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Influence of Imaging Modality on the Detection of Periapical Lesions in Root-Filled Teeth: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Apical periodontitis is a common finding in root-filled teeth (RFT) and an important indicator of treatment outcomes. Its reported prevalence may vary depending on the imaging modality used for diagnosis.

Objectives: To estimate the prevalence of periapical lesions in RFT teeth and to assess the influence of imaging modality on these estimates:

Methods: A systematic review and meta-analysis were conducted following PRISMA 2020 guidelines and registered in PROSPERO (CRD420261320661). Electronic databases (PubMed, Scopus, Web of Science and Embase) were searched up to February 2026. Studies reporting the prevalence of periapical lesions in endodontically treated permanent teeth assessed using cone-beam computed tomography (CBCT), periapical radiography or panoramic radiography were included. Random-effects meta-analyses (DerSimonian–Laird) with logit-transformed proportions were used to estimate pooled prevalence at tooth and patient levels. Subgroup analyses and meta-regression explored the impact of imaging modality. Risk of bias was assessed using an adapted prevalence tool, and certainty of evidence was evaluated using GRADE.

Results: Fifty-seven studies were included, comprising 64 026 root-filled teeth and 35 569 patients. The pooled prevalence of periapical lesions was 41.3% (95% CI: 38.2%–44.6%) at the tooth level and 20.5% (95% CI: 9.3%–39.4%) at the patient level. Higher detection rates were observed in studies using CBCT compared with most two-dimensional techniques. However, meta-regression showed that combined panoramic and periapical radiography produced estimates comparable to CBCT, while each modality alone yielded significantly lower values. No significant differences were found when imaging methods were grouped as two-dimensional versus three-dimensional. Substantial heterogeneity was present ($I^2 = 98\%–99\%$), and potential publication bias was suggested (Egger's test, $p = 0.048$). Most studies showed moderate risk of bias, with low to very low certainty of evidence.

Conclusions: Periapical lesions are highly prevalent in endodontically treated teeth. Although imaging modality influences prevalence estimates, improved detection does not rely exclusively on three-dimensional imaging. Combining two-dimensional techniques may achieve comparable results to CBCT, emphasizing the importance of diagnostic strategy. Further high-quality studies with standardized criteria are needed.

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1 | Introduction

Apical periodontitis (AP) is a chronic inflammatory condition that affects the periapical tissues as a consequence of microbial infection within the root canal system and is a common sequela of pulpal necrosis or inadequate endodontic treatment (Nair 2004). Although root canal treatment (RCT) aims to eliminate intracanal infection and promote periapical healing (Sjögren et al. 1997), treatment may sometimes fail, leading to the development of post-treatment apical periodontitis (PAP), which is typically manifested radiographically as a periapical radiolucent lesion (Çalışkan et al. 2016). Persistent or secondary AP reflects unresolved or re-established microbial infection within the root canal system and is a well-recognized outcome in a substantial proportion of endodontically treated teeth, even in the absence of clinical symptoms (Nair 2006).

PAP has significant clinical implications. From a biological standpoint, it indicates ongoing or unresolved infection within the root canal system, potentially compromising long-term tooth survival (Nair 2006). Clinically, PAP may remain asymptomatic for prolonged periods, yet it represents a chronic inflammatory condition that can exacerbate, leading to pain, swelling or acute apical abscess (Fransson and Dawson 2023). Moreover, persistent periapical inflammation has been associated with systemic inflammatory burden and may influence general health in susceptible individuals (Segura-Egea et al. 2015, 2023). For clinicians and policymakers, the prevalence of AP in endodontically treated teeth serves as a key indicator of the overall quality and effectiveness of endodontic care within a population (Di Filippo et al. 2014).

Epidemiological studies consistently report that radiolucent periapical lesions remain common findings in root-filled teeth (RFT), highlighting the limitations of treatment and the ongoing challenge of achieving complete periapical healing (Segura-Egea et al. 2004; López-López et al. 2012; Van der Veken et al. 2017). Meta-analytic data estimate that the frequency of periapical radiolucent images in RFT is around 39% across populations (Tibúrcio-Machado et al. 2021), substantially higher than in nontreated teeth, underscoring the continued clinical challenge of achieving periapical health post-treatment. The reported prevalence of PAP varies widely across populations and study designs (Boucher et al. 2002; Berlinck et al. 2015), which may reflect differences in treatment quality, follow-up period and, importantly, diagnostic methodology. Understanding the true burden of PAP in RFT is essential for evaluating endodontic outcomes at both the individual and population levels.

Radiographic examination is fundamental for diagnosing PAP, as clinical signs and symptoms are often absent (Siqueira et al. 2014); chronic AP is diagnosed primarily by radiography and many persistent periapical lesions remain asymptomatic while detectable on radiographic images (Orstavik 1996). Traditionally, periapical radiography and panoramic radiography have been used in epidemiological studies to assess periapical status, commonly employing indices such as the Periapical Index (PAI) (Orstavik et al. 1986). However, these two-dimensional imaging modalities are limited by anatomical superimposition, geometric distortion and reduced sensitivity in detecting small or early lesions (Tanomaru-FIlho et al. 2015). Cone-beam computed tomography (CBCT), by contrast, provides three-dimensional visualization and has demonstrated greater sensitivity in identifying periapical radiolucencies (Estrela, Bueno, Azevedo, et al. 2008), although its impact on epidemiological prevalence estimates remains subject to methodological factors. Consequently, the choice of imaging modality may substantially influence the reported prevalence of AP in endodontically treated teeth, potentially leading to underestimation when conventional radiography is used. It should be recognized that radiographic periapical lesions detected in cross-sectional studies may represent either persistent disease or lesions undergoing healing following endodontic treatment, as radiographic resolution may occur gradually over time. Therefore, the presence of a radiolucent lesion at the time of examination does not necessarily indicate treatment failure or active disease.

Although several systematic reviews have evaluated the overall prevalence of AP in the general population (Tibúrcio-Machado et al. 2021) and the prevalence of RCT worldwide (León-López et al. 2022), none have specifically focused on the prevalence of periapical lesions in endodontically treated teeth stratified by imaging modality. Given the increasing use of CBCT in clinical and research settings, it is crucial to determine whether differences in diagnostic technique account for variability in reported prevalence rates. Therefore, the aim of this systematic review and meta-analysis is to assess and compare the prevalence of PAP in endodontically treated permanent teeth according to imaging modality, including CBCT, periapical radiography and panoramic radiography. This approach will provide a clearer understanding of the impact of diagnostic method on epidemiological estimates and may help standardise future outcome reporting in endodontic research.

2 | Methods

This systematic review was conducted in accordance with the PRISMA 2020 guidelines (Page et al. 2021). The review protocol was prospectively registered in PROSPERO (CRD420261320661) before study selection, data extraction, risk of bias assessment and statistical analysis.

2.1 | Review Question

The research question was developed according to the CoCoPop mnemonic (Munn et al. 2015), which is specifically designed to structure research questions in prevalence studies. Within this framework, the prevalence of periapical lesions (post-treatment AP) was defined as the Condition; endodontically treated permanent teeth were identified as the Population; and the Context encompassed radiographic assessment using different imaging modalities (CBCT, periapical radiography, panoramic radiography) across any geographic setting.

Accordingly, the research question guiding this review was: What is the prevalence of periapical lesions, assessed radiographically, in endodontically treated permanent teeth, and does the reported prevalence differ according to imaging modality?

2.2 | Eligibility Criteria

Inclusion and exclusion criteria were defined according to the CoCoPop framework.

2.2.1 | Inclusion Criteria

Studies were eligible if they reported the prevalence of periapical lesions in endodontically treated permanent teeth and assessed periapical status using cone-beam computed tomography (CBCT), periapical radiography or panoramic radiography. Cross-sectional studies and cohort studies reporting baseline or otherwise extractable prevalence data were included. Studies reporting data at the patient level, tooth level or both were considered eligible. Publication date was not used as an inclusion criterion because older studies more frequently relied on two-dimensional imaging, whereas more recent studies often used CBCT; restricting studies by publication date could therefore have biassed the comparison between imaging modalities, which was a primary objective of this review.

2.2.2 | Exclusion Criteria

Case reports and case series including fewer than 10 teeth were excluded, as well as narrative reviews, systematic reviews and editorials. In vitro and animal studies were also excluded. Studies that did not report extractable prevalence data on periapical lesions in endodontically treated teeth or did not specify the imaging modality used for periapical assessment were excluded. Only studies with an English abstract were considered eligible for screening; no additional language restrictions were applied.

These criteria were defined to ensure the inclusion of studies providing clear diagnostic definitions of periapical lesions and extractable prevalence data, thereby enhancing the validity of the qualitative and quantitative synthesis.

2.3 | Search Strategy and Information Sources

A comprehensive electronic search was conducted in PubMed/MEDLINE, Scopus, Web of Science and EMBASE from database inception to 25 February 2026. The review project was initiated in 2024 as part of an academic research project, during which the research question was developed and preliminary literature searches were undertaken. The review protocol was subsequently registered in PROSPERO (CRD420261320661) before study selection, data extraction, risk of bias assessment and statistical analyses were performed. Following protocol registration, the electronic search was updated on 25 February 2026 to identify any additional eligible studies published before completion of the review.

The reference lists of included studies and relevant reviews were manually screened to identify additional eligible studies. The search strategy combined controlled vocabulary (MeSH and Emtree terms) and free-text terms related to AP, periapical lesions, endodontically treated teeth, cone-beam computed tomography (CBCT), periapical radiography, panoramic radiography and prevalence, using Boolean operators ('AND', 'OR') and truncation to ensure comprehensive coverage.

The complete search strategies for each database are provided in Table S1.

2.4 | Study Selection

All records were exported to Mendeley Desktop for duplicate removal and subsequently imported into Rayyan (Qatar Computing Research Institute) for screening. The investigators performed independent electronic searches in PubMed/MEDLINE, Web of Science, Scopus and Embase. Articles were initially screened by three authors (J.J.S-E., C.S.-R. and A.C.-F.) independently. The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al. 2021) and was conducted in two stages: title and abstract screening, and full-text assessment for eligibility. Three reviewers independently screened records. Disagreements were resolved through discussion and consensus. A PRISMA flow diagram will be constructed to illustrate study selection.

2.5 | Data Extraction and Outcomes

Data extraction was performed independently by three reviewers (J.J.S-E, J.M.-G., & D.C.-B.) using a standardized form developed in Microsoft Excel. For each included study, the following information was recorded: first author, year of publication, country, study design, total sample size (patients and/or teeth), number of endodontically treated teeth assessed, number of teeth presenting periapical lesions, imaging modality (CBCT, periapical radiography or panoramic radiography), diagnostic criteria used for lesion identification (e.g., PAI, CBCT-PAI or author-defined radiographic criteria), reported prevalence at the patient level, reported prevalence at the tooth level and examiner calibration procedures when available.

The primary outcome was the prevalence of periapical lesions in endodontically treated permanent teeth. Prevalence was analysed separately at the patient level (proportion of individuals with at least one endodontically treated tooth presenting a periapical lesion) and at the tooth level (proportion of endodontically treated teeth presenting a periapical lesion).

Secondary outcomes included pooled prevalence estimates stratified by imaging modality and, when available, comparative prevalence measures between three-dimensional (CBCT) and two-dimensional radiographic techniques.

When both patient-level and tooth-level data were reported, outcomes were extracted and analysed independently. Extracted data were cross-checked among reviewers and any discrepancies were resolved through discussion and consensus. Root-level prevalence estimates were not converted to tooth-level estimates because the number and distribution of affected roots per tooth were not consistently reported, preventing reliable data harmonization.

2.6 | Data Analysis

The quantitative synthesis aimed to estimate the pooled prevalence of periapical lesions in endodontically treated permanent teeth as reported in radiographic observational studies. For each study, prevalence was extracted as the proportion of affected individuals or teeth. Standard errors were calculated assuming a binomial distribution.

Pooled prevalence estimates were calculated separately at the patient and tooth levels. Given the anticipated clinical and methodological variability among studies, random-effects meta-analyses were performed using the DerSimonian–Laird estimator for between-study variance (τ^2). To stabilize variances and allow appropriate pooling of proportions, prevalence estimates were logit-transformed prior to meta-analysis, as recommended for meta-analyses of prevalence data (Barendregt et al. 2013). Pooled estimates and corresponding 95% confidence intervals were subsequently back-transformed to the original proportion scale for interpretation. The inverse-variance method was used to weight individual studies.

All quantitative analyses were conducted using OpenMeta[Analyst] (Brown University, version 10.10) (Wallace et al. 2012) and cross-verified using the web-based platform Meta-Analysis Online (https://metaanalysisonline.com/ accessed 12 March 2026). Ninety-five percent prediction intervals were calculated under the random-effects model to estimate the expected range of prevalence in a comparable future study.

Between-study heterogeneity was assessed using Cochran's Q statistic and quantified using the I^2 and τ^2 statistics (Higgins and Thompson 2002). Subgroup analyses were conducted according to radiographic modality (periapical radiography, panoramic radiography and CBCT) to explore potential sources of variability. Sensitivity analyses were performed using a leave-one-out approach to evaluate the influence of individual studies on pooled estimates. Small-study effects were assessed using Egger's regression test. Forest plots were generated to display individual study estimates and pooled prevalence values for both patient-level and tooth-level analyses.

All transformation procedures, weighting methods and statistical parameters reported in this study correspond to the OpenMeta[Analyst] implementation.

2.7 | Risk of Bias Assessment

Three reviewers (V.A.-Q., J.M.-G., & J.J.S.-E.), independently assessed the methodological quality of the included studies using an adapted appraisal tool for prevalence studies, based on previously published instruments for observational research (Hoy et al. 2012; Modesti et al. 2016) (Table S2). The tool was specifically tailored to the characteristics of radiographic prevalence studies. The assessment included eight items grouped into two main domains: (1) sample selection and representativeness and (2) measurement and data collection. The evaluated items were: (1) representativeness of the sample, (2) adequacy of recruitment method, (3) sample size justification, (4) description of study subjects and setting, (5) clarity of case definition, (6) validity of the diagnostic/imaging method, (7) consistency and reliability of data collection and (8) appropriateness of statistical analysis.

Each item was rated as low risk (+), high risk (–) or unclear risk (?). Particular emphasis was placed on key domains considered especially relevant for radiographic prevalence studies, namely: sample representativeness, clarity of case definition, validity of the imaging method, consistency of outcome assessment and adequacy of statistical analysis.

An overall risk of bias judgement was assigned to each study based on the assessment of these domains. Studies were classified as low risk of bias when all or most key domains were rated as low risk; moderate risk of bias when at least one key domain was rated as unclear or when a limited number of items were rated as high risk; and high risk of bias when one or more key domains were rated as high risk.

Disagreements between reviewers were resolved through discussion, and when necessary, consultation with a fourth reviewer (D.C.-B.).

2.8 | Grading of Recommendations Assessment, Development and Evaluation

The overall certainty of the evidence for the estimated pooled prevalence of periapical lesions in endodontically treated teeth was evaluated using the GRADE (Grading of Recommendations, Assessment, Development and Evaluation) approach, adapted for prevalence studies (Guyatt et al. 2011).

As all included studies had a cross-sectional design, the certainty of evidence was initially rated as low, in accordance with GRADE guidance for observational studies. The certainty was subsequently downgraded based on the following domains:

2.8.1 | Risk of Bias

Downgrading was applied when the majority of studies contributing to the pooled estimate were assessed as having moderate or high risk of bias according to the adapted appraisal tool. Particular emphasis was placed on sample representativeness and sampling methods.

2.8.2 | Inconsistency

The degree of heterogeneity among studies was evaluated using the I^2 statistic and the overlap of confidence intervals. Substantial heterogeneity ($I^2 > 50\%$) or marked variability in prevalence estimates led to downgrading.

2.8.3 | Indirectness

Downgrading was applied when study populations were not representative of the general population (e.g., dental school or

hospital-based samples) or when variability in imaging modalities and diagnostic criteria limited comparability.

2.8.4 | Imprecision

Downgrading was considered when confidence intervals were wide or when the number of included studies was small, particularly for patient-level analyses.

2.8.5 | Publication Bias

The presence of funnel plot asymmetry and/or statistically significant Egger's test ($p < 0.05$) was considered indicative of potential publication bias, leading to downgrading.

No upgrading criteria were applied, as the objective of the review was to estimate prevalence rather than effect size.

The overall certainty of evidence for each outcome was categorized as high, moderate, low or very low, following standard GRADE criteria. Summary judgements were presented in a Summary of Findings (SoF) table, including the pooled prevalence estimates, corresponding 95% confidence intervals, number of studies, total sample size and final certainty rating for each outcome.

3 | Results

3.1 | Study Selection

A total of 2151 records were identified through database searches and imported into Rayyan for screening (Figure 1). Automated duplicate detection identified 1669 potential duplicates, of which 1299 were removed after verification, leaving 852 records for screening.

During title screening, 337 records were excluded as they did not meet the eligibility criteria (e.g., case reports, reviews, in vitro or animal studies and surgical technique reports). The remaining 515 records underwent abstract screening, after which 139 were excluded for not addressing the prevalence or radiographic assessment of periapical lesions in endodontically treated permanent teeth.

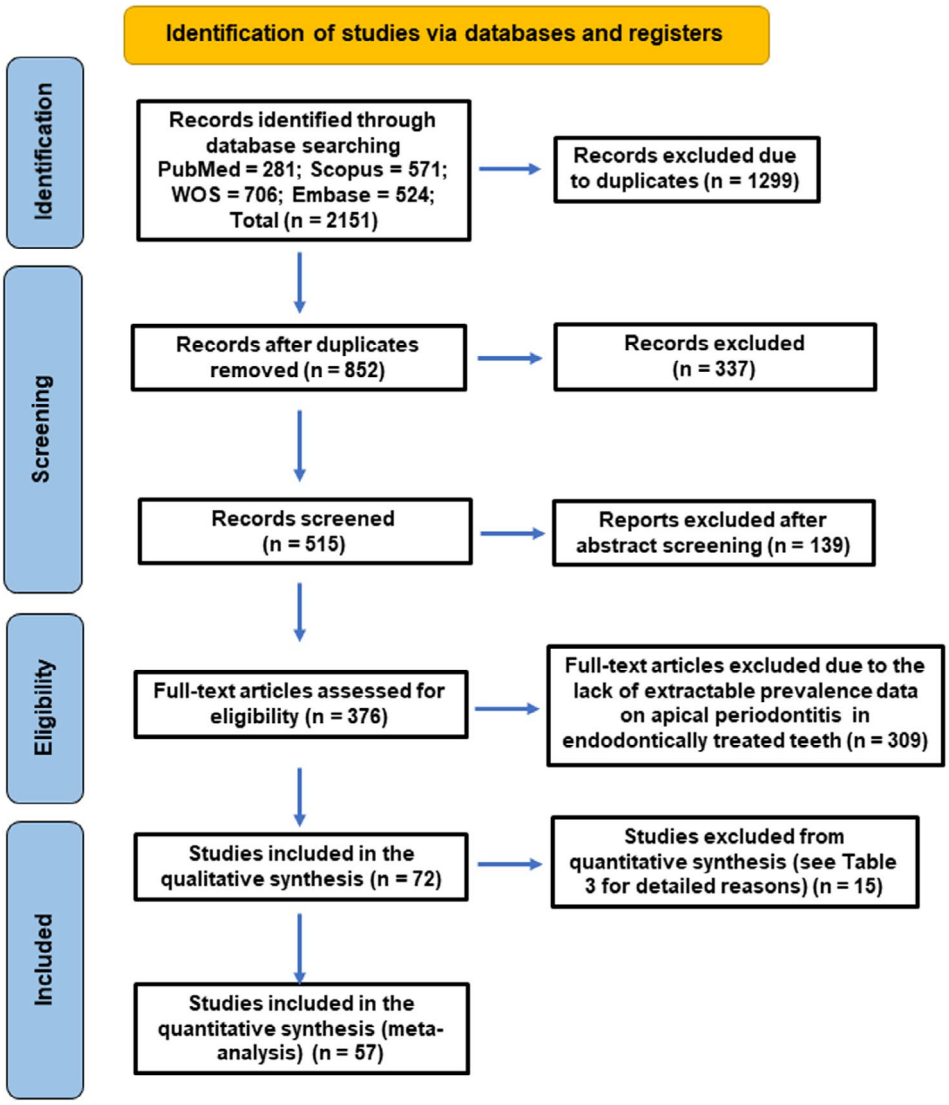


FIGURE 1 | Flowchart of the studies included in the systematic review and meta-analysis.

A total of 376 studies were assessed for full-text eligibility. Of these, 309 were excluded due to the lack of extractable prevalence data on periapical lesions in endodontically treated permanent teeth. Finally, 72 studies were included in the qualitative synthesis, the characteristics of which are presented in Table S3. Of these, 15 studies were excluded from the quantitative synthesis (Table S4) due to methodological heterogeneity, including differences in unit of analysis (root vs. tooth level) (Bergström et al. 1987; Buckley and Spångberg 1995; Touré et al. 2008; Karteva et al. 2021), high risk of selection bias (referral-based CBCT samples) (Dutta et al. 2014; Mashyakhy and Alkahtany 2021; Diaconu et al. 2025), non-comparable diagnostic criteria (Kalender et al. 2013), insufficient data (Allard and Palmqvist 1986; Willershausen et al. 2009), lack of appropriate population denominator or non-independent study population (Eriksen 1995; Segura-Egea et al. 2004), unclear or inappropriate definition of RFT or endodontic treatment (Petersson et al. 1989; Soikkonen 1995) and non-relevant or non-independent datasets (Hugoson et al. 1995). Consequently, 57 studies were included in the quantitative synthesis (meta-analysis).

3.2 | Characteristics of the Included Studies in the Quantitative Synthesis

A total of 57 studies were included in the quantitative synthesis and meta-analysis (Eckerbom et al. 1987; Ödesjö et al. 1990; Eriksen and Bjertness 1991; De Cleen et al. 1993; Weiger et al. 1997; Saunders et al. 1997; Marques et al. 1998; Sidaravicius et al. 1999; De Moor et al. 2000; Kirkevang et al. 2000; Lupi-Pegurier et al. 2002; Boucher et al. 2002; Dugas et al. 2003; Bołtacz-Rzepkowska and Pawlicka 2003; Jiménez-Pinzón et al. 2004; Georgopoulou et al. 2005; Kabak and Abbott 2005; Loftus et al. 2005; Tsuneishi et al. 2005; Skudutyte-Rysstad and Eriksen 2006; Sunay et al. 2007; Gulsahi et al. 2008; Covello et al. 2010; Gencoglu et al. 2010; Gumru et al. 2011; Al-Omari et al. 2011; Peters et al. 2011; Özbaş et al. 2011; Kamberi et al. 2011; Matijević et al. 2011; Mukhaimer et al. 2012; López-López et al. 2012; Rocha et al. 2012; Jersa and Kundzina 2013; Ureyen Kaya et al. 2013; Da Silva Ramos Fernandes et al. 2013; Di Filippo et al. 2014; Oginni et al. 2015; Archana et al. 2015; Berlinck et al. 2015; Ahmed et al. 2017; Al-Nazhan et al. 2017; Kielbassa et al. 2017; Van der Veken et al. 2017; El Merini et al. 2017; Timmerman et al. 2017; Vengerfeldt et al. 2017; Connert et al. 2019; Alawjali 2020; Meirinhos et al. 2020, 2021; Ali et al. 2022; Silnovic et al. 2023; Keratiotis et al. 2024; Morjaria et al. 2025; Alhomrany et al. 2025; Baban et al. 2026). The main characteristics of the included studies are summarized in Table 1, with Morjaria et al. (2025) comprising two independent cohorts.

All studies had a cross-sectional design and were conducted in a wide range of geographical locations, including Europe, Asia, Africa and South America. The sample sizes varied considerably across studies, reflecting differences in study populations and settings, which included dental school clinics, university hospitals, private practices and population-based samples.

The number of RFT assessed showed substantial variability. Radiographic assessment methods included periapical radiographs, orthopantomograms (OPG) and cone-beam computed tomography (CBCT), with CBCT-based studies generally reporting more detailed three-dimensional evaluations. The diagnostic criteria for periapical lesions (apical periodontitis) were not uniform across studies, ranging from the use of periapical index (PAI) scores to the identification of periapical radiolucency or widening of the periodontal ligament space. The unit of analysis differed among studies, being reported at the tooth level, patient level or both. Notably, Morjaria et al. (2025) contributed two independent cohorts (2008–09 and 2018–19), which were analysed separately.

3.3 | Extracted Data About the Prevalence of Periapical Lesions in Root-Filled Teeth

A total of 57 studies were included in the quantitative synthesis, comprising 35 569 patients and 64 026 RFT, of which 28 418 presented periapical lesions (Table 2).

At the tooth level, the reported prevalence of periapical lesions in RFT showed considerable variability across studies, ranging from 11.6% (Rocha et al. 2012) to 80.2% (Ali et al. 2022). Most studies reported prevalence values between 30% and 60%, indicating a substantial burden of post-treatment apical periodontitis across populations.

When stratified by imaging modality, clear differences were observed. Studies using cone-beam computed tomography (CBCT) consistently reported higher prevalence values, frequently exceeding 50% (e.g., Meirinhos et al. 2020, 55.5%; Meirinhos et al. 2021, 54.0%; Ali et al. 2022, 80.2%). In contrast, studies based on conventional two-dimensional radiography (periapical or panoramic radiographs) generally reported lower prevalence estimates, typically ranging between 20% and 50%. These findings suggest that three-dimensional imaging techniques are associated with higher reported prevalence values.

Substantial heterogeneity was observed among studies, which reflects variability in study populations, imaging modalities, diagnostic criteria and units of analysis. Differences in diagnostic thresholds, particularly between studies using the Periapical Index (PAI) and those using CBCT-based criteria, likely contributed significantly to this heterogeneity.

At the patient level, fewer studies reported extractable data (Jiménez-Pinzón et al. 2004; López-López et al. 2012; Ahmed et al. 2017; Timmerman et al. 2017; Vengerfeldt et al. 2017). Among those that did, the prevalence of patients presenting at least one root-filled tooth with periapical lesion also varied widely, reflecting similar patterns to those observed at the tooth level.

Overall, the quantitative synthesis highlights a consistently high prevalence of periapical lesions in RFT and underscores the influence of imaging modality on epidemiological estimates.

3.4 | Quantitative Synthesis and Meta-Analysis

A random-effects meta-analysis was conducted to estimate the overall prevalence, encompassing a total of 64 026 RFT, of which

TABLE 1 | Characteristics of the studies included in the quantitative synthesis.

Author, year, country	Study design	Sample (Patients)	Clinical setting/ Population source	No. of RFT	Imaging	Diagnostic criteria for AP	Unit
Ahmed et al. (2017)—Sudan	Cross-sectional	200	Dental clinic	80	OPGs & Periapical	Clear periapical radiolucency or widening of the periodontal ligament greater than twice the normal size	Patient/ Teeth
Alawjali (2020)—Libya	Cross-sectional	305	Dental clinic	439	D-OPGs	Periapical radiolucency or widening of periodontal ligament > 2× normal width	Teeth
Alhomrany et al. (2025)–Saudi Arabia	Cross-sectional	420	Dental school	1051	CBCT	Periapical radiolucency ≥ 2× periodontal ligament space	Teeth
Ali et al. (2022)—Iraq	Cross-sectional	385	Radiology centre	339	CBCT	Apical/lateral radiolucency > 2× periodontal ligament width	Teeth
Al-Nazhan et al. (2017)—Saudi Arabia	Cross-sectional	926	Dental clinic	1541	OPGs	Periapical radiolucency or PDL widening (> 2× normal width)	Teeth
Al-Omari et al. (2011)—Jordan	Cross-sectional	294	Dental clinic	424	D-OPGs	Periapical radiolucency or PDL widening (> 2× normal width)	Teeth
Archana et al. (2015)—India	Cross-sectional	1340	Dental clinic	1234	D-OPGs	PAI ≥ 3	Teeth
Baban et al. (2026)—Iraq	Cross-sectional	251	Dental clinic	352	CBCT	Radiolucency at apex ≥ 2× periodontal ligament width	Teeth
Berlinck et al. (2015)—Brazil	Cross-sectional	1126	Dental school	1754	Periapical	PAI ≥ 3	Teeth
Bołtacz-Rzepkowska and Pawlicka (2003)—Poland	Cross-sectional	236	Mixed clinical setting	282	Periapical	Radiolucency > 2× periodontal ligament width	Teeth
Boucher et al. (2002)—France	Cross-sectional	208	Dental clinic	481	Periapical	PAI ≥ 3	Teeth
Connert et al. (2019)—Germany	Cross-sectional	353	Dental clinic	337	OPGs & Periapical	PAI ≥ 3	Teeth
Covello et al. (2010)—Italy	Cross-sectional	384	Dental clinic	1076	OPGs	Periapical radiolucency or PDL widening (> 2× normal width)	Teeth
Da Silva Ramos Fernandes et al. (2013)—Brazil	Cross-sectional	300	CBCT database	415	CBCT	Hypodense periapical lesion (CBCT-based, CBCT-PAI)	Teeth
De Cleen et al. (1993)—Netherlands	Cross-sectional	184	Hospital	97	OPGs	Periapical radiolucency or PDL widening (> 2×)	Teeth
De Moor et al. (2000)—Belgium	Cross-sectional	206	Dental school	312	OPGs	Periapical radiolucency or PDL widening (> 2×)	Teeth

(Continues)

TABLE 1 | (Continued)

Author, year, country	Study design	Sample (Patients)	Clinical setting/ Population source	No. of RFT	Imaging	Diagnostic criteria for AP	Unit
Di Filippo et al. (2014)—United Kingdom	Cross-sectional	136	Dental hospital	115	OPGs	Periapical radiolucency (> 2× PDL width)	Teeth
Dugas et al. (2003)—Canada	Cross-sectional	610	Dental school	383	OPGs & Periapical	PAI score ≥ 3	Teeth
Eckerbom et al. (1987)—Sweden	Cross-sectional	200	General population	636	Periapical	Periapical radiolucency	Teeth
El Merini et al. (2017)—Morocco	Cross-sectional	508	Dental school	537	OPGs & Periapical	PAI ≥ 3	Teeth
Eriksen and Bjertness (1991)—Norway	Cross-sectional	119	General population	175	OPGs & Periapical	Periapical radiolucency	Teeth
Gencoglu et al. (2010)—Turkey	Cross-sectional	400	Dental school	890	OPGs & Periapical	PAI ≥ 3	Teeth
Georgopoulou et al. (2005)—Greece	Cross-sectional	320	Dental clinic	680	Periapical	Periapical radiolucency/ widened PDL (> 2× normal)	Teeth
Gulsahi et al. (2008)—Turkey	Cross-sectional	1000	Dental school	812	D-OPGs	Periapical radiolucency or PDL widening (> 2× normal)	Teeth
Gumru et al. (2011)—Turkey	Cross-sectional	1077	Dental school	459	OPGs	PAI ≥ 3	Teeth
Jersa and Kundzina (2013)—Latvia	Cross-sectional	312	Dental clinic	1255	OPGs	PAI ≥ 3	Teeth
Jiménez-Pinzón et al. (2004)—Spain	Cross-sectional	180	Dental schools	93	Periapical	PAI ≥ 3	Teeth
Kabak and Abbott (2005)—Belarus	Cross-sectional	1423	Dental school	2867	OPGs	Periapical radiolucency or widened periodontal ligament (> 2× normal)	Teeth
Kamberi et al. (2011)—Kosovo	Cross-sectional	193	Dental schools	95	OPGs	PAI ≥ 3 (radiolucency > 2× PDL width)	Teeth
Keratiotis et al. (2024)—Belgium	Cross-sectional	614	Dental schools	858	OPGs	PDL widening > 2× normal width	Teeth
Kielbassa et al. (2017)—Austria	Cross-sectional	1000	Dental schools	2504	OPGs	Radiolucency/PDL widening > 2×/loss of lamina dura	Teeth
Kirkevang et al. (2000)—Denmark	Cross-sectional	614	General population	773	Periapical	PAI ≥ 3	Teeth
Loftus et al. (2005)—Ireland	Cross-sectional	302	Mixed clinical settings	152	OPGs	PAI ≥ 4 (only scores 4–5 considered AP)	Teeth

(Continues)

TABLE 1 | (Continued)

Author, year, country	Study design	Sample (Patients)	Clinical setting/ Population source	No. of RFT	Imaging	Diagnostic criteria for AP	Unit
López-López et al. (2012)—Spain	Cross-sectional	397	Dental schools	144	OPGs	PAI > 2	Patient/ Teeth
Lupi-Pegurier et al. (2002)—France	Cross-sectional	344	Dental schools		OPGs	Periapical radiolucency or PDL widening > 2× normal	Teeth
Marques et al. (1998)—Portugal	Cross-sectional	179	General population	69	OPGs	PAI > 2	Teeth
Matijević et al. (2011)—Croatia	Cross-sectional	1462	Mixed clinical settings	3279	OPGs	PAI > 2	Teeth
Meirinhos et al. (2020)—Portugal	Cross-sectional	1160	CBCT database	2305	CBCT	CBCT-PAI AP = radiolucency > 0.5 mm	Teeth
Meirinhos et al. (2021)—Portugal	Cross-sectional	1249	CBCT database	2497	CBCT	CBCT-PAI (Estrela), lesion > 0.5 mm	Teeth
Morjaria et al. (2025)—United Kingdom	Cross-sectional	490 Cohort 1 (2008–09)	Hospital	611	OPGs	Radiolucency ≥ 2× PDL width	Teeth
Morjaria et al. (2025)—United Kingdom	Cross-sectional	490 Cohort 2 (2018–19)	Hospital	476	OPGs	Radiolucency ≥ 2× PDL width	Teeth
Mukhaimer et al. (2012)—Palestine	Cross-sectional	258	Dental schools	855	OPGs	Radiolucency OR PDL widening (> 2× normal width)	Teeth
Ödesjö et al. (1990)—Sweden	Cross-sectional	743	General population	1492	Periapical	Periradicular radiolucent area associated with the root	Teeth
Oginni et al. (2015)—Nigeria	Cross-sectional	756	University hospital	2625	Periapical	PAI > 2	Teeth
Özbaş et al. (2011)—Turkey	Cross-sectional	438	Dental schools	179	Periapical	PAI ≥ 2	Teeth
Peters et al. (2011)—Netherlands	Cross-sectional	178	Hospital	224	OPGs	Periapical radiolucency ≥ 2× PDL width	Teeth
Rocha et al. (2012)—Portugal	Cross-sectional	222	Dental schools	215	Periapical	PAI > 2	Teeth
Saunders et al. (1997)—United Kingdom	Cross-sectional	340	Hospital	472	Periapical	Periradicular radiolucencies	Teeth
Sidaravicius et al. (1999)—Lithuania	Cross-sectional	147	Population-based sample	320	OPGs & Periapical	PAI > 2	Teeth
Silnovic et al. (2023)—Sweden	Cross-sectional	196	Population-based simple	491	Periapical	PAI > 2	Teeth

(Continues)

TABLE 1 | (Continued)

Author, year, country	Study design	Sample (Patients)	Clinical setting/ Population source	No. of RFT	Imaging	Diagnostic criteria for AP	Unit
Skudutyte-Rysstad and Eriksen (2006)—Norway	Cross-sectional	146	Population-based sample	61	OPGs & Periapical	PAI > 2	Teeth
Sunay et al. (2007)—Turkey	Cross-sectional	375	Dental schools	470	OPGs	Widening of PDL OR radiolucency ≥ 2× PDL	Teeth
Timmerman et al. (2017)—Australia	Cross-sectional	695	Dental hospital	284	OPGs	PAI > 2	Teeth
Tsuneishi et al. (2005)—Japan	Cross-sectional	672	University dental hospital	3320	Periapical	PAI > 2	Teeth
Ureyen Kaya et al. (2013)—Turkey	Cross-sectional	1000	Public dental health centre	601	D-OPGs	PAI > 2	Teeth
Van der Veken et al. (2017)—Belgium	Cross-sectional	631	University hospital	1357	CBCT	Radiolucency ≥ 2× width of PDL	Teeth
Vengerfeldt et al. (2017)—Estonia	Cross-sectional	6552	University hospital	12 605	OPGs	Presence of periapical radiolucency (yes/no)	Teeth
Weiger et al. (1997)—Germany	Cross-sectional	323	Dental clinic	215	OPGs & Periapical	Radiolucency/widening of PDL ≥ 2× normal width	Teeth

Note: Diagnostic criteria for apical periodontitis varied across studies. Clinical setting refers to the environment in which the diagnostic imaging data were collected. The unit of analysis differed among studies (tooth- and/or patient-level). Morjaria et al. (2025) included two independent cohorts (2008–09 and 2018–19), which were analysed separately.
Abbreviations: AP, apical periodontitis; CBCT, cone-beam computed tomography; D-OPG, digital orthopantomography; OPG, orthopantomography; PAI, periapical index; RFT, root-filled teeth.

TABLE 2 | Extracted data and prevalence of periapical lesions in endodontically treated teeth included in the quantitative synthesis.

Author, year, country	Total patients	Total teeth	Total RFT	No. of RFT + AP	Percentage of RFT + AP	Patients with >1 RFT + AP (%)	Imaging
Ahmed et al. (2017)—Sudan	200	4976	80	26	32.5	25 (12.5)	OPGs & Periapical
Alawjali (2020)—Libya	305	7957	439	243	55.4	NR	D-OPGs
Alhomrany et al. (2025)—Saudi Arabia	420	6440	1051	451	42.9	NR	CBCT
Ali et al. (2022)—Iraq	385	9250	339	272	80.2	NR	CBCT
Al-Nazhan et al. (2017)—Saudi Arabia	926	25028	1541	617	40.0	NR	OPGs
Al-Omari et al. (2011)—Jordan	294	7390	424	305	71.9	NR	D-OPGs
Archana et al. (2015)—India	1340	30098	1234	462	37.4	NR	D-OPGs
Baban et al. (2026)—Iraq	251	6738	352	176	50.0	NR	CBCT
Berlinck et al. (2015)—Brazil	1126	25292	1754	293	16.7	NR	Periapical
Bołtacz-Rzepkowska and Pawlicka (2003)—Poland	236	355	282	69	24.5	NR	Periapical
Boucher et al. (2002)—France	208	4602	481	189	39.3	NR	Periapical
Connert et al. (2019)—Germany	353	9269	337	115	34.1	NR	OPGs & Periapical
Covello et al. (2010)—Italy	384	9423	1076	448	41.6	NR	OPGs
Da Silva Ramos Fernandes et al. (2013)—Brazil	300	5585	415	147	35.4	NR	CBCT
De Cleen et al. (1993)—Netherlands	184	4196	97	38	39.2	NR	OPGs
De Moor et al. (2000)—Belgium	206	4617	312	126	40.4	NR	OPGs
Di Filippo et al. (2014)—United Kingdom	136	3396	115	44	38.3	NR	OPGs
Dugas et al. (2003)—Canada	610	9269	383	174	45.4	NR	OPGs & Periapical
Eckerbom et al. (1987)—Sweden	200	4889	636	168	26.4	NR	Periapical
El Merini et al. (2017)—Morocco	508	12719	537	359	66.9	NR	OPGs & Periapical
Eriksen and Bjertness (1991)—Norway	119	2940	175	64	36.6	NR	OPGs & Periapical
Gencoglu et al. (2010)—Turkey	400	9460	890	658	73.9	NR	OPGs & Periapical

(Continues)

TABLE 2 | (Continued)

Author, year, country	Total patients	Total teeth	Total RFT	No. of RFT + AP	Percentage of RFT + AP	Patients with >1 RFT + AP (%)	Imaging
Georgopoulou et al. (2005)—Greece	320	7378	680	408	60.0	NR	Periapical
Gulsahi et al. (2008)—Turkey	1000	24 433	812	148	18.2	NR	D-OPGs
Gumru et al. (2011)—Turkey	1077	28 974	459	193	42.0	NR	OPGs
Jersa and Kundzina (2013)—Latvia	312	7065	1255	384	30.6	NR	OPGs
Jiménez-Pinzón et al. (2004)—Spain	180	4453	93	60	64.5	48 (26.7)	Periapical
Kabak and Abbott (2005)—Belarus	1423	31 212	6339	2867	45.2	NR	OPGs
Kamberi et al. (2011)—Kosovo	193	4131	95	44	46.3	NR	OPGs
Keratiotis et al. (2024)—Belgium	614	14 655	858	385	44.9	NR	OPGs
Kielbassa et al. (2017)—Austria	1000	22 586	2504	1066	42.6	NR	OPGs
Kirkevang et al. (2000)—Denmark	614	NR	773	404	52.3	NR	Periapical
Loftus et al. (2005)—Ireland	302	7424	152	38	25.0	NR	OPGs
López-López et al. (2012)—Spain	397	9390	604	144	23.8	60 (15.1)	OPGs
Lupi-Pegurier et al. (2002)—France	344	7561	1429	450	31.5	NR	OPGs
Marques et al. (1998)—Portugal	179	4446	69	15	21.7	NR	OPGs
Matijević et al. (2011)—Croatia	1462	38 440	3279	1772	54.0	NR	OPGs
Meirinhos et al. (2020)—Portugal	1160	20 836	2305	1280	55.5	NR	CBCT
Meirinhos et al. (2021)—Portugal	1249	22 899	2497	1348	54.0	NR	CBCT
Morjaria et al. (2025)—United Kingdom	490 Cohort 1 (2008–09)	11 172	611	179	29.3	NR	OPGs
Morjaria et al. (2025)—United Kingdom	490 Cohort 2 (2018–19)	11 451	476	133	27.9	NR	OPGs
Mukhaimer et al. (2012)—Palestine	258	6482	855	509	59.5	NR	OPGs
Ödesjo et al. (1990)—Sweden	743	17 430	1492	366	24.5	NR	Periapical
Oginni et al. (2015)—Nigeria	756	21 468	2625	1068	40.7	NR	Periapical
Özbaş et al. (2011)—Turkey	438	11 542	179	68	38.0	NR	Periapical

(Continues)

TABLE 2 | (Continued)

Author, year, country	Total patients	Total teeth	Total RFT	No. of RFT + AP	Percentage of RFT + AP	Patients with >1 RFT + AP (%)	Imaging
Peters et al. (2011)—Netherlands	178	4594	224	54	24.1	NR	OPGs
Rocha et al. (2012)—Portugal	222	5552	215	25	11.6	NR	Periapical
Saunders et al. (1997)—United Kingdom	340	8420	472	244	51.7	NR	Periapical
Sidaravicius et al. (1999)—Lithuania	147	3892	320	231	72.2	NR	OPGs & Periapical
Silnovic et al. (2023)—Sweden	196	491	491	167	34.0	NR	Periapical
Skudutyte-Rysstad and Eriksen (2006)—Norway	146	3971	61	26	42.6	NR	OPGs & Periapical
Sunay et al. (2007)—Turkey	375	8731	470	240	51.1	NR	OPGs
Timmerman et al. (2017)—Australia	695	16 936	284	118	41.5	91 (13.1)	OPGs
Tsuneishi et al. (2005)—Japan	672	16 232	3320	1329	40.0	NR	Periapical
Ureyen Kaya et al. (2013)—Turkey	1000	23 268	601	95	15.8	NR	D-OPGs
Van der Veken et al. (2017)—Belgium	631	11 117	1357	444	32.7	NR	CBCT
Vengerfeldt et al. (2017)—Estonia	6552	181 495	12 605	6540	51.9	2920 (44.6)	OPGs
Weiger et al. (1997)—Germany	323	7987	215	132	61.4	NR	OPGs & Periapical
Overall	35 569	832 003	64 026	28 418		NR	

Note: Morjaria et al. (2025) included two independent cohorts (2008–09 and 2018–19), which were analysed separately.
Abbreviations: AP, apical periodontitis; CBCT, cone-beam computed tomography; D-OPG, digital orthopantomography; NR, not reported in the original study; OPG, orthopantomography; PAI, periapical index; RFT, root-filled teeth; RFT + AP, RFT with apical periodontitis.

28 418 presented periapical lesions. The forest plot of the pooled prevalence of periapical lesions in RFT at the tooth level is presented in Figure 2. Using a DerSimonian–Laird random-effects model applied to logit-transformed proportions, the pooled prevalence of RFT with periapical lesions (tooth level) was 41.3% (95% CI: 38.2%–44.6%).

A substantial degree of between-study heterogeneity was observed ($I^2 = 98\%$, $p < 0.001$), indicating considerable variability in prevalence estimates across the included studies. Individual study estimates ranged widely, from as low as 11.6% (Rocha et al. 2012) to as high as 80.2% (Ali et al. 2022), reflecting differences in study populations, diagnostic criteria and imaging modalities.

Despite this variability, the majority of studies reported prevalence values clustered between 30% and 60%. Notably, studies employing cone-beam computed tomography (CBCT) tended to report higher prevalence estimates compared with those using conventional two-dimensional radiographic techniques, contributing to the observed dispersion of results. The wide confidence intervals observed in several studies, particularly those with smaller sample sizes, further contributed to the overall heterogeneity. Nevertheless, the pooled estimate indicates that approximately four out of ten RFT are associated with periapical lesions.

In addition to tooth-level estimates, a separate quantitative synthesis was conducted to assess the prevalence of periapical lesions in RFT at the patient-level. Five studies reporting patient-level data were included in the meta-analysis (Jiménez-Pinzón et al. 2004, López-López et al. 2012, Ahmed et al. 2017, Timmerman et al. 2017, Vengerfeldt et al. 2017). The pooled prevalence of patients presenting at least one RFT with periapical lesion was 20.5% (95% CI: 9.3%–39.4%), based on 8024 patients, of whom 3144 had at least one affected tooth (Figure 3).

Individual study estimates showed substantial variability, ranging from 12.5% (Ahmed et al. 2017) to 44.6% (Vengerfeldt et al. 2017). Most studies reported prevalence values below 30%, although one large study contributed a notably higher estimate.

A very high level of heterogeneity was observed among studies ($I^2 = 99\%$, $p < 0.001$; $\tau^2 = 1.086$), indicating considerable variability in patient-level prevalence estimates. This heterogeneity may be explained by differences in study populations, diagnostic criteria and imaging modalities, as well as variations in the definition of patient-level outcomes. These findings indicate that approximately one in five patients presents at least one RFT with periapical lesion, although the wide confidence interval and high heterogeneity suggest that this estimate should be interpreted with caution.

3.5 | Subgroup Analysis: Prevalence According to Imaging Modality

Subgroup analysis according to imaging modality revealed notable differences in the estimated prevalence of periapical lesions in RFT (Figure S1). Studies combining orthopantomography and periapical radiography (OPG + periapical) showed the highest pooled prevalence, estimated at 52.4% (95% CI: 40.6%–63.9%), although based on a limited number of studies and with wide confidence intervals.

CBCT studies also demonstrated high prevalence values, with a pooled estimate of 50.4% (95% CI: 41.5%–59.3%). In contrast, studies using conventional two-dimensional imaging techniques alone reported lower prevalence estimates. The pooled prevalence was 38.8% (95% CI: 35.2%–42.5%) for OPG and 36.0% (95% CI: 29.4%–43.1%) for periapical radiography. Digital panoramic radiography (D-OPG) showed a similar pooled prevalence of 37.6% (95% CI: 20.6%–58.3%), although with considerable imprecision due to wide confidence intervals.

Substantial heterogeneity was observed across all subgroups (I^2 ranging from 97% to 99%, $p < 0.001$), indicating marked variability in prevalence estimates within each imaging modality.

Overall, although some overlap in confidence intervals was observed, studies using CBCT and combined imaging approaches tended to report higher prevalence values compared with those based solely on two-dimensional radiographic techniques, supporting the greater sensitivity of three-dimensional imaging for detecting periapical lesions.

3.6 | Subgroup Analysis: Comparison Between 3D and 2D Imaging

When imaging modalities were grouped into three-dimensional (CBCT) and two-dimensional techniques (periapical and panoramic radiography), a clear difference in the estimated prevalence of RFT with periapical lesions was observed (Figure S2). Studies using three-dimensional imaging (CBCT) showed a higher pooled prevalence of 50.1% (95% CI: 40.3%–59.9%), whereas studies based on two-dimensional imaging techniques yielded a lower pooled estimate of 40.8% (95% CI: 36.9%–44.7%).

Although confidence intervals overlapped partially, the point estimates consistently indicated a higher detection rate when CBCT was used. The distribution of individual study estimates also showed a tendency toward higher prevalence values in the three-dimensional subgroup, whereas two-dimensional studies were more frequently clustered around lower values.

Substantial heterogeneity was observed in both subgroups ($I^2 = 99\%$, $p < 0.001$), indicating considerable variability across studies that was not fully explained by imaging dimensionality alone. These findings suggest that three-dimensional imaging techniques tend to detect a greater proportion of periapical lesions; however, this effect should be interpreted with caution, as it may be influenced by differences in diagnostic strategy and study design. Moreover, these results suggest that prevalence estimates derived from 2D imaging may underestimate the true burden of post-treatment apical periodontitis.

3.7 | Meta-Regression Analysis

Combined panoramic and periapical radiography was used as the reference category in the meta-regression model. Meta-regression

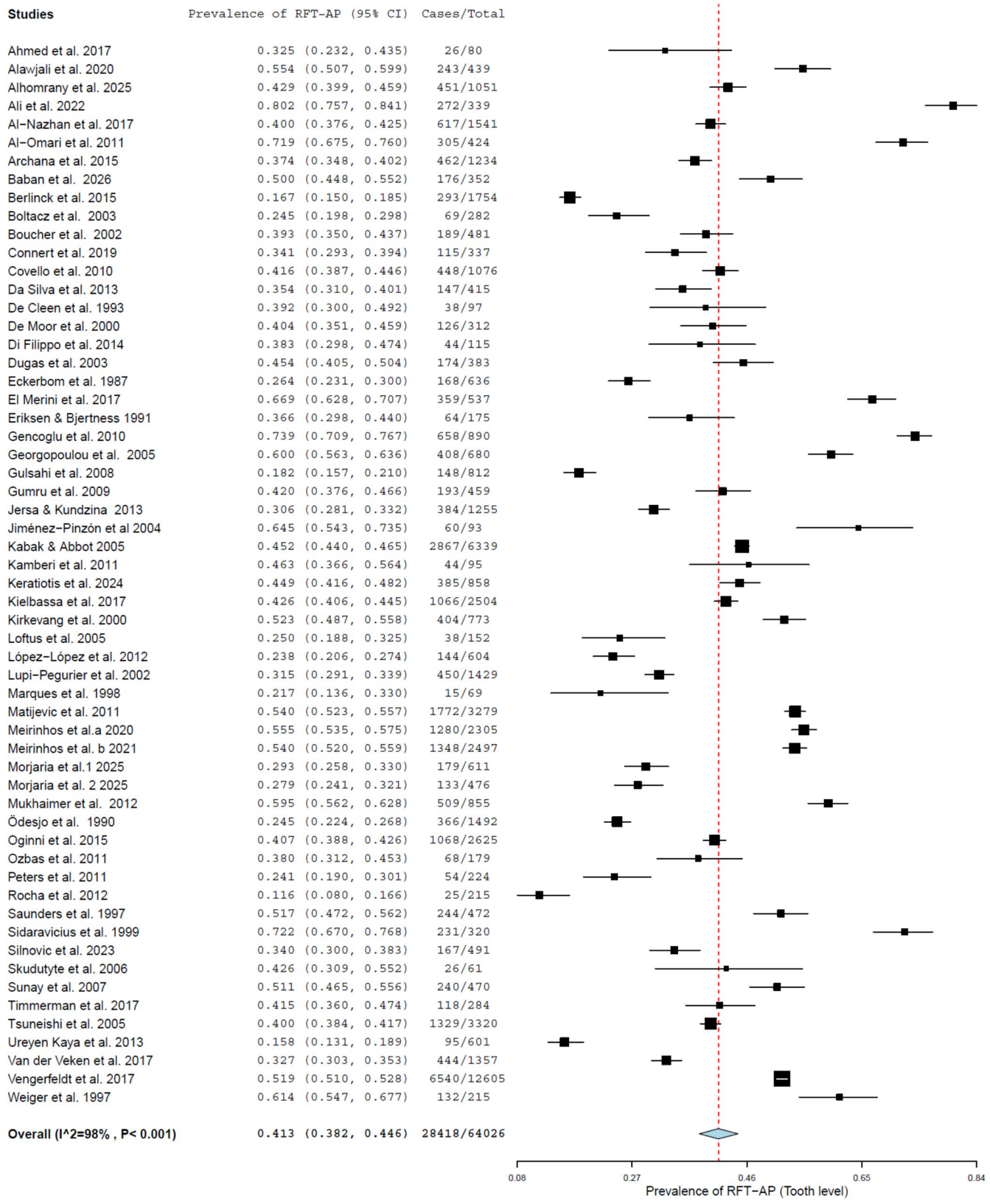


FIGURE 2 | Forest plot of the prevalence of periapical lesions in RFT showing individual study estimates and the pooled prevalence of periapical lesions in RFT at the tooth level. Prevalence estimates were logit-transformed prior to meta-analysis and pooled using a random-effects model (DerSimonian–Laird method). The pooled estimate is presented with 95% confidence intervals and back-transformed to the original proportion scale for interpretation. Squares represent individual study estimates (with size proportional to study weight), and horizontal lines indicate 95% confidence intervals. The red dashed line and the blue diamond represent the overall pooled prevalence. Substantial heterogeneity was observed among studies ($I^2 = 98\%$, $p < 0.001$).

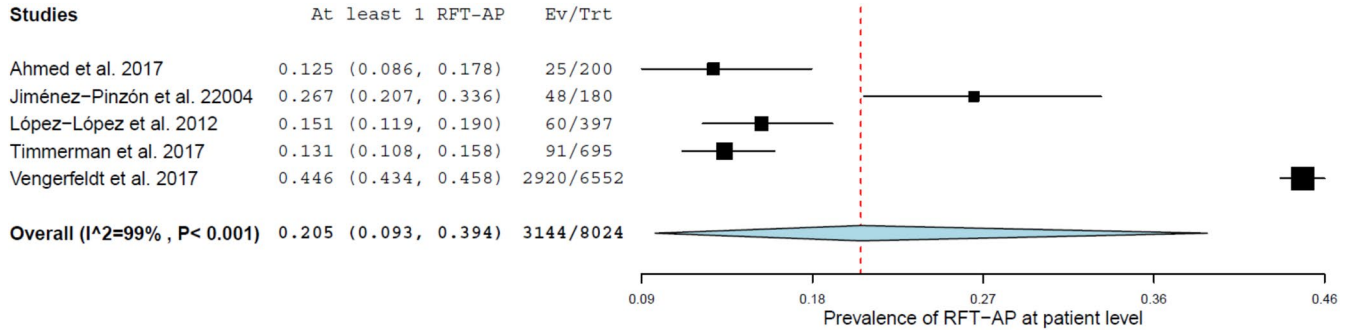


FIGURE 3 | Forest plot of the prevalence of RFT with apical periodontitis showing individual study estimates and the pooled prevalence of patients presenting at least one root-filled tooth with periapical lesion. Prevalence estimates were logit-transformed prior to meta-analysis and pooled using a random-effects model (DerSimonian–Laird method). Results are presented as back-transformed proportions with 95% confidence intervals. Squares represent individual study estimates (with size proportional to study weight), and horizontal lines indicate 95% confidence intervals. The red dashed line and the blue diamond represent the overall pooled prevalence. Substantial heterogeneity was observed among studies ($I^2 = 99\%$, $p < 0.001$).

analysis using imaging modality as a moderator showed a statistically significant overall effect (Omnibus $p = 0.045$), indicating that imaging modality contributed to between-study heterogeneity. Using combined orthopantomography and periapical radiography (OPG + periapical) as the reference category, no significant difference was observed for CBCT ($\beta = -0.080$, SE = 0.320, $p = 0.802$). However, studies using OPG alone ($\beta = -0.569$, SE = 0.252, $p = 0.024$) and periapical radiography alone ($\beta = -0.678$, SE = 0.273, $p = 0.013$) reported significantly lower prevalence estimates. Digital panoramic radiography (D-OPG) showed a non-significant trend toward lower prevalence ($\beta = -0.607$, SE = 0.354, $p = 0.087$).

When imaging modalities were grouped into two-dimensional and three-dimensional techniques, no statistically significant difference was observed ($\beta = 0.425$, SE = 0.270, $p = 0.115$; Omnibus $p = 0.115$).

3.8 | Sensitivity Analysis

A leave-one-out sensitivity analysis was conducted to evaluate the influence of individual studies on the overall pooled prevalence estimate (Figure S3). Sequential exclusion of each study did not result in any substantial change in the pooled prevalence, which remained highly stable across all iterations.

The pooled estimates ranged within a narrow interval around the overall prevalence of approximately 41%, with all recalculated values showing minimal deviation from the original estimate (41.3%, 95% CI: 38.2%–44.6%). No single study exerted a disproportionate influence on the overall results.

Furthermore, the confidence intervals remained largely consistent across iterations, indicating the robustness of the meta-analytic model. These findings suggest that the overall prevalence estimate is not driven by any individual study and that the results of the meta-analysis are stable and reliable.

A sensitivity analysis at the patient level did not show any substantial influence of individual studies on the pooled estimate; however, given the small number of included studies ($n = 5$), these results should be interpreted with caution.

3.9 | Publication Bias

A funnel plot based on logit-transformed prevalence estimates was constructed to assess potential small-study effects and publication bias (Figure S4). Visual inspection of the plot suggested a degree of asymmetry, with a wider dispersion of studies on the left side of the funnel, indicating a potential underrepresentation of studies reporting higher prevalence estimates.

This observation was supported by Egger's regression test, which indicated statistically significant funnel plot asymmetry (intercept: −3.56, 95% CI: −7.02 to −0.11; $t = -2.023$; $p = 0.048$). These findings suggest the presence of potential publication bias or small-study effects.

Nevertheless, the interpretation of these results should be approached with caution, as the substantial between-study heterogeneity observed in the meta-analysis may also contribute to funnel plot asymmetry.

3.10 | Risk of Bias Assessment

The methodological quality of the included studies is summarized in Table S5. Overall, the majority of studies were judged to have a moderate risk of bias ($n = 49$), while a smaller number were classified as low risk of bias ($n = 8$). No studies were considered to have a high overall risk of bias.

Across studies, the main sources of potential bias were related to the sample selection domain, which is a common limitation in prevalence studies (Hoy et al. 2012; Modesti et al. 2016). Most studies were based on convenience samples derived from dental school clinics, hospital settings or radiographic databases, which may limit the representativeness of the target population. Consequently, sample representativeness and sampling methods were frequently rated as high or unclear risk of bias. In addition, sample size justification and non-response bias were rarely reported, leading to predominantly unclear risk assessments for these items.

In contrast, the measurement and data collection domain showed consistently low risk of bias across most studies. The definition

of radiolucent periapical lesion, the radiographic sign of chronic apical periodontitis, was generally clear and based on established radiographic criteria, such as the Periapical Index (PAI) or predefined thresholds of periapical radiolucency. Similarly, the imaging methods used (periapical radiography, OPG or CBCT) were considered valid and appropriate for outcome assessment. Most studies applied consistent diagnostic criteria across participants and statistical analyses were generally adequate, including the reporting of prevalence estimates and measures of uncertainty.

Studies classified as low risk of bias were typically those based on large or population-based samples and/or standardised radiographic databases with clearly defined diagnostic protocols and appropriate statistical reporting.

Although limitations in sample representativeness were common, the consistency in outcome definition, imaging methodology and statistical analysis supports the internal validity of the included studies. However, the risk of bias across the included studies was considered moderate, as most studies presented limitations in sample representativeness despite generally robust measurement and analytical methods.

3.11 | GRADE Assessment of Certainty of Evidence

The overall certainty of the evidence for the pooled prevalence of periapical lesions in RFT was rated as low at the tooth level and very low at the patient level, according to the GRADE approach (Figure 4). As all included studies had a cross-sectional design, the certainty of evidence was initially considered low. No upgrading factors were identified.

The certainty of evidence was further downgraded by one level due to risk of bias, as the majority of included studies were assessed as having a moderate risk of bias ($n = 49$), primarily related to limitations in sample representativeness and sampling methods.

A further downgrade was applied for inconsistency, as substantial heterogeneity was observed across studies ($I^2 = 98\%$ at the tooth level and $I^2 = 99\%$ at the patient level), with wide variability in prevalence estimates that could not be fully explained by subgroup analyses.

The evidence was also downgraded for indirectness, since many studies were based on selected clinical populations (e.g., dental school or hospital patients) rather than representative population-based samples, which may limit the generalizability of the findings.

Additionally, publication bias could not be ruled out, as suggested by the asymmetry observed in the funnel plot and supported by Egger's test ($p = 0.048$), leading to further downgrading.

Imprecision was not considered serious for the tooth-level analysis due to the large sample size and relatively narrow confidence intervals; however, it was considered serious at the patient

Certainty assessment							Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations		
Root-filled teeth with apical periodontitis (tooth level)								
57	observational studies	serious [a]	very serious [b]	serious [c]	not serious [d]	Suspected publication bias. Funnel plot asymmetry and Egger's test (p = 0.048)	●●○○ Low	IMPORTANT
Root-filled teeth with apical periodontitis (patient level)								
5	observational studies	serious [a]	very serious [b]	serious [c]	serious [d]	Publication bias not assessed (n=5)	●○○○ Very low	IMPORTANT

Explanations:

a. Majority of studies at moderate risk (n = 49), mainly due to non-representative samples.
b. Very high heterogeneity (I^2 = 98% - 99%) with wide variability in estimates.
c. Predominance of clinical/dental school populations and limited representativeness of populations.
d. Large sample size and relatively narrow confidence interval (CI) (teeth) / Wide CI (patient).

High certainty: The authors have a lot of confidence that the true effect is similar to the estimated effect
Moderate certainty: The authors believe that the true effect is probably close to the estimated effect
Low certainty: The true effect might be markedly different from the estimated effect
Very low certainty: The true effect is probably markedly different from the estimated effect

FIGURE 4 | Certainty of the evidence for the prevalence of periapical lesions in endodontically treated teeth assessed using the GRADE framework considering risk of bias, inconsistency, indirectness, imprecision and publication bias. Each domain was judged independently, leading to an overall rating of low for the tooth level and very low certainty for the patient-level prevalence of RFT with periapical lesions.

level due to the limited number of studies and wide confidence intervals.

Overall, these considerations resulted in a low certainty of evidence for tooth-level estimates and very low certainty for patient-level estimates, indicating that the true prevalence may be substantially different from the pooled values.

4 | Discussion

4.1 | Principal Findings

The present systematic review and meta-analysis aimed to estimate the prevalence of periapical lesions in root-filled teeth (RFT) and to evaluate the influence of imaging modality on these estimates. Based on 57 studies included in the quantitative synthesis, the pooled prevalence of periapical lesions was 41.3% at the tooth level and 20.5% at the patient level, indicating that a substantial proportion of both RFT and individuals exhibit radiographic signs of periapical pathology. The pooled prevalence observed in the present study is consistent with previous epidemiological and meta-analytic reports (Jiménez-Pinzón et al. 2004; López-López et al. 2012; Van der Veken et al. 2017; Tibúrcio-Machado et al. 2021).

Notably, subgroup analyses showed higher detection rates in studies using three-dimensional imaging (CBCT) compared with most conventional two-dimensional radiographic techniques. However, meta-regression analysis indicated that this difference was influenced by the diagnostic approach, as combined panoramic and periapical radiography yielded prevalence estimates comparable to CBCT, whereas studies using single two-dimensional modalities reported significantly lower values. These findings highlight the important role of diagnostic strategy, in addition to imaging modality, in shaping epidemiological estimates of apical periodontitis. They also underscore both the high burden of post-treatment apical pathology and the clinical relevance of accurate radiographic diagnosis (Fransson and Dawson 2023), as well as the need to carefully consider imaging methodology when interpreting prevalence data (Nair 2006; Di Filippo et al. 2014).

4.2 | Comparison With Previous Literature

The pooled prevalence observed in this review is consistent with previous epidemiological studies and meta-analyses reporting a high frequency of periapical lesions in RFT (Segura-Egea et al. 2004). For instance, Tibúrcio-Machado et al. (2021) estimated a prevalence of approximately 39% in RFT, which is closely aligned with the tooth-level estimate of 41.3% reported in the present study. Similarly, numerous cross-sectional studies conducted in diverse populations have consistently shown that between one-third and one-half of root-filled teeth exhibit radiographic signs of periapical pathology (Kirkevang et al. 2000; Touré et al. 2008). These findings reinforce the notion that, despite advances in endodontic techniques and materials, complete periapical healing is not achieved in a substantial proportion of treated teeth. Moreover, the variability in prevalence across studies has been previously attributed to differences in treatment quality, follow-up time and methodological factors (Ng et al. 2008), which is in agreement with the high heterogeneity observed in the present meta-analysis.

Beyond differences in study populations and treatment-related factors, the substantial heterogeneity observed across studies also reflects important methodological differences in the radiographic definition of periapical lesions. While many investigations used standardized criteria such as the Periapical Index (PAI) or CBCT-PAI, others identified lesions based on the presence of a periapical radiolucency or widening of the periodontal ligament space. Although these approaches evaluate the same radiographic manifestation of chronic apical periodontitis, they differ in diagnostic thresholds and sensitivity, particularly when comparing two-dimensional and three-dimensional imaging. Consequently, part of the observed variability is likely attributable to differences in outcome definition rather than true epidemiological differences. For this reason, the pooled estimates should be interpreted as summary epidemiological measures across heterogeneous populations and diagnostic approaches rather than as precise universal prevalence values. The use of a random-effects model, together with subgroup analyses, meta-regression, prediction intervals and the downgrading of certainty in the GRADE assessment, was intended to support this cautious interpretation of the findings.

In addition, the present findings suggest that differences in diagnostic approach, particularly imaging modality and the combination of radiographic techniques, may further contribute to this variability.

4.3 | Heterogeneity and Methodological Considerations

A substantial degree of heterogeneity was observed across studies, both at the tooth level ($I^2 = 98\%$) and at the patient level ($I^2 = 99\%$), indicating considerable variability in prevalence estimates (Higgins and Thompson 2002). The observed heterogeneity is likely multifactorial and cannot be fully explained by differences in imaging modality alone. An important contributor to this variability is the methodological diversity identified during study selection, as reflected by the studies excluded from the quantitative synthesis. These studies revealed key inconsistencies in the literature, including differences in the unit of analysis (root-level versus tooth-level data), the use of non-standardized or non-comparable diagnostic criteria for apical periodontitis, and insufficient data reporting that precluded extraction of prevalence estimates. In addition, several CBCT-based studies were conducted in referral or specialist populations, introducing a substantial risk of selection bias and likely inflating prevalence estimates compared with population-based samples. Although the exclusion of these studies was necessary to ensure methodological consistency in the meta-analysis, it does not eliminate the broader issue of heterogeneity within the field and may have resulted in more conservative pooled estimates.

An additional consideration is that several excluded CBCT studies were based on referral populations undergoing advanced

imaging because of suspected endodontic pathology. Although their exclusion improved methodological comparability with the remaining studies, it may also have reduced the representation of more complex clinical cases. Consequently, the pooled CBCT prevalence estimates reported in the present review may be more conservative than those that would have been obtained if referral-based populations had been included. This highlights the importance of considering study setting and patient selection when interpreting prevalence estimates derived from different imaging modalities.

The meta-regression analysis demonstrated that imaging modality significantly influenced the reported prevalence of periapical lesions. Interestingly, studies combining panoramic and periapical radiography yielded prevalence estimates comparable to those obtained with CBCT, whereas studies using either modality alone reported significantly lower values. These findings suggest that the increased detection of periapical lesions may not depend exclusively on three-dimensional imaging, but also on the combined use of complementary two-dimensional techniques. When imaging modalities were grouped into two-dimensional and three-dimensional techniques, no statistically significant difference was observed, likely reflecting the heterogeneity within the two-dimensional category. This highlights the importance of diagnostic strategy, rather than imaging modality alone, as a determinant of epidemiological estimates.

Beyond these factors, heterogeneity also reflects variability in study populations, clinical settings and methodological approaches. Differences in diagnostic thresholds—particularly in the application of the Periapical Index (PAI) and CBCT-based criteria—likely contributed significantly to the dispersion of results (Orstavik et al. 1986; Estrela, Bueno, Azevedo, et al. 2008). Moreover, variation in study settings, including dental school clinics, hospital-based populations and community samples, may influence the underlying prevalence of disease. Although subgroup analyses according to imaging modality partially accounted for this variability, substantial heterogeneity persisted within each subgroup, suggesting that additional factors—such as treatment quality, operator experience and population characteristics—may also play an important role. Therefore, the pooled estimates should be interpreted with caution (Barendregt et al. 2013), as they represent an average across highly diverse study conditions.

An additional source of heterogeneity relates to the variability in the diagnostic thresholds used to define apical periodontitis. Although many studies employed the Periapical Index (PAI) or CBCT-based adaptations, the threshold used to classify a lesion as apical periodontitis was not uniform. Some investigations considered PAI scores ≥ 3, whereas others used less restrictive radiographic definitions based on the presence of any periapical radiolucency or widening of the periodontal ligament space. Such differences may influence prevalence estimates by altering the balance between sensitivity and specificity. More stringent criteria may reduce false-positive findings but underestimate disease prevalence, whereas broader definitions may increase lesion detection at the expense of potentially including lesions of uncertain clinical significance. Greater standardization of diagnostic criteria would improve comparability across studies and enhance the reliability of future prevalence estimates.

Although the high levels of heterogeneity may raise concerns regarding the appropriateness of pooling prevalence estimates, meta-analysis remains a useful approach for summarizing the available evidence when substantial clinical and methodological diversity is expected. In the present review, all included studies addressed a common research question and evaluated the prevalence of periapical lesions in root-filled teeth using predefined radiographic criteria. Therefore, the pooled estimates should be interpreted as average prevalence values across diverse populations and study settings rather than as universally applicable measures. Future studies would benefit from greater standardization of diagnostic criteria, imaging protocols and reporting practices to improve comparability and reduce between-study variability.

4.4 | Influence of Imaging Modality

A key finding of this study is the significant influence of imaging modality on the estimated prevalence of periapical lesions. Studies using three-dimensional imaging (CBCT) generally reported higher prevalence values compared with most conventional two-dimensional radiographic techniques, with pooled estimates of approximately 50% and 41%, respectively. These findings are in agreement with previous studies demonstrating the higher sensitivity of CBCT for detecting periapical lesions (Estrela, Bueno, Leles, et al. 2008; Patel et al. 2009) his difference likely reflects the greater diagnostic sensitivity of CBCT, which enables the detection of smaller lesions and avoids the anatomical superimposition inherent to periapical and panoramic radiography. Previous studies have shown that CBCT is more sensitive in identifying periapical radiolucencies, particularly in early or limited lesions that may not be visible on two-dimensional images (Estrela, Bueno, Azevedo, et al. 2008).

However, the present meta-regression analysis indicated that this effect is influenced by the diagnostic approach. In particular, studies combining panoramic and periapical radiography (Dugas et al. 2003; Ahmed et al. 2017; Connert et al. 2019) yielded prevalence estimates comparable to those obtained with CBCT, whereas studies using either modality alone reported significantly lower values. Moreover, when imaging modalities were grouped into two-dimensional and three-dimensional techniques, no statistically significant difference was observed, suggesting that the apparent advantage of CBCT may be attenuated when more comprehensive two-dimensional diagnostic strategies are applied.

An interesting finding of the present meta-regression was that studies combining panoramic and periapical radiography yielded prevalence estimates comparable to those obtained with CBCT. This subgroup included nine studies, most of which employed similar radiographic definitions of apical periodontitis based on the presence of periapical radiolucency and/or widening of the periodontal ligament space, although some variability in diagnostic criteria remained. A possible explanation is that the two imaging modalities provide complementary diagnostic information. Panoramic radiographs allow assessment of the entire dentition and jaws, whereas periapical radiographs offer greater detail and spatial resolution in specific regions. Consequently, the combined use

of both techniques may reduce some of the diagnostic limitations associated with either modality used in isolation. Nevertheless, this finding should be interpreted cautiously because it was based on a limited number of studies and may be influenced by differences in study populations, diagnostic criteria and imaging protocols. However, this finding should not be interpreted as evidence of diagnostic equivalence between combined two-dimensional imaging and CBCT at the individual patient level, as the present analysis was based on study-level prevalence estimates.

Therefore, the lower prevalence values reported in studies using conventional radiography may reflect, at least in part, an underestimation of the true burden of periapical pathology, particularly when single-modality imaging is used. These findings are consistent with previous evidence indicating that two-dimensional imaging may underestimate the prevalence of periapical lesions (Orstavik et al. 1986; Estrela, Bueno, Leles, et al. 2008). Overall, these results highlight the importance of interpreting epidemiological data in light of both imaging modality and diagnostic strategy, and suggest that comparisons across studies should be made with caution when different radiographic approaches are employed.

An additional consideration when interpreting differences between imaging modalities is radiation exposure. Although CBCT generally provides greater diagnostic sensitivity for the detection of periapical lesions, its use should be justified according to radiation protection principles and current clinical guidelines. The potential diagnostic benefits of CBCT must therefore be balanced against its higher radiation dose compared with conventional two-dimensional imaging, particularly in epidemiological and screening contexts.

Furthermore, CBCT should not be regarded as a uniform imaging modality. Acquisition parameters such as voxel size and field of view (FOV) may influence lesion detectability and diagnostic performance. Smaller voxel sizes and limited FOV protocols have been associated with improved visualization of periapical lesions, whereas larger voxel sizes and broader FOVs may reduce diagnostic sensitivity. Because these parameters were inconsistently reported across the included studies, their potential contribution to between-study heterogeneity could not be formally assessed and should be considered in future research.

4.5 | Limitations of the Study

This study has several limitations that should be considered when interpreting the findings. First, a substantial degree of heterogeneity was observed across the included studies, which may be explained by differences in study populations, imaging modalities, diagnostic criteria and units of analysis. In particular, the variability in diagnostic thresholds for defining periapical lesions, as well as the use of different radiographic techniques, may have contributed significantly to the dispersion of prevalence estimates. Such extreme heterogeneity limits the interpretability of pooled estimates and suggests that summary prevalence values should be considered as indicative rather than definitive.

Second, most included studies were based on clinical or convenience samples derived from dental schools, hospital settings or radiographic databases, which may limit the representativeness of the target population and introduce selection bias. In addition, information regarding sample size justification and non-response bias was frequently lacking, further limiting the external validity of the findings.

Third, although most studies used established radiographic criteria, the lack of standardisation in diagnostic definitions and imaging protocols may have affected the comparability of results. Furthermore, the presence of potential publication bias, as suggested by funnel plot asymmetry and Egger's test, indicates that studies reporting lower or higher prevalence estimates may be underrepresented. In addition, only a limited number of studies provided patient-level data, which may have contributed to the wide confidence intervals observed in this analysis. Patient-level estimates should be interpreted with caution due to the limited number of included studies and the resulting imprecision.

Another important limitation is that most included studies had a cross-sectional design and assessed periapical status at a single point in time. Consequently, radiographic periapical lesions identified in root-filled teeth may represent either persistent apical periodontitis or lesions undergoing healing after treatment. Since radiographic healing may take several years to become complete, prevalence studies cannot distinguish between active disease and lesions in the process of resolution. Therefore, the prevalence estimates reported in this review should not be interpreted as direct measures of endodontic failure.

Finally, the overall certainty of the evidence was low to very low according to the GRADE approach, indicating limited confidence in the pooled prevalence estimates. This suggests that the true burden of periapical lesions in root-filled teeth may differ from the estimated values. The downgrading of evidence was primarily driven by substantial heterogeneity, methodological limitations related to sample representativeness and variability in imaging modalities and diagnostic criteria. In addition, indications of publication bias contributed to further uncertainty. Therefore, these findings should be interpreted with caution. Further well-designed, population-based studies using standardized diagnostic criteria are warranted to improve the reliability of prevalence estimates.

4.6 | Strengths of the Study

Despite these limitations, the present study has several important strengths. To the best of our knowledge, this is the first systematic review and meta-analysis specifically designed to evaluate the influence of imaging modality on the prevalence of periapical lesions in endodontically treated teeth. The inclusion of a large number of studies and a substantial overall sample size enhances the robustness and generalizability of the findings. In addition, the use of appropriate statistical methods for prevalence meta-analysis, including logit transformation, random-effects modelling, subgroup analyses and sensitivity analyses, strengthens the reliability of the results. Finally, the application of an adapted risk of bias tool and the GRADE approach

provides a transparent and comprehensive assessment of the methodological quality and certainty of the evidence.

4.7 | Clinical Implications and Future Research

The findings of this study have important clinical and research implications (Segura-Egea et al. 2015). From a clinical perspective, the high prevalence of periapical lesions in endodontically treated teeth highlights the need to improve the quality of root canal treatment and long-term follow-up, as a substantial proportion of treated teeth may harbour persistent periapical pathology despite the absence of symptoms (Fransson and Dawson 2023). The observed differences between imaging modalities also suggest that conventional two-dimensional radiography may underestimate the true prevalence of periapical lesions, which should be considered when making diagnostic and treatment decisions. Although CBCT provides greater diagnostic accuracy, its use should be justified based on clinical indications and radiation exposure considerations (Patel et al. 2014). From a research perspective, there is a clear need for greater standardization in the definition and assessment of periapical lesions, particularly with regard to diagnostic thresholds and imaging criteria, to enhance comparability across studies (Barendregt et al. 2013). Future epidemiological studies should prioritize population-based sampling strategies, standardized imaging protocols and transparent reporting of methodological details, including examiner calibration and statistical uncertainty. Additionally, further research is needed to better understand the relationship between radiographic findings, treatment quality and clinical outcomes, as well as to evaluate the impact of emerging imaging technologies on the detection and management of periapical pathology.

5 | Conclusions

Periapical lesions remain highly prevalent in endodontically treated teeth, affecting approximately four out of ten teeth and one in five patients. The findings of this study demonstrate that imaging modality significantly influences prevalence estimates, with three-dimensional imaging (CBCT) consistently reporting higher detection rates than conventional radiographic techniques. These results suggest that the true burden of post-treatment apical pathology may be substantially underestimated when assessed using two-dimensional imaging alone.

Given the overall low certainty of the evidence, these findings should be interpreted with caution. Future well-designed, population-based studies using standardized diagnostic criteria and consistent imaging protocols are needed to provide more accurate, reliable and generalizable estimates.

Author Contributions

Juan J. Segura-Egea: conceptualization, methodology, formal analysis, supervision, writing – original draft, writing – review and editing. Carlos Segura-Raya: investigation, visualization, writing – original draft, writing – review and editing. Jenifer Martín-González: conceptualization, investigation, formal analysis, writing – original draft, writing – review and editing. Alberto Cabrera-Fernández: data curation, investigation, writing – original draft, writing – review and editing. Victoria Areal-Quecuty: investigation, writing – original draft, writing – review and editing. Daniel Cabanillas-Balsera: conceptualization, methodology, investigation, formal analysis, writing – original draft, writing – review and editing.

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Ethics Statement

Registration: This systematic review was registered in PROSPERO (CRD420261320661).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** PRISMA 2020 Checklist. Checklist detailing the reporting items addressed in this systematic review and meta-analysis. **Figure S1:** Subgroup analysis according to imaging modality. **Figure S2:** Subgroup analysis comparing two-dimensional and three-dimensional imaging techniques. **Figure S3:** Sensitivity analysis. **Figure S4:** Assessment of publication bias. **Table S1:** Complete search strategies for all databases included in the systematic review. **Table S2:** Risk of bias assessment tool adapted for radiographic prevalence studies. **Table S3:** Characteristics of all the included studies in the qualitative analysis. **Table S4:** Studies excluded from the quantitative synthesis, grouped according to the reason for exclusion. **Table S5:** Risk of bias assessment of the included studies using an adapted tool for radiographic prevalence studies.