REVIEW ARTICLE

Outcome of Partial Pulpotomy in Cariously Exposed Posterior Permanent Teeth: A Systematic Review and Meta-analysis

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SIGNIFICANCE

A partial pulpotomy can be considered a reliable conservative treatment option for treating cariously exposed permanent posterior teeth, presenting high success rates in different follow-up periods. Cases with the presumptive diagnosis of irreversible pulpitis presented a lower success rate and should be treated with caution.

ABSTRACT

Introduction: The current systematic review and meta-analysis aimed to evaluate the success rate of partial pulpotomy in treating permanent posterior teeth with carious vital pulp exposure. A secondary aim was to assess the prognostic factors using a meta-regression. **Methods:** An electronic search was performed for studies from January 1950 to November 2018 in the following databases: PubMed, ScienceDirect, and Cochrane. All searches were performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Clinical studies evaluating the success rate of cariously exposed vital human permanent posterior teeth treated with a partial pulpotomy were selected. Only randomized clinical trials and prospective clinical studies were included for evaluation. The Newcastle-Ottawa Scale and the Cochrane Collaboration's tool were used to evaluate risk assessment. **Results:** From the 218 studies identified through the initial search, 11 studies qualified for the final analysis (5 randomized clinical trials and 6 prospective studies). The results of the meta-analysis indicate a success rate of 98% (confidence interval [CI]: 0.94–1), 96% (CI: 0.92–0.99), and 92% (CI: 0.83–0.97) after 6 months and 1 and 2 years of follow-up. Examining the probable prognostic factors using meta-regression analysis, only preoperative pulp status ($P = .001$) was identified as a significant factor, with studies including teeth with the presumptive diagnosis of irreversible pulpitis displaying significantly lower results. The final solution, pulp capping material, apex closure, and the age of the patient did not affect the treatment success rate ($P > .05$). **Conclusions:** The available data suggest that a partial pulpotomy results in high success rates in treating cariously exposed permanent posterior teeth up to 2 years. Six months of monitoring can be considered an appropriate period when evaluating the success of a partial pulpotomy although more clinical and radiographic controls are essential to ensuring success. *(J Endod 2019;45:1296–1306.)*

KEY WORDS

Dental caries; dental pulp exposure; evidence-based dentistry; pulpitis; pulpotomy; vital pulp

According to the recommendations made at the International Caries Consensus Collaboration meeting in Leuven, Belgium, in 2015, the maintenance of pulpal health should be a primary goal in treating deep carious lesions[1]. Pulp exposure should be avoided whenever possible by adopting the less invasive approach of incomplete or selective caries removal[1]. However, even using a more conservative approach, pulp exposure is sometimes inevitable[2]. In cases in which pulp exposure is inevitable, root canal treatment (RCT) is considered as the treatment of choice because it has a considerably high success and survival rate[3,4]. Nevertheless, a more conservative approach should be considered for the management of pulp exposures in vital teeth. Vital pulp therapy treatment modalities have been introduced as an alternative to RCT. They include indirect and direct pulp capping, partial pulpotomy, and complete pulpotomy[5,6]. These techniques promote the possibility of continued tooth vitality along with functional and structural healing of the pulp-dentin complex by preserving the remaining pulp tissue[7,8]. In addition, these treatments present the opportunity for a cost-effective and less technique-sensitive

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approach when compared with RCT[9]. The choice of treatment is usually based on the presumption diagnosis of each case. However, doubts remain about the criteria that must be taken into account when choosing the optimal treatment. It has been stated that the effectiveness of healing or biological regeneration depends on the degree of inflammation of the pulp tissue[10]. In deep carious lesions, inflammation in the superficial layers of the pulp is more pronounced compared with that in the deeper layers. Despite the presence of some dilatation of the blood vessels, the pulp tissue in the root canal remains normal[10,11].

A partial pulpotomy consists of the amputation of 2–3 mm of pulp tissue below the exposed pulp. This treatment is used in cases in which the exposed pulp tissue is considered to be damaged or affected[12]. Amputating the infected tissue before capping the exposure may offer a higher chance of healing when compared with capping the affected tissue as in a direct pulp capping procedure[13,14]. In contrast, partial pulpotomy is considered a more conservative approach in comparison with complete pulpotomy. Nevertheless, a partial pulpotomy still offers the benefit of preserving the cell-rich coronal pulp, which ensures the continual deposition of cervical dentin and reduces the risk of root canal obliteration[10,15].

According to the literature, the success rate of vital pulp treatments varies widely according to the type of study[15,16]. In the case of cariously exposed pulp, it is essential to have sufficient evidence when choosing an appropriate treatment plan. Nevertheless, the literature exhibits a lack of high-degree evidence examining this treatment option, solely presenting 1 systematic review almost a decade ago[14]. Furthermore, a recent review[17] noted that it had several limitations, including pooling of the follow-up periods, inconsistent success criteria, and inclusion of different approaches for carious tissue removal such as the stepwise approach. Moreover, only 2 studies included used mineral trioxide aggregate (MTA) as the capping material. Hydraulic calcium silicate cements are often proposed as an alternative to calcium hydroxide (CH) for vital pulp therapy procedures because they induce a more rapid formation of a less porous and thicker hard tissue barrier[18,19].

The last decade has seen a considerable increase in the number of clinical studies using MTA or MTA-like cements as a pulp capping material[16,20–23], providing more cases for reevaluating the effectiveness of this treatment method. The main aim of this systematic review and meta-analysis was to evaluate the success rate of a partial pulpotomy in treating permanent posterior teeth with carious vital pulp exposure. A secondary aim was to assess the confounding prognostic factors using a meta-regression.

MATERIAL AND METHODS

The present systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses principles[24]. Population, Intervention, and Outcome items of the PICO framework were used to formulate the following clinically related question: What is the success rate of performing a partial pulpotomy in treating permanent posterior vital teeth with carious pulp exposure?

Search Strategy

The online search was conducted independently by 2 of the investigators (F.M. and J.G.O.) in the following databases: PubMed (National Center for Biotechnology Information, US National Library of Medicine), ScienceDirect (Elsevier, RELX Group, Amsterdam, Netherlands), and Cochrane (John Wiley & Sons, Ltd, London, UK). The following combination of key words was used including partial pulpotomy, miniature pulpotomy, and pulp curettage (partial[All Fields] AND ("pulpotomy"[MeSH Terms] OR "pulpotomy"[All Fields]) OR miniature[All Fields] AND ("pulpotomy"[MeSH Terms] OR "pulpotomy"[All Fields]) OR ("dental pulp"[MeSH Terms] OR ("dental"[All Fields] AND "pulp"[All Fields]) OR "dental pulp"[All Fields] OR "pulp"[All Fields]) AND ("curettage"[MeSH Terms] OR "curettage"[All Fields]). Studies published from January 1950 to November 2018 were included in the search with no language restriction. In addition, the reference lists of the selected studies were revised to find possible relevant studies, and gray literature was also searched including OpenGrey. Also, a hand search was performed in the following journals: *Journal of Dentistry*; *Journal of Endodontics*; *International Endodontic Journal*; *Australian Endodontic Journal*; and *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*. Study authors were contacted privately via e-mail whenever any doubts were encountered about the study.

Study Selection

Inclusion and Exclusion Criteria

The current review was set to select clinical studies evaluating the success rate of cariously exposed vital human permanent posterior teeth treated with a partial pulpotomy. Only randomized clinical trials and prospective clinical studies were included for evaluation. A follow-up period of a minimum of 6 months and a sample size of at least 10 teeth were required for review inclusion. A follow-up rate of a minimum of 80% was required for study inclusion. The success rate had to be available or at least calculable from the data provided. In addition, only studies that reported outcome data including pain, tenderness to palpation/percussion, and other clinical and radiographic signs of inflammation or necrosis or root resorption were included.

Data Extraction

A flow diagram of the search process was performed with the number of excluded/included articles. After the first screening and evaluation of all the articles according to title and abstract, the same 2 investigators assessed the full text for all potential studies to be included. In the event that the full-text article was not available, the authors were personally contacted by e-mail to gain access to the full-text article. An Excel spreadsheet (Microsoft Office; Microsoft, Redmond, WA) was created with the following information for each study: study design, presumption diagnosis, level of pulp amputation, pulp capping material, time of follow-up, time for hemostasis, hemostatic solution, patient's age, sex, apex status, sample size, number of dropouts, success rate, time before final restoration, and type of final restoration. The studies that did not meet the inclusion criteria, including primary teeth studies, were excluded.

Quality Assessment

The quality assessment of the selected studies was performed according to the design of each study. The Newcastle-Ottawa scale was used for risk assessment of prospective cohort studies[25]. For randomized clinical trials, the Cochrane Collaboration's tool was used[26]. In addition, the level of evidence for each study was graded using the Oxford Centre for Evidence-based Medicine levels of evidence recommendations[27]. Two investigators independently performed the risk assessment and evidence level rating (F.M. and X.F.R.). In case of disagreement, a consensus was reached by discussion with a third investigator (J.G.O).

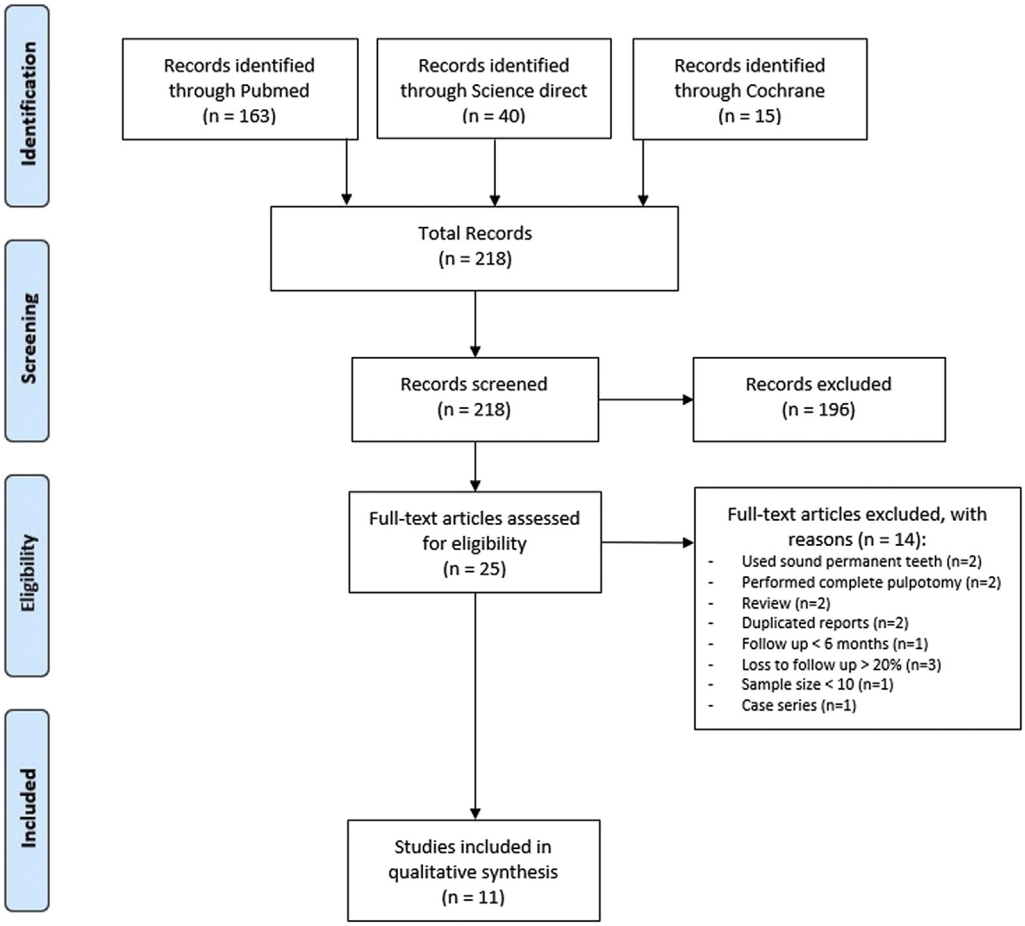

FIGURE 1 – A diagram flowchart.

Statistical Analysis and Synthesis of Results

The metafor package version 2.0 of the R software (Free Software Foundation, Boston, MA) was used for data analysis. A level of statistical significance of 5% was set. For the studies that reported raw transfer frequency data, the proportions were calculated by dividing the number of cases considered as a success among the total exposed (without taking into account the lost data). The transformation of Freeman-Tukey double arcsine was applied to stabilize the variances.

The data were analyzed for 6 months and 1 and 2 years with 2 groups according to the study design (ie, randomized clinical trial or prospective studies). The heterogeneity between studies was measured with the Cochran Q test and the value of I^2 (values of I^2 >60% were considered as significant heterogeneity). A random-effects model was conducted. Sensitivity analysis was predetermined to evaluate and isolate the effect of the results of the different studies in the global result. Meta-regression analysis was adjusted to determine if success could be modulated with prespecified factors including preoperative pulp diagnosis, final solution, pulp capping material, age, apex closure, and type of study. In case of heterogeneity, subgroup analysis was performed, and the results were visualized with a forest plot, and publication bias was evaluated with the funnel plot and Egger contrast.

TABLE 1 - The Excluded Articles and the Reason for Exclusion

Article	Reason for exclusion
Bakhtiar et al, 2017[28]	Used sound teeth
Sübay et al, 1995[29]	
Eren et al, 2017[30]	Follow-up less than 6 months
Bjørndal et al, 2017[31]	Loss to follow-up more than 20%
Asgary et al, 2018[32]	
Kang et al, 2017[22]*	
Asgary et al, 2014[33]	Case series
Awawdeh et al, 2018[34]	Performed complete pulpotomy
Nosrat et al, 2013[35]	
Bjørndal et al. 2010[36]	Duplicated reports
Zilberman et al. 1989[37]	
Nosrat & Nosrat, 1998[38]	Sample size less than 10
Mass et al, 1995[39]	Review
Janicha & Wacinska-Drapińska, 1986[40]	

*Only results at 1 year excluded.

RESULTS

Study Selection

The process of selecting the included studies is described in Figure 1. Twenty-five studies underwent full-text review. Reasons for study exclusion are presented in Table 1. Eleven

TABLE 2 - A Summary of the Included Studies

Study	Study type	Sample	Age (years) (mean±SD)	Follow-up months (mean±SD)	Pulp capping material	Restoration (*n*)	Apex (*n*)	Preoperative pulp diagnosis (*n*)
Baratieri, 1989[41]	Prospective study	25	12–44 (22.1±8.98)	8–36 (18±6.11)	CH	Amalgam	Closed	Normal/reversible
Mass, 1993[42]	Prospective study	35	7.5–25 (12.5)	12–>48	CH	Amalgam (29) SS crown (6)	Closed (26) Open (9)	Normal/reversible
Mejare, 1993[43]	Prospective study	22	6–15 (9)	24–140 (56)	CH	Amalgam Composite	Closed/open	Normal/reversible (17) Irreversible (5)
Barrieshi-Nusair, 2006[15]	Prospective study	28	7.2–13.1 (10)	12–26 (17.5)	MTA	Amalgam SS Crown	Closed (24) Open (7)	Normal/reversible
Qudeimat, 2007[44]	Randomized clinical trial	51	6.8–13.3 (10.3±1.8)	25.4–45.6 (34.8±4.4)	CH (32) MTA (32)	Amalgam (22) Composite (9) SS crown (33)	Closed (46) Open (18)	Normal/reversible
Mass, 2011[45]	Prospective study	49	6.9–17.7 (11.4)	12–154 (49)	CH	Amalgam (33) Composite (3) SS crown (13)	Closed (43) Open (6)	Normal/reversible
Chailertvanitkul, 2014[20]	Randomized clinical trial	84	7–10	3–24	CH (40) MTA (44)	Amalgam	Open	Normal/reversible
Peng, 2015[21]	Prospective study	10	6.1–15.4 (10.17±3.01)	12	MTA	Composite	Open	Irreversible
Kang, 2017[22]	Randomized clinical trial	83	(29.3±14.8)	1 to 12	MTA	Composite Indirect restoration	Closed	Normal/reversible
Özgür, 2017[23]	Randomized clinical trial	79	6–13 (8.57±1.25)	6–24 (23±3.98)	CH (40) MTA (40)	Composite	Open	Normal/reversible
Taha, 2017[16]	Randomized clinical trial	46	20–52 (30.3±9.6)	6–24	CH (23) MTA (27)	Amalgam (22) Composite (27)	Closed	Irreversible

CH, calcium hydroxide; MTA, mineral trioxide aggregate–like material; SD, standard deviation; SS, stainless steel.

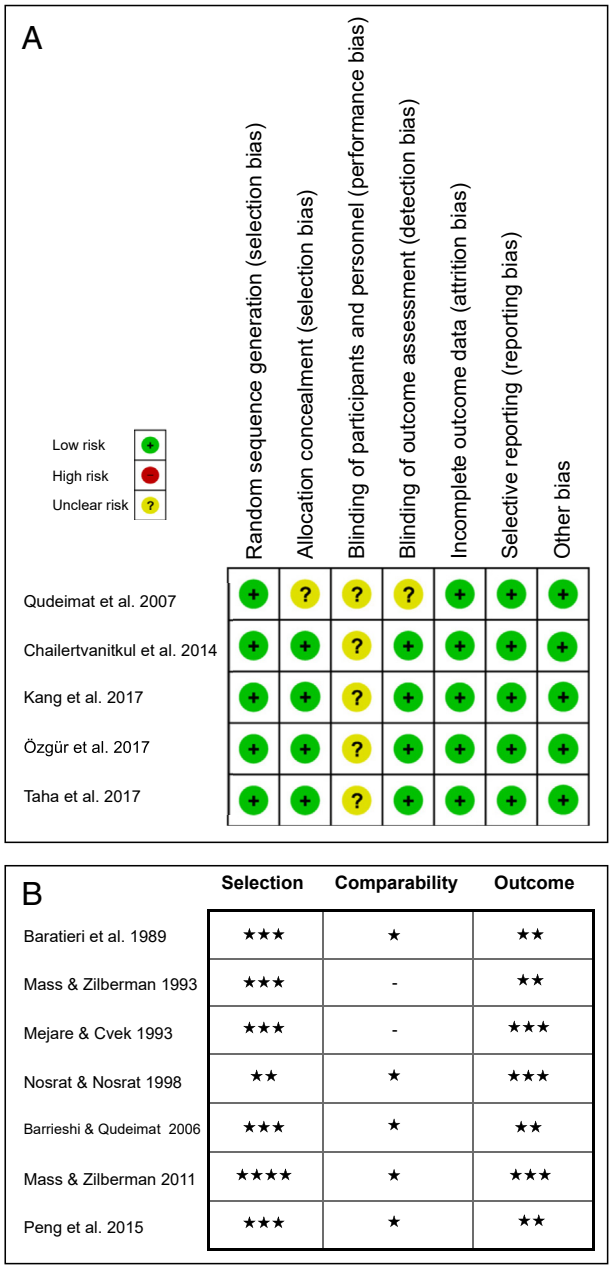

FIGURE 2 – A risk of bias summary for the different studies. (*A*) Cochrane Collaboration's tool for randomized controlled trials and (*B*) Newcastle-Ottawa quality assessment scale for cohort studies.

studies[15,16,20–23,41–45] were included in the final analysis. Table 2 presents the features of the included studies. Two investigators independently performed all the search steps and reviewed all the studies (F.M. and J.G.O.). In case of disagreement, a consensus was reached through discussion.

Quality Assessment

In general, the randomized clinical trials evaluated [16,20,22,23,44] displayed a low risk of bias in the different items evaluated (Fig. 2). In 1 study[44], allocation concealment was performed according to a table of random allocation; there is insufficient information to permit judgment whether the table was available for the operator(s) before patient selection. Thus, unclear risk was selected. Because of the treatment nature, blinding of the operators did not seem possible. Material selection could be blinded to the patient in the different studies but not the dentists who performed the procedure. Nevertheless, the primary aim of the review was to evaluate the success rate of a partial pulpotomy as a procedure and not a capping material comparison although material as a variable was further evaluated via meta-regression. In this case, the outcome was not likely influenced by the lack of operator blinding. Thus, unclear risk was selected for all included studies for this item. Regarding blinding of outcome assessment, in 1 study[44], all follow-up examinations were performed by 1 of the investigators; whether this investigator was aware of the treatment details of each patient remains unknown with the available information, and accordingly unclear risk was selected. No other biases were found across the included studies. For the Newcastle-Ottawa scale assessment, 4 studies reported a good quality[15,21,41,45] and 3 a fair quality[35,42,43] according to the Agency for Healthcare Research and Quality standards. The main reasons were regarding comparability and outcome blinding of the evaluators (Fig. 2).

Summary of Results

6-month Results

After combining the 5 randomized clinical trials[16,20,22,23,44], based on a random-effects model, the reported success rate at the 6-month follow-up was 0.96 (confidence interval [CI], 0.87–1), with significant heterogeneity across the studies (I^2 = 88.47%). For the 6 prospective studies[15,21,41–43,45], based on the random-effects model, the success rate at 6 months was 0.99 (CI, 0.97–1), with an absence of heterogeneity (I^2 = 6.48%). When combining all the studies, there was significant heterogeneity across the studies (I^2 = 72.9%). Thus, a random-effects model was used, which reported a success rate of 0.98 (CI, 0.94–1; Fig. 3).

1-year Results

The pooled rate based on a random-effects model for the 4 randomized clinical trials[16,20,23,44] was 0.94 (CI, 0.81–1), with significant heterogeneity across the studies (I^2 = 90.52% and 0.98; CI, 0.94–1) for the 6 prospective studies[15,21,41–43,45] and an absence of heterogeneity (I^2 = 4.42%). When combining all the studies, a random-effects model was used (I^2 = 72.4%), which reported a success rate of 0.96 (CI, 0.91–0.99; Fig. 3).

2-year Results

The success rate based on a random-effects model for the 4 randomized clinical trials[16,20,23,44] was 0.91 (CI, 0.76–1), with significant heterogeneity across the

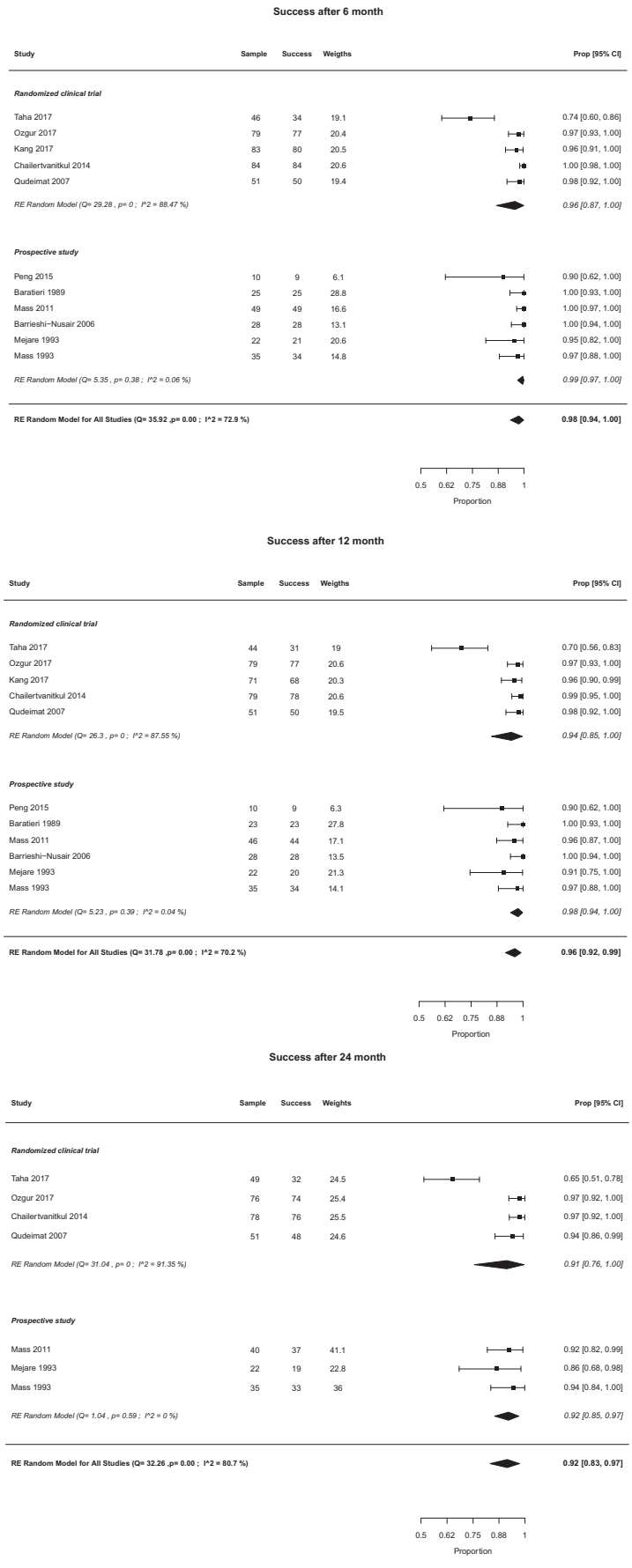

FIGURE 3 – The 6-month, 1-year, and 2-year meta-analysis results.

studies (I^2 = 91.35%). For the 3 prospective studies[42,43,45], the pooled rate was 0.92 (CI, 0.85–0.97), with an absence of heterogeneity (I^2 = 0%). When analyzing all the studies together, it resulted in a significant heterogeneity across all the studies (I^2 = 80.7%). The random-effects model reported a success rate of 0.92 (CI, 0.83–0.97; Fig. 3).

Additional Analysis

Sensitivity analysis revealed that only 1 study[16] modified the results in the 3 evaluated periods. At the 6-month period, the estimated proportion was 0.99 (CI, 0.93–0.98), with a heterogeneity of I^2 = 11.58%. At the 1-year follow-up, the estimated proportion was 0.98 (CI, 0.96–0.99), with a heterogeneity of I^2 = 0%. After 2 years, the estimated proportion was 0.96 (CI, 0.93–0.98), with a heterogeneity of I^2 = 0%. The heterogeneity results are primarily caused by the results from the study of Taha and Khazali[16], more precisely by the CH group in that study, in which the outcome rates were low when compared with the rest of the results (62%, 55%, and 43% for the 6-month, 1-year, and 2-year follow-up). The results observed in the funnel plot were almost symmetrical (Supplemental Fig. 1), and the *P*-value of the Egger test was .89 for the reversible group and .23 for the irreversible group, which suggest no significant publication bias, except for the study of Taha and Khazali[16], which presents slightly different results. This can explain the heterogeneity observed among the randomized clinical trials, especially considering that this heterogeneity was not observed in the separate analysis of the prospective studies (Supplemental Table S2).

Using meta-regression analysis, preoperative pulp status (P = .001) was the only variable significantly associated with the success rate at the 1-year follow-up period (Table 3, Supplemental Table S2). According to subgroup analysis, the success rate for teeth diagnosed as irreversible pulpitis at the 12-month follow-up was 0.75 (CI, 0.62–0.86) compared with 0.98 (CI, 0.96–1) in studies with teeth diagnosed as reversible pulpitis (Fig. 4).

DISCUSSION

According to the results of the present systematic review and meta-analysis, a partial pulpotomy is an adequate treatment option when treating carious exposures in permanent posterior teeth. It presents a high success rate in different follow-up periods although there is no accurate established timing for when a partial pulpotomy can be considered a

TABLE 3 - Meta-regression Analysis of the Effect of Clinical Variables on the Success Rate after 1 Year

Dependent variable	Weighted mean 1-year success rate	
Independent variable	**Coefficient (CI)**	***P* value**
Capping materials (ref: CH)		
MTA	0.04 (−0.06 to 0.16)	.438
Pulp status (ref: irreversible)		
Reversible	0.31 (0.13–0.50)	.001
Study type (ref: prospective)		
Randomized clinical trials	−0.02 (−0.16 to 0.12)	.751
Age	−0.01 (−0.05 to 0.02)	.366
Apex		
Closed (ref: no)	−0.01 (−0.19 to 0.17)	.920
Open (ref: no)	−0.24 (−0.79 to 0.29)	.377

CH, calcium hydroxide; CI, confidence interval; MTA, mineral trioxide aggregate.

success. However, in a similar treatment, Matsuo et al[46] considered 21 months as the appropriate time to determine a successful prognosis for direct pulp capping. They also considered 3 months as adequate for a tentative prognosis because no differences were found from 3 to 18 months. This is in accordance with the results of this review in which the success rate did not result in statistical differences among the 3 evaluation periods (6 months, 1 year, and 2 years). Thus, 6 months can be considered as a suitable period when evaluating success after a partial pulpotomy. Although treatment can be considered a success in a consensual period, patients already should be scheduled for regular annual visits according to the American Dental Association recommendations for low-risk patients[47] were clinical controls, and also radiographic evaluation, when considered necessary, should be performed to assure the success of the treatment."

Zanini et al[48] pointed out that for long periods of examination, the possible reason for failure or bacteria pathway should be described. In accordance, restoration status and the periodontal condition at the time of the failure should be reported. However, studies included in this review do not provide this information[16,20,23,42–45]. Possibly as a future recommendation, the periodontal condition and restoration status of the tooth should be

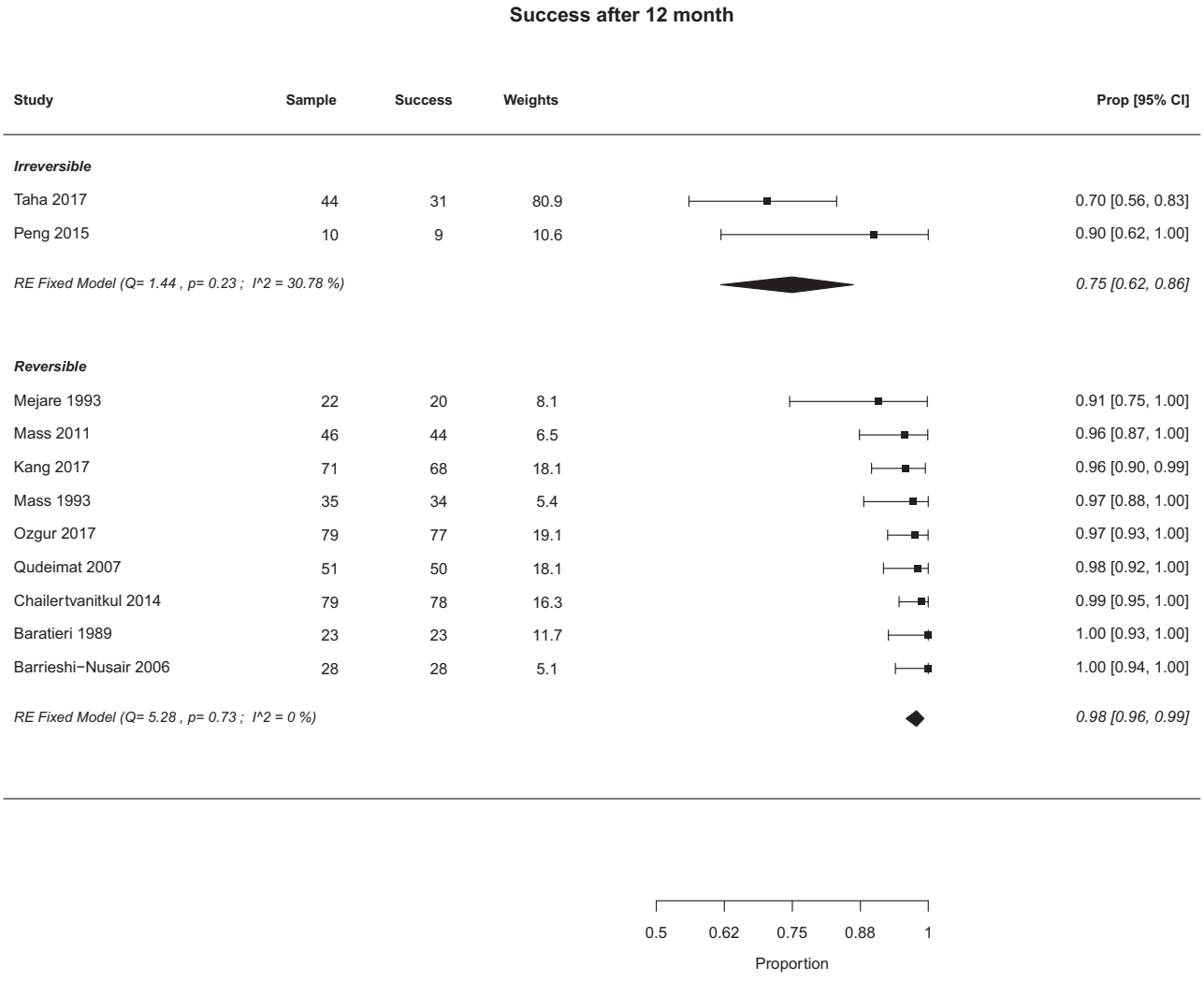

FIGURE 4 – The success rate after 1 year according to the preoperative pulp diagnosis.

reported at the time of failure in order to try to determine if the failure was related to external factors or the vital pulp therapy itself.

Clinical and radiographic signs and symptoms in failure cases (Supplemental Table S1) can be divided into immediate/early and late/delayed failures. Theoretically, early failures should be associated with an inflammatory process[48], which was commonly expressed as spontaneous pain in the selected studies, and, thus, root canal treatment was performed. Because final restorations were placed in the same visit in 9 of 11 studies and a healthy periodontal status was a prerequisite in all the studies, thus eliminating any possible pathway for bacterial contamination, it can be assumed that the treatment itself was the reason for failure. Necrosis and periapical involvement were mainly associated with delayed failures where bacterial infection may be involved. In more extended follow-up periods, bacterial leakage could play a role as coronal barriers of the restoration, and the newly formed dentinal bridge can no longer protect the underlying pulp tissue. However, some cases with spontaneous pain were also reported after a 2-year follow-up period, indicating that an irreversible radicular pulpitis event can also be presented as a late event and not only in the first 2 months as reported previously in coronal pulpotomies[48]. Another possible explanation is that in those cases pulp status was inadequately diagnosed, and inflammation was further progressed apically than previously thought.

The longer the observation period is, the higher the risk of patient loss to follow-up. A loss to follow-up of more than 20% carries a threat to the validity of the results[49]; hence, articles with a follow-up rate lower than 80% were excluded to avoid this unwanted effect[31,32]. The study by Kang et al[22] was included even though at the 1-year follow-up a dropout rate of 26% was reported. Thus, only the results at the 6-month follow-up period were included for statistical analysis. An attempt was made to include studies with a similar clinical protocol. Subsequently, articles that used different treatment approaches were excluded. In their study, Mejàre and Cvek[43] included 15 teeth in which before performing the partial pulpotomy a stepwise carious tissue removal approach with CH was performed to avoid pulp exposure. A stepwise approach before performing a partial pulpotomy can modify the pulp-dentin complex defense mechanism by inducing the formation of secondary dentin and pausing the caries progression[50,51].

Only the preoperative pulp status held significance and could explain the variance in results between the studies and thus can be considered as a potential prognostic factor ($P < .0001$). In cases of presumption diagnosis of normal pulp or reversible pulpitis, a partial pulpotomy results in a 1-year success rate of 98% (CI, 96–99). This result is comparable when performing a complete pulpotomy under the same initial diagnosis[17]. Thus, a partial pulpotomy should be selected in those cases as being a more conservative approach with a similar outcome. Studies with the presumption diagnosis of irreversible pulpitis had a lower success rate compared with the other studies (75% CI, 62–86). This could be explained by the fact that in a more advanced stage, pulp inflammation will further progress apically in the pulp complex. Thus, removing only the coronal 2–3 mm might not be enough to eliminate all the affected tissue, which may jeopardize the healing response, and a less conservative approach should be considered such as coronal pulpotomy or a root canal treatment. However, only 2 studies[16,21] including cases with presumption diagnosis of irreversible pulpitis were available for analysis with a total sample of 62 teeth. Therefore, these results should be interpreted with caution, and further studies are needed to estimate the validity of this factor accurately.

Neither the patient's age nor the root apex closure results affect the prognosis of a partial pulpotomy. It has to be highlighted that age was evaluated as mean ± standard deviation in every study, and data of specific failures were not available. However, studies included patients aged 6–52 years old. Young patients' pulp is more cellular and has been considered to have a higher potential for healing compared with older patients' pulp, which is more fibrous and less cellular with a reduced blood supply[52]. However, studies include older patients ranging from 25–52 years old with no significant differences when compared with younger patients[16,22,41,42]. Similarly, most studies included involved mature teeth with a closed apex with no significant differences when compared with immature teeth with an open apex[15,44,45]. This is more relevant because traditionally vital pulp therapy treatment has been recommended as a treatment exclusively for young patients with immature apices[12,53,54]. The current review may indicate that partial pulpotomy could be effective in both mature and immature teeth.

MTA and MTA-like materials have been introduced as an alternative to CH in vital pulp therapy treatments. For many years, CH was considered as the material of choice in pulp capping procedures[55–57]. However, CH tends to reabsorb over time and degradation to bending. In addition, it is soluble in oral fluids, and it has a low mechanical resistance that could result in microfiltration over long periods[18,19,58]. Besides, MTA requires less time to produce a thicker dentinal bridge with fewer tunnel defects when compared with CH[18]. Taking all that into account and that bacterial leakage is regarded as the primary cause of failure of vital pulp therapies[52], MTA-like materials should result in an improved success rate. However, there was no significant difference in the results obtained by both materials in either direct or indirect comparison, suggesting that either material could be used clinically with a similar prognosis. Aguilar and Linsuwanont[14] reported that partial pulpotomy with CH resulted in a higher success rate in an indirect comparison. Differences can be caused by the sample size because at that time only 2 studies included MTA-like materials for evaluation.

Barthel et al[59] reported significantly higher success rates when the final restoration was placed within 2 days after direct pulp capping procedures. All the included studies in the present review placed the final resonation within this period, except for 2 studies[41,43] in which the cavity was temporally restored with zinc oxide eugenol (ZOE) cement before placing the final restoration after 3 to 6 months. ZOE cements do not result in a fluid-tight seal under *in vitro* conditions and have not been considered as an appropriate interim restorative material in extensive cavities[60–62]. Nevertheless, although this delay in a definitive restoration placement with a temporary ZOE restoration seems not to affect the overall success rate under clinical conditions, it is recommended to perform the final restoration in the same visit to avoid the risk of microleakage. The risk of leakage can also be reduced by performing the tissue removal under a rubber dam isolation. However, not enough data were available to evaluate a statistical relationship. Only 23 of the 51 cases in the study by Queidmat et al[44] were performed with no rubber dam, and partial isolation with cotton rolls was performed. In their study, only 4 cases resulted in treatment failure, and all 4 cases were not isolated with a rubber dam. Thus, it is probably an appropriate recommendation to perform all the procedure under rubber dam isolation.

There was a variation among the included studies regarding the type of the final restoration used, varying from amalgam, composite, and

stainless steel crowns. Unfortunately, not enough data were available to study this variable as a prognostic factor, and analysis could not be performed. Even though various authors were contacted, not enough replies were received to perform the analysis.

CONCLUSION

According to the results of the present systematic review and meta-analysis, a partial pulpotomy is considered a reliable treatment option for the treatment of cariously exposed permanent posterior teeth. It presents a high success rate of 92% after 2 years. The preoperative pulp diagnosis results in a significant prognostic factor, and cases diagnosed as irreversible pulpitis result in a lower success rate. There is no significant difference between MTA-like materials and CH as a pulp capping agent nor the other variables evaluated.

ACKNOWLEDGMENTS

The authors deny any conflicts of interest related to this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2019.07.005).

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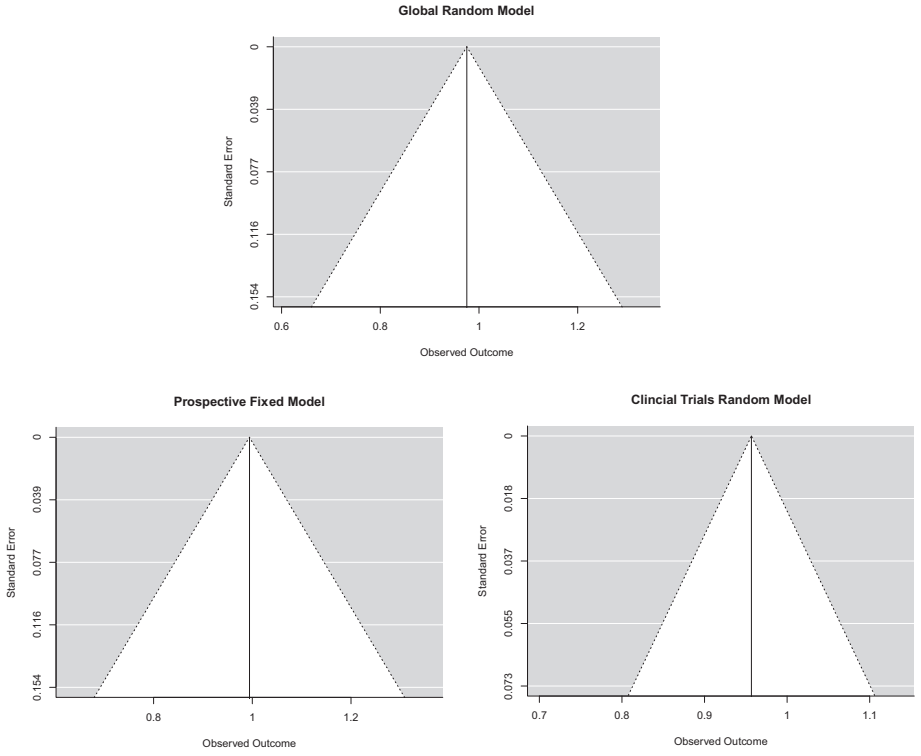
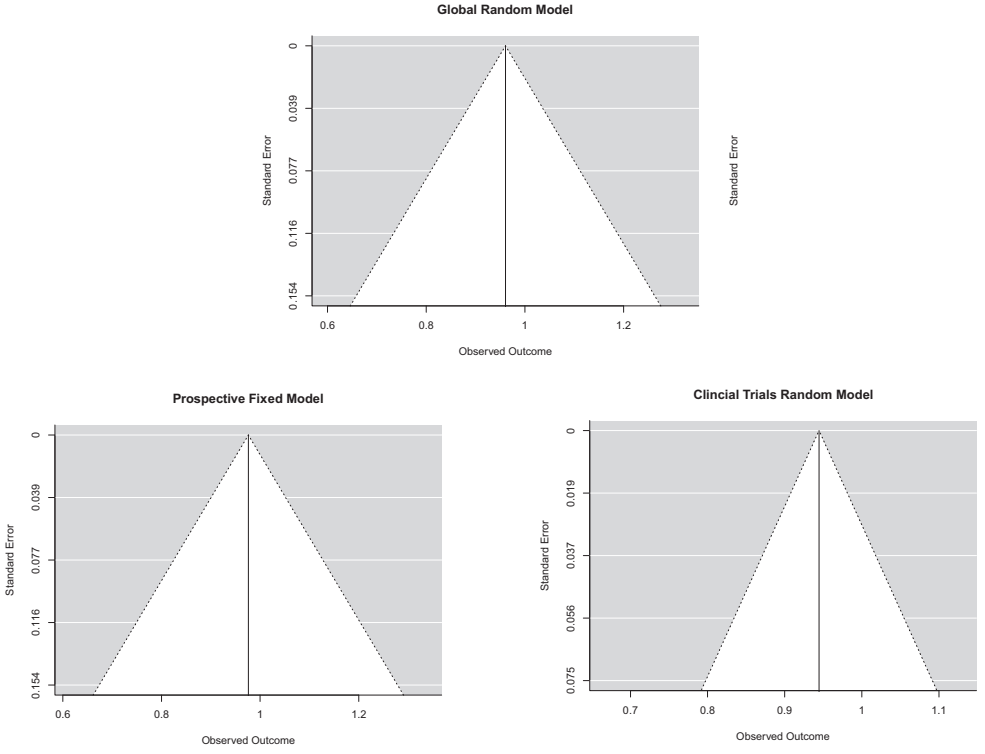
Funnel plots for 6 months results

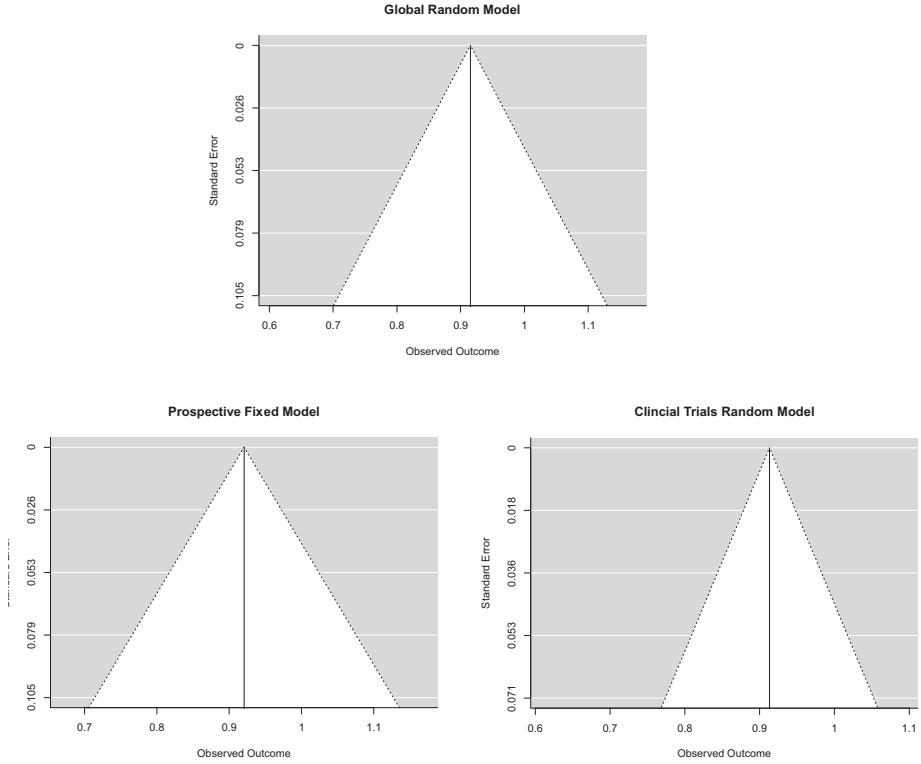


Funnel plots for 1-year results

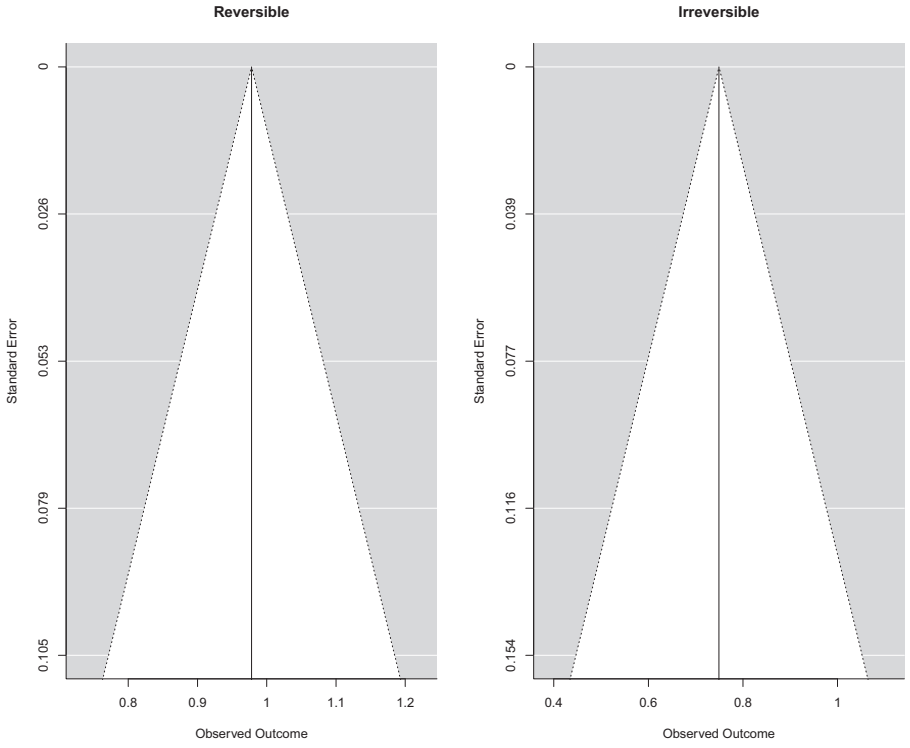


SUPPLEMENTAL FIGURE S1 – Funnel Plots.

Funnel plots for 2-years results



Funnel plot with 95% confidence limits examining publication bias of success rate at 1-year according to preoperative pulp status



SUPPLEMENTAL FIGURE S1 – Continued

SUPPLEMENTAL TABLE S1 - Clinical and Radiographic Signs and Symptoms in Failure Cases

Study	Clinical and radiographic Signs and symptoms	Observation period
Mejáre and Cvek, 1993[43]	Pulpitis (pain)	10 days
	Periapical radiolucency (2 teeth)	10 and 24 months
Mass and Zilberman, 1993[42]	Pulp necrosis (2 teeth)	20 days and 17 months
Mass and Zilberman, 2011[45]	Spontaneous pain (3 teeth)	Did not specify
Kang et al, 2017[22]	Spontaneous pain (2 teeth)	2 weeks and 1 month
	Sinus tract formation and periapical radiolucency	5 months
Özgür et al, 2017[23]	Spontaneous pain and periapical radiolucency (2 teeth)	6 months
Taha and Khazali, 2017[16]	Spontaneous pain (4 teeth)	Immediate failure
	Spontaneous pain (4 teeth)	6 months
	Negative response with periapical radiolucency (4 teeth)	
	Pain on biting and periapical radiolucency	1 year
	Spontaneous pain (3 teeth)	2 years
	Extraction because of tooth and restoration fracture	

A summary of the clinical/radiographic signs and symptoms of the reported failed cases in the selected studies. It can be noticed that they could be divided into immediate/early (which are mainly associated with pulpitis/pain) and late/delayed failures (which are primarily associated with necrosis and periapical radiolucency).

SUPPLEMENTAL TABLE S2 - Meta-regression Analysis of the Effect of Clinical Variables on the Success Rate (1 Year). Model 2. Model for Capping Material, Final Solution, Preoperative Pulp Diagnosis, and Type of Study

Dependent variable	Weighted mean 1-year success rate	
Independent variable	**Coefficient (95% CI)**	***P* value**
Capping materials (ref: CH)		
MTA	0.03 (−0.09 to 0.15)	.639
Final solution		
NaOCl (ref: no)	0.03 (−0.15 to 0.20)	.766
Saline (ref: no)	−0.02 (−0.17 to 0.13)	.795
Pulp diagnosis (ref: irreversible)		
Reversible	0.38 (0.21–0.56)	.001
Study type (ref: prospective)		
Randomized clinical trials	−0.03 (−0.17 to 0.10)	.624

CH, calcium hydroxide; CI, confidence interval; MTA, mineral trioxide aggregate; NaOCl, sodium hypochlorite.