Influence of remaining axial walls on failure of root filled teeth restored with a single crown and adhesively bonded fibre post: a systematic review and meta-analysis

E Alsaleh, A Dutta, P M H Dummer, D J J Farnell, M E Vianna

Abstract

Objectives: To synthesise evidence on structural failures and prevalence of post-treatment endodontic disease (PTD) in anterior and posterior root filled teeth with a single crown and adhesively bonded fibre post with regards to the number of axial walls.

Data: An electronic search was performed, no language constraints or restriction on the year of publication were applied.

Sources: PubMed, Medline, Cochrane and Scopus on 13th of July 2021.

Study selection: Clinical studies that reported the remaining number of axial walls for permanent anterior and posterior root filled teeth (RFT) restored with single crowns and adhesively bonded fibre posts with a minimum of 1 year follow-up were included. Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [1] were used. The number of axial walls and the success/failures were analysed as follows: fibre post and/or core decementation, post and/or core fracture, post treatment endodontic disease, and root fracture.

Conclusions: A total of 811 studies were identified with 5 meeting the inclusion criteria. The two randomized controlled trials included had 'some concerns' as determined by the Cochrane risk-of-bias 2 tool while the Newcastle-Ottawa scale found low risk of bias for the remaining three studies. The random effects model for subgroup meta-analysis revealed failures for posterior RFT increased with decreasing numbers of remaining walls. Failures for 0 remaining walls were 23% (95% CI = 10% - 36%) and for one remaining wall 15% (CI: 3% -26%), irrespective of follow-up times. Fibre post debonding and PTD increased with decreasing numbers of walls. Relative & catastrophic failure of posterior teeth restored with a fibre post and single crown after root canal treatment increased with decreasing numbers of remaining axial walls.

Clinical Significance: This synthesis is unique as it minimizes the presence of confounding factors by reviewing evidence of failures and post-treatment endodontic disease associated with teeth restored with single crowns. Therefore, it provides valuable predictive evidence of potential coronal restoration catastrophes and post-treatment endodontic disease associated with root filled teeth.

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Introduction

An effective coronal restoration with a good seal is important for the long-term survival of root filled teeth [2-6]. The design of the restoration following root canal treatment is influenced by various factors [7] such as evaluation of (a) the remaining tooth structure [8], (b) the anatomic position of the tooth in the arch [9, 10], (c) the interference of occlusal forces, and (d) the condition of the periodontal support [11]. The long-term outcome of coronal restorations is related to the structural integrity of root filled teeth, which is influenced by (a) remaining tooth macrostructure [12, 13] that is often diminished due to pre-existing dental caries and restorations (usually with loss of marginal ridges) and root canal procedures (e.g. access cavity) [14, 15] and (b) effects of irrigants and intra canal medicaments on the microstructure of dentine [16-19].

A circumferential cervical ferrule improves the load capacity of root filled teeth with insufficient coronal tooth structure and influences survival of such teeth with post-retained restorations [20]. However, there is no universal agreement on a specific post system for root filled teeth. Adhesively bonded fibre posts, combined with a bonded core manifest as a mono-block that functions as a mechanically homogenous unit [21] with simpler technical procedures [22] as compared with cast posts. Nevertheless, it has been reported that root filled teeth with reduced coronal tooth structure are more prone to restoration-related failures [23, 24] and teeth with post-retained cores are subject to post debonding, post/core breakage or other catastrophic modes of failures, such as root fracture [22], often resulting in extraction.

Failure of fibre post restorations in root filled teeth with varying amounts of remaining coronal tooth structure have been reported in laboratory [25-27] and clinical studies [8, 28-37]. Laboratory studies have used a variety of tests to determine load capacity and failure modes of samples with various post designs and coronal restorations. The results are heterogeneous and difficult to extrapolate to clinical settings. The results of clinical studies are also heterogeneous and difficult to interpret for a variety of reasons. Firstly, variations in the type of teeth analysed. Some studies evaluated anterior teeth [31, 32], only premolars [29, 30, 33, 36], or a variety of different teeth [28, 35, 37, 38] with only a few studies reporting specific results for each group [34, 39]. Secondly, variation on type of posts [10, 35, 40]. Thirdly, variation in evaluation and report of remaining coronal structure either before crown preparation [29, 30, 33, 39] or after crown preparation [8, 36,

41]. Fourthly, variability in reporting failure which could be either relative or absolute [30, 35, 37, 38], grouped per tooth type [8, 29, 30, 32, 36, 39], as failure of the post [8, 29, 30, 36, 39], as failure of the core [33-35] or as failure of both post and core [30, 33]. The types of definitive restorations are variable [10, 28, 32, 34, 38], as are the follow-up periods and recall rates.

Therefore, the aim of this systematic review & meta-analysis was to synthesise evidence and to examine the impact of the remaining number of axial walls (0 to 4) on relative and catastrophic structural failures of root filled teeth restored with an adhesively bonded fibre post and single crown after a follow-up of at least 12 months. The relative structural failures evaluated were fibre post debonding, post and/or core fracture. The catastrophic structural failure evaluated was root fracture. Post-treatment endodontic disease was also evaluated.

The PICOT question was as follows: Population: root treated anterior and posterior permanent teeth in adult patients. Intervention: root filled teeth restored under rubber dam with an adhesively bonded fibre post and single crown. Comparison: amount of remaining coronal dentine structure (number of axial walls 0 - 4 walls). Outcome: (a) relative failures - fibre post debonding, post and/or core fracture and post-treatment endodontic disease and (b) catastrophic failure - root fracture. Time: at least 12 months follow up.

Materials and methods

The present systematic review was conducted according to the Preferred Reporting Items for Systemic reviews and Meta-Analysis (PRISMA) [1]. Following development of the protocol and implementing the search strategy, the study was registered in the Open Science Framework (https://osf.io/7j9y6).

Information sources and search strategy

Four electronic searches were performed using the following databases: Pubmed, Cochrane, Scopus and Medline via Ovid. The first two searches, on 12/7/2019 and on 26/9/2019, were used to refine the key words to be used in the main search, which was performed on 31st of October 2019. An updated search was undertaken on the 13th of July 2021 to check for new studies published since the initial searches. The search terms and the detailed search strategy for the databases searched are included in Table 1. No language or year of publication restrictions were

applied. The key words included: ferrule, coronal wall, residual* coronal, remain* coronal, fibre post. An asterisk was used at the end of some words to return any possible endings to those words. From 1st of November 2019 to 31st of January 2020, a manual search was undertaken for the titles, keywords and abstracts and main texts and Grey literature (in "OpenGrey"). Subsequently, all references of the identified articles and relevant reviews were inspected manually for other potentially eligible studies.

Study selection and eligibility criteria

The complete list of articles and selected manuscripts were first obtained by one author (EA) and results confirmed independently by two other authors (AD and MV). Studies were included/excluded based on titles, and subsequently on abstracts. The remaining articles were assessed after full text evaluation to meet the entry criteria. The studies that did not meet the eligibility criteria were excluded and reason for their exclusion were recorded (Table 2).

The inclusion criteria were as follows:

(1) Randomized control trials, prospective and retrospective studies with minimum follow up time of 12 months in permanent root filled anterior and posterior teeth restored with an adhesively bonded fibre post (without customization) and single extra-coronal restoration (single crown).

(2) The number of remaining axial walls specified.

(3) Good quality standard for post placement (use of rubber dam and at least 4 mm remaining root filling).

(4) Asymptomatic teeth (baseline periapical health without periradicular disease or recent root canal treatment) with information about possible post-treatment or persistent endodontic disease at the follow-up visit(s).

(5) Description of success or failure of restoration (fibre post debonding, fracture) related to the number of axial walls and tooth type (anterior/posterior).

The exclusion criteria were as follows:

(1) Case reports, *in vitro*, *ex-vivo* studies, "finite element analysis" studies, animal studies, and narrative reviews.

(2) Randomized control trials, prospective and retrospective studies that included permanent teeth without restorations or coronal restorations other than single crowns; other types of post and core (e.g. customized fibre posts) other than prefabricated fibre posts.

(3) Studies that failed to present good standards for post placement (no use of rubber dam or apical root filling was less than 4 mm).

(4) Randomized control trials, prospective and retrospective studies that did not report if teeth were asymptomatic at baseline and no information on periapical status at the follow-up visit(s),

(5) Randomized control trials, prospective and retrospective studies with no follow-up or follow-up of 11 months or less, and

(6) Studies that failed to describe success/ failure of fibre posts based on different axial wall groups.

Data extraction

Data was extracted by one author (EA) and later reviewed by two other authors (MV and AD). The following essential information was extracted: author's name, year of publication, study design, sample size, type of teeth included in the studies, description of walls, post type, cement type, core, extra-coronal coverage, follow up, results and missing information. Where information was missing, or where clarifications were required, the corresponding authors were contacted via email and requested to respond within 4 weeks (with a reminder email after 2 weeks). If relevant data were not obtained, the studies were excluded from the analysis.

Quality of evidence assessment

The included articles were critically appraised based on standard checklists and given a score established on the checklist used. The quality assessment of the selected studies was performed according to the design of the included studies (randomized control trials or prospective/retrospective studies). The second version of the Cochrane risk-of-bias tool for randomized trials (RoB 2) was used for risk assessment of randomized control trials [42] and the Newcastle-Ottawa quality assessment scale for cohort studies was used for prospective and retrospective studies (http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp) [43].

Statistical analysis and synthesis of results

A meta-analysis was performed to determine the pooled estimate across a group of studies (subgroup analysis) or overall studies (overall analysis) for the point estimate and confidence interval of single proportion. Subgroup analysis was carried out for a subset of the studies according to established criteria. Pooled estimates from meta-analysis were found for these subgroups in addition to any overall analysis. Overall pooled point estimates and 95% confidence intervals of a single proportion were found using the "metaprop" command in the statistical software package R software (version R 3.6.1, R Foundation for Statistical Computing, Vienna, Austria). The raw data or "no transformation" was used to calculate an overall proportion, although other transformations (e.g. arcsine) gave similar results. Due to the small number of studies, only partial data could be analysed (e.g. posterior teeth) and no exploration of bias via funnel plots could be carried out. However, statistical heterogeneity was measured by using I^2 test, where an I^2 value of close to 100% indicated strong heterogeneity and an I^2 a value close to 0% indicated weak (or no) heterogeneity. Meta regression was used to analyse the results of different studies as a function of another variable, such as the number of walls and reduced/no ferrule and adequate ferrule when no axial walls were present. Results of meta regression were depicted as a scatter plot with the regression line superimposed. The weight for each study was shown by the size of the "bubble".

Results

The process of selecting the included studies is described in Figure 1. Eight hundred and eleven articles were retrieved from the search (90 from Pubmed, 372 from Cochrane, 170 from Medline, 179 from Scopus and 9 via manual hand searching of cross-referenced studies). Six hundred and twenty studies remained after duplicates were removed. After screening for titles and abstracts, 592 articles were excluded. Twenty-six articles were obtained for full text assessment.

After full text assessment, the corresponding authors of 13 studies were contacted by email for completion of data for analysis [10, 28-30, 32, 34-38, 40, 44-46]. Three corresponding authors for five studies provided the required information for inclusion or exclusion of the studies in the systematic review and meta-analyses [28-30, 36, 46]. A total of twenty-one articles were excluded (Table 2). The reasons for exclusion included lack of description of residual axial walls present, lack of raw data, segmented/combined data for different coronal configurations, mixed data for

anterior and posterior teeth, no statement of rubber dam (RD) use, teeth that were used as abutments for partial or fixed prosthodontic dentures or those that did not receive a crown.

Data collection and analysis

Five studies were included in the qualitative and quantitative analysis of this systematic review [29, 30, 33, 39, 46]. Study characteristics for the five included articles were extracted (Table 3). The included studies were: two prospective clinical trials, one retrospective study, and two randomised control trials. Three studies included maxillary and mandibular premolars [29, 30, 33] and two studies included both anterior and posterior teeth [39, 46]. The number of teeth included ranged from 107 to 154 with follow-up of up to 108 months. Three studies used RTD Light-Post™ (fibre post) [29, 30, 39], one used White Post DC (FGM, Joinville, Brazil) [46], and one used an oval shaped post (Bioloren Fibreglass post) [33]. All studies used dual cure resin cement for post cementation and a composite core. The restorations were either all ceramic crowns or porcelain fused to metal crowns. Although some studies compared different posts (or absence of post) and different cuspal coverage restorations (or absence of crown), only the results for teeth with pre-fabricated fibre posts restored with single crowns were included in the present systematic review and meta-analysis.

The remaining number of axial walls and number and type of failures for anterior teeth and posterior teeth restored with a fibre post and single crown according to the distribution of teeth in the arch are presented in Table 4. As only two studies included anterior teeth with single crowns [39, 46], a meta-analysis could not be performed. Seventy-nine anterior root treated teeth were restored with a fibre post and single crown, and followed-up to two years in one study [39] and up to nine years in the other [46]. Four anterior teeth with no remaining axial walls had post decementation. Three anterior teeth had post-treatment endodontic disease (presence of periapical radiolucency in the radiograph – PAR), Two teeth had no remaining axial wall and the one tooth had only 1 remaining axial wall. One root fracture and one crown dislodgment were observed in anterior teeth with no remaining axial walls.

The posterior teeth were included from five studies [29, 30, 33, 39, 46] (Table 4). Two studies [29, 30] included 6 groups for the remaining coronal structure [reduced/no ferrule (less than 2 mm) with no remaining walls (0 walls), adequate ferrule (2 mm or more) with no remaining walls (0 walls), 1

wall, 2 walls, 3 walls, 4 walls). The other two studies [33, 39] included 5 groups (at least 1 mm ferrule when no walls were present, 1 wall, 2 walls, 3 walls, 4 walls). One study only included teeth without coronal walls or 1 wall in enamel without dentine support (with a ferrule height of 0 to 0.5 mm) [46].

The sample size in each group of each included study varied between 10 and 67 teeth. General outcomes ranged between no failures (relative or catastrophic failures), mainly in "4 walls group", to 44 and 11 failures (relative or catastrophic failures) in "0 wall group" and "1 wall group" respectively, over a mean follow up period extending from two to nine years [29, 30, 33, 39, 46]. The total number of failed fibre posts in posterior teeth were 62 out of 534 (11.6%) in a follow up period from 2 to 9 years. The most commonly reported failure in posterior teeth was post debonding (n= 29), followed by post-treatment endodontic disease (PAR, n= 13) and core/post fracture (n= 10). A less common complication was root fracture (n= 7). Signore *et al*. [33] stated that all failures were in groups that had less than 2 remaining walls with no further details. They also reported that the relative failures were repairable (n= 5). Ferrari *et al*. (2007b) [29] and Signore *et al*. [33] reported that 5 crowns were dislodged, and this was not included in the failure of the teeth and/ or fibre posts.

Quality assessment

The risk of bias of the studies included in the meta-analysis was assessed (Figure 2). Ferrari *et al*. [30] and Sarkis-Onofre *et al*. [46], both randomised control trials, were assessed using the Cochrane risk-of-bias tool (RoB2) and revealed that the trial had 'some concerns' for the risk of bias (Figure 2A). Cagidiaco *et al*. [39], Ferrari *et al*. [29], and Signore *et al*. [33], three cohort studies, were assessed using the Newcastle-Ottawa quality assessment scale. These studies scored 7 to 8 stars which indicate 'low risk for bias' (Figure 2B).

Meta-analysis

Fibre post and all causes of failure (relative and catastrophic failures grouped)

The four studies included in the systematic review had low heterogeneity for pooled data for 2-4 axial walls (I^2= 0%, P>0.05). A random-effects meta-analysis was used due to moderately high

heterogeneity for 0 and 1 axial walls; moderate heterogeneity in the 1 axial wall group (I^2= 53%, P=0.10) and substantial heterogeneity for the 0 axial wall group (I^2= 81%, P<0.01).

Failures were classified as either relative [post debonding, post fracture, and post-treatment endodontic disease noted as presence of periapical radiolucency (PAR)] or catastrophic (root fracture). The random effect model for meta-analysis for all causes of failure (relative and catastrophic failures) revealed that the proportion of failure decreased with increasing numbers of axial walls (Figure 3) (No overall pooled results of meta-analysis for over all data, i.e., irrespective of the number of walls, was carried out due to this strong trend with respect to the number of walls). Chances of fibre post and/ or all causes of failure grouped together (Figure 3A) were as follows: 4 remaining axial walls, percentage failure = 0% (95% CI = 0% to 3%); 3 remaining axial walls, percentage failure = 1% (95% CI = 0% to 3%); 2 remaining axial walls, percentage failure = 2% (95% CI = 0% to 5%); 1 remaining coronal wall, percentage failure = 15% (95% CI = 3% to 26%, i.e., significantly different to 0%); 0 remaining axial walls, percentage failure = 23% (95% CI = 10% to 36%, i.e., significantly different to 0%). Linear meta regression analysis showed that the proportion of all failures decreased with increasing numbers of axial walls (Figure 3B). On average, the chances of relative and catastrophic failure reduced significantly (P < 0.0001) by 5% for each unit increase in the number of axial walls. Further meta-analysis could be performed for fibre post debonding and post treatment endodontic disease, but not for post fracture or root fractures.

Fibre post debonding

Low heterogeneity was found for subgroup analysis for 1 (I^2= 9%, P=0.33) through 4 remaining walls (I^2= 0%, P>0.05) in a random effects model (Figure 4). Random-effects meta-analysis was used due to moderate heterogeneity between studies when no axial walls remained (I^2=82%, P<0.01).

The meta-analysis included four studies for 0 remaining axial walls [29, 30, 39, 46], three studies for 1 and 2 remaining axial walls configurations [29, 30, 39] and four studies for 3 and 4 remaining axial walls [29, 30, 33, 39]. Signore *et al*. [33] did not report the type of failure in relation to specific 0 - 2 walls group (Table 4 and Figure 4 A). The proportion of fibre post debonding decreased with increasing numbers of remaining axial walls (no overall pooled results of meta-analysis for over all data, i.e., irrespective of the number of walls, was carried out due to this strong trend with respect

to the number of walls). There was no noticeable relationship between follow-up time and post debonding failure (Figure 4 A). The linear meta regression analysis revealed that the proportion of fibre post debonding decreased with increasing numbers of walls. Overall, the chances of fibre post debonding reduced significantly (P = 0.012) by 2% for each increase in the number of remaining walls.

Post-treatment endodontic disease in teeth restored with fibre posts

A random effect models was used for analysing development of post-treatment endodontic disease (presence of periradicular radiolucency on periapical radiographs - PAR) in teeth restored with adhesively bonded fibre posts and single crown in relation to the number of axial walls demonstrated (Figure 5). A random-effects meta-analysis was used due to moderately high heterogeneity in some cases. This model included four studies for 0 remaining axial walls [29, 30, 39, 46] 0 walls (I^2= 59%, P=0.06); three studies for 1 and 2 wall configurations [29, 30, 39] [1 wall (I^2= 29%, P=0.25; 2 walls (I^2= 0%, P=0.66)] and four studies for 3 and 4 remaining axial walls [29, 30, 33, 39] (I^2= 0%, P>0.05) (Table 4 and Figure 5 A). Post-treatment endodontic disease in teeth restored with a fibre post and single crown decreased with increasing numbers of remaining axial walls (no overall pooled results of meta-analysis for over all data, i.e., irrespective of the number of walls, was carried out due to this strong trend with respect to the number of walls). There was no noticeable relationship between follow-up period and development of periapical radiolucency (Figure 5 A). The linear meta regression analysis revealed that the proportion of post-treatment endodontic disease in teeth restored with a fibre post and single crown decreased with increasing number of remaining axial walls (Figure 5 B). On average, the chances of post-treatment endodontic disease reduced insignificantly (P = 0.676) by 0.2% for each increase in the number of remaining axial walls.

Discussion

This systematic review and meta-analysis evaluated the effect of the number of remaining axial walls in root filled teeth restored with adhesively bonded fibre posts and a single crown on the relative- and catastrophic-structural failure of the teeth or restoration as well as the prevalence of post-treatment endodontic disease when followed-up for at least one year. Although randomised

control trials are the gold standard [47], the search revealed that only a small number of studies had been conducted in this area [10, 30, 35, 37, 38, 41, 46]. Therefore, both prospective and retrospective studies were included [29, 30, 33, 39].

The risk of bias [48], included in this systematic review and meta-analysis revealed that three studies [29, 33, 39], evaluated by the NOS, were of good quality with low risk of bias. Ferrari *et al*. [30] and Sarkis-Onofre *et al*. [46] were evaluated by another tool and scored moderate risk of bias. Therefore, the reliability of this meta-analysis could be considered relatively at lower risk of bias.

Stringent inclusion/exclusion criterion were used to minimize ambiguity. The criteria were set *a priori* and based on a conceptual model using a protocol that was revised internally by three academics. Clinical factors that may affect outcomes of the fibre post restored teeth such as the use of rubber dam [49] and the need of a minimum apical seal of 4 mm [50-52] were essential for study inclusion.

Customization of fibre posts via moulding to the root canal with direct composite resin helps enhance adaptation of the post to the walls of the root canal. Such studies were excluded to help engender homogeneity [53]. Only studies with direct placement of fibre posts were included. Three studies used RTD LIGHT-POST™ and Calibra® composite resin cement [29, 30, 39], one used White Post DC (FGM, Joinville, Brazil) luted using regular or self-adhesive resin cement (RelyX ARC or U100/200, 3M, ESPE, St Paul, USA) [46] and one study used Bioloren Fibreglass post and *LuxaCoreZ* composite [33]. According to manufacturers' information, these post systems are radiopaque alternatives to metal and have moduli of elasticity similar to dentine in laboratory conditions. These posts are tapered at their tip to adapt passively to root canal anatomy.

A 1.5- to 2-mm circumferential ferrule is recommended for root filled teeth. However, if the clinical situation does not permit a circumferential ferrule, an incomplete ferrule is considered a better option than a complete lack of ferrule [54]. At least 1 mm ferrule height is recommended for the use of glass fibre posts to reduce the occurrence of unfavourable failures [55]. The definition of ferrule varied amongst the included studies. Cagidiaco *et al*. [39] defined the height of the ferrule as 2 mm whereas Signore *et al*. [33] defined ferrule as a circumferential collar of dentine at least 1.5mm (to 2mm) in height in teeth that had lost all coronal walls. Several cases in both studies

reported that the loss of tooth structure was non-uniform, but ferrule height was never below 1 mm. On the other hand, Ferrari *et al*. [29, 30] defined ferrule as the absence of an axial wall, but with at least a 2 mm high collar of dentine that was preserved circumferentially while no-ferrule indicated the absence of an axial wall with less than 2 mm height of dentine but with no description of minimal circumferential dentine. Their definition implies that no ferrule could be any height from below 2 mm to as low as the gingival margin.

Only teeth restored with single crowns were included in this review as root filled teeth restored with fibre posts that served as abutments for fixed prosthodontic dentures are known to have reduced survival rates [8]. Thus, a unique aspect of this systematic review and meta-analysis was to minimise the effect of confounding factors that could influence the success rate of post and crowns. As the success rate is dependent on tooth position in the arch [10, 34], data for anterior and posterior teeth were collected separately in this study. However, a meta-analysis was only possible for posterior teeth as only two studies reported the number of axial walls for anterior teeth [39, 46]. More clinical studies using anterior teeth that report the relationship of failure with the number of remaining of walls are required for a meta-analysis.

Although occlusal functionality was not part of the inclusion criteria, three of the included studies reported occlusal function with natural teeth and interproximal contacts with two adjacent natural teeth [29, 30, 33] demonstrating that the data analysed in this meta-analysis represented the outcome of functional teeth.

In the present systematic review and meta-analysis, the included studies were performed within hospital [33, 39], university [46] and private dental offices [29, 30] thus highlighting the scope for external validity of the results to the general population. However, it is important to note that all studies were conducted within the same geographical area (Siena and Genoa, Italy), except for Sarkis-Onofre *et al*. [46], which was carried out in Brazil. Also, further studies conducted in general dental practice settings will help strengthen the findings of this systematic review.

Whist studies reported results in relation to different configurations of the remainder axial walls, this lacked precise definition with variation in both height and volume. In all five studies, the data obtained about the number of remaining axial walls took place before the core build up and crown preparation. This limitation is difficult to overcome as the assessment of remaining tooth at this stage may lead to overestimation of remaining structure [8]. The preparation of finish lines and

axial walls leads to further loss of coronal tooth structure [30]. Similarly, the detailed description of thickness of remaining walls and height was not possible. Perhaps future studies using 3D image and volumetric analysis via intraoral scanning and digitization before and after coronal preparation may provide significant data on this aspect and should be considered for more accurate analysis of the remaining dentine. This would also eliminate the subjectivity of assessment of remaining walls visually.

The results of the present systematic review and meta-analysis revealed that an adhesively bonded fibre post is an adequate treatment option for root filled posterior permanent teeth with coronal tooth structure when two or more remaining axial walls are restored with single crowns. As most teeth from the selected studies included premolars, the results are especially applicable to this group of teeth. The causes of relative- and catastrophic-structural failure of post debonding, post and root fracture as well as post-treatment endodontic disease were related to the reduced remaining number of axial walls. In teeth with “0 wall”, post debonding was the most common cause of failure, whereas post fracture and root fractures were not frequent [29, 30]. This finding is constrained by the small sample size, but it is likely to characterise the problem when no axial walls remain. Debonding of fibre posts in these cases have been attributed to (a) the higher flexibility of fibre posts [56] which generates more stress at the cervical level [57], (b) less reliable resin cement adhesion to intra-radicular dentine when compared with coronal dentine due to dentine configuration [30] and (c) C-factor [58].

The failures related to post-treatment endodontic disease (PAR) were between 2 and 4% for teeth with 0 and 1 remaining coronal walls during a follow up period of 2 to 9 years. Post-treatment endodontic disease has been related to coronal microleakage [5] and may also explain PAR in teeth restored with fibre posts especially since procedures were performed under rubber dam and 4 mm of apical seal was maintained. Difficulty bonding to root dentine [59] and the canal configuration may also play a role in microleakage. Prefabricated posts usually have a round cross section that are used in different canal configurations whereas canal walls are oval in the coronal third [60]. This might result in lack of close adaptation of the post to canal walls resulting in voids in the luting cement thereby compromising retention and seal.

The relative- and catastrophic-structural failure of fibre posts in teeth with more than 2 remaining axial walls, especially 3 and 4 walls, were less significant than 0 or one remaining axial wall. The

need for remaining axial walls is in agreement with Juloski *et al*. and Ferrari *et al*. who reported that 50% or more of remaining tooth structure results in better outcome [8, 36].

No relationship between follow-up time and failure of fibre posts could be tested statistically in the included studies due to the small sample size. The literature suggested that variation in clinical performance could occur over time due to weakening of the adhesive interface or mechanical stress [36]. Longer follow-up periods are also associated with increased patient dropout, which could also affect the results.

There were only a small number of operators in most of the included studies. Only one operator performed the treatments in Signore *et al*. [33], Ferrari *et al*. [29], Ferrari *et al*. [30] and it is likely that the latter two studies had the same operator. Cagidiaco *et al*. [39] reported that two clinicians performed the clinical procedures but there were no significant differences in the number of restorations that failed between the two operators. Similarly, the follow-up examinations were performed by two clinicians. Signore *et al*. [33] reported that two independent dentists performed the follow up examinations, whereas in the other studies, one of the two examiners did not place the restorations [29, 30, 39]. In Sarkis-Onofre *et al*., [46] treatment was carried out by undergraduate and graduate students that attended restorative dentistry training on the subject. With more operators, variability in outcomes is more likely.

A relatively recent systematic review and meta-analysis addressed remaining coronal structure and posts in clinical studies but these used different research questions, inclusion criteria, data collection, and analysis [61]. The authors included five clinical studies (randomised control trials and prospective cohort studies) with low to moderate risk of bias and follow-up of at least 2 years. The use of rubber dam during post preparation/cementation was not reported in the included studies. Fibre posts included in the studies were variable, both pre-fabricated and custom-made. The final restorations in the included studies were also variable and comprised direct composite, single full or partial crowns, fixed partial denture and combined fixed and removable partial dentures. A relative risk of 2.73 was reported for groups without remaining axial walls compared with presence of walls on the failure of fibre posts [61]. However, that study did not stratify risk based on the number of axial walls. The effect of posts and ferrule on the survival of root treated teeth has been evaluated in another systematic review [20]. These authors included eight prospective clinical studies with five of them having high risk of bias and a minimum follow-up of 5

years. This systematic review included all post types and did not separate the results for anterior and posterior teeth. Moreover, a meta-analysis could not be performed because of the heterogenicity in the design of included studies and possible overlap between patients. Despite the limitations, the authors also concluded that a ferrule and remaining tooth structure was the most important factor for the survival of the restoration and the tooth.

The results of the present study differ with the findings of Wang *et al*. and Batista *et al*. [62, 63]. Wang *et al*. [62] compared the success and survival of fibre and metal posts in severely damaged root filled teeth with two or fewer axial walls. The authors included four randomized control trials with low risk of bias and follow-up of at least three years. Data collection and analysis for teeth with/without ferrule and one or two axial walls were combined. Anterior and posterior teeth were analysed separately but did not reveal a significant difference. Although fibre post survival was reported to be better than metal posts, no difference was observed in the success rate, post debonding and root fracture rate between both post types [62]. This may be attributed to the analysis of the combined data which is in contrast with the present study that has segregated data based on number of walls and applied more stringent criteria.

Batista *et al*. [63] evaluated the influence of a ferrule on the failure of fibre post restorations. Four prospective studies (3 RCT and 1 prospective) with follow-up period longer than 6 months were included (3 low and 1 high quality). It is possible that patients' data of two studies overlapped [30, 31]. While both anterior and posterior teeth were included, one article did not report the use of rubber dam in all cases [44]. The presence or absence of ferrule did not influence restoration survival, albeit, a higher number of failures were noted in teeth without ferrule. However, the definition of ferrule was not clearly described within the inclusion criteria and may have influenced these results. In the present study, teeth with or without ferrule were both combined in the 0 remaining walls group to overcome discrepancies between the definition of complete/incomplete/no ferrule between included studies. This is reflected in the heterogeneity scores (I^2 values) for this sub group.

Despite variations in methodology between the systematic reviews and on limited evidence, remaining coronal tooth structure affected failures of root filled teeth restored with fibre posts based. The design of the current systematic review and meta-analysis intended to assess whether the presence/absence of remaining axial walls and the placement of fibre posts have an influence

on the relative and catastrophic failures of fibre post and/ or root treated teeth. But perhaps, in the future, general guidelines for randomized control trials should be created to facilitate gathering specific data, e.g. remaining tooth structure (height, thickness, location and volume from 3D images) to enhance validity, reliability and reproducibility. This could facilitate conducting future systematic reviews and meta-analyses. Herein, an effort has been made to standardize several variables that might affect failure via strict inclusion and exclusion criteria. These variables included specific description of remaining axial walls, tooth type, fibre post type (prefabricated fibre post only with no customization), definitive restoration (single-unit crowns), rubber dam use and apical seal. The standardization of brands of fibre post, core material (composite), adhesive luting cement and type of crown is theoretically difficult. However, after data extraction it was noted that 3 included studies [29, 30, 39] used the same brand of fibre post, luting agents and core, which helped reduce confounding and risk of bias of their results. Given all previous points and low to moderate risk of bias of included studies, the findings of this systematic review and meta-analysis can be extrapolated to clinical restoration of root filled posterior teeth, and premolars specifically.

Conclusions

Within the limitations of this systematic review and meta-analyses, it was possible to conclude that relative- and catastrophic-structural failures as well as post-treatment disease of posterior teeth restored with a fibre post and single crown after root canal treatment increased with decreasing numbers of remaining axial walls. Post debonding was the most commonly reported relative failure, followed by, to a lesser extent, post-treatment endodontic disease and post fracture. Root fractures were rare. More clinical trials using anterior teeth are required to determine if findings for posterior teeth can be applied to anterior teeth.

Conflict of interest declaration

The authors declare that there is no conflict of interest.

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Table 1. Search terms used in the electronic databases (July 2021).

Database	Search terms used in the electronic databases
Pubmed	(ferrule) OR coronal wall) OR residual* coronal) OR remain* coronal) AND fibre post) NOT in vitro) NOT finite element) NOT Fracture resistance)
Cochrane	(ferrule):ti,ab,kw OR (residual* coronal*):ti,ab,kw OR (remain* coronal*):ti,ab,kw OR (coronal wall*):ti,ab,kw AND (fibre post):ti,ab,kw" (Word variations have been searched)
Scopus	(TITLE-ABS-KEY (*fibre* AND *post*) AND TITLE-ABS-KEY (*ferrule*) OR TITLE-ABS-KEY (*residual** AND *coronal**) OR TITLE-ABS-KEY (*coronal* AND *wall**) AND NOT TITLE-ABS-KEY (*in* AND *vitro*) AND NOT TITLE-ABS-KEY (*finite* AND *element*)
Medline via Ovid)	1- Fibre post. Ti,ab. 2- Ferrule.ti,ab. 3- Endodontic*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 4- Residual coronal*.mp. [mp=title, abstract, original title, name of substance word, subject heading word,

floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

5- Coronal wall*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

6- Tooth, Nonvital/

7- “post and core Technique”/

8- 1 or 7

9- 2 or 4 or 5

10- 3 or 6

11- 8 and 9 and 10

Table 2. Excluded studies from the systemic reviews and meta-analysis based on full text assessment and reasons for exclusion.

	Excluded studies	Reason for exclusion of studies
1	Naumann *et al.* (2005a) [64]	Interim report for Naumann *et al.* (2012) [65]
2	Naumann *et al.* (2005b) [66]	Interim report for Naumann *et al.* (2012) [65]
3	Ferrari *et al.* (2007a) [28]	Raw data were not available for the description of remaining coronal structure
4	Schmitter *et al.* (2007) [67]	Interim report for Schmitter and Hamadi [68]
5	Naumann *et al.* (2007) [69]	Interim report for Naumann *et al.* (2017) [35]
6	Cagidiaco *et al.* (2008) [31]	Interim report for Ferrari *et al.* (2012) [30]
7	Signore *et al.* (2009) [32]	Combined data for 1 and 2 walls, 3 and 4 walls*
8	Bitter *et al.* (2009) [38]	Missing data regarding number of walls for anterior and posterior teeth and related failures. No report on the use of RD. *
9	Mancebo *et al.* (2010) [44]	RD was used (if possible) but did not discriminate on the results where it was used or not. *
10	Schmitter and Hamadi [68]	No report on the use of RD, no description of remaining tooth structure. Some teeth were used as abutments for FPD and RPD. *
11	Zicari *et al.* (2011) [70]	Interim report for Cloet *et al.* (2017) [37]
12	Sterzenbach *et al.* (2012) [71]	Interim report for Naumann *et al.* (2017) [35]
13	Naumann *et al.* (2012) [65]	Data segregation: remaining cavity walls grouped (either ≥ 1 wall or none). No data for tooth type and remaining tooth structure in relation to failure. *
14	Monticelli and Ferrari [72] (IADR poster presentation)	Same data as Juloski *et al.* (2014) [36]
15	Sarkis-Onofre *et al.* (2014) [40]	Interim report for Sarkis-Onofre *et al.* [46]

16	Juloski *et al.* (2014) [36]	Data segregation: remaining dentine was grouped either >50% of coronal tooth structure (at least 2 walls) or ≤50% of coronal tooth structure (at least 1 sound wall and 1.5 mm ferrule). Corresponding author was unable to provide separate raw data for analysis.
17	Ferrari *et al.* (2017) [8]	Data segregation: tooth structure either >50% of coronal residual structure (at least 2 sound walls + 1.5-mm ferrule) or ≤ 50% of coronal structure (at least 1 sound wall + a 1.5-mm ferrule). Corresponding author was unable to provide required data for analysis.
18	Guldener *et al.* (2017) [73]	Data segregation: all data reported were combined for teeth with one wall and ferrule. Failure was not related to tooth type (except root fracture). Corresponding author was unable to provide raw data for analysis.
19	Naumann *et al.* (2017) [35]	No statement on the use of RD. Various types of final restorations (single crown/ FPD/ RPD). No data on number of cavity walls in relative to tooth type. *
20	Cloet *et al.* (2017) [37]	No report on the use of RD, length of apical seal not mentioned. Data segregation: teeth grouped to sufficient (at least 2 dentine walls ≥ 2mm thick) and insufficient tooth tissue (no definition in article).*
21	Ferrari *et al.* (2019) [74]	Data segregation: included teeth with 50% or more tooth structure without specific description of remaining coronal walls. Corresponding author was unable to provide separate raw data for analysis.

RD: rubber dam, FPD: Fixed Partial Dentures, RPD: removable partial denture; * No response to email request for clarification.

Table 3. Characteristics of included studies in the systemic review and meta-analysis.

Author/ year	Study type	Patients/ teeth (n=)	Type of teeth	Wall description	Post type	Luting agent	Core	Coverage type	Follow up* (Months)
Cagidiaco *et al.* 2007 [39]	prospective clinical trial	150 patients 162 teeth	57 anterior 105 posterior teeth	69 had 3 or 4 walls 93 had 2 or less walls	RTD LIGHT-POST™ (fibre post)	Dual cure resin cement (Calibra®)	Flowable resin composite (X-Flow) and Microhybrid resin composite (CeramX)	All ceramic crowns (n=121)	24
Ferrari *et al.* 2007b [29]	prospective clinical trial	210 patients 240 teeth 120 teeth received fibre post	maxillary & mandibular premolars	4 walls (all) 3 walls 2 walls 1 wall 0 walls	RTD LIGHT-POST™ (fibre post) no post	Dual cure resin cement (Calibra®)	Flowable resin composite (X-Flow) and Microhybrid resin composite (CeramX)	Porcelain fused to metal crown	1,6,12,24
Signore *et al.* 2011 [33]	retrospective study	134 patients 154 teeth	71 maxillary 83 mandibular premolars with oval root canals	4 walls (all) 3 walls 2 walls 1 wall 0 walls	Oval translucent post (Bioloren Fibre glass posts)	Dual cure composite resin cement (LuxaCoreZ)	Dual cure composite resin cement (LuxaCore Z)	All ceramic crown	Mean 42.3

Ferrari *et al.* 2012 [30]	randomized control trial	345 patients 360 teeth 6 group based on walls (60 premolars)	premolars	4 walls (all) 3 walls 2 walls 1 wall 0 walls	RTD LIGHT-POST™ (fibre post) customized fibre post (EverStick fibres) No post	Dual cure resin cement (Calibra®)	Flowable resin composite (X-Flow) and Microhybrid resin composite (CeramX)	Porcelain fused to metal crown	1,6,12,24, 36, 72
Sarkis-Onofre 2020 [46]	randomized control trial	135 patients 199 teeth (111 receivied fibre post)	Anteriors & posteriors	0 walls	White Post DC (FGM, Joinville, Brazil) Cast metal posts	regular or self-adhesive resin cement (RelyX ARC or U100/200, 3M, ESPE, St Paul, USA)	composite resin (ScotchBond Multi-Purpose and Z250, 3 M, ESPE)	Porcelain fused to metal crown	6 months then annually up to 108

Table 4. Samples in relation to remaining coronal structure, number and type of failures for anterior and posterior teeth restored with fibre post and single crowns.

	Study ID	Remaining axial walls	Intervention sample size for single crowns	Number of failures for intervention	Type of failure				Follow up time (months)
					PoDe	PAR	PoF	RoF	
Anterior teeth	Cagidiaco *et al.* 2007 [37]	0 walls	26	3	2	1	0	0	24
		1 wall	4	1	0	1	0	0	
		4 walls	5	0	0	0	0	0	
	Sarkis-Onofre *et al.* 2020 [46]	0 walls	44	3	1	1	0	1	Up to 108
	Total anterior teeth		79	7	3	3	0	1	Up to 108
Posterior teeth	Cagidiaco *et al.* 2007 [37]	0 walls	30	2	2	0	0	0	24 (total)
		1 wall	10	4	2	2	0	0	
		2 walls	13	1	1	0	0	0	
		3 walls	15	1	0	1	0	0	
		4 walls	18	0	0	0	0	0	
	Ferrari *et al.* 2007b [27]	0 walls	40	8	8	2	0	0	24 (total)
		1 wall	20	1	1	0	0	0	
		2 walls	20	0	0	0	0	0	
		3 walls	20	0	0	0	0	0	
		4 walls	20	0	0	0	0	0	
	Signore *et al.* 2011 [31]	0 walls	13	3					
		1 wall	25	3	2	1	5**	0	42.3 ± 2.7

	2 walls	49	1					(mean)
	3 walls	48	0	0	0	0	0	
	4 walls	19	0	0	0	0	0	
Ferrari *et al.* 2012 [28]	0 walls	36	18	8	5	4**	1	72
	1 wall	18	4	3	1	0	0	(total)
	2 walls	18	2	0	1	1	0	
	3 walls	17	1	1	0	0	0	
	4 walls	18	0	0	0	0	0	
Sarkis-Onofre *et al.* 2020 [46]	0 walls	67	13	1	0	0	6	Up to 108
Total posterior teeth		534	62	29	13	10	7	24 to 108

PoDe: post debonding, PAR: periapical radiolucency (root canal treatment failure), PoF: post fracture or **post/core fracture, RoF: root fracture

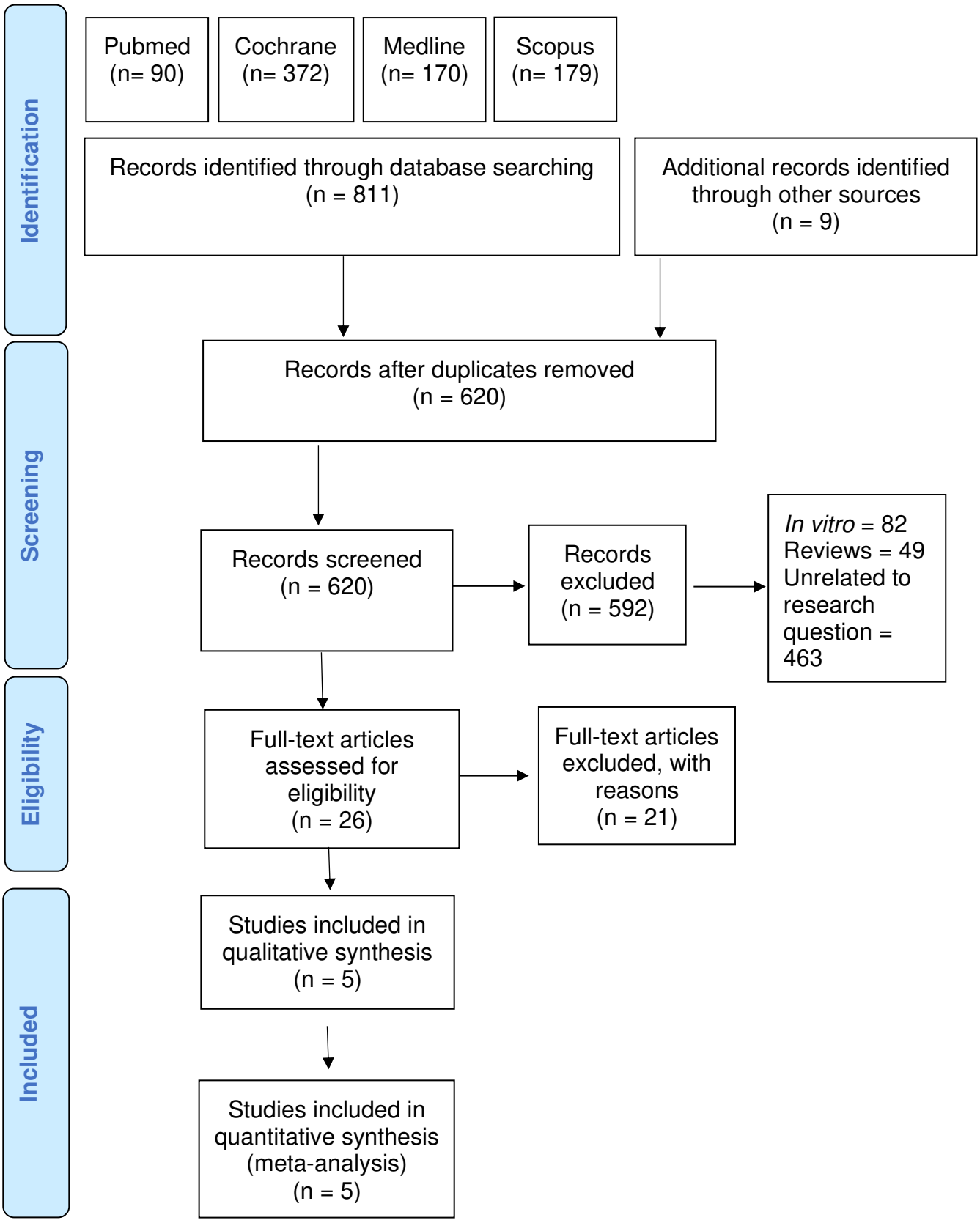


Figure 1. PRISMA flow diagram. The flow diagram represents the flow of information through the different phases of the systematic review.

A

+ Low risk ? Some concerns - High risk	Experimental	Compactor	Outcome	Weight	Randomization Process	Deviations from intervention	Missing outcome data	Measurement of outcome	Selection of the report result	Overall
Ferrari *et al.* 2012 [28]	Fibre post	No post/ custom post	Failure	1	?	?	+	+	+	!
Sarkis-Onofre *et al.* 2020 [46]	Fibre post	Cast metal post	Failure	1	+	?	+	+	+	!

B

	Selection (max 4 star)	Comparability (max 2 star)	Outcome (max 3 star)
Signore *et al.* 2011	★★★	★	★★★
Ferrari *et al.* 2007b	★★★★	★	★★★
Cagidiaco *et al.* 2007	★★★★	-	★★★

Figure 2. Risk bias summary for the included studies in the meta-analysis. (**A**) Quality assessment for randomized control trial using Cochrane risk-of-bias tool (ROB2); (**B**) Summary of quality assessment for cohort studies (risk of bias) using the Newcastle-Ottawa quality assessment scale.

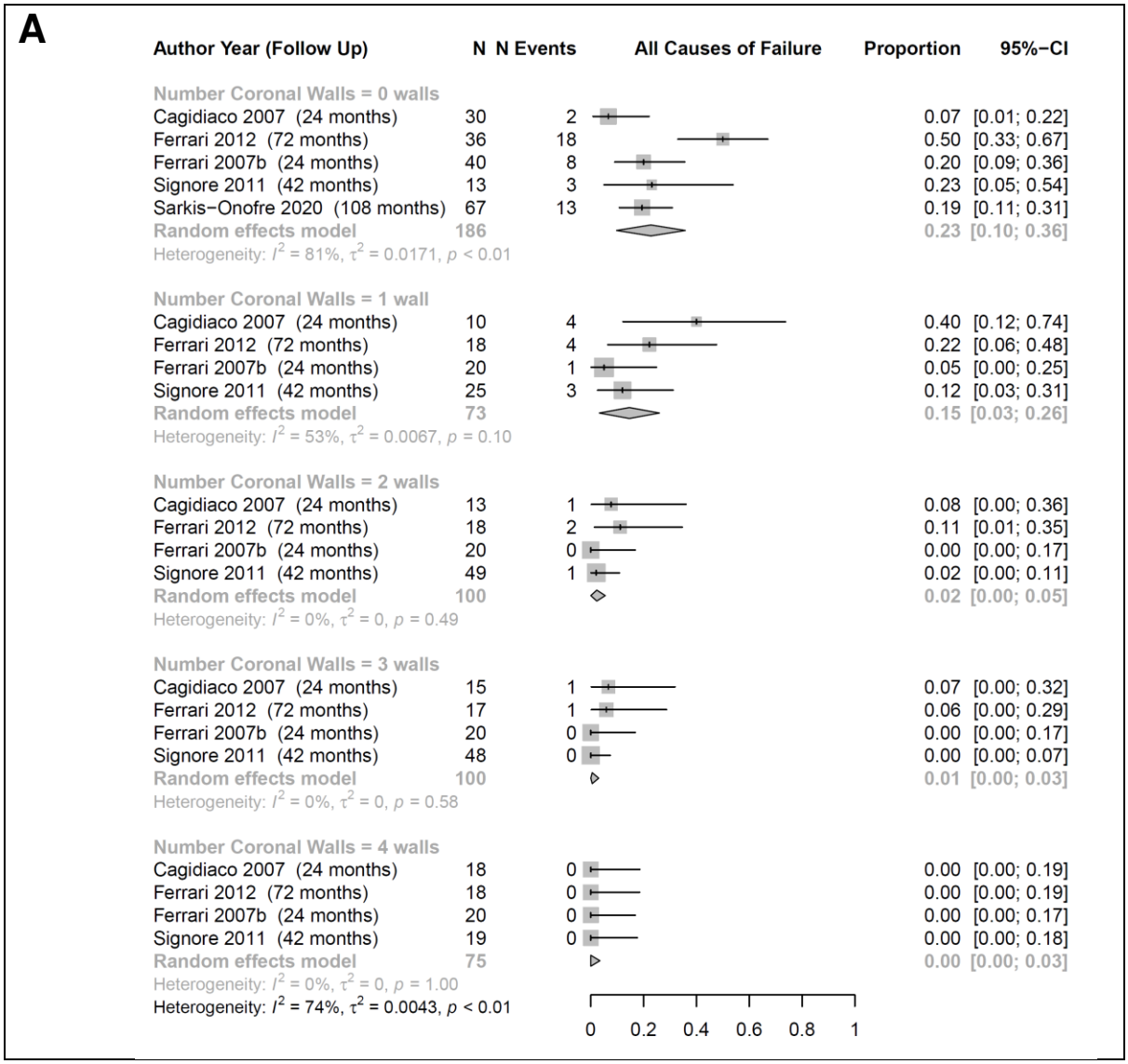


Figure 3. **A.** Forest plot for all causes of failure (relative and catastrophic failures grouped) and subgroup analysis by number of axial walls (0 to 4 axial walls). **B.** Linear meta regression (blue line) of percentage of all failures as a function of the number of walls with 95% confidence interval of the estimate shown also (red dashed lines).

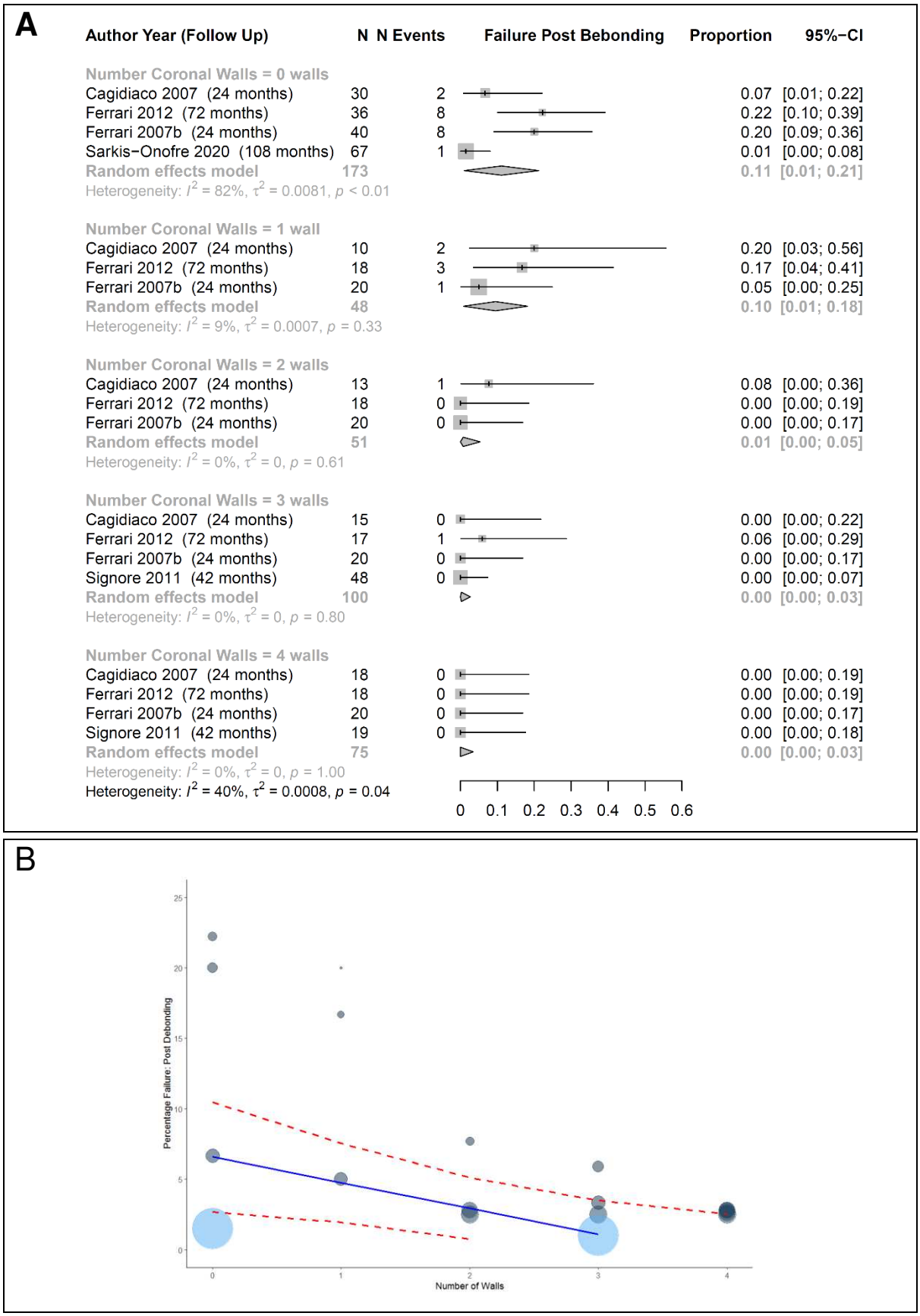
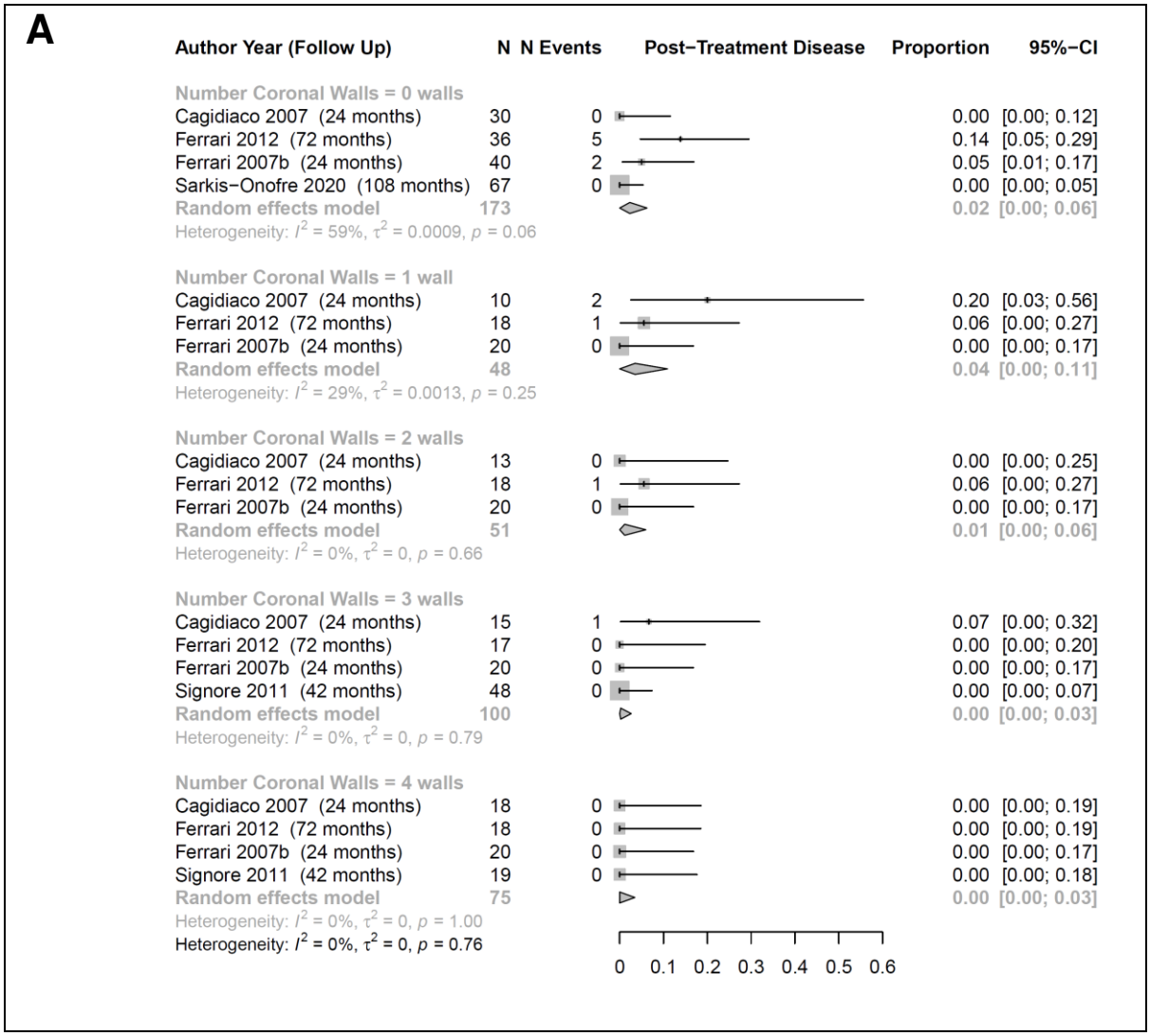


Figure 4. **A**. Forest plot for fibre post debonding and subgroup analysis by number of axial walls (0 to 4 axial walls). **B**. Linear meta regression (blue line) of percentage fibre post debonding as a function of the number of axial walls with 95% confidence interval of the estimate also shown (red dashed lines).



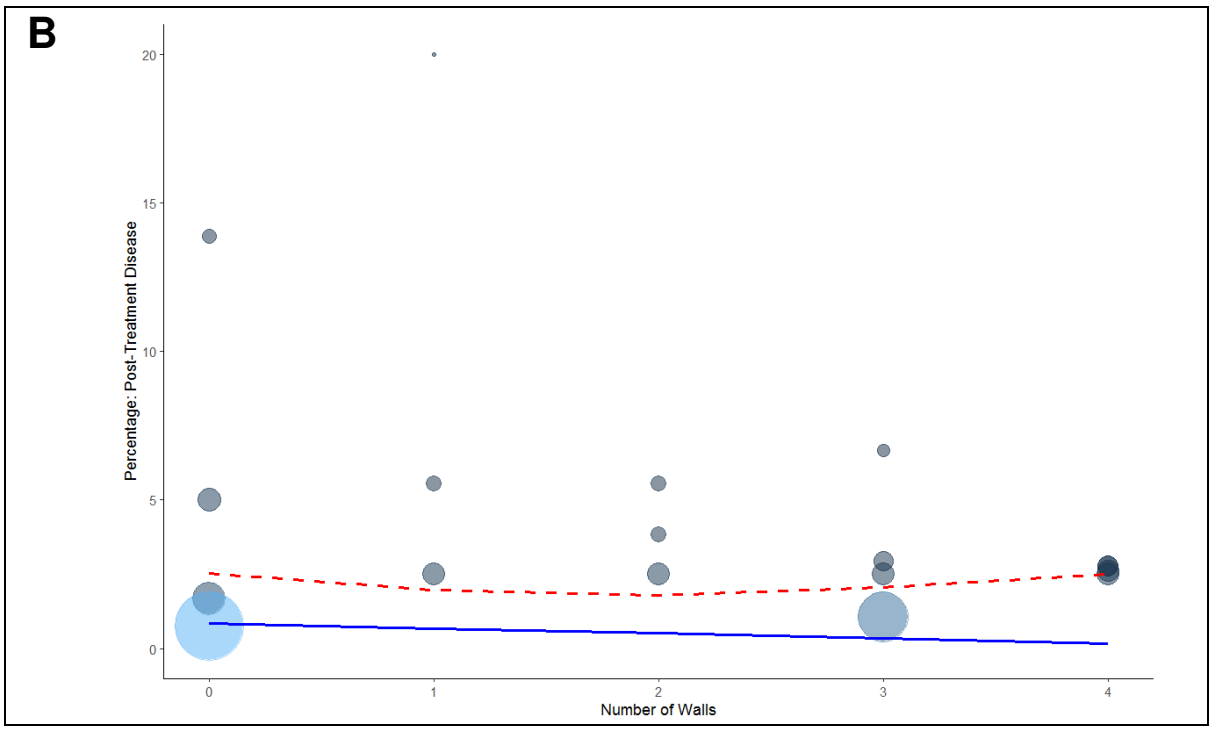


Figure 5. **A**. Forest plot for post treatment endodontic disease and subgroup analysis by number of axial walls (0 to 4 axial walls). **B**. Linear meta regression (blue line) of percentage post treatment endodontic disease as a function of the number of walls with 95% confidence interval of the estimate shown also (red dashed lines).