.05).

RESULTS

An overview of the inclusion process is depicted in Figure 1. Characteristics of the included studies are presented in Tables 2 and 3. A total of 22 studies met the inclusion criteria, which consisted of 2 RCTs,[16,17] 3 prospective,[18-20] and 17 retrospective studies.[21-35] The number of included teeth varied from 57 to 1 462 936 (median 220). Mean follow-up time varied from short term (2 to 5 years) for 13 studies[16,21,23,24,28,29,32,33,35] and medium term (7.3 to 11 years) for 9 studies.[8,22,25,27,30,31,34,36] Five studies[8,21,29,31,33] obtained data from an insurance or national dental health database, 14 from a university setting,[16,17,19,22,28,30,35,36] and 3 from a private practice.[18,32,34] In 6 studies,[20,22,29,31,36] the number of extracted teeth restored with direct composite resin was not specified. Instead, direct composite resin was listed with other direct restorative materials, such as amalgam or glass ionomer. Most of the indirect restorations were complete crowns. Only 2 studies included partial restorations: 24 gold partial crowns and 69 inlays.[30,32] Cementation procedure was described in 8 studies: using polycarboxylate,[23,25,35] zinc phosphate,[16,26] glass ionomer,[18,26] or a self-adhesive resin cement.[17,24] A post was used in the restoration of the endodontically treated teeth in 13 studies, varying from 12% to 100% (median 46%) of the restorations.[16,20,22,25,30,32,34-36] For the remaining studies, the proportion of posts was not described. The proportion of posterior teeth ranged from to 51% to 100% (median 79.5%). Six studies considered posterior teeth exclusively.[16,24,26,29,30,36] Additionally, data extraction for posterior composite resin and indirect restorations was possible for 5 studies.[8,17,19,28,31] Of the remaining 11 studies, data extraction for posterior composite resin and indirect restorations was not possible.[18,20,23,25,27,32-35]

Both short-term RCTs had some concerns considering risk for the outcome of tooth retention (Fig. 2). One RCT only included endodontically treated premolars with 1 missing marginal ridge, which were restored with a fiber post and composite resin restoration or a metal-ceramic crown with a fiber post foundation.[16] No teeth were extracted at recall after 3 years. The other RCT included both anterior and posterior endodontically treated teeth restored with composite resin or a metal-ceramic crown.[17] A larger proportion of the composite resin restorations were teeth with 3 to 4 remaining walls (25% versus 11%). One vertical root fracture of a mandibular molar was reported in the composite resin group. No significant difference between the restorations was found for tooth retention. Risk of bias summaries for the

Table 3. Overview of outcomes for tooth retention and restorative success comparing direct with indirect restorations

Study	Direct vs Indirect: Tooth Retention	Definition Restorative Failure	Direct vs Indirect: Restorative Success
RCT	—	—	—
Mannocci et al, 2002[16]	No difference after 3 y • Composite resin (premolars): 0/53 • SC (premolars): 0/54	VRF, post fracture/debonding, marginal gap, secondary caries	No difference (Newman-Keuls test; *P*>.050) • Composite resin (premolars): 4/53 (1 post debonding, 3 marginal gaps) • SC (premolars): 3/54 (2 post debonding, 1 marginal gap)
Skupien et al, 2016[a],[17]	No difference (Log-rank; *P*=.034) • Composite resin (posterior): 1/26 (VRF, molar) • SC (posterior): 0/17	FDI score $\geq$ 4	Significantly more restorative failures composite (Log-rank; *P*=.020) • Composite resin (posterior): 7/26 (1 VRF, 6 fractures) • SC (posterior): 1/17 (-)
Prospective	—	—	—
Salvi et al, 2007[18]	No difference (chi-square; *P*>.050) • Composite resin: 10/148 • SC (MC): 7/112	Technical and biological complications	No difference (chi-square; *P*>.050) • Composite resin: 15/148 (10 extractions, 5 restorative failures) • SC (MC): 16/112 (7 extractions, 9 restorative failures)
Cagidiaco et al, 2007[19]	No difference after 2 years • Composite resin (posterior): 0/19 • SC (posterior): 0/86	VRF, post fracture or debonding, failure core	No difference (logistic regression; *P*>.050) • Composite resin (posterior): 0/19 • SC (posterior): 5/86 (post debonds)
Ng et al, 2011[20]	Significant higher survival for cast restoration (Cox regression; HR 0.38 [95% CI: 0.22-0.64]) • Direct: 47/716 • SC: 29/901	-	-
Retrospective	—	—	—
Lazarski et al, 2001[21]	Direct restoration significantly associated with extraction (chi-square; *P*<.001) • Direct: 294/4684 • SC: 466/18 365	-	-
Aquilino et al, 2002[b],[22]	Increased risk extraction for direct restorations (Cox regression; HR 6.0 [95% CI: 3.2-11.2]). • Composite resin (posterior): 1/4 • SC (posterior): 17/139	-	-
Lynch et al, 2004[28]	No difference between composite and cast restorations (Fisher exact test; *P*>.05) • Composite resin (premolars): 1/5 • SC (premolars): 0/13	-	-
Salehrabi et al, 2004[8]	Direct restoration significantly associated with extraction (chi-square; *P*<.001) • Direct (posterior): 29 132 • SC (posterior): 4932	-	-
Tickle et al, 2008[29]	Increased risk extraction for direct restorations (Log-rank; *P*<.001). • Direct: 15/107 • SC: 0/67	-	-
Dammaschke et al, 2013[30]	No difference between composite, prefab post+crown, individual post+crown and gold partial crown (Log-rank; *P*=.520, *P*=.120, *P*=.140) • Composite (posterior): 3/37 • SC (posterior): 12/147	-	-
Lucarotti et al, 2014[31]	-	New treatment on ET tooth.	Higher success rate for crowns 10 y after placement. • Direct: premolars 34% (SE: 1.1%), molars 34% (SE: 1.1%) • SC: premolars 57% (SE 2.0%), molars 60% (SE: 2.6%)
Skupien et al, 2013[32]	No significant difference between composite resin, new crowns, and inlays (Cox regression; *P*>.050) • Composite: 9/376 • SC: 18/307	Repair or replacement of restoration or tooth extraction	No significant difference (Cox regression; *P*>.050) • Composite resin: 46/376 • SC: 40/307
Pratt et al, 2016[36]	Increased risk extraction for direct restorations (Cox regression; *P*<.001). • Direct restoration: 23/198 • SC: 25/441	-	-
Dawson et al, 2017[b],[33]	Direct restoration significantly associated with extraction (chi-square; *P*<.001) • Composite resin: 13 667/143 295 • SC: 2786/55 974	Additional direct or indirect restoration.	More reinterventions for direct composite resin ET teeth (chi-square; *P*<.001) • Composite: 43 363/143 295 • SC: 3594/55 974
Guldener et al, 2017[34]	No difference (chi-square; *P*=.390) • Composite resin: 12/98 • SC: 3/46	Technical and biological complications	No significant difference (chi-square; *P*=.180) • Composite resin: 23/98 • SC: 6/46

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Table 3. (*Continued*) Overview of outcomes for tooth retention and restorative success comparing direct with indirect restorations

Study	Direct vs Indirect: Tooth Retention	Definition Restorative Failure	Direct vs Indirect: Restorative Success
Pirani et al, 2018[23]	No significant difference (chi-square; P=.800). • Composite resin: 17/144 • SC: 9/69	-	-
Pirani et al, 2018-2[35]	Risk of extraction increased for direct (multilevel model; P<.001, β=-1.2 [95% CI: -2.0; -0.3]) • Composite resin: 11/28 • SC: 16/104	-	-
Jirathanyanatt et al, 2019[24]	No significant difference in unrestorable fractures (Log-rank; P>.050). • Composite resin (posterior): 5/124 • SC (posterior): 7/102	Fracture of tooth (restorable/ unrestorable)	More risk of fracture for composite resin (Cox regression; P=.010, HR 3.9 [95% CI: 1.8-8.7]). • Composite resin (posterior): 28/124 • SC (posterior): 8/102
Pirani et al, 2019[25]	No significant difference (chi-square; P=.220) • Composite: 6/67 • SC: 21/139	-	-
Stenhagen et al, 2020[26]	No significant difference (chi-square; P>.05) • Composite (posterior): 2/60 • SC (posterior): 2/56	Repair or replacement of the restoration or tooth extraction	More reinterventions for composite resin (chi-square; P<.001) • Composite resin (posterior): 22/60 • SC (posterior): 5/56
Sadaf et al, 2020[27]	Risk of tooth extraction increased for indirectly restored teeth (Cox regression; P<.001) • Composite resin: 431/650 • SC: 2369/3362	-	-

-, missing data; ET, endodontically treated; FDI, World Dental Federation; HR, hazard ratio; MC, metal-ceramic; SC, single crown; SE, standard error; VRF, vertical root fracture. [a]Data provided by author. [b]Data provided by author, but no specific data available for restorative success.

prospective and retrospective studies are given in Figure 3. Nine studies were scored as "critical risk," primarily because of confounding on tooth prognosis as compared with the target RCT.[8,20,22,28,29,31,33,36] In these studies, assessment of the indication for an indirect or a direct restoration was not possible. Eleven studies were considered "serious risk."[18,19,23,27,30,32,34,35] Although the risk of confounding was high, the studies described the indication for an indirect or a direct restoration. Of these studies,[23,25,27,30,32,35] teeth with severe coronal destruction (loss of 2 marginal ridges) received a complete crown more often than teeth with less coronal destruction (1 remaining marginal ridge). In the other studies,[24,26,34] direct composites resins were more often fabricated for teeth with an uncertain prognosis. For meta-analysis on short-term tooth retention, clustered data of the two RCTs showed no difference in the odds for tooth retention (OR=2.06 [95% CI: 0.08-53.52]; P=.66; Fig. 4). For the observational studies, no meta-analysis was possible. Four of 5 studies with serious risk of bias[18,23,32,35] were excluded because it was not possible to extract data for posterior restorations. In 1 retrospective study,[24] no difference was found after 5 years between direct composite resin and complete contour crowns on endodontically treated posterior teeth, even though direct composite resin restorations were fabricated on teeth with a less favorable prognosis or when the patient could not afford an indirect restoration. Quality of the evidence for short-term tooth survival was low (Table 4).

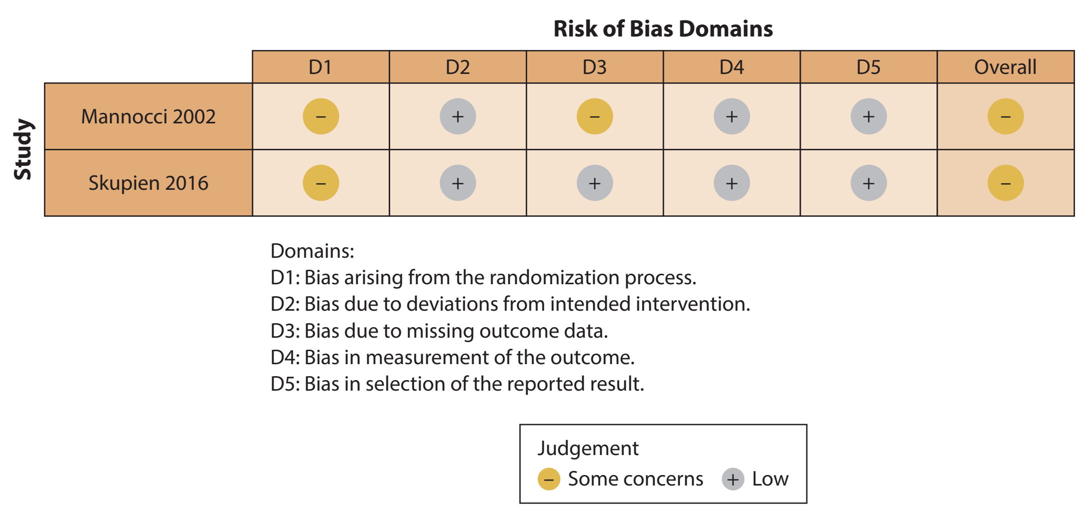

Figure 2. Risk of bias (RoB) assessment for randomized clinical trials.

Risk of Bias Domains

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Lazarski 2001	!	+	X	X	+	+	+	!
Aquilino 2002	!	+	X	X	–	+	+	!
Salehrabi 2004	!	+	X	X	+	+	–	!
Lynch 2004	!	+	–	X	–	+	–	!
Salvi 2007	X	+	+	+	+	+	+	X
Cagidiaco 2007	X	+	+	+	+	+	+	X
Tickle 2008	!	–	X	–	X	–	X	!
Ng 2011	!	+	X	+	–	+	+	!
Dammaschke 2013	X	–	+	–	X	+	+	X
Skupien 2013	X	–	+	+	–	+	+	X
Lucarotti 2014	!	+	X	–	+	+	+	!
Pratt 2016	!	+	X	–	–	+	+	!
Dawson 2017	!	+	+	–	+	+	+	!
Guldener 2017	X	–	+	–	X	+	–	X
Pirani 2018	X	–	+	–	X	+	+	X
Pirani 2018-2	X	–	+	–	X	+	+	X
Jirathanyanatt 2019	X	X	+	X	X	+	+	X
Pirani 2019	X	X	+	X	X	+	+	X
Sadaf 2020	X	–	+	–	–	+	+	X
Stenhagen 2020	X	X	+	–	X	–	+	X

Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

Judgement
! Critical X Serious – Moderate + Low

Figure 3. Risk of bias (ROBINS-1) assessment for prospective and retrospective studies.

Study or Subgroup	Direct Events	Direct Total	Indirect Events	Indirect Total	Weight	Odds Ratio M-H, Random, 95% CI	Year
Mannocci et al, 2002	0	60	0	57		Not estimable	2002
Skupien et al, 2016	1	26	0	17	100.0%	2.06 [0.08, 53.52]	2016
Total (95% CI)		**86**		**74**	**100.0%**	**2.06 [0.08, 53.52]**	
Total events	1		0				
Heterogeneity: Not applicable							
Test for overall effect: Z=0.43 (*P*=.660)							

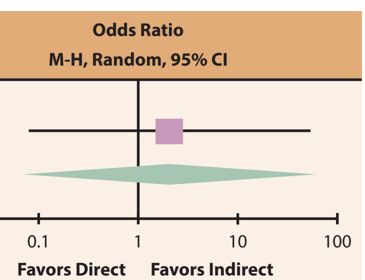

Figure 4. Forest plot for short-term odds of tooth retention (3 years) between direct composite resin and indirect restorations clustered for randomized clinical trials.

Table 4. GRADE summary of findings table for short-term tooth survival

Patient or Population: Patients With Endodontically Treated Posterior teeth Intervention: Direct Composite Restoration Comparison: Indirect Restoration Outcome: Tooth Survival					
Outcomes	**Absolute Effect Direct Restorations**	**Absolute Effect* Indirect Restorations**	**Relative Effect (95% CI)**	**No. of Participants (Studies)**	**Quality of the Evidence (GRADE)**
Short-term survival Mean follow-up: 2.5-3 y	0/1000	0/1000	2.06 (0.08-53.52)	150 (2 studies)	⊕⊕○○ LOW[1,2,3]

GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: The estimate is very uncertain.

1. All studies randomized clinical trials, starting from high quality level of evidence.
2. In the study by Skupien et al, 2016,[17] more composite resin restorations made on teeth with 3 or 4 remaining walls. Evidence downgraded by 1 level.
3. Risk of imprecision high because of limited number of patients and events. Evidence downgraded by 1 level.

*Based on baseline risk.

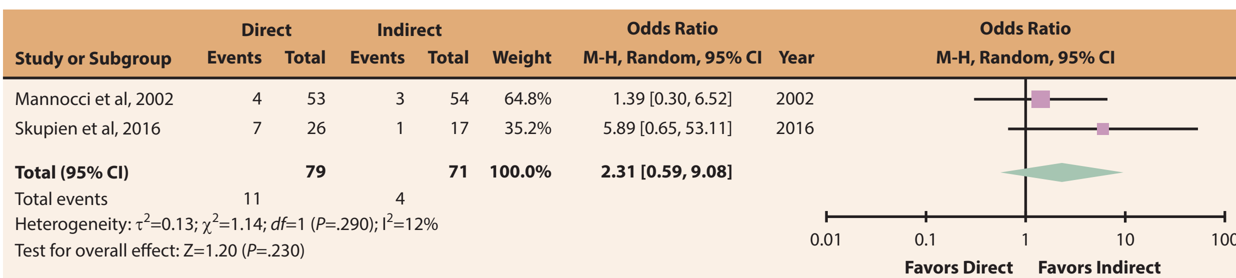

Figure 5. Forest plot for short-term odds of restorative success (3 years) between direct composite resin and indirect restorations clustered for randomized clinical trials.

One RCT[16] reported no significant difference in restorative success, with a nearly equal proportion of postcementation failures and marginal gaps in both types of restorations. All restorative failures were repairable. However, restorative success was lower for composite resin restorations in the other RCT, mainly due to fractures.[17] All fractures were repairable. Of the prospective and retrospective studies with serious risk of bias, 6 studies described restorative success.[18,19,24,26,32,34] Of these, 3 studies did not report the failures for posterior direct composite resin and indirect restorations specifically.[18,32,34] One short-term study[19] did not find a significant difference, whereas 1 short-term study[24] (HR: 3.9 [95% CI: 1.8-8.7]) and 1 medium-term study[26] found an increased risk for reintervention for the direct composite resin restorations. In the last 2 studies, composite resin restorations were fabricated on teeth with an uncertain prognosis, whereas in the first short-term study, composite resin was more often used for teeth with loss of up to 1 marginal ridge. A forest plot of the studies on short-term restorative success clustered on the RCTs is depicted in Figure 5.[16,17] There was no significant difference in odds for restorative failure (OR=2.31 [95% CI: 0.59-9.08]; P=.29). Observed heterogeneity was low (I2=12%). Overall evidence was considered low (Table 5).

DISCUSSION

The null hypotheses that no difference in tooth survival or restorative success would be found between direct composite resin and indirect restorations on endodontically treated teeth was not rejected based on the meta-analysis. In the short term, there was no apparent difference in the odds for tooth loss for endodontically treated posterior teeth restored with either a direct composite resin or an indirect restoration. However, all longitudinal studies had a serious or critical risk of bias as compared with the target RCT, mainly because of the risk of confounding. In the studies with an overall serious risk of bias, the amount of coronal destruction and tooth prognosis determined the type of restoration received. Focusing only on the influence of the restoration type on the survival of endodontically treated teeth would therefore not be valid, and the results should be interpreted in another way. Teeth with different amounts of coronal destruction showed no difference in survival in the short term when adequately restored with either a direct composite resin or an indirect restoration, which also seems to be true for the medium-term clinical studies. However, this might also be attributed to a lack of power because of the relatively low number of failures.

Table 5. GRADE summary of findings table for short-term restorative success

Patient or Population: Patients With Endodontically Treated Posterior teeth Intervention: Direct Composite Restoration Comparison: Indirect Restoration Outcome: Restoration Survival					
Outcomes	Absolute Effect Direct Restorations (95% CI)	Absolute Effect* Indirect Restorations	Relative Effect (95% CI)	No. of Participants (Studies)	Quality of the Evidence (GRADE)
Short-term survival Mean follow-up: 2.5-3 years	56/1000 (-22-295)	120/1000	2.31 (0.59-9.08)	150 (2 studies)	⊕⊕○○ LOW[1,2]

GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: The estimate is very uncertain.

1. All studies randomized clinical trials, starting from high quality level of evidence.
2. In the study by Skupien et al, 2016,[17] more composite resin restorations made on teeth with 3 or 4 remaining walls. Evidence downgraded by 1 level.
3. Risk of imprecision high because of limited number of patients and events. Evidence downgraded by 1 level.

*Based on baseline risk.

Furthermore, longer follow-up times might also be necessary to better differentiate between the 2 treatment options.

For endodontically treated teeth, only 2 RCTs[16,17] compared direct composite resin restorations with indirect restorations. However, to assess the influence of the type of restoration on survival, baseline characteristics such as the amount of coronal tooth tissue and endodontic quality should have been controlled for. On vital teeth, no significant difference was found for the restorative success between direct and indirect cusp-covering restorations on premolars after 5 years.[37] This was also true for posterior restorations made of a direct composite resin or a glass-ceramic.[38]

Aging of direct composite resin restorations in the oral cavity occurs from hydrolysis and mechanical fatigue, and leaching of the filler-matrix interfaces can eventually lead to compromised mechanical properties. Also, incomplete polymerization might compromise the fabrication of a large composite resin restoration.[39] When comparing direct composite resin restoration on vital teeth with endodontically treated posterior teeth, more fractures of tooth tissue occurred after a period of 8 years. However, only 34.1% of cusps were covered.[40] In a retrospective study, the 5-year survival rate for severely compromised endodontically treated molars restored with direct composite resin was 18% (SE: 0.06%).[41] In contrast, when the maximum amount of tooth tissue was present (comparable to a class I cavity), the cumulative survival rate increased to 78% (SE: 0.12%). Three possible confounding factors could be responsible for this result: restoration type, cusp coverage, and patient risk factors. The analysis included both amalgam and interim restorations. In teeth with severe coronal destruction, it was not specified whether the cusps were covered. Because of the high elastic modulus of composite resin, cusp deflection might have occurred and increased the risk of an unrestorable fracture,[42] but the reasons for failure were not described. Patients with a high caries risk or parafunctional habits are more prone to loss of direct restorations than patients with a low risk.[7,43] More severely compromised molars may have been present in these high-risk patients. Therefore, the results of this study[41] should be interpreted with care. Glass-ceramic restorations age mainly from mechanical fatigue and subcritical crack growth.[44] In recent years, the use of bonded partial indirect restorations on endodontically treated posterior teeth has been reported to be favorable.[6,45] In the current systematic review, however, the majority of the indirect restorations were complete crowns or nonadhesive partial crowns. More RCTs are needed to compare adhesive direct and indirect restorations on endodontically treated teeth. A large proportion of the included studies incorporated posts in the restorations. For endodontically treated molar teeth, the use of a post might be unnecessary because of the large area available for adhesion in the pulp chamber. Endocrowns, a bonded indirect restoration with an extension in the pulp chamber, have been reported to be an adequate alternative to traditional post-and-cores for endodontically treated molars.[5,45,46]

With a paucity of clinical studies, a comparison between direct composite resin and indirect restorations for the rehabilitation of posterior endodontically treated teeth cannot be made. RCTs for endodontically treated teeth are difficult to design because of the number of factors that need to be considered, such as patient's risk profile and the quality of the endodontic treatment. Controlling for the amount of tooth structure would lead to a more valid comparison of the influence of the restoration type on tooth survival and the restorative success. However, the amount of tooth tissue cannot always be estimated beforehand because of the presence of caries, cracks, or thin walls. Furthermore, in clinical practice, the choice between a direct and indirect restoration is often influenced by the finances of the patient.

The hypotheses of this systematic review could not be rejected. To assess the influence of the type of restoration on the survival and restorative success of endodontically treated posterior teeth, clinical trials that control for the amount of coronal tooth tissue and other baseline characteristics are needed.

CONCLUSIONS

Based on the findings of this systematic review and meta-analysis, the following conclusions were drawn:

1. For the short term (2.5 to 3 years), low-quality evidence suggests no difference in tooth survival or restoration quality.
2. To assess the influence of the type of restoration on the survival and restorative success of endodontically treated posterior teeth, clinical trials that control for the amount of coronal tooth tissue and other baseline characteristics are needed.

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