

## REVIEW

# Failure of single-unit restorations on root filled posterior teeth: a systematic review

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## Abstract

**Afrashtehfar KI, Ahmadi M, Emami E, Abi-Nader S, Tamimi F.** Failure of single-unit restorations on root filled posterior teeth: a systematic review. *International Endodontic Journal*, 50, 951–966, 2017.

This systematic review investigated the failure rate of conventional single-unit restorations in root filled posterior permanent teeth. Two reviewers independently applied eligibility criteria, extracted data and assessed the quality of the evidence of each included study according to the Cochrane Collaboration's procedures for randomized control trials (RCTs) and the STROBE criteria for observational studies. The MEDLINE (via Ovid), EMBASE (via Ovid), Cochrane Oral Health Group Trials Register and CENTRAL (via Cochrane Library) databases were searched electronically (January 1993 to week 1, February 2015). This was complemented by an additional hand search of selected journals and the references of relevant studies. Clinical studies published on root filled single-unit restorative treatments with a mean follow-up period

of at least 3 years were selected. The outcome measured was clinical or radiological failure. Overall, the four RCTs and the single observational study included were of low and high quality, respectively. Therefore, a meta-analysis was not possible. The pooled mean failure rates were reported according to the type of treatment and remaining coronal tooth structure. The current evidence suggested that the failure rates of the treatments may depend on the amount of remaining tooth structure and type of treatment. Post-retained crowns were associated with the most favourable outcome in teeth with one to two remaining coronal tooth wall(s), whereas post-free crowns were superior when greater tooth structure was available. Restorations in teeth without ferrules had such a high rate of failure that other treatment options should be considered.

**Keywords:** dental fillings, direct restorations, posterior restorations, risk factors, single crowns, survival rate.

Received 7 March 2016; accepted 17 November 2016

## Introduction

The success of restorations in posterior root filled teeth depends on the quality of work, type of treatment selected and host-related factors (Cheung 2005,

Gillen *et al.* 2011). The quality of work depends on the training and skills of the restoring dentists. Host factors such as remaining tooth structure depend on the specific conditions of each patient. However, selection of the type of treatment depends on our knowledge of the advantages and limitations of the available options.

Root filled teeth are usually restored with intracoronal (i.e. amalgams, resins) or extracoronal restorations (i.e. crowns; Mannocci *et al.* 2005, Ferrari *et al.* 2012). Several new types of treatments are widely accepted,

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such as prefabricated fibre-reinforced posts and composite Nayyar cores (Eliyas *et al.* 2015). A crown is generally superior to intracoronal restorations, but it is more expensive, its preparation is more time consuming, and it removes more tooth structure than intracoronal restorations (Fedorowicz *et al.* 2012).

The challenge for clinicians is to recommend the best treatment option according to each patient's specific demands, financial situation and associated risk factors (Aquilino & Caplan 2002, Fedorowicz *et al.* 2012, Landys Boren *et al.* 2015, Sequeira-Byron *et al.* 2015, Afrashtehfar *et al.* 2016a). This issue is relevant as prosthetic and restorative malpractice claims constitute the majority of litigations in dentistry (Schwarz 1988, Rene & Owall 1991, Hapcook 2006, Kiani & Sheikhezadi 2009, Lopez-Nicolas *et al.* 2011), and the main reason is usually overtreatment (Grembowski *et al.* 1997, Maupome 1998, Clark *et al.* 2003, Zadik & Levin 2008).

There have been attempts through expert opinions and reviews to create guidelines for restorative treatment planning (Christensen 1996, Chadwick *et al.* 1999, Aquilino & Caplan 2002, Manhart *et al.* 2004, Schwartz & Robbins 2004, Esteves *et al.* 2011, Meyenberg 2013, Mannocci & Cowie 2014, Trushkowsky 2014). However, these guidelines have not been generally adopted, and they may be subject to bias due to invalid methodology or poor reporting (Faggion 2010, 2012, 2013). The best way to facilitate restorative treatment planning of root filled teeth would be to determine the failure rate of all treatment options according to the potential risk factors. There is currently no study in the literature addressing the survival of restorations that would answer the question whether to select a crown or an intracoronal restoration for root filled teeth taking into account the remaining tooth structure. To address this need, a systematic review of randomized clinical trials (RCTs) and observational studies was conducted. The purpose of this review was to identify the literature published on the failure rate of conventional single-unit restorations in root filled posterior permanent teeth.

## Materials and methods

A systematic review was conducted and reported adhering to the PRISMA statement (Liberati *et al.* 2009, Moher *et al.* 2009), the Cochrane Collaboration guidelines (Higgins & Green 2012) and the quality standards proposed by AMSTAR on therapies (Shea *et al.* 2007, 2009). This was performed to minimize

potential bias in the review process by promoting transparency (Faggion 2013), quality methodology (Faggion 2010) and better reporting (Faggion 2012).

## Search method and type of studies

With the assistance of two experienced librarians, a systematic search of electronic databases was conducted (Cochrane Oral Health Group Trials Register, Cochrane Central Register of Controlled Trials (CENTRAL) via the Cochrane Library, MEDLINE via Ovid and EMBASE via Ovid) until February 2015 with no language restriction. The search strategies are reported in Table 1 and Appendices S1–S3. The search on both MEDLINE and EMBASE was filtered with their respective Effective Practice and Organisation of Care (EPOC) Methodological Study Filter (*see* <http://www.epoc.cochrane.org/en/newPage1.html>). Two reviewers independently screened the titles and abstracts of publications that met the initial selection criteria to retrieve and review the entire publication of the relevant ones. Reviewers were not blinded. The reasons for exclusion were reported for each study that was not in the final included studies. When disagreements between the reviewers were not resolved, a third reviewer (EE or FT) would assist to reach consensus. The agreement (Viera & Garrett 2005) between the two reviewers was considered 'almost perfect' as the Cohen's kappa test had a coefficient of 0.90.

In addition, one reviewer performed supplemental hand searches by cross-referencing preliminary identified related studies and screening the following journals between 2005 and 2014: Journal of Prosthodontics, International Journal of Prosthodontics, Journal of Prosthetic Dentistry, The International Journal of Periodontics and Restorative Dentistry, Journal of Dental Research, Journal of Operative Dentistry, Journal of the American Dental Association, Journal of Dentistry, The International Endodontic Journal and The Journal of Endodontics. Grey literature was not evaluated. A flow diagram was designed following the PRISMA statement to depict each step of the identification–inclusion process (Moher *et al.* 2009).

## Types of studies and selection criteria

### Inclusion criteria

For this review, both RCTs and observational studies were considered for answering the research question as suggested in the literature (Peinemann *et al.* 2013). Reports were included if they met the

**Table 1** Search strategy used for OVID MEDLINE + EPOC\*

Search no. and keywords involved	
1	longevity.mp.
2	exp Treatment Outcome/or success.mp.
3	Dental Restoration Failure/or failure.mp.
4	Dental Prosthesis Repair/
5	Dental Stress Analysis/
6	prognos\$.mp. or exp Prognosis/
7	exp Survival Analysis/or Survival.mp.
8	Follow-Up Studies/
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	Dental Amalgam/
11	Resins, Synthetic/or Composite Resins/or Compomers/or exp Epoxy Resins/
12	resin\$.mp.
13	composite\$.mp.
14	compomer\$.mp.
15	amalgam\$.mp.
16	'direct restor\$'.mp.
17	'conventional fill\$'.mp.
18	'dental filling\$'.mp.
19	crowns\$.mp. or exp Crowns/
20	full cast\$.mp.
21	10 or 11 or 12 or 13 or 15 or 16 or 17 or 18 or 19 or 20
22	dentistry, operative/or dental restoration, permanent/or dentition/or tooth/
23	9 and 21 and 22
24	randomized controlled trial.pt.
25	controlled clinical trial.pt.
26	randomized.ab.
27	placebo.ab.
28	clinical trials as topic.sh.
29	randomly.ab.
30	trial.ab.
31	24 or 25 or 26 or 27 or 28 or 29 or 30
32	exp animals/not humans.sh.
33	31 not 32
34	23 and 33
35	'limit 34 to yr='1993-2015

\*MEDLINE: sensitivity- and precision-maximizing version (2008 revision Box 6.4d <http://www.cochrane-handbook.org/>).

following inclusion criteria that were defined *a priori* in the protocol:

- Population: posterior permanent dentition in dental patients (humans) recruited from any clinical setting (university, hospital, primary care and private office).
- Intervention: single full crowns (all-metal, all-ceramic, metal-ceramic) or dental fillings (amalgams and composite resins) with or without post and core.
- Control: no control group was necessary for inclusion.
- Outcome measure: the number and/or percentage of restorations of interest that failed clinically or

radiologically. Additionally, qualitative data were analysed across all the included studies. Failure was defined as clinically unacceptable restorations that required the replacement or repairmen of the restoration as studies not always record ratings of the US Public Health Service (USPHS) (Bayne & Schmalz 2005) or Ryge (Ryge & Snyder 1973, Ryge 1975, 1980).

- Time: a mean follow-up of 3–10 years after treatment.

To consider a study, the number of restored tooth surfaces or number of remaining coronal walls before restoration, as well as the presence or absence of post and core, had to be reported.

#### Exclusion criteria

Reports were excluded if they did not pertain to the search terms described in the inclusion criteria; were *in vitro* or nonhuman studies; did not mention the type of targeted restoration in the title or abstract; did not report the outcome of interest; did not discriminate data on anterior, wisdom or primary dentition; included periodontally compromised dentition; did not provide or did not allow extraction of the required data; reported indirect restorations other than full crowns (e.g. inlays/onlays); reported cases that did not have antagonist teeth; included implant-supported restorations; had <10 subjects completing the study; placed restorations on abutments of partial dentures (i.e. FPD/RPD pillars); and if 25% or more of the included subjects were bruxers.

#### Data extraction

If multiple articles presented trial data, only outcome data from the most recent report or the one closer to 5 years of follow-up was assigned as the main study. The following data were extracted and recorded by one reviewer into a specifically designed electronic spreadsheet: names of authors, year of publication, country of the trial, study design, mean follow-up, characteristics of participants (age, gender, setting), dropouts, type of restoration (prostheses, dental fillings), materials used in the restoration (amalgams, resins, etc.), tooth localization (molar, premolar, maxillary, mandibular), outcomes, methodological quality of the trials and conclusions. Lastly, based on the restoration material, the data (*n* restorations, % failure) from the studies were categorized into subgroups according to the remaining

tooth structure prior to restoration placement, and of post-presence. When important data were missing, a reviewer (KIA) attempted to contact the authors of the publications to resolve ambiguity; however, the responses did not add relevant information.

### Quality assessment and risk of bias

Two independent reviewers carried out the methodological quality assessment on the basis of the type of the study and compared their results. For RCTs, the methodological quality of the trials was assessed using a domain-based evaluation (Cochrane Collaboration tool), including reports of sample size estimation and five parameters of quality: sequence generation, allocation concealment, completeness of follow-up, intention-to-treat analysis and masking/blinding (Emami *et al.* 2009, de Souza *et al.* 2010, Higgins & Green 2012). Each parameter of trial methodological quality was graded as 'adequate', 'inadequate', 'unclear' or 'not applicable' (de Souza *et al.* 2014). Studies were defined as low risk of bias if the five criteria listed above were clearly met in the study. If one or more of these criteria were not met, a study would be considered at moderate or high potential risk of bias, respectively. An additional measure of the completeness of follow-up parameter, studies with more than 20% attrition was considered as 'inadequate' (Ebell *et al.* 2004).

For the observational studies, the STROBE (Strengthening the Reporting of Observational studies in Epidemiology) statement (von Elm *et al.* 2007) was used to assess reporting. STROBE provides a checklist with 22 items that should be described in observational studies, such as pre-specified hypothesis, sample size estimation and reasons for dropout. Additionally, each study was categorized according to the Olmos classification: A, (high level) the study is in agreement with more than 80% of the STROBE criteria; B, (moderate level) 50–80% of STROBE criteria were fulfilled; and C, (low level) <50% of the criteria were fulfilled (Olmos *et al.* 2008).

To identify the best available evidence on the reviewed topics, the level of evidence of the included RCTs and observational studies was further assessed based on the American Association of Critical-Care Nurses' (ACCN) new evidence-levelling system (Appendix S4; Armola *et al.* 2009).

### Data synthesis

Based on the moderate amount of information available from the systematic review (small number of studies), an inferential statistical analysis was not possible. However, the overall results were combined to provide a pooled average value for each clinical scenario (Afrashtehfar *et al.* 2016b). Five-year survival rates are useful values for comparing the effectiveness of treatments (Cosetti *et al.* 2008), especially for dental restorations as most treatments perform well in the short term (<3-year follow-up; Demarco *et al.* 2012) and difference is only clear at longer follow-up periods (Manhart *et al.* 2004).

Therefore, in this systematic review, the extracted quantitative data related to failure were reported as the pooled mean group 5-year mean failure rate. The pooled mean was calculated using Microsoft Excel 2010 (Microsoft, Redmond, WA, USA).

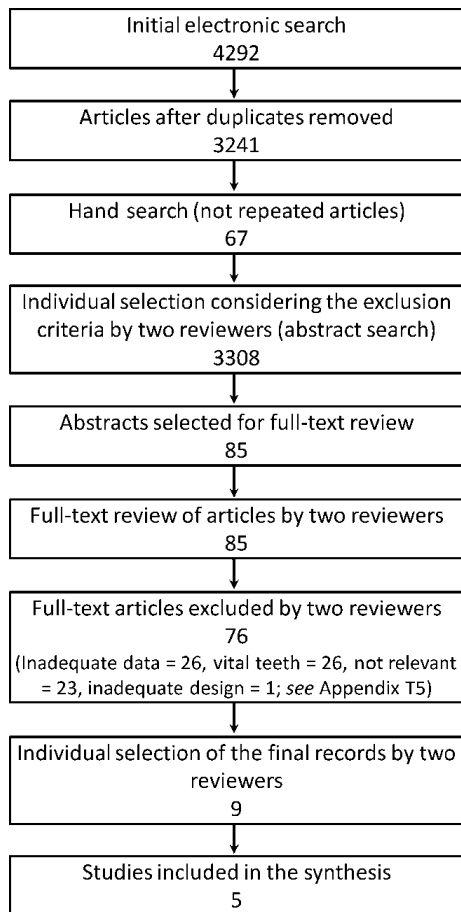
This model in which failure rate was treated as a continuous variable (0–100%) was used for RCTs and observational studies combined and separated, with and without the influencing studies. A meta-regression model was then used to assess the correlation between the remaining walls and the pooled mean group 5-year mean failure rate in each of the three treatment options. These correlation statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC, USA).

## Results

### Search results

Although the systematic search was designed to identify all risk factors that affect the survival of restorative treatments on root filled teeth, this systematic review focused on two factors only: the amount of remaining coronal tooth structure, and type of treatment and restorative material. Other factors that influence survival of restorative treatments will have to be assessed in future systematic reviews. Examples of these may be host-dependent (angle classification, age, gender, type of antagonists) and operator-dependent factors (level of experience, dexterity, knowledge, clinical setting).

The electronic and hand search strategies yielded 3308 references of studies after removal of duplicates (Fig. 1). After examination of titles and abstracts, 85 potentially relevant references reporting on restorations performed on root filled teeth were examined in full text, and 76 of these references were excluded



**Figure 1** PRISMA flow diagram of study selection process.

(Appendix S5). From the nine references that fulfilled the proposed inclusion criteria (Appendix S6), a total of five key studies were included for further assessment (Table 2). They consisted of four RCTs (Plasmans & van 't Hof 1993, Mannocci *et al.* 2002, 2005, Ferrari *et al.* 2012) and one retrospective observational study (Signore *et al.* 2011).

The literature on crowns was extensive; however, only one study provided data on post-free crowns (Ferrari *et al.* 2012; Table 3). However, there were no studies on post-free composite resin restorations, and there were data available only for teeth with three remaining walls on post-free amalgams.

There was substantial heterogeneity amongst the included studies in terms of study design, evaluation of outcomes, participants' age mean at baseline, sample size and type of restorations assessed (Table 2). Considering the limited availability of studies and potential heterogeneity amongst them, neither a meta-analysis nor a meta-regression of RCTs could be

attempted (Baccaglini *et al.* 2010, Hannigan & Lynch 2013). However, the meta-regression of the combined data from both RCTs and observational studies showed that in teeth with three and less remaining walls, the failure rate of post-retained crowns was significantly ( $P < 0.05$ ) lower than all other treatments (Appendix S7). There were insufficient data to perform a meta-regression analysis on teeth with four remaining walls.

### Quality and risk of bias assessment of included studies

The quality risk of bias assessment for RCTs is presented as a risk of bias summary and a risk of bias graph (Fig. 2). For observational studies, a STROBE-based quality appraisal is available (Appendix S8) and an overall quality appraisal is presented (Table 4).

#### Randomized control trials

Eight RCTs were included, and their risk of bias is presented as percentages across studies in Fig. 2b. Three studies were found adequate regarding sequence generation and intention-to-treat analysis; however, all the studies were inadequate regarding concealment of allocation and blinding (Fig. 2a). Blinding was not possible in two RCTs (Mannocci *et al.* 2002, 2005) due to the nature of the interventions (i.e. amalgams vs. resins, crowns vs. resins). The handling of withdrawals and dropouts was adequately described only in one study (Plasmans & van 't Hof 1993). The estimated risk of bias was considered to be high (low level of evidence) in all RCTs. The ACCN's level of evidence (where A is the highest level, and M the lowest) for the included RCTs was ranked as C (Fig. 2a).

#### Observational studies

Only one observational study was included, and according to the Olmos criteria (Olmos *et al.* 2008) on quality of reporting, it was classified as high level (Table 4). According to the STROBE criteria, this retrospective observational study had reporting deficiencies regarding its variables, study size, other analyses and funding (Appendix S8). The study design level of evidence was ranked as C according to ACCN's criteria (Table 4).

### Availability of literature

From the five selected studies, a total of 1160 direct and indirect restorations were identified from 955

**Table 2** Summary of characteristics of definitive five studies included

Study	Country	Setting	Study design	Follow-up, # patients at baseline, year	Age mean/range at baseline, year	Teeth restored	Pulp status	# remaining walls	Type of restoration material	# restorations at baseline	% dropout Patients/restorations	Funding
Ferrari <i>et al.</i> (2012)	Italy	Private practice	Randomized control trial	6	58/18–76	Premolar	Nonvital	0–4	Crowns with post and core	360	11.9/12.2	Not reported
Mannocci <i>et al.</i> (2005)	Italy	Private practice	Randomized control trial	5	45/32–63	Premolar	Nonvital	3	Amalgams Resins with post and core	219	10/10	Not reported
Mannocci <i>et al.</i> (2002)	Italy	Private practice	Randomized control trial	3	48/35–55	Premolar	Nonvital	3	Crowns with post and core	117	11.1/11.1	Not reported
Plasmans & van 't Hof (1993)	Netherlands	Private practice & University	Randomized control trial	4	32/17–54	Molar	Vital & Nonvital	0–1	Amalgams (different retaining methods) Amalgams with posts Crowns with post and core	300	0.8/1.3	Public institution & Cavex Holland
Signore <i>et al.</i> (2011)	Italy	University	Retrospective	3.8	56.4/18–72	Premolar	Nonvital	0–4	Crowns with post and core	164	6.9/6.1	Not reported

Maximum follow-up over all groups is reported.

**Table 3** Failure rates of tooth restorations in endodontically treated teeth according to the remaining tooth structure

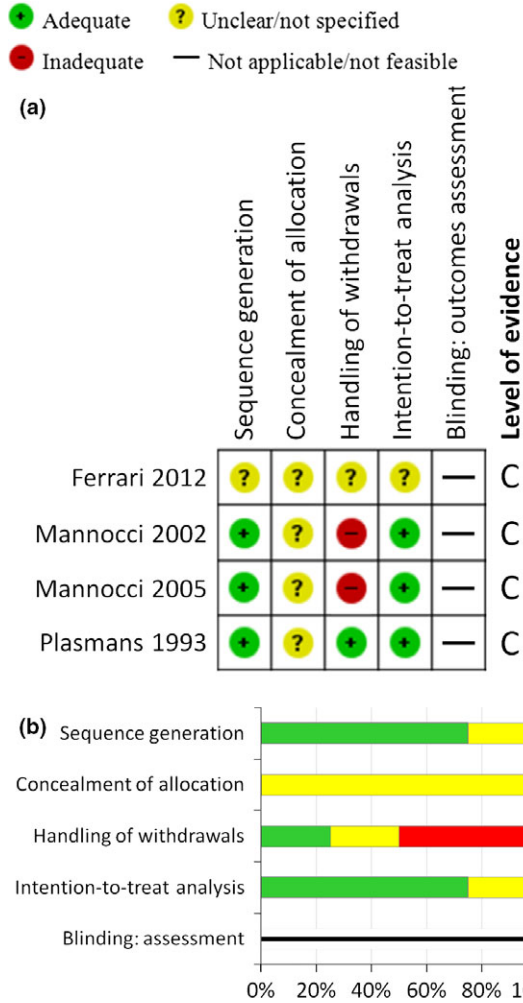
	Amalgam						Resin						Crown								
	Post			No Post			Post			No Post			Post			No Post					
	Ref	F (y)	N	Failure %	Ref	F (y)	N	Failure %	Ref	F (y)	N	Failure %	Ref	F (y)	N	Failure %	Ref	F (y)	N	Failure %	
Less than a wall	[2] <sup>†</sup>	4	41	10										[5]	3.8	13	23.1	[1]	6	18	22.2
														[1]	6	32	0	[1]	6	20 <sup>§</sup>	35
One wall	[2] <sup>†</sup>	4	41	10										[1]	6	37 <sup>§</sup>	8.1	[1]	6	17	17.6
														[5]	3.8	25	12	[1]	6	17	17.6
Two walls														[1]	6	34	0	[1]	6	17	17.6
														[5]	3.8	49	2	[1]	6	17	5.9
Three walls														[1]	6	36	0	[1]	6	17	5.9
					[4]	5	100	9	7.6	[3]	3	53	10.3	[3]	3	54	5.6	[1]	6	18	0
Four walls														[5]	3.8	45	0	[5]	3.8	18	0
														[1]	6	34	0	[1]	6	17	0
														[5]	3.8	19	0	[1]	6	17	0
														[1]	6	36	0	[1]	6	17	0

<sup>†</sup>This reference reports on teeth with one and fewer remaining walls without discriminating between the two scenarios.

<sup>§</sup>This value is for teeth without ferrule.

F (y), follow-up in years; N, number of restorations; Ref, reference of study.

Reference [5] is the only observational study. The grey area indicates that no studies were found reporting on these conditions (i.e. amalgams with posts, and resin restorations without posts). [1] Ferrari et al. 2012, [2] Plasmans & van 't Hof 1993, [3] Mannocci et al. 2002, [4] Mannocci et al. 2005, [5] Signore et al. 2011.



**Figure 2** Risk of bias. (a) Risk of bias summary: review authors' judgements about each risk of bias item for each included study. (b) Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

patients at baseline. Of these restorations, 521 were single crowns, 150 composite resins and 149 amalgams. The sample size of each study ranged from 117 (Mannocci *et al.* 2002) to 360 restorations (Ferrari *et al.* 2012). Participants included in each study ranged from 117 (Mannocci *et al.* 2002) to 345 (Ferrari *et al.* 2012). One study (Plasmans & van 't Hof 1993) included teeth with vital pulps but reported the data on root filled teeth separately. The mean age ( $\pm$ SD) of participants across studies was  $50 \pm 10.4$  years, and the age range of participants in these studies varied between 17 (Plasmans & van 't Hof 1993) and 76 years (Ferrari *et al.* 2012). Participants of one

**Table 4** Overall quality appraisal of the observational studies included in the review

Study ID	Applicable quality appraisal criteria – Number (proportion; %)	Classification of report according to Olmos <i>et al.</i>	Level of evidence according to AACN's new evidence-leveilling system
Signore <i>et al.</i> 2011. Italy	18 (82)	A	C

Olmos classification criteria: (A) high level, the study is in agreement with more than 80% of the STROBE criteria could be achieved. ACCN's level of evidence: (C) qualitative studies, descriptive or correlation studies, integrative reviews, systematic reviews or randomized trials with inconsistent results.

study were recruited from both a university dental clinic and a private practice (Plasmans & van 't Hof 1993), whereas participants of three studies were recruited from private practice (Mannocci *et al.* 2002, 2005, Ferrari *et al.* 2012), and participants of the observational study were only from a university dental clinic (Signore *et al.* 2011). Of the five included studies, one study reported financial support from both a private company and a public institution (Plasmans & van 't Hof 1993) and the remaining four studies did not report any source of support (Mannocci *et al.* 2002, 2005, Signore *et al.* 2011, Ferrari *et al.* 2012). The dropout of patients and restorations ranged from 0.8% to 11.9% and from 1.3% to 12.2%, respectively. One study (Signore *et al.* 2011) assessed only post-retained crowns. One study (Mannocci *et al.* 2005) compared post-retained composite resins with post-free amalgams, one study (Ferrari *et al.* 2012) compared post-retained crowns with crowns, another study (Mannocci *et al.* 2002) compared composite resins and posts with crowns and posts, and one study (Plasmans & van 't Hof 1993) reported on amalgams retained with different methods in both root filled teeth and teeth with vital pulps. Data on crowns were the most extensive and complete (Table 3); two studies (Plasmans & van 't Hof 1993, Ferrari *et al.* 2012) provided extensive data on the outcome of crowns placed on teeth with one to four remaining walls. Seventy-four per cent of single crowns were retrieved from one study (Ferrari *et al.* 2012). All of the studies were located in Europe; the four Italian studies, which were published between 2002 and 2011, only examined restorations in premolars (Mannocci *et al.* 2002, 2005, Signore *et al.*

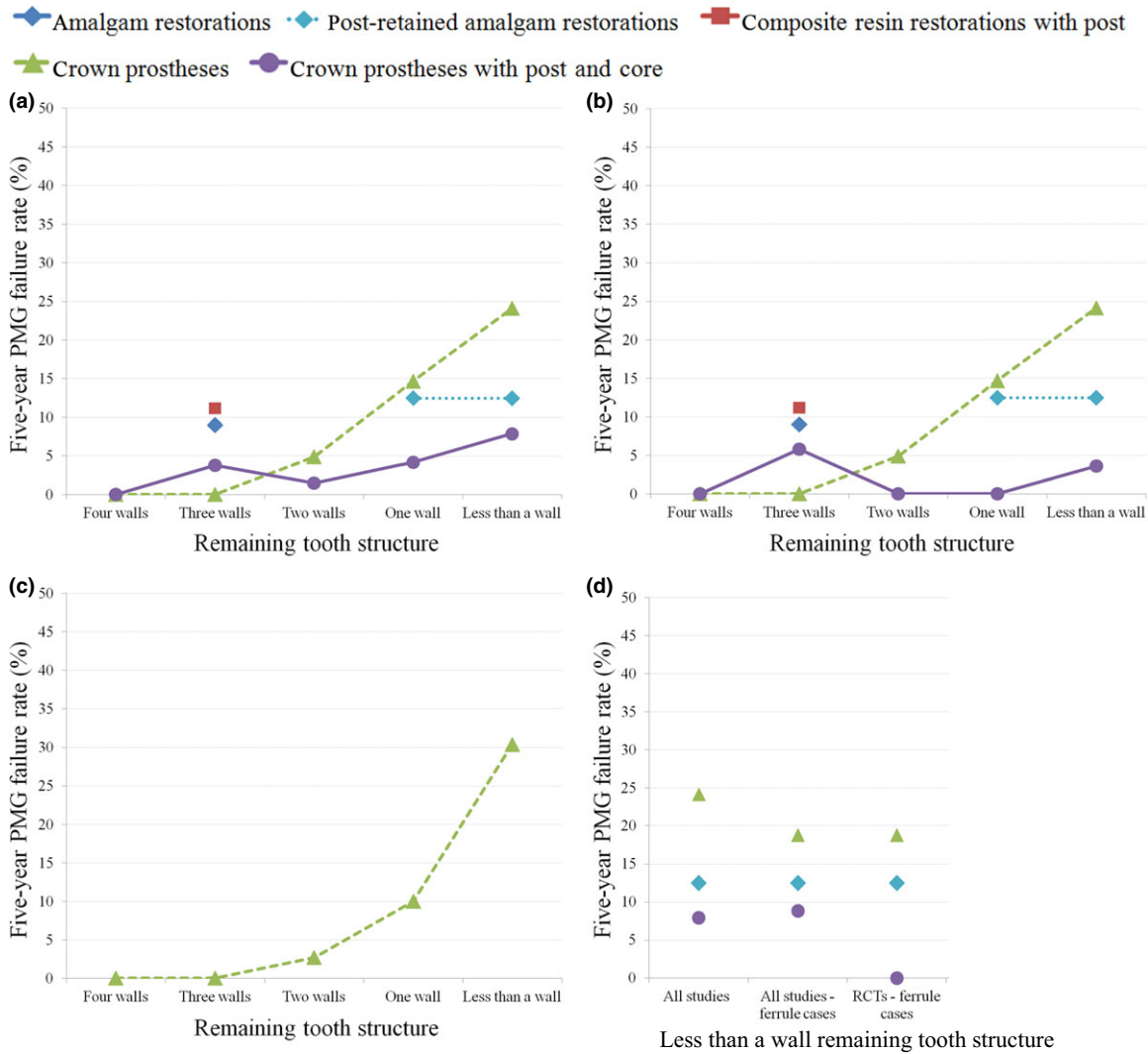


2011, Ferrari *et al.* 2012), whereas the Dutch study, which was published in 1993, only examined molars (Plasmans & van 't Hof 1993). All included studies were published in English. The included studies reported follow-up periods ranging between 3 and 6 years (Table 2). Data for the study outcome were presented as the number of restorations lost, retention rates, cumulative failure rates (%) or modified USPHS criteria scores. The pooled average failure rate for each specific condition indicated that the failure rate was higher for teeth with less remaining structure compared to teeth with more structure left (Fig. 3).

These differences were more pronounced for composite resin restorations.

**Discussion**

This is the first systematic review reporting the clinical failure of restorations in posterior permanent root filled teeth that considers remaining coronal tooth structure as a key risk factor. The relevance of the present study is that it clarifies the overall picture of restorative interventions outcome and could aid in the decision-making process.



**Figure 3** Representation of the 5-year accumulated failure rate of restorative treatments according to the remaining coronal structure in root filled teeth. (a) Data from both study designs. (b) Data from only RCTs. (c) Data from the observational study. (d) Data from different cases of the less than a remaining wall group (all studies, only ferruled cases and only ferruled cases reported from RCTs).

## Summary of main results

Five studies involving 1160 posterior restorations and more than 955 patients at baseline met the inclusion criteria and were evaluated in this review. The only observational study included was judged as having a low risk of bias (Table 4). The studies suggested that when four and three walls remained, crowns were the best choice of treatment, whereas when two walls or less remained, post-retained crowns were superior to other treatments. Overall, teeth with more remaining tooth structure had a better prognosis than teeth with less coronal structure. Every specific clinical scenario is discussed below.

### *Teeth with four remaining walls*

The included studies (Signore *et al.* 2011, Ferrari *et al.* 2012) reported a 0% failure up to a 6-year follow-up for crowns with or without posts (Table 3). There was no information available in the literature on amalgams and composite resins on teeth with this condition. The findings suggested that crowns may be a good treatment option for teeth with four remaining walls and post placement may not be necessary (Fig. 3a,b).

### *Teeth with three remaining walls*

Crowns, with or without posts, reported the lowest failure rate for this clinical scenario ranging from 0% (Signore *et al.* 2011, Ferrari *et al.* 2012) to 5.6% (Mannocci *et al.* 2002). Post-free amalgams and post-retained composite resins had higher failure rates ranging from 9% to 10.3% at a 5-year follow-up (Mannocci *et al.* 2005; Table 3). Therefore, intracoronary restorations may not be considered as an option in teeth with three remaining walls (Fig. 3a,b). Although only one single study, with a limited sample size (<20), provided data on post-free crowns (Ferrari *et al.* 2012), its findings suggested that posts might not be needed in teeth with three remaining walls (Fig. 3a,b).

### *Teeth with two remaining walls*

In root filled teeth with two remaining walls, crowned teeth had a higher failure rate (Ferrari *et al.* 2012) than crowns with posts and core (Signore *et al.* 2011, Ferrari *et al.* 2012; Table 3). Moreover, the differences between these two treatment options were even greater when the analysis was limited to the single randomized control trial (RCT) that made a direct comparison between post-free crowns on the one

hand and crowns with posts and core on the other hand (Ferrari *et al.* 2012; Fig. 3b). This could be attributed to the fact that two remaining walls may not provide sufficient tooth structure to maintain crowns without dislodgment or any other complications leading to absolute (catastrophic) or relative failures. There was no retrievable information on intracoronary restorations. Thus, the findings recommend using post-retained crowns to restore teeth with two walls remaining (Fig. 3a,b).

### *Teeth with one remaining wall*

The failure rate for post-retained amalgams and crowns, in addition to post-free crowns in teeth with one wall, is presented in Table 3. The only RCT on this clinical condition (Ferrari *et al.* 2012) compared crowns with and without posts and reported that post-retained crowns had a lower failure rate than post-free crowns (Table 3). There was no retrievable information on composite resins and post-free amalgams. When revising the pooled average failures for treatments, post-retained crowns were the superior treatment in terms of clinical outcomes compared to post-retained amalgams and post-free crowns (Fig. 3a, b). Therefore, these findings recommend using post-retained crowns in root filled teeth with only one wall left.

### *Teeth with <1 remaining wall*

In teeth with <1 wall left, the failure rate of post-retained amalgams, and crowns with or without posts (ferruled or not), ranged from 0% to 35% (Ferrari *et al.* 2012) at 6 years (Table 3). Overall, the studies indicated that the failure of post-retained crowns was lower than for post-free crowns and post-retained amalgams (Table 3; Fig. 3a,b). There was no information available on teeth restored with composite resins and post-free amalgams (Table 3). The only RCT available (Ferrari *et al.* 2012) compared the longevity of crowns with and without posts and test whether the remaining coronal structure had a ferrule or not (Table 3). Ferrari *et al.* (2012) revealed that crowns on teeth with ferrule have lower failure rates than those without ferrules (Table 3; Fig. 3d). Prostheses with and without a post on ferruled teeth seemed to have a similar failure rate (Fig. 3d – all studies).

Despite the fact that crowns with posts offer better outcomes overall, dental implants may be considered in this clinical scenario, especially when no ferrule is available or a retreatment has failed (Pennington *et al.* 2009). Restoring a devitalised posterior tooth

with scarce coronal structure is probably less cost-effective than placing an implant as the former treatment option has a questionable prognosis and requires a considerable investment (root canal treatment, post and core reconstruction, crown, crown lengthening, etc.).

### Overall completeness and applicability of the evidence

The included RCTs reporting on root filled teeth compared amalgams versus resins with posts (Mannocci *et al.* 2005), different retaining methods (i.e. amalgam pins, solitary amalgam slots, circumferential amalgam slot, self-threading pins, radicular posts) for amalgams (Plasmans & van 't Hof 1993), crowns with and without posts (Ferrari *et al.* 2012), and post-retained crowns and resins (Mannocci *et al.* 2002). It is acknowledged in the literature that RCTs in prosthodontics are not common (Harwood 2008) and most of them are classified as low quality (Pandis *et al.* 2010); therefore, it was decided to include observational studies as well. However, adding observational studies to the systematic review may increase the risk of bias (Faggion 2012). The included observational study reported on post-retained crowns (Signore *et al.* 2011).

The information regarding composite resin restorations was scarce because two studies reported data in only one clinical scenario with posts. In addition, there were no studies reporting on post-free composite resin restorations. The follow-up period of all the included main studies ranged from 3 to 6 years. The analysis of failure rate was chosen for this review because it is a true/definitive outcome that reflects unequivocal evidence of tangible benefit to the patient and may directly affect clinical practice and public health policies (Bidra 2014). To provide useful data to clinicians and manage the differences amongst the included studies in terms of follow-up time, pooled mean group 5 year was provided, mean failure rate estimations from extracted data. The sample size is crucial for a study to have a large clinical impact and provide sufficient evidence to change a particular clinical practice. The included studies were considered to have sample sizes ranging from 117 to 360 restorations. Overall, the lack of high-quality reports regarding failure rates of the restoration may limit the conclusions. The generalizability of the findings from these populations is also unclear.

A possible bias might also have been the limited number of risk factors that were taken into account as these may act as cofounders. An additional limitation to consider in this review is that four of five reports were based on premolars. These teeth seem to have proportionally less salvageable tooth structure than molars (Opdam *et al.* 2014), which leads to a higher prevalence of tooth fracture, especially in the maxilla (Ng *et al.* 2011). In addition, the study that included molars is from 1993 and only provides data on amalgams. These restorations are being largely abandoned as a treatment option to reduce the use of mercury-containing products (Alexander *et al.* 2014). Therefore, the findings of this review may not be generalizable to all posterior teeth. More studies on molars should still be considered for making recommendations. Another limitation of these studies is that they do not take into consideration the height and thickness of the remaining dentine walls, in addition to the continuous developments in restorative materials, especially since the 2000s, which may limit to some degree the applicability of the findings.

All studies but one (Plasmans & van 't Hof 1993) had a single operator who placed all the restorations and two independent calibrated examiners who assessed the restorations outcome. Another particular difficulty was the blinding of operators and evaluators who tested the different interventions as the material and clinical protocol had to be known, and therefore, it was difficult to conceal (Fig. 2; Table 2). Also due to the unavoidable awareness of patients over the treatment received, it is difficult to perform double- or triple-blinded studies (Bidra 2014).

Most of the included studies (four of five) were conducted in private practice settings by operators with university affiliation, and all of the studies were conducted in Europe. Consequently, it is difficult to generalize any of the findings to other settings and countries.

### Quality of the evidence

The body of evidence is based on the results of one high-quality observational study, and four RCTs low of quality due to the high risk of bias (Fig. 2; Table 4). High risk of bias in RCTs was due to an inability to satisfactorily conduct the concealment of allocation and blinding of outcome assessors. There is a degree of uncertainty whether the results of the included studies were reliable as a sample size calculation was neither conducted nor reported. Overall, the (AACN's) level of evidence from the included studies

was judged to be low (C) in all studies except the observational study (Signore *et al.* 2011). The heterogeneity of the methods and techniques and the risk of bias made it undesirable or impossible to pursue a meta-analysis. Hence, this review was limited to the qualitative description of studies.

In addition, it should be noted that a potential source of bias in a systematic review investigating restoration longevity is that the USPHS criteria may not be consistently applied across studies (Chadwick *et al.* 2001). Other reasons contributing to the inconsistent failure rate outcome may be differences owing to various settings, the age of participants, caries risk, the four studies with missing to report funding sources and the one private and industry-funded study.

### Potential biases in the review process

The search strategy was carefully developed by two reviewers and two experienced information technologists. The same reviewers independently scrutinized all identified references and assessed the risk of bias to score their reporting quality. However, the possibility that some references have been missed cannot be excluded. In addition, reviewers were not blinded, and grey literature was not evaluated. Moreover, only one reviewer extensively hand-searched cross-referencing and relevant journals, as well as the reference lists of systematic reviews and nonsystematic reviews identified from the electronic search. The same reviewer alone extracted the data from all the included studies. A funnel plot assessment of publication bias was not undertaken; therefore, the risk of publication bias is unknown.

To overcome the most obvious bias in the study, the pooled mean group was not only performed combining study designs but also they were reported separately.

### Agreements and disagreements with other research

This review found trends that may be clinically relevant. Overall, a trend was noticed where failure rate increased in groups with less remaining tooth structure and decreased in groups with a greater amount of structure (Fig. 3). The variation may be due to the heterogeneity of the studies included in this remaining wall category (Table 3). The findings broadly are in agreement with those of other studies (Frencken & Sithole 1998, Lyons 2003, da Rosa Rodolpho *et al.* 2006, Moura *et al.* 2011, Opdam *et al.* 2014, Mesko

*et al.* 2016), which found that larger restorations had a higher risk of failure because the risk increased for every extra surface.

### Implications for practice

Providing the most appropriate restorative treatment for different clinical scenarios in root filled teeth was the aim of this study. This may reduce personal and financial healthcare costs as well as increase the quality of life of patients and prevent the selection of treatments with poor prognosis (Grol & Grimshaw 2003, Darmstadt *et al.* 2005). However, in some cases, no substantive implications for practice can be drawn. There is mostly low-quality evidence to suggest one treatment over another. When only RCTs were examined, this review suggested restoring root filled teeth with post-free crowns when three tooth walls remained, whereas composite resin restorations were the least favourable material for this clinical scenario (Fig. 3b; Appendix S7). Furthermore, post placement should be considered for crown retention in cases with <3 remaining walls. However, more tooth structure is lost when the root canal system is prepared for a post, which in turn leads to a higher fracture and failure risk (Balevi 2013). In addition, endodontic access cavities should be kept conservative to maximize the amount of remaining tooth structure.

The data included in this review were based on four RCTs (Plasmans & van 't Hof 1993, Mannocci *et al.* 2002, 2005, Ferrari *et al.* 2012) and one retrospective cohort (Signore *et al.* 2011). The high-quality study showed a failure rate from 0% to 23.1% at nearly 4 years in root filled teeth restored with post-retained crowns in every clinical scenario (Signore *et al.* 2011; Table 3).

One potential benefit of using intracoronal restorations instead of crowns is the lower costs and ease of access for the most vulnerable populations, particularly the popular use of amalgams in lower-income countries. Moreover, future studies will have to be performed to address the failure rate of different restorative treatments for those specific dental conditions in more representative clinical settings.

### Implications for research

There is limited evidence on the benefits that one restorative treatment may present over another. This review identified four eligible RCTs which presented a high risk of bias. Consequently, future prospective

clinical studies with lower risk of bias should be performed and assess treatment outcomes as a function of a larger number of risk factors (Afrashtehfar & Manfredini 2013, Afrashtehfar et al. 2016a), such as degrees of caries risk and remaining dentine volume. There is also a need to conduct long-term prospective studies with larger sample sizes (including molar teeth) executed across a wide range of settings (i.e. students, and clinicians from private and public practices) and reporting failure based on reproducible and valid assessments (i.e. USPHS evaluation methods). Ideally, this should be carried out by performing RCTs conformed to the Consolidated Standards of Reporting Trials (CONSORT) guidelines to facilitate meta-analysis (Moher et al. 2003).

## Conclusions

Most of the information obtained was retrieved from studies with high risk of bias; therefore, the results should be interpreted with caution. However, despite limitations, the study provided two main conclusions regarding restorations on posterior root filled teeth:

- The greater the amount of remaining tooth structure, the better the treatment outcome.
- Post-retained crowns seem to be the superior treatment, followed by post-free crowns and intracoronary restorations.

Accordingly, endodontic access cavities should be kept conservative to maximize the amount of remaining tooth structure, which in turn should determine the choice of dental restoration. Despite the superiority of post-retained crowns, post-free crowns can be considered when there are three to four walls left, whereas post-retained crowns may be preferred in teeth with one to two walls left. Other prosthetic replacements may be considered in cases with <1 wall left, especially with no ferrule.

## Acknowledgements

The authors express their gratitude to PhD candidate O. Eilayyan for conducting the statistical analysis. Many thanks to the librarians Mrs. A. Lambreau, McGill University and Mr. P. DuPont, Université de Montréal, for their assistance in designing the electronic search strategies. The first author (KIA) would like to thank the McGill University Faculty of Dentistry, the Network for Oral and Bone Health Research (RSBO) of the Province of Quebec, the Alpha

Omega Foundation of Canada and the International Team for Implantology (ITI) Foundation.

## Conflict of interest

Dr. Afrashtehfar reports a scholarship from the Network for Oral and Bone Health Research (RSBO), student grant from the Alpha Omega Foundation of Canada and an award from the McGill University Faculty of Dentistry during the conduct of the study. Dr. Ahmadi reports a payment from the Network for Oral and Bone Health Research grant during the conduct of the study. Dr. Emami and Dr. Tamimi report grants from the Network for Oral and Bone Health Research (RSBO) during the conduct of the study.

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### Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** Search strategy used for Cochrane Oral Health Group's Trials Register.

**Appendix S2.** Search strategy used for CENTRAL.

**Appendix S3.** Search strategy used for Embase <1947 to 2015 February>.

**Appendix S4.** Table of the levels of evidence according to the AACN's new evidence-leveling system.

**Appendix S5.** Full-text excluded articles and reasons for the exclusion.

**Appendix S6.** References to studies included in this review.

**Appendix S7.** Meta Regression of 5-year mean failure rates interventions in endodontically-treated teeth compared to crown and post (all studies).

**Appendix S8.** Table of quality appraisal of the observational studies included in the systematic review.