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REVIEW

The influence of apical extent of root canal obturation on endodontic therapy outcome: a systematic review

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Abstract

Objectives This systematic review (SR) aimed to investigate the influence of obturation extent on the final outcome of root canal treatment (RCT), by answering the question "among patients requiring RCT on fully formed permanent teeth, is there an association between obturation extent and the final treatment outcome?"

Materials and methods Five electronic databases and three gray literature searches were performed. Observational studies investigating the association between obturation extent and RCT outcome in fully formed permanent teeth with a minimum follow-up of 12 months were included. We evaluated the risk of bias (RoB) in with MAStARI for cohort studies. The overall quality of the evidence was assessed with the GRADE-tool.

Results Twenty-two studies were included, 2 had high RoB, 7 moderate RoB, and 13 low RoB. Underextended obturation demonstrated increased odds of an unfavorable outcome in seven studies, in which the odds varied between 6.94 (95%CI 2.20–21.87) and 1.73 (95%CI 1.02–2.95). Overextended obturation also demonstrated this association in four studies, with odds varying from 1.90 (95%CI 1.23–2.94) to 23.00 (95%CI 5.58–94.75). Due to heterogeneity and the very low level of evidence found in the GRADE analysis, the results from this SR should be interpreted with caution.

Conclusions Obturation extent seems to influence RCT outcome; overextended and underextended obturations showed higher chance of association with less favorable outcomes than adequate obturation; however, this association was not categorically supported.

Clinical relevance This SR provides information about obturation extent influence on RCT outcome and guides clinicians to make evidence-based decisions during endodontic practice.

Keywords Periapical tissue · Root canal obturation · Systematic review · Tooth apex

Introduction

Root canal treatment (RCT) outcome can only be assessed through case follow-up [1]. According to the European Society of Endodontology (2006), follow-up should be regularly performed for at least 1 year after RCT conclusion, aiming to monitor apical health progress [1].

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Several studies have suggested that the quality of RCT may influence its outcome, and RCT quality is frequently assessed through periapical radiographs (PA) [2–4]. The criteria mostly used include the incidence of procedural errors and obturation characteristics, such as length and density [5, 6].

Working length, as well as obturation extent, is traditionally defined by PA [4, 6, 7], and currently, the use of electronic apex locators has made those measurements more objective and reliable [8]. As reported by the American Association of Endodontists, underextended obturation is considered an incomplete obturation of the root canal space, and overextended obturation is described as material extending beyond the radiographic apex [9]. However, there is no consensus among researchers regarding the ideal obturation extent [3, 4, 6]. On the other hand, other investigators suggested that acceptable obturation extent should end less than 2 mm away from the radiographic apex [7].

A previous systematic review published in 2008 used the terminology of short, flush, and over-filling to categorize the characteristics of root canal obturation; however, the precise obturation extent (mm) was not reported or considered by the authors [4]. Nonetheless, according to the authors, short and flush obturations were related to higher odds of favorable outcome than over-filling. Conversely, when only teeth with preoperative periapical lesions were considered, the odds of a favorable outcome for short and over-filling obturations were not significantly different [4].

Because that study was published more than 10 years ago from this publication and new data on RCT outcomes have been published, a further systematic review with more recent data is proposed. Therefore, this systematic review aims to assess the influence of obturation extent in RCT outcome by answering the following question "among patients requiring RCT on fully formed permanent teeth, is there an association between obturation extent and final treatment outcome?"

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist [10].

Protocol and registration

A systematic review protocol based on the PRISMA Protocols (PRISMA-P) [11] was registered at the International Prospective Register of Systematic Reviews (PROSPERO) under the number CRD42017079444 [12].

Eligibility criteria

The question of this systematic review was formulated using the acronym PECOS (Population, Exposition, Comparison, Outcomes, Studies), of which (P) human permanent teeth with complete root formation; (E) primary root canal treatment (with the root canal obturation apical extent reported); (C) none or studies comparing different apical extent groups; (O) endodontic therapy outcome (odds ratio, success rate, post-operative symptomatology, signs of infection, periodontal ligament status, or periodontal bone status); and (S) clinical trials and observational studies. It is important to emphasize that only primary RCT data were considered in this systematic review, and therefore, articles on root canal retreatment were excluded. No time restrictions for publications were applied.

The following exclusion criteria were applied: (1) Studies in primary teeth; (2) studies in open apex teeth; (3) studies in which the RCT outcome was not described or correlated with obturation extent; (4) studies with less than 12 months of clinical follow-up; (5) studies with mixed treatment and retreatment data; (6) studies in which data were not clearly reported; (7) reviews, case reports, protocols, short communications, personal opinions, letters, posters, conference abstracts, and laboratory research; (8) studies not in Latin (Roman) alphabet; (9) full copy not available.

Information sources and search strategy

Individual search strategies were developed for the following databases: Latin American and Caribbean Health Sciences (LILACS), LIVIVO, PubMed, Scopus, and Web of Science. A search in gray literature was performed, including Google Scholar, Open Grey, and ProQuest. All searches were conducted from the earliest date available until October 10th, 2017 (Appendix 1). All references were managed in a reference software (EndNote X7®, Thomson Reuters, Philadelphia, PA), in which collection of references and duplicate removal were conducted.

Study selection

Selection of studies was conducted in two phases. Phase 1 was performed in a systematic review web application (Rayyan®, Qatar Computing Research Institute), in which two authors reviewed the identified references' titles and abstracts. In phase 2, the same reviewers applied the eligibility criteria for full-text studies. In addition, the reviewers screened the reference list of selected studies individually aiming to identify potentially relevant articles. Any disagreement was resolved between the two authors and, if there was not a consensus, a third author was consulted to make a final decision.

Data collection process and data items

Two authors collected key data from selected references; any disagreement was solved between the authors. Data collection consisted of study characteristics (author, year of publication, country, and study design), sample characteristics (size, obturation extent, RCT technique, and follow-up period), outcome assessment (clinical and radiographic criteria), and studies' main results. If the required data were not complete or the data presented could not be extrapolated, attempts were made to contact the authors by e-mail to retrieve the missing information. No further information was obtained through these contact attempts.

Risk of bias in individual studies

The Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) for cohort studies was utilized to evaluate included studies [13]. Two reviewers assessed the risk of bias (RoB) for each study and crosschecked the information. RoB was categorized as "high" when the study reached up to 49% score "yes"; "moderate" when the study reached 50% to 69% score "yes"; and "low" when the study reached more than 70% score "yes." The figures were generated with Review Manager 5.3 (RevMan 5.3, The Nordic Cochrane Centre, Copenhagen, Denmark).

Summary measures

The association between RCT outcome and obturation extent was the main outcome evaluated. RCT outcome was reported or calculated as odds ratio (95%CI), success rates, and healing rates (reported or calculated as percentage). For the purposes of synthesis, "favorable" outcome was defined according to the report of the included studies, based on the success and healing parameters. Studies were grouped based on the ideal endpoint reported for the obturation.

Synthesis of results

A qualitative analysis based on RCT outcome was performed. A meta-analysis was planned if sufficient data were available and whenever the studies were considered homogeneous regarding study design, interventions, and outcomes. A qualitative analysis of results based on the influence of obturation extent on RCT outcome was performed. In order to decrease heterogeneity among studies, results were separated according to the ideal endpoint reported.

Risk of bias across studies

The quality of evidence, as well as the strength of the recommendations, was assessed and a summary was presented using "Grading of Recommendations Assessment, Development and Evaluation" (GRADE) Summary of Findings (SoF) tables, from GRADEpro software (McMaster University, Hamilton, Canada) [14].

Additional analyses

Sensitivity analysis with regard to RoB subgroups (low, moderate, and high RoB) was conducted to verify whether the results of the systematic review were altered.

Results

Study selection

The search strategy resulted in 2170 references once the duplicates were removed. After phase 1, 61 articles were included for full-text assessment. In phase 2, 39 articles were excluded due to different reasons (Appendix 2). Finally, 22 cohort studies were included for final evaluation [3, 15–35] (Fig. 1).

Studies characteristics

The follow-up period ranged from 1 [15, 21, 24, 28, 31, 35] to 19 years [29]. The examined parameter varied, including teeth, roots, canals, and more than one of these parameters. Furthermore, the studies' sample size varied from 85 [27] to 1139 teeth [20]; from 143 [26] to 551 roots [19]; and from 236 [35] to 1369 canals [30].

Obturation extent assessment

The obturation extent assessment varied between studies; variable endpoints were suggested as ideal. One study considered an adequate obturation within 3 mm from the radiographic apex [29], ten studies within 2 mm [3, 17, 21, 23, 25, 26, 28, 31, 33, 35], three within 1 mm [20, 22, 24], and three at the apex (0 mm) [15, 19, 30]. One study not stated an endpoint and considered an adequate obturation the range of 0.5 to 1.5 mm from the apex [32]. Two studies measured the obturation extent in mm from the radiographic apex and reported the results in means [16, 34]. Finally, one study classified as over-filling or underfilling, which was assorted in three categories: 0 to 0.4 mm, 0.5 to 1.0 mm, and 1.1 to 2.0 mm [27].

For pooled data analysis purposes, included studies were grouped based on the ideal endpoint reported. For studies that stated an endpoint (in mm) as adequate obturation extent, the underextended obturation was considered when that endpoint extent was not reached, and incomplete obturation was radiographically observed. In contrast, for all included studies, an overextended obturation was described as obturation material extending beyond the radiographic apex.

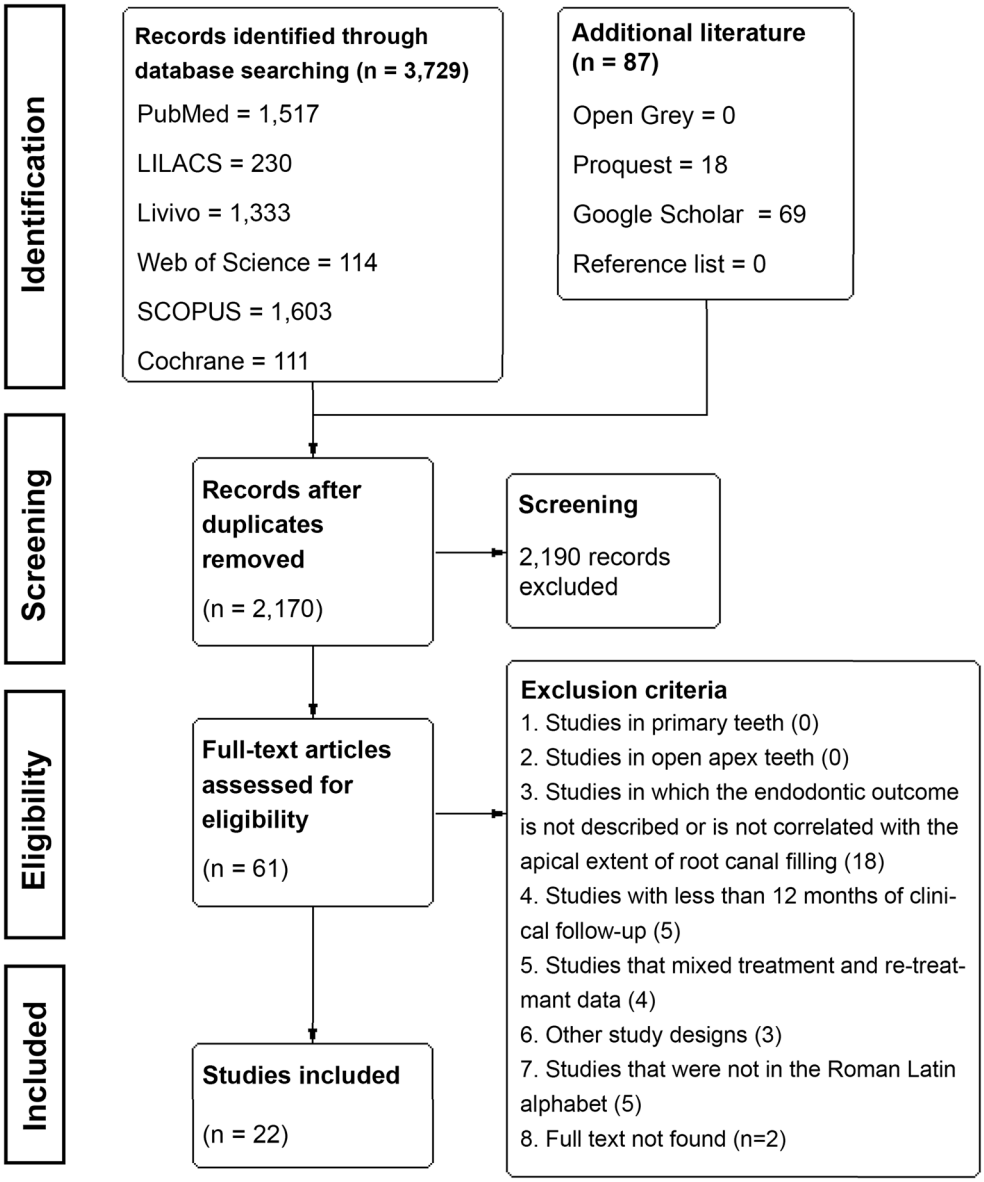

Fig. 1 Flow diagram of literature search and selection criteria*. *Adapted from PRISMA

RCT outcome

RCT outcome evaluation was performed mainly by PA assessment. Only one study compared cone beam computed tomography (CBCT) and PA assessments [26]. Additionally, five studies classified the apical healing according to the Periapical Index (PAI) [17, 18, 23, 29, 31]. Three of them executed a dichotomized analysis grouping PAI 1 and 2 for normal periapical status, and PAI 3, 4, and 5 representing the presence of apical periodontitis [17, 29, 31].

Risk of bias within studies

Two studies were classified as high RoB [15, 24], seven as moderate RoB [20–22, 27, 28, 34, 35], and thirteen as low RoB [3, 16–19, 23, 25, 26, 29–33] (Appendix 3). For most studies, the questions "are confounding factors identified and strategies to deal with them stated?", and "are outcomes assessed using objective criteria?" were scored as "high RoB", since data were not presented separately for vital and non-vital teeth nor PAI criteria or other validated criteria were utilized for periapical healing assessment. The question "has bias been minimized in relation to selection of cases and of controls?" was considered as "not applicable" for all included studies as none of them presented data in regard to controls (Fig. 2).

Results of individual studies

Since most included studies considered that adequate obturation was within 2 mm from the radiographic apex, this endpoint was considered as "adequate" for the purpose of this

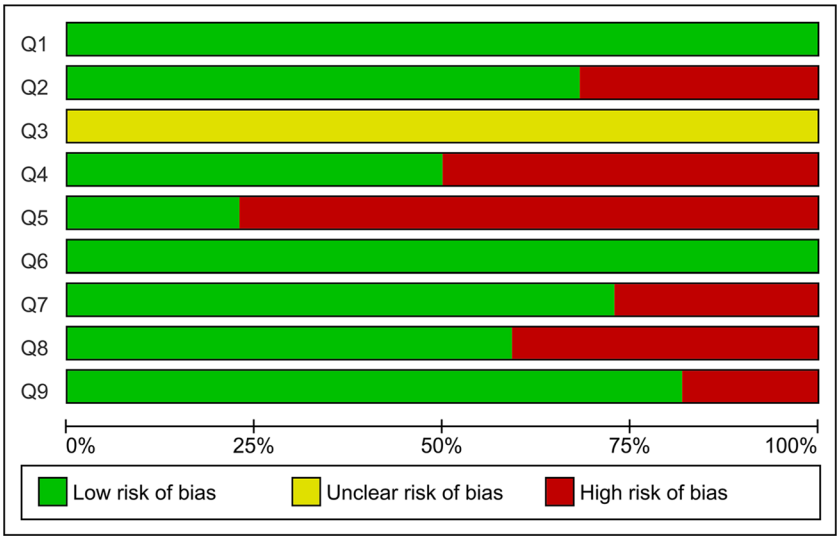

Fig. 2 Risk of bias graph. Q1 Is sample representative of patients in the population as a whole?; Q2 Are the patients at a similar point in the course of their condition/illness?; Q3 Has bias been minimized in relation to selection of cases and of controls?; Q4 Are confounding factors identified and strategies to deal with them states?; Q5 Are outcomes assessed using objective criteria?; Q6 Was follow-up carried out over a sufficient time period?; Q7 Where the outcomes of people who withdrew described and included in the analysis?; Q8 Were outcomes measured in a reliable way?; Q9 Was appropriate statistical analysis used?

section, unless otherwise stated. Detailed information about included studies' results are available in Table 1.

Adequate obturation presented higher "healed" rates than inadequate obturations (which included both over and underextended) in the study of Chugal et al. (2003) [16], while both adequate (within 3 mm from the radiographic apex) and overextended obturations showed higher "healed" rates compared to underextended obturations in the study of Pirani et al. (2015) [29]. Moreover, Lee et al. (2012) suggested that adequate obturations presented higher rates of periapical healing than overextended obturations, although no differences in periapical healing were observed between underextended and overextended obturations [25].

Four studies found that the success rates were lower in under and overextended than in adequate obturations (at the apex [15], within 1 mm [20, 24], and within 2.5 mm from the radiographic apex [30]), from which one [20] found no statistical difference between under and overextended obturations. In addition, Helling et al. (2001) found no differences in the success rates between adequate, under, and overextended obturations [21], while Tamarut et al. (2006) suggested that teeth with unsuccessful outcomes presented on average with underextended obturations [34].

Ilgüy et al. (2012) showed that PAI of adequate obturations (within 1 mm from the radiographic apex) was lower than under and overextended obturations [23]. In addition, Ridell et al. (2006) reported that teeth with apical periodontitis in the follow-up period were more likely to have under or overextended obturations [31].

Halse and Molven (1987) reported that overextended obturations had lower rates of success than obturations ending at the radiographic apex [19]. Similarly, Matsumoto et al. (1987) concluded that overextended obturations presented lower repair rates than obturations within 0.5 and 1 mm from the radiographic apex [27]. In addition, two studies reported that the extrusion of endodontic cement was not significantly associated with lower healing rates [17, 18].

Liang et al. (2011) compared the influence of obturation extent in the presence of post-treatment periapical lesions using PA and CBCT [26]. As a result, in PA, the presence of under or overextended obturation presented higher rates of post-treatment apical lesions when compared to adequate obturations, while in CBCT analysis, obturation extent did not affect the presence/absence of post-treatment apical lesions ($p > 0.05$).

Regarding the influence of obturation extent on periapical repair, ten studies investigated teeth with preoperative normal/diseased apical tissues separately [3, 16, 18, 19, 22, 28, 30, 32, 33, 35]. Three of them reported that teeth with preoperative vital pulp or absence of radiolucency have higher rates of a favorable outcome related to underextended obturation [16, 22, 28], and Tani-Ishii and Teranaka (2003) reported that all teeth with normal preoperative apical conditions remained unchanged during the follow-up appointments [35].

Considering teeth with preoperative periapical lesions, Chugal et al. (2003) showed that obturation extent was closer to the radiographic apex in cases with favorable than with unfavorable outcomes [16]. Similarly, two other studies concluded that failure rates were higher on underextended or overextended than in adequate obturations [3, 33]. Additionally, Halse and Molven (1987) reported that overextend obturations have higher rates of an unfavorable outcome in teeth with preoperative periapical lesions [19]. Interestingly, Santos et al. (2010) found no association between obturation extent and maintenance of apical lesion [32].

Table 1 Summary of descriptive characteristics of included articles ($n = 22$)

Author (year), country. Study design	Size (*N*)	Apical extent**	RCT technique	Follow-up	Outcome assessment	Main results
Barbakow & Friedman (1980) [15], South Africa.	332 teeth	At apex* Short through	Not reported	Min 1 y	Successful: no symptoms + no tenderness to percussion or radiographic abnormalities. Unsuccessful: when any one of these criteria was not met	Success rates lower in short RF (75.6%) than in fillings through (82.1%) and at apex* (94.2%) (p value not reported)
Chugal et al. (2003) [16], United States.	408 roots	Measured in mm	Postgraduate endodontic clinic. Working length: radiographs. Irrigation: 1% NaOCl. Obturation: GP lateral condensation + AH26® sealer	4 ± 0.5 y	Normal periapex*: No periapical changes/widened periodontal ligament. Diseased periapex*: Presence of any discernible periapical radiolucency. Success: no symptoms + contour and width of periodontal ligament normal Failure: symptoms + little or no reduction/decrease/appearance/increase in radiolucency	RF not different ($p = 0.273$) in successes (mean = − 1.46)/failures (mean − 1.13) in normal periapex*. Diseased periapex*: RF extent different ($p = 0.001$) in successes (mean − 0.83) and failures (mean − 1.56). Success higher ($p = 0.009$) in normal pulp* if extend away (mean = − 1.3) than closer (mean = − 0.1)
Farzaneh et al. (2004) [17], Canada.	122 teeth –II 242 teeth – I + II	Adequate 0–2 Inadequate: short or long Sealer extrusion	Supervised graduate students SBLC (modified step-back + GP cold lateral compaction) FPVC (flared preparation + GP war vertical compaction)	4–6 y	PAI ≤ 2 = no apical periodontitis. PAI ≥ 3 = presence of apical periodontitis. Healed = no apical periodontitis, signs and symptoms other than tenderness to percussion. Disease = presence of apical periodontitis/signs or symptoms	Filling length associated with "healed" rates ($p = 0.05$). Adequate filling length 87% healing. Inadequate filling length 77% healing. Preoperative apical periodontitis: RCT length/sealer extrusion not associated with "healed" rates ($p > 0.05$)
Friedman et al. (2003) [18], Canada	120 teeth	Sealer extrusion	Supervised graduate students Working length: electronic locator. Hand instrumentation Irrigation: 2.5% NaOCl. Obturation: GP lateral condensed/ "Schilder technique"	4–6 y	PAI ≤ 2 = no apical periodontitis. PAI ≥ 3 = presence of apical periodontitis. Healed = no apical periodontitis, signs and symptoms other than tenderness to percussion. Disease = presence of apical periodontitis/signs or symptoms	Healed rates not different in teeth with periapical radiolucency + sealer extrusion (69% "healed"), or no sealer extrusion (80% "healed") ($p = 0.299$)
Halse & Molven (1987) [19], Norway	239 teeth 551 roots	Overfillings: B1 – Flush B2 - < 1 C1–1-2 C2 - > 2	Undergraduate students. Working length: 1–2 mm from the apex* (pulpectomy)/0.5 mm (non-vital teeth). Obturation: Kloroperka N-Ö® + GP lateral condensation	10–17 y	No pathological findings (success) Increased width PLS (uncertain) Pathologic finding (failure)	79% overfillings disappeared, 18% and 3% remained unchanged. Success was greater (83%) in no overfillings than in overfillings (76%). Overfilling did not influence the success ($p > 0.05$) except in C2 with radiolucency ($0.05 > p > 0.025$).
Harty et al. (1970) [20], United Kingdom	1139 teeth	Long (+ sealer overflow) Short: > 1 Satisfactory: within 1	Working length: radiographs. Mechanically cleaned. Irrigation: sterile distilled water. Medication: antibiotic paste. Obturation: after two dressings if dry and symptomless	Min 2 y	Radiographic: normal (continuous, uniformly thick PLS), thickened (< 1 mm thickness), or area present (more than 1 mm)	"Satisfactory" (success = 92.6%) RF presented higher success than "long" (success = 86.81%) and "short" (success = 87.82%) ($p < 0.01$). No significant difference between "long" and "short" ($p > 0.05$)
Helling et al. (2001) [21], Israel	319 teeth	< 2 Overfilling	Irrigation: 0.5% NaOCl.	1–12 y	Computerized quantitative (PA): measure the area fraction of periapical lesion.	

Table 1 (continued)

Author (year), country. Study design	Size (*N*)	Apical extent**	RCT technique	Follow-up	Outcome assessment	Main results
			Obturation: GP + AH26® sealer		Success: decrease in the size of lesion. Failure: increase in the size of the lesion	No correlation between short or overfillings and success rates of RCT ($p > 0.05$). The success rate was 63.91% in well performed, 65.20% in short and 70.96% in overfillings
Hellwig et al. (1982) [22], Germany	93 teeth	Adequate Underfilling: > 1 Overfilled	Undergraduate students. Working length: radiographs. Hand instrumentation Irrigation: 3% H_2O_2 + 5% NaOCl. Obturation: AH26® sealer + GP	3 y	Clinical success: no symptoms. Radiographic success: maintained normal PLS (vital teeth)/ regression of periapical radiolucency	Vital + adequate filling: no changes in apical area. Vital + overfilling: lesion in 11 out of 14 cases. Vital + underfilling: 1 development of lesion. 30 of 38 radiolucencies decreased after 3 years. Unchanged or enlargement in 8 RCT (3 adequate, 4 over and 1 under RF)
Ilgüy et al. (2012) [23], Turkey	319 teeth	0–2. > 2 Overfilling	Operator: 4th and 5th undergraduate students. Step-back technique. Hand instrumentation. Obturation: AH plus® + GP by lateral condensation	2 y	Radiographic evaluation: PA. PAI 1 = normal PAI 2 = small changes in bone structure. PAI 3 = little mineral loss. PAI 4 = well-defined radiolucent area. PAI 5 = severe periodontitis	PAI of acceptable length were lower (1.67 ± 1.06) than short filled (2.3 ± 1.20) and overfilled (2.16 ± 1.17) ($p = 0.001$)
Kane et al. (1998) [24], France	143 teeth	Adequate: within 1 Short: ≥ 1 Long	Undergraduate students	12–16 m	Success: no signs and symptoms + no/reduced of lesion. Failure: lesion in teeth without preexisting lesion/ lesion the same size or increased	Adequate level: higher success rate (84.8%) than short (63.42%) and long fillings (75%) ($p = 0.039$)
Lee et al. (2012) [25], China	870 teeth	Flush (0–2) Short (> 2) Overfilling	Manual preparation: stainless steel K-files. Step-back or Step-down technique. Irrigation: sterile saline or 0.5% NaOCl. Obturation: GP cold lateral compaction + AH26® Duration: 2 or more visits	Min 4 y	Clinical assessment: signs or symptoms Radiographic evaluation (PA): Complete periapical healing: no clinical signs/ symptoms/radiolucency. Post-treatment disease: extracted or retreated/ clinical signs symptoms/ radiolucency	Flush fillings influenced periapical healing compared to overfillings (HR = 0.68; 95%CI = 0.49–0.93) ($p = 0.041$). No significant association among apical healing and short fillings (HR = 0.84; 95%CI = 0.57–1.23) compared with overfillings
Liang et al. (2011) [26], China	115 teeth 143 roots	Flush: 0–2 Short: > 2 Long: beyond	Operators: Department staff Working length: electronic locator + radiographs. Crown-down technique: ProTaper® or EndoFlare®. Irrigation: 1% NaOCl. Obturation: GP lateral compaction + Cortisomol®	2 y	Clinical assessment: sign and symptoms + quality of restoration. Radiographic evaluation (PA and CBCT): CBCT: Short filling: root filling short in all coronal and sagittal sections; long filling: root filling extended beyond apex* one section. Absence periapical lesion: periodontal ligament space < 0.5 mm	PA: apical extent = predictor of post-treatment apical lesions ($p = 0.018$). 91.3% flush/ 84% short / 76.9% long RF without periapical lesion. CBCT: apical extent did not influenced the presence/absence of periapical lesion ($p = 0.925$). 74.3% flush/ 66.7% short/ 75% long RCT without periapical lesion
Matsumoto et al. (1987) [27], Japan	85 teeth	Overfilling 0–0.4 0.5–1.0 1.1–2.0	Working length: dentin-cementum junction (0.5–1.0 mm from apex*) Irrigation: 10% NaOCl +3% H_2O_2	2–3 y	Successful: no signs/symptoms, no/ smaller radiolucency	Difference between incidence of repair in overfilling (40%) and 0.5 to 1.0 mm (88%) ($p < 0.05$). 0–0.4 mm: 61.5% success. 1.1–2.0-mm: 100% success

Table 1 (continued)

Author (year), country. Study design	Size (*N*)	Apical extent**	RCT technique	Follow-up	Outcome assessment	Main results
			Cavity sealed with ZOE cement			
Peak et al. (2001) [28], United Kingdom	344 teeth	< 2 ≥ 2 Overfilling	Royal Air Force dental practitioners Obturation: GP lateral condensation/ single cone GP/ silver/titanium point technique/ Endomethasone ® alone	Min 1 y	Definite success: no signs/symptoms + no radiographic evidence of pathology. Probably success: no signs/symptoms + reduced periapical area. Failure: signs/symptoms + bone loss equal or greater than original	Overfilled: higher success rates than ≥ 2 mm. No radiolucencies + overfilled: low success rates. Radiolucencies + overfilled: higher success rates. Root filling within 2 mm + reviewed within 3 years: higher success than ≥ 2 mm/overfilled. ≥ 3 years + overfilled (success = 93%)/within (success = 90%): higher success than > 2 mm (success = 76%)
Pirani et al. (2015) [29], Italy	209 teeth	≤ 3 > 3 Overfilling	Modified step-back technique. Coronal third: Gates-Glidden Apical third: stainless steel files Irrigation: NaOCl 5% + H_2O_2 Obturation: warm GP cones + CRCS	10–19 y	Radiographic evaluation: PA (based on the Toronto study criteria). "Healed": PAI ≤ 3 + signs or symptoms other than tenderness to percussion. "Diseased": PAI ≥ 3	≤ 3 mm 86% "healed" (OR = 3.78; 95%CI = 1.85–7.74) > 3 mm 60% "healed" Overfilling 83% "healed" (OR = 2.48; 95%CI = 0.44–13.8)
Ricucci et al. (2011) [30], Italy	816 teeth 1369 canals	< 0 0 (flush) 0.0–0.5 0.5–1.0 1.0–1.5 1.5–2.0 2.0–2.5 2.5–3.0 > 3.0	Operator: general dentist Step-back technique. Working length: electronic locator + radiographs. Coronal third: Gates-Glidden Apical third: hand instrumentation Irrigation: 1% NaOCl. Obturation: GP cold lateral compaction + sealer (randomly selected among six)	5 y	Clinical assessment: signs and symptoms. Radiographic assessment (PA): Successful: No signs/symptoms. Resolution of lesion + continuous lamina dura + normal PLS. Doubtful: No sign or symptoms + decrease of lesion + normal periapical conditions not stablish. Unsuccessful: signs or symptoms present + initial lesion with same size or increased in size	There was a significant curvilinear effect for fill level ($p = 0.001$), such that those with fill levels in the center distribution (from 0 to 2.5 mm) showed significantly higher likelihoods of success that both those that were < 0 mm as well as those > 2.5 mm
Ridell et al. (2006) [31], Sweden	124 teeth	≤ 2 > 2 Overfilling	Sample from a previous published study (Ridell, Sundin, and Matsson, 2003)	Min 1 y	PAI 1 and 2 = normal periapical status. PAI 3, 4 and 5 = apical periodontitis. Multirooted teeth: scored based on the most severely affected root	Technical quality—including filling extent—related to periapical status (*p* value not reported). Tooth with apical periodontitis: most probable filing with > 2 mm or overfilled (OR = 3.6, 95%CI = 1.4–8.9) (*p* value not reported)
Santos et al. (2010) [32], Brazil	157 teeth 291 roots	Ideal: 0.5–1.5 Altered: underfilling (> 1.5) or overfilling	Postgraduate students. Step-down technique. Irrigation: 1% NaOCl (vital pulp), 2.5% (necrotic pulp) or 5.25% (periapical lesions). Working length: electronic locator + radiograph. Obturation: thermomechanical (GP + epoxy-based sealer)	4–7 y	Radiographic evaluation (PA): Normal: good periapical condition. Slight widening of apical periodontal ligament Periapical lesion: exceeding ≥ 2 times width of lateral periodontal ligament	Apical extent different only between normal periapical (72.9% ideal and 27.1% altered) and slight widening of apical periodontal ligament (53.6% ideal and 46.4% altered) ($p = 0.006$). No association between filling extend and periapical lesion ($p > 0.05$)
Sjogren et al. (1990) [3], Sweden	356 teeth	0–2 > 2	Undergraduate students.	8–10 y	Clinical + radiographic assessment	RF level influenced outcome of RCT in necrotic pulps and periapical lesions.

Table 1 (continued)

Author (year), country. Study design	Size (*N*)	Apical extent**	RCT technique	Follow-up	Outcome assessment	Main results
		Overfilling	Step-back: K and Hedstrom files. Irrigation: 0.5% NaOCl. Obturation: GP lateral condensation		Radiographic success: contours, width, and structure of periodontal margin normal/periodontal contours widened mainly around excess of filling material	RF 0–2 mm: 94%/ Overfilled: 76% ($p = 0.003$)/ RF > 2: 68% ($p = 0.004$) of normal periapical conditions. No difference in outcome for overfilled or RF > 2 mm ($p = 0.3$)
Smith et al. (1993) [33], United Kingdom	821 teeth	Long Short Satisfactory: within 2	The working length: 1 mm short of apex*. Obturation: silver cones + sealer/ GP + sealer/ silver amalgam without sealer	Min 5 y	Clinical (success): no symptom + no sinus tract or tenderness to palpation in vestibular sulcus. Radiographic (success): PLS remained unchanged/ healing of radiolucency and normal PLS. Multirooted: tooth was considered as a single unit	Long/short (25%/22.41% failures): higher fail than "satisfactory" (13.05% failures) ($p < 0.001$). Non-vital + long/short filled: higher failures than "satisfactory" ($p < 0.006$). Vital ($p > 0.05$). Non-vital + preoperative lesion: more failures when long or short ($p < 0.036$). Normal/thickened apex* ($p > 0.05$)
Tamarut et al. (2006) [34], Croatia	257 teeth	Measured in mm	Private practice. Working length: authors own method + electronic locator. Negotiable canals + sensitive pulp: crown-down + step-back + ultrasound. Curved canals: crown-down+ balanced force + step-back + ultrasound. Periapical changes: crown-down + step-back + ultrasound + foramen treatment Obturation: guttapercha-eucapercha.	10 y	Success: No signs and symptoms + continuity of periodontal ligament + normal bone surrounding apex* (at least within 2 y) Multirooted teeth: tooth was considered as a single unit	Length RF in successful outcome was at apical constriction (− 0.42 mm ± 0.74 mm). Unsuccessful outcome average RCT underfilled (− 1.05 mm ± 1.23 mm). The difference was statistically significant ($p < 0.05$)
Tani-Ishii & Teranaka (2003) [35], Japan	236 canals	Short: > 2 Flush: within 2 Overfilling	Working length: electronic locator. Apical coronal technique with hand k-files. Irrigation: 2.5% NaOCl +3% H_2O_2. Obturation: Obtura II®	1 y	Previous radiolucency: (Healing) regeneration of PLS + lamina dura. (Decreased) smaller. (Unchanged) same size. (Increased) larger. Absence of radiolucency: Remaining normal/Lesion development	The healing rate between overfilling, flush filled, or short RF, was 92.9%, 96.8%, and 92.9%, respectively. Normal preoperative apical conditions: all remained normal

*radiographic apex/periapex. ** considering only RCT filling length variable.CI, confidence interval; GP, gutta-percha; HR, Hazard ratio; Min, minimum; NaOCl, sodium hypochlorite; OR, odds ratio; PLS, periodontal ligament space; RF, obturation; RCT, root canal treatment; Y, years;

Synthesis of results

Among all included studies, eleven studies described an endpoint (in mm) considered as adequate obturation extent and reported enough data to calculate the odds ratio of unfavorable outcome related to underextended and overextended obturations [3, 15, 20–22, 24, 26, 28, 29, 33, 35]. These studies were grouped by their ideal endpoint stated. Forest plots were constructed for the odds ratio measured (Figs. 3 and 4). High clinical and methodological heterogeneity across studies was found, reflecting differences in RCT techniques, outcome assessments, obturation extent assessments, and follow-up periods. Thus, a pooled quantitative synthesis was not recommended.

Underextended obturation

One study considered the adequate obturation extent within 3 mm from the radiographic apex, and showed that underextended obturation (less than 3 mm) presented increased odds (4.26; 95%CI = 2.1–8.7) of unfavorable outcome when compared to adequate obturation extent. For studies ($n = 6$) that considered the adequate obturation extent within 2 mm from the radiographic apex, odds of unfavorable outcome for underextended obturations (less than 2 mm) varied between 0.93 (95%CI = 0.5–1.6) and 6.94 (95%CI = 2.2–21.9) when compared to adequate obturation extent.

For studies ($n = 3$) that considered the adequate obturation extent within 1 mm from the radiographic apex, odds of unfavorable outcome for underextended obturations (less than 1 mm) varied between 1.73 (95%CI = 1.0–2.9) and 7.67 (95%CI = 0.9–60.2) when compared to adequate obturation extent. One study considered the adequate obturation extent at the apex (0 mm), in which the underextended obturation (shorter than 0 mm) presented increased odds (5.67; 95%CI = 2.1–15.5) of unfavorable outcome when compared to adequate obturation extent.

Overextended obturation

Odds of unfavorable outcome for overextended obturations ($n = 11$) varied between 0.72 (95%CI = 0.3–1.7) and 23.00 (95%CI = 5.6–94.7) when compared to adequate obturation extent.

Risk of bias across studies

The quality of evidence of this systematic review was classified as very low for all outcome measures (Table 2). The high and moderate RoB of some included studies and the high inconsistency between them influenced these results. Inconsistency was rated according to the heterogeneity of studies.

Additional analyses

Among the eleven studies that enabled calculation of odds ratio of unfavorable outcomes related to under and overextended obturations, the odds of unfavorable outcomes for underextended obturations in studies classified as low RoB ($n = 4$) varied between 1.45 (95%CI = 0.2–8.3) and 6.94 (95%CI = 2.2–21.9), and for overextended obturation varied between 0.96 (95%CI = 0.4–2.5) and 4.60 (95%CI = 1.8–11.9) when compared to adequate obturation. Odds of unfavorable outcome for underextended obturations in studies classified as moderate RoB ($n = 5$) varied between 0.93 (95%CI = 0.5–1.6) and 7.67 (95%CI = 0.9–60.2), and for overextended obturation varying between 0.72 (95%CI = 0.3–1.7) and 23.00 (95%CI = 5.6–94.7). Only two studies were classified as high RoB; therefore, sensitivity analysis was not justifiable.

Discussion

Summary of evidence

This systematic review aimed to investigate the association between obturation extent and RCT outcome including studies with a minimum 1-year follow-up. The selected sample consisted of 22 studies, with a total of 1139 endodontic treated teeth. Among the included studies, various obturation extents were suggested as adequate. Thus, studies were grouped based on the endpoint (in mm) stated as adequate. Since these subgroups reflected differences in under and overextended parameters that differently interfer RCT outcome, and considering the high heterogeneity of the included studies, a meta-analysis was not executed.

The adequate obturation extent reported in the included studies ranged from 3 to 0 mm from the radiographic apex. Among them, only eleven studies reported enough data to enable calculation of the odds ratio, and were separated in the following subgroups according to the distance of the obturation from the radiographic apex: 3 mm [29], 2 mm [3, 17, 21, 23, 25, 26, 28, 31, 33, 35], 1 mm [20, 22, 24], and at the apex (0 mm) [15]. Underextended obturation was considered when obturation extent did not reach the ideal endpoint stated, and an incomplete obturation was radiographically observed, whereas, for all included studies, an overextended obturation was defined as obturation material extending beyond the apex.

As a result, seven studies reported a positive association between underextended obturation and increased odds of failure in RCT [3, 15, 20, 24, 28, 29, 33]. In these studies, underextended obturation was associated with higher odds of failure when compared with adequate obturations, with reported odds ranging between 1.73 (95%CI = 1.02–2.95) and 6.94 (95%CI = 2.2–21.9). The presence of underextended

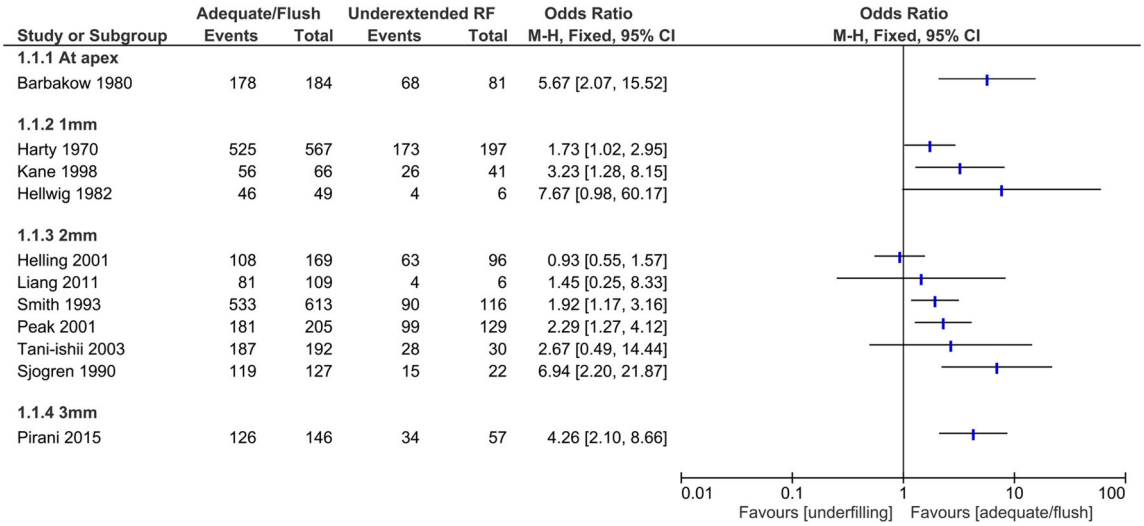

Fig. 3 Subgroup analysis for underextended obturations* in included articles ($n = 11$). *Values considered as adequate by the articles. FO, favorable outcome

obturation may represent the presence of contaminated tissue in the final extension of the root canal system, which can contribute to the maintenance of apical bacterial biofilms, and therefore influence the outcome of RCT [36, 37]. However, due to the lack of standardized criteria for obturation extent assessment, future studies evaluating these criteria are required to reach safe conclusions.

Regarding overextended obturations, four studies reported increased odds of failure in overextended obturations compared to adequate obturation, with odds ranging between 1.90 (95%CI = 1.23–2.94) and 23.00 (95%CI = 5.58–94.75). The presence of overextended obturation represents the existence of foreign bodies in the periapical region, which may not be biocompatible, and therefore can increase inflammation and influence the healing rates in cases of RCT [38]. Two of the studies included [16, 34] provided data as the mean distance from the radiographic apex, which can facilitate comparisons with other studies and provide more reliable data.

Considering the data collected by the present study, obturation extent seems to influence the RCT outcome in function of the pulp tissue condition. Teeth with irreversible pulpitis (vital teeth) exhibiting bacterial colonization usually do not show colonies in the apical third of the roots [39]. Therefore, instrumentation and obturation at the foramen level is not necessary [3, 40]. In contrast, non-vital teeth show bacterial infection extending throughout the entire root canal system, with common formation of biofilms in the apical portion and beyond the apical foramen [41, 42]. Instrumentation at the apex level is highly recommended in teeth with periapical lesions, followed by apical enlargement attempting to reduce the microbial content and to facilitate periapical healing [43, 44]. In the present study, teeth without apical lesion

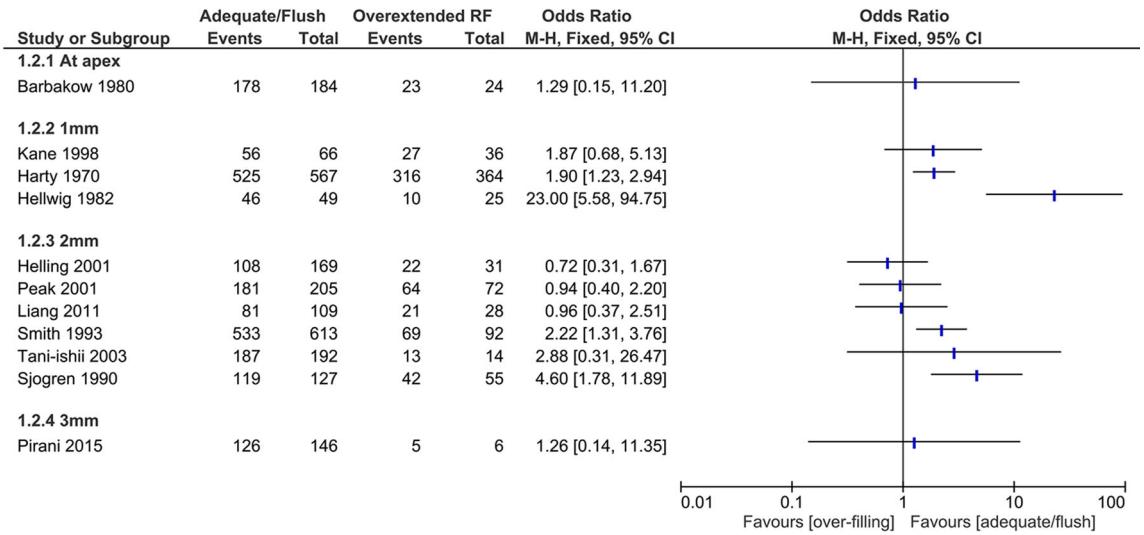

Fig. 4 Subgroup analysis for overextended obturations* in included articles ($n = 11$). *Values considered as adequate by the articles. FO, favorable outcome

Table 2 GRADE assessment

Outcome	Quality assessment					GRADE quality
	Studies (*n*)	Risk of bias	Inconsistency	Indirectness	Imprecision	
Overall association between RF and RCT outcome	22 observational studies	serious[a]	very serious[b]	not serious	not serious	⊕○○○ Very low
Association between underextended RF and RCT outcome	18 observational studies	serious[c]	very serious[b]	not serious	not serious	⊕○○○ Very low
Association between overextended RF and RCT outcome	19 observational studies	serious[c]	very serious[b]	not serious	not serious	⊕○○○ Very low

GRADE Working Group grades of evidenceHigh quality: We are very confident that the true effect lies close to that of the estimate of the effect.Moderate quality: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.Low quality: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect.Very low quality: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

[a] Two studies were classified as high risk and seven as moderate risk of bias; [b] The heterogeneity of studies was considerably high; [c] Two studies were classified as high risk and six as moderate risk of bias; RF, obturation; RCT, root canal treatment

demonstrated higher chances of favorable outcomes when obturation was placed shorter from the apex.

The authors of the present study understand that, for an effective decrease in the toxic content of the root canal system, not only instrumentation and obturation at a level close to the apical foramen are necessary to reach a favorable outcome in non-vital teeth [45]. Other factors, such as foraminal patency [43, 46], the use of intracanal medication prior to obturation [47], and the use of irrigation techniques with solutions that optimize sanification of the root canal system [48, 49], in addition to the advent of engine-driven instruments [50, 51], newer warm gutta-percha obturation techniques [52] and more tapered preparation [53], are also fundamental.

The findings of this study demonstrated that an obturation extent as close as possible to the apical foramen presented a positive correlation with treatment success in non-vital teeth. A retrospective study regarding 2000 clinical cases with proper samples and adequate exclusion and inclusion criteria reported high success rates when root canal instrumentation and obturation limits were established close to apical constriction [54]. Thus, it can be presumed that a root canal obturation close to the apical limit, in spite of other factors that may affect the success of the treatment, is indicative of a favorable prognosis.

The extrusion of endodontic sealers (cement) did not influence RCT outcome in the two studies [17, 18] that evaluated this association. Additionally, one study [19] investigated the influence of overextended obturation (both gutta-percha and sealer) on the rates of favorable outcomes and found that it did not influence the healing rates as most extruded material had been reabsorbed at the follow-up appointment. However, these findings are not consistent with the results of several studies, which demonstrated that the extrusion of obturation materials beyond the apical foramen is responsible for RCT complications [55–58]. Flare-ups and foreign body type reaction are the most common occurrences and are positively correlated with RCT complications [55]. Thus, due to the limited number of studies assessed in this systematic review, further prospective cohort studies are required to reach a definitive conclusion.

Most included studies used PA for RCT outcome assessment, which is limited by its bi-dimensional nature. However, a consensus regarding RCT outcome assessment is lacking. The PAI scoring system has been proposed for assessing periapical status through PA, and consequently addressing the apical healing status after RCT in teeth with apical lesions [59]. This system grades the apical lesions from 1 to 5, from which scores 4 and 5 at the follow-up are considered as an ultimate failure, and 1 or 2 as an absolute success. Score 3 is controversial, and some studies considered it as a success [59]. From the included studies, only five evaluated apical healing through the PAI [17, 18, 23, 29, 31], which emphasizes the need for standardized criteria for assessing RCT outcome.

Moreover, the obturation extent assessment through PA is limited by the anatomical variation of the anatomic foramen [60]. Usually, the anatomical foramen does not coincide with the radiographic apex [61–63]. Thus, obturation distance from radiographic apex must be analyzed with caution. One included study [26] compared the periapical healing of vital teeth treated endodontically between PA and CBCT. CBCT detected periapical lesions in 25.9% of cases and PA in 12.6%; obturation extent did not influence RCT outcome in the CBCT analysis. Although CBCT provides useful information, it has been recommended for selected cases according to ALARA (As Low As Reasonably Achievable) where the radiation dose should follow safety principles [64–66].

Limitations

The 22 included studies were considerably heterogeneous, especially regarding study design, sample size, RCT technique, follow-up period, obturation extent, and outcome assessment criteria. Therefore, meta-analysis was not possible. Overextended and underextended obturation had a higher chance of association with a less favorable outcome than adequate obturation, as reported in the majority of the included articles. However, the methods used for investigating RCT outcome were usually poorly described and not validated. It is worth mentioning that most of included articles did not reported data on confounding factors such as preoperative pulpal status, coronal leakage, or carious involvement. As previous mentioned, several confounding factors can influence RCT outcome [2, 3], and therefore, they should be considered in future studies assessing RCT outcome characteristics. For these reasons, this systematic review's conclusions must be interpreted with caution, and further studies with standardized and validated methods should be conducted. Future studies on this topic are required, aiming to reduce methodological heterogeneity in this topic. The authors suggest that these studies utilize the PAI method for the assessment of the endodontic outcome, and obturation extent should be measured in millimeter and present as mean values.

Conclusion

Obturation extent seems to influence the RCT outcome. Overextended and underextended obturation showed a higher chance of association with less favorable outcome than adequate obturation. However, this influence could not be categorically supported due to other factors which are crucial and may affect proper shaping and cleaning of the root canal system. Due to the limitations of this systematic review, this conclusion must be interpreted with caution.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This work does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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