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REVIEW ARTICLE

Prevalence of root canal treatment worldwide: A systematic review and meta-analysis

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Abstract

Background: The prevalence of root filled teeth (RFT) worldwide will inform about the amount of clinical activity of dentists dedicated to treat endodontic disease.

Objectives: To carry out a systematic review with meta-analysis answering the following question: What is the prevalence of RFT around the world? The percentage of people with at least one RFT was also investigated.

Methods: A systematic review including population-based studies using the following databases: PubMed, EMBASE and Scielo. Studies related to prevalence of RFT were included. The outcome of interest of the study was the prevalence of RFT. The meta-analyses were calculated with the Open Meta Analyst software to determine the global prevalence of RFT. Subgroups analyses were performed comparing geographical distribution, radiographic method and year of the study (classified in 20th or 21th century). The prevalence of people with at least one RFT was also analysed.

Results: Seventy-four population-based studies fulfilled the inclusion criteria. Twenty-eight, forty-four and two studies reported high, moderate and low risk of bias, respectively. No obvious publication bias was observed. Prevalence of RFT was estimated with 1 201 255 teeth and 32 162 patients. The calculated worldwide prevalence of RFT was 8.2% (95% CI = 7.3%–9.1%; $p < .001$). The global prevalence of people with at least one RFT was 55.7% (95% CI = 49.6%–61.8%; $p < .001$). In 20th century, the prevalence of RFT was 10.2% (95% CI = 7.9%–12.5%; $p < .001$), whereas in the 21st century the overall calculated prevalence of RFT was 7.5% (95% CI = 6.5%–8.6%; $p < .001$). Brazilian people (12%) and the European population (9.3%) showed the highest prevalence of RFT. In Europe, 59.6% (95% CI = 52.4%–66.8%) of people has at least one RFT.

Conclusions: This review showed that root canal treatment is a very common therapy throughout the world. More than half of the studied population have at least one RFT. A limitation of the present study is that most of the studies did not consider random sampling for population selection.

Registration: PROSPERO Systematic review registration number: (CRD42022329053).

KEYWORDS
epidemiology, population-based study, prevalence, root canal treatment, root filled teeth, survey

INTRODUCTION

Irreversible pulpitis and pulp necrosis, without treatment, progress to apical periodontitis (AP), an inflammation of the periapical periodontium, accompanied or not by clinical symptoms, and commonly showing periapical bone resorption (American Association of Endodontists, 2020). Numerous epidemiological studies have investigated the prevalence of apical periodontitis in the general population (Segura-Egea et al., 2004; Tibúrcio-Machado et al., 2021). The systematic review carried out by Tibúrcio-Machado et al. (2021), including studies carried out all over the world, showed a very high global prevalence (52%), with values ranging from less than 30% (Eriksen, 1995; Gulsahi et al., 2008; Skudutyte-Rysstad & Eriksen, 2006), to values greater than 80% (Al-Omari et al., 2011; Marotta et al., 2012).

Root canal treatment (RCT) is the indicated endodontic therapy in cases of irreversible pulpitis and/or apical periodontitis (American Association of Endodontists, 2020). Studies carried out recently suggest that the clinical diagnosis of irreversible pulpitis should not always imply root canal treatment (Wolters et al., 2017), as cure of pulpitis has been achieved with less invasive treatments, such as pulp capping and pulpotomy (Asgary et al., 2014, 2018; Careddu & Duncan, 2021). Nevertheless, to date, no study has investigated how these new diagnostic paradigms are affecting endodontic practice.

Root canal treatment continues to be the treatment with which the majority of AP cases are treated and with which it is possible to keep the affected mature tooth functional in the patient's mouth (Trowbridge, 1990).

Considering the high prevalence of AP globally (Tibúrcio-Machado et al., 2021), the prevalence of RCT can be also expected to be very high. Some studies have investigated the frequency of RCT in different countries (Jiménez-Pinzón et al., 2004, Kamberi et al., 2011, López-López et al., 2012), finding a very wide range of percentages of RFT, from 0.7% (Hussein et al., 2016) to 87% (Marotta et al., 2012), as well as people with at least one RFT, from 19.9% (Timmerman et al., 2017) up to 97.3% (Allard & Palmqvist, 1986).

In short, the data on the prevalence of RFT differs from one study to another, reflecting the differences in the needs and availability of RCT in different countries and populations (Caires et al., 2018; Connert et al., 2019), as well as the different impact of the new diagnostic and therapeutic trends in the management of deep carious lesions and pulpitis (Crespo-Gallardo et al., 2019; Edwards et al., 2021; Wolters et al., 2017). Knowing the prevalence of RFT in the worldwide will allow dentists and policy makers to evaluate the impact that RCT has on the world population.

Taking into account that RCT is the most frequent treatment carried out by endodontists, determining the worldwide prevalence of RFT will also inform about the fraction of clinical activity of dentists dedicated to treat endodontic diseases, which will allow the frequency of RCT to be compared with that of other medical or dental therapies. Finally, the prevalence of RFT worldwide will also tell us how often dentists around the world continue to carry out RCT.

Since no systematic review has been conducted to investigate the prevalence of RFT worldwide, the aim of this study was to conduct a systematic review and meta-analysis analysing the prevalence of RFT in the adult worldwide population.

MATERIAL AND METHODS

This systematic review is reported using the PRISMA guidelines (Page et al., 2021). The review was registered in the PROSPERO database: (CRD42022329053). This study was conducted following the methodological guidance for systematic reviews of observational epidemiological studies reporting prevalence and cumulative incidence data (Munn et al., 2015).

Search strategy

A literature search was undertaken with no limits on time or language until the 6th of February 2022 in PubMed-MEDLINE (1949 – present), EMBASE (1949 – present) and Scielo. Most cited descriptors in the previous publication on this theme were used in the electronic search strategy, using combining Medical Subject Heading (MeSH) terms and text word (tw). The search strategies are presented in Table S1. A complementary screening on the references of the selected studies was performed to find any additional study that did not appear in the primary database search. Grey literature was searched (https://opengrey.eu/; https://scholar.google.com/; https://www.greynet.org/) but did not provide useful data.

Eligibility criteria

The review question was formulated following the CoCoPop mnemonic (Munn et al., 2015), as follows:

Condition (Co): What is the prevalence of RFT.
Population (Pop): In the adult population.
Context (Co): Around the world.

The main outcome was the percentage of RFT. Nevertheless, a secondary outcome, the percentage of people with at least one RFT was also considered.

All studies reporting the prevalence of RFT in a healthy adult population by radiographic examination (panoramic, periapical radiographs or cone beam computed tomography) were included.

The following exclusion criteria were applied:

(i) Studies that did not report information about the prevalence of RFT.
(ii) Studies that did not provide full mouth information (excluded third molars).
(iii) Studies whose entire sample were RFT.
(iv) Studies including patients with mixed dentition.
(v) Studies that did not contrast their findings with radiographic examination.
(vi) Reviews, letters, posters, conference abstracts or case series and dissertations/thesis with data available in a journal article.

Selection of the studies

Three authors (M.L-L., D.C-B. and J.J.S-E.) selected the studies individually by screening the titles and abstracts. When the title and abstract did not allow judging the study, the full text was accessed. A second stage consisted of reading the full texts and judging the potential studies to be included based on the eligibility criteria. Disagreements on study inclusion were solved by consensus between the three authors. Duplicated studies in the databases search were considered only once.

Data collection/extraction process

The three authors collected the information of the studies that matched the inclusion criteria individually. A fourth author (J.M-G.) solved disagreements. All the information related to publication were extracted:

(i) Article's identification: Authors, country and year of publication.
(ii) Participants: Gender, range and/or mean age of the sample and sample size.
(iii) Methods: Method of image acquisition.
(iv) Results: Number of people with at least one RFT, number of teeth, number of root filled teeth and distribution of RFT in the sample.

Quality assessment

The quality of evidence of the included studies was analysed according to the guidelines provided by the Centre for Evidence-Based Medicine at Oxford: http://www.cebm.net/index.aspx?o=5653 (Howick et al., 2011).

Each study was evaluated for inner methodological risk of bias independently by three authors (M.L-L, D.C-B and J.M-G). In case of disagreement, the authors discussed until they reached an agreement.

The methodology used for quality assessment and risk of bias of the individuals studies was based on the Newcastle-Ottawa Scale adapted for cross-sectional studies proposed by (Herzog et al., 2013), with the modifications of Tibúrcio-Machado et al. (2021). This scale was adapted to the outcome of interest, classifying the items into two domains: sample selection and outcome. They were given a point (*) depending on the aspect required were present or missing.

Sample selection (maximum of six points)

Representativeness of the sample

The representativeness of the sample was evaluated depending on the aim of the primary study. To study the prevalence from a certain country, the size and characteristics of the sample should be accordingly to the population and selected randomly. It should use the total target population or use random or non-random (such as systematic sampling) strategies.

(i) Truly representative of the average in the target population (all subjects or random sampling) ➔ three points.
(ii) Somewhat representative of the average in the target population (non-random sampling) ➔ two points.
(iii) Selected group of users ➔ one point.
(iv) No description of the sampling strategy ➔ no points.

Sample size

(i) Justified and satisfactory size (study provided sample size calculation) ➔ one point. If the sample size calculation was not available, but the entire population was recruited (and the loss rate was ≤20%), and it was also considered as justified and satisfactory.
(ii) Not justified size.

Non-respondents

(i) Comparability between respondents and non-respondents characteristics is established, and the response rate is satisfactory (>80%) ➔ two points.

(ii) The response rate is unsatisfactory, or the comparability between respondents and non-respondents is unsatisfactory ➔ one point.
(iii) No description of the response rate or the characteristics of the responders ➔ no points.

Outcome (maximum of six points)

Assessment of the outcome

(i) Training and calibration for the methodology of assessing root filled teeth, with inter- and intra-agreement values provided ➔ two points.
(ii) Training and calibration for the methodology of assessing root filled teeth, with inter- or intra-agreement values not provided ➔ one point.
(iii) Training and calibration not mentioned ➔ no points.

Inclusion of third molar in total sample of teeth

(i) Third molar included ➔ one point. If the study did not mention that third molar was excluded, it got one point in this domain.
(ii) Third molar not included ➔ no points.

Inclusion of edentulous in total sample of patients

(i) Edentulous not included ➔ two points.
(ii) Edentulous included ➔ one point.
(iii) Study did not mention if edentulous were included or not ➔ no points.

Number of observers

(i) Radiographs were studied by two or more examiners ➔ one point.
(ii) Only one examiner studied the radiographs ➔ no points.

Studies could score a maximum of 12 points; they were defined as high risk of bias if they scored 0–4 points, moderate risk of bias if they scored 5–8 points and low risk of bias if they scored 9–12 points.

Only dentate patients were taking into account for statistical analysis in studies that included edentulous patients in the sample. Those studies that did not specified if they had or not edentulous patients in the total sample were also included, but it was considered a risk of bias.

Outcome of interest

The main outcome variable was the prevalence of RFT in the population sample study. The prevalence of RFT was first calculated, taking the teeth as the unit of analysis, as the total number of RFT in the sample divided by the total number of teeth in the sample and expressed as a percentage. As a secondary outcome variable, the prevalence of people with at least one RFT was calculated.

Meta-analysis

To determine the global prevalence of RFT, a meta-analysis was performed with the OpenMeta Analyst version 10.10 software (Wallace et al., 2012), using the binary random effects model. Additionally, other meta-analyses were performed using subgroups based on the continent in which the study was carried out, the year of publication and the radiographic method for diagnosis.

To estimate the variance and heterogeneity amongst trials, the Higgings I^2 test was employed, considering a slight heterogeneity if it is between 25 and 50%, moderate between 50% and 75%, and high if >75% (Higgins & Thompson, 2002).

RESULTS

Selection of the studies

The flow diagram of literature search strategy and selected studies for this review is shown in Figure 1, according to PRISMA 2020 instructions. Initial search of different databases resulted in 1821 published studies. Duplicated studies ($n = 322$) were excluded. Then, of the 1499 eligible papers, after analysing the titles and abstracts, 1394 that did not investigate RFT were excluded, selecting 105 for reading the full text. After comprehensive reading, 29 studies were excluded for the reasons specified in Table S2, and 76 studies were selected for the systematic review and meta-analysis.

Characteristics of the included studies

The main characteristics of the 76 included studies are summarized in Table 1. All the included studies showed the prevalence of RFT in a sample of patients in different populations and countries around the world (Table 2). Thirty-five of them also provided data on the percentage of people with at least one RFT.

Outcomes of the primary meta-analysis and publication bias

To conduct the meta-analysis, only the last year of follow-up in longitudinal studies were included. The

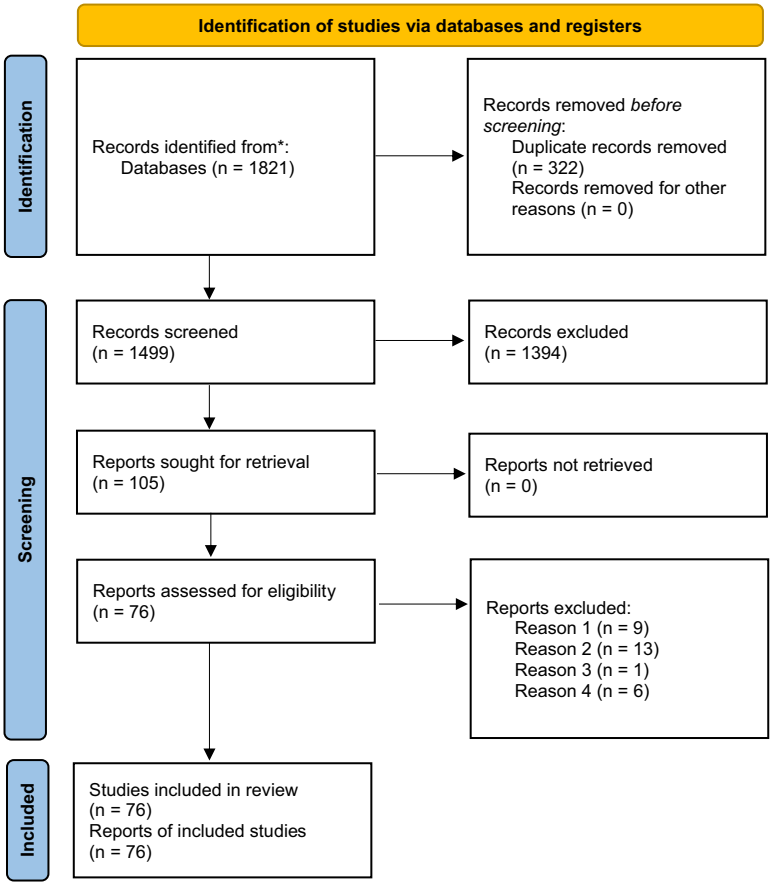

FIGURE 1 Flow diagram of the search strategy of the systematic review and meta-analysis following the preferred reporting items for systematic reviews and Meta-analyses (PRISMA) guidelines 2020 (Page et al., 2021).

76 studies included added 32 162 people, who had 1 201 255 teeth, of which 92 999 were RFT. Figure 2 shows the forest plot of the primary meta-analysis. The overall calculated prevalence of RFT was 8.2% (95% CI = 7.3%–9.1%). Heterogeneity value was I^2 = 99.8% ($p < .001$).

Subgroup analysis: Prevalence of people with at least one RFT

A subgroup analysis was made including 35 studied that provided information about patients with at least one RFT (Figure 3). This meta-analysis included 31 715 people, of which, 18 577 had at least one RFT (55.7%; 95% CI = 49.6%–61.8%). The heterogeneity was I^2 = 99.3% ($p < .001$).

Subgroup analysis: Geographical distribution

The geographical distribution of the prevalence of RFT was analysed by grouping the studies according to the continent in which they had been carried out. The results are shown on the world map in Figure 4. By countries, Brazilian people showed the highest prevalence of RFT (12.0%; 95% CI = 5.2%–18.9%), five Brazilian studies being the only data available on the South American continent. For the rest of continents, the European population showed the highest prevalence of RFT, 9.3% (95% CI = 8.2%–10.4%), having 59.6% (95% CI = 52.4%–66.8%) of people at least one RFT. On the contrary, the North American population showed the lowest prevalence of RFT, 4.1% (95% CI = 3.0%–5.2%), and 48.5% (95% CI = 31.7%–65.2%) had at least one RFT.

Subgroup analysis: Year of publication

To analyse the possible variation in the prevalence of RFT over time, separate meta-analyses were performed for studies conducted in the 20th century and those conducted in the 21st century, including 19 articles from the 20th century and 54 articles from the 21th century (Figure 5). In the 20th century, the prevalence of RFT was 10.2% (95% CI = 7.9%–12.5%), whereas in the 21st century the overall calculated prevalence of RFT was 7.6% (95% CI = 6.5%–8.6%). Heterogeneity values were I^2 = 99.7% ($p < .001$) for 20th century studies, and I^2 = 99.8% ($p < .001$) for the studies carried out in the 21st century.

TABLE 1 Summary of descriptive characteristics of included studies classified geographically

Authors	Year	Country	Study design	Number of teeth (N)	Sample size	Gender (%)	Age	Image method	Type of evidence
Africa									
Touré et al.	2008	Senegal	Cross-sectional	6234	208	MS (55) FS (45)	>18 years	Periapical	3
Oginni et al.	2015	Nigeria	Cross-sectional	21 468	756	MS 414 FS 342	>20 years	Periapical	3
Ahmed et al.	2017	Sudan	Cross-sectional	4976	200	FS 153 MS 47	34 ± 12.9 years mean	Panoramic and periapical	3
America									
Buckley et al.	1995	USA	Cross-sectional	5272	208	MS (47.3) FS (52.7) ME 135 FE156	44.5 years mean	Bitewing and periapical	3
Dugas et al.	2003	Canada	Cross-sectional	16 148	610	FS 328 (53.8) MS 282 (46.2)	25–40 years	Panoramic and periapical	3
Terças et al.	2006	Brazil	Cross-sectional	5008	200	FS 112 MS 88		Periapical	3
Chen et al.	2007	USA	Cross-sectional	3533	206	FS (58) MS (42.2)	55–97 years 67 years mean	Panoramic	3
Hollanda et al.	2008	Brazil	Cross-sectional	29 467	1401		48 years	Panoramic	3
Zhong et al.	2008	USA	Cross-sectional	27 296	853	Only men	25–85 years	Periapical	3
Paes da Silva Ramos et al.	2013	Brazil	Cross-sectional	5585	214	FS 124 MS 90		CBCT scan	3
Hebling et al.	2014	Brazil	Cross-sectional	942	98	FS 57 MS 41	>60 years	Periapical	3
Berlinck et al.	2015	Brazil	Cross-sectional	25 292	1126	FS 738 MS 388	37.1 ± 16.4 years mean	Periapical	3
Jalali et al.	2017	USA	Cross-sectional	3395	131	FS 112 MS 19	56.14 years	Panoramic or periapical	3
Asia									
Tsuneishi et al.	2005	Japan	Cross-sectional	16 232	672	MS 244 FS 428	20–89 years	Periapical	3
Sunay et al.	2007	Turkey	Cross-sectional	8731	375	MS 147 (39.2) FS 228 (60.8)	16–82 years	Panoramic	3

TABLE 1 (Continued)

Authors	Year	Country	Study design	Number of teeth (N)	Sample size	Gender (%)	Age	Image method	Type of evidence
Gulsahi et al.	2008	Turkey	Cross-sectional	24433	1000	MS (39.3) FS (60.7) 555 (3.75) female teeth with endo 257 (2.67) male teeth with endo	16–80 years 41.4 ± 15.8 years mean	Panoramic	3
Asgary et al.	2010	Iran	Cross-sectional	28463	1064	MS 445 (41.8) FS 619 (58.2)	>18 years	Panoramic	3
Gencoglu et al.	2010	Turkey	Cross-sectional	9460	400	MS 138 (34.5) FS 262 (65.5)	>20 years 38.7 ± 13.8 years mean	Panoramic and periapical	3
Al-Omari et al.	2011	Jordan	Cross-sectional	7390	294	FS 136 (46.3) MS 158 (53.7)	16–59 years	Panoramic	3
Gumru et al.	2011	Turkey	Cross-sectional	28974	1077	FS 663 MS 414	19 years	Panoramic	3
Ozbas et al.	2011	Turkey	Cross-sectional	11542	438	FS 234 MS 204	10–79 years	Periapical	3
Mukhaimer et al.	2012	Palestine	Cross-sectional	6482	258	FS 142 MS 116	39 years 17–62 years	Panoramic	3
Kalender et al.	2013	Turkey	Cross-sectional	24730	1006	MS 423 FS 583	18–50 years	Panoramic	3
Ureyen Kaya et al.	2013	Turkey	Cross-sectional	23268	1000		>18 years	Panoramic	3
Archana et al.	2015	India	Cross-sectional	30098	1340			Panoramic	3
Alrahabi et al.	2016	Saudi Arabia	Cross-sectional	15686	630	FS 314 MS 316		Panoramic	3
Hussein et al.	2016	Malaysia	Cross-sectional	6409	233	FS 147 (63.1) MS 86 (36.9)	26 years	Panoramic	3
Europe									
Allard et al.	1986	Sweden	Cross-sectional	2567	188		>65 years	Periapical series	3
Petersson et al.	1986	Sweden	Cross-sectional	4985	861		20–60 years	Bitewing and periapical	3
Bergström et al.	1987	Sweden	Cross-sectional	6593	250		21–60 years	Periapical series	3
Eckerbom et al.	1988	Sweden	Longitudinal	4889	200	MS 93 FS 107	>20 years	Bitewing and periapical	3
Eriksen et al.	1988	Sweden	Cross-sectional	3917	141		35 years	Panoramic and periapical	3

(Continues)

TABLE 1 (Continued)

Authors	Year	Country	Study design	Number of teeth (N)	Sample size	Gender (%)	Age	Image method	Type of evidence
Petersson et al.	1989	Sweden	Cross-sectional	11 497	567		>20 years	Periapical series	2
Odesjo et al.	1990	Sweden	Cross-sectional	17 430	733	MS 392 FS 351	>20 years	Periapical series	2
Eriksen et al.	1991	Norway	Cross-sectional	2940	119		50 years	Panoramic	3
Imfeld et al.	1991	Switzerland	Cross-sectional	2004	143	MS 69 (47.7) FS 74 (52.3)	66 years	Panoramic and periapical	3
De Cleen et al.	1993	Netherlands	Cross-sectional	4196	184	FS 90 (48.9) MS 94 (51.1)	>20 years	Panoramic	3
Ainamo et al.	1994	Finland	Cross-sectional	2355	169	MS 54 FS 115	76–86 years	Panoramic and periapical	3
Eriksen et al.	1995	Norway	Longitudinal	3282	118		35 years	Panoramic	3
Soikonen et al.	1995	Finland	Cross-sectional	2355	169	MS 54 FS 115		Panoramic and periapical	3
Weiger et al.	1997	Germany	Cross-sectional	7987	323	FS (54) MS (46)	35.2 years	Panoramic and periapical	3
Marques et al.	1998	Portugal	Cross-sectional	4446	179		30–39 years	Panoramic and bitewings	3
Sidaravicius et al.	1999	Lithuania	Cross-sectional	3892	147			Panoramic	2
De Moor et al.	2000	Belgium	Cross-sectional	4617	206			Panoramic	3
Narhi et al.	2000	Finland	Cross-sectional	1016	77	FS 51 MS 26		Panoramic	3
Kirkevang et al.	2001	Denmark	Cross-sectional	15 984	614	FS 303 (49.3) MS 311 (50.7)	20–60 years	Bitewing and periapical	2
Boucher et al.	2002	France	Cross-sectional	5373	208	FS (62)	45.9 ± 12.9 years	Periapical	3
Lupi-Pegurier et al.	2002	France	Cross-sectional	7561	344	MS 164 FS 180	>20 years	Panoramic	3
Jimenez-Pinzon et al.	2004	Spain	Cross-sectional	4453	180	MS 66 FS 114		Periapical	3
Georgopoulou et al.	2005	Greece	Cross-sectional	7664	320	FS (65.3) MS (34.7)	16–77 years	Periapical	3
Kabak et al.	2005	Belarus	Cross-sectional	31 212	1423		>15 years	Panoramic	3

TABLE 1 (Continued)

Authors	Year	Country	Study design	Number of teeth (N)	Sample size	Gender (%)	Age	Image method	Type of evidence
Loftus et al.	2005	Ireland	Cross-sectional	7424	302	MS 127 FS 175 M.RFT 57 F.RFT 95	16–98 years	Panoramic	3
Kirkevang et al.	2006	Denmark	Longitudinal	12 329	473	FS 239 MS 234	>18 years	Bitewing and periapical	3
Skudutyte-Rysstad et al.	2006	Norway	Cross-sectional	3971	146		35 years mean	Panoramic	3
Frisk et al.	2008	Sweden	Longitudinal	12 433	491	MS 242 FS 249	10–80 years	Panoramic and periapical	3
Segura-Egea et al.	2008	Spain	Cross-sectional	4453	180	MS 66 (36.7) FS 114 (63.3)	>18 years	Periapical	3
Covello et al.	2010	Italy	Cross-sectional	9423	384	MS (44.3) FS (55.7)	18–60 years 43 years mean	Panoramic	3
Kamberi et al.	2011	Kosovo	Cross-sectional	4131	193	ME (3) FE (1.8)	34.5 ± 11.2 years	Panoramic	3
Matijevic et al.	2011	Croatia	Cross-sectional	38 440	1462		>15 years	Panoramic	3
Peters et al.	2011	Netherlands	Cross-sectional	4594	178	MS 84 FS 94	Female 35.4 ± 13.2 Male 40.2 ± 12.6	Panoramic	3
Huumonen et al.	2012	Finland	Cross-sectional	120 250	5244	MS 48%	30–95 years	Panoramic	3
López-López et al.	2012	Spain	Cross-sectional	9390	397	FS 203 MS 194	52 years	Panoramic	3
Rocha et al.	2012	Portugal	Cross-sectional	5552	222	FS 119 (53.76) MS 103 (46.24)	>18 years 41.26 ± 15.86 years mean	Panoramic	3
Jersa et al.	2013	Latvia	Cross-sectional	7065	312		35–44 years	Panoramic	3
Di Filippo et al.	2014	UK	Cross-sectional	3396	136	FS 73 MS 63		Panoramic	3
Dutta et al.	2014	Scotland	Cross-sectional	3595	245	FS 117 MS 128	>18 years	CBCT scan	3
Lemagner et al.	2015	France	Cross-sectional	2368	100	FS 53 MS 47	47.1 years	CBCT scan	3

(Continues)

TABLE 1 (Continued)

Authors	Year	Country	Study design	Number of teeth (N)	Sample size	Gender (%)	Age	Image method	Type of evidence
Huumonen et al.	2017	Finland	Cross-sectional	120 635	5335	MS (47)	50.2 years	Panoramic	2
Kielbassa et al.	2017	Austria	Cross-sectional	22 586	1000	FS 570 MS430		Panoramic	3
Van der Veken et al.	2017	Belgium	Cross-sectional	11 117	631	MS 267 FS 364	45.6 years	CBCT scan	3
Vengerfeldt et al.	2017	Estonia	Cross-sectional	181 495	6552	FS 3989 (60.9) MS 2563 (39.1)	3–93 years	Panoramic	3
Bürklein et al.	2019	Germany	Cross-sectional	8244	500	FS 297 (59.4) MS 203 (40.6)	50.21 years	CBCT scan	2
Meirinhos et al.	2020	Portugal	Cross-sectional	20 836	1160	FS 663 MS 497	48.4 years	CBCT scan	3
Oceania									
Punch	1997	Australia	Cross-sectional	5216	204			Panoramic	3
Da Silva et al.	2009	Australia	Cross-sectional	5647	243			Panoramic	3
Timmerman et al.	2017	Australia	Cross-sectional	16 936	695	FS (58.3)	10–88 years 41 years mean	Panoramic	3

Abbreviations: FS, prevalence in female subject; MS, prevalence in male subject; RFT, root filled teeth.

TABLE 2 Prevalence of root filled teeth (RFT) and percentage of people with at least one RFT in the 74 included studies

Authors	Year	Country	Prevalence of RFT (%; 95% CI)	Percentage of people with at least one RFT (95% CI)
Africa				
Touré et al.	2008	Senegal	2.6 (2.2–3.0)	Not provided
Oginni et al.	2015	Nigeria	12.2 (11.8–12.7)	61.2 (57.8–64.7)
Ahmed et al.	2017	Sudan	1.6 (1.3–2.0)	21.0 (15.4–26.6)
America				
Buckley et al.	1995	USA	5.5 (4.9–6.1)	Not provided
Dugas et al.	2003	Canada	2.5 (2.3–2.8)	62.8 (59.0–66.6)
Terças et al.	2006	Brazil	11.0 (10.2–11.9)	Not provided
Chen et al.	2007	USA	4.8 (4.1–5.5)	38.8 (32.2–45.5)
Hollanda et al.	2008	Brazil	21.4 (21.0–21.9)	Not provided
Zhong et al.	2008	USA	2.2 (2.1–2.4)	33.8 (30.6–36.9)
Paes da Silva Ramos et al.	2013	Brazil	7.4 (6.7–8.1)	Not provided
Hebling et al.	2014	Brazil	13.4 (11.2–15.5)	49.0 (39.1–58.9)
Berlinck et al.	2015	Brazil	6.9 (6.6–7.2)	Not provided
Jalali et al.	2017	USA	5.7 (4.9–6.4)	58.8 (50.3–67.2)
Asia				
Tsuneishi et al.	2005	Japan	20.5 (19.8–21.1)	86.5 (83.9–89.0)
Sunay et al.	2007	Turkey	5.1 (4.7–5.6)	46.9 (41.9–52.0)
Gulsahi et al.	2008	Turkey	3.3 (3.1–3.5)	Not provided
Asgary et al.	2010	Iran	3.6 (3.3–3.8)	41.4 (38.5–44.4)
Gencoglu et al.	2010	Turkey	9.4 (8.8–10.0)	Not provided
Al-Omari et al.	2011	Jordan	5.7 (5.2–6.3)	Not provided
Gumru et al.	2011	Turkey	1.6 (1.4–1.7)	61.2
Ozbas et al.	2011	Turkey	1.6 (1.3–1.8)	Not provided
Mukhaimer et al.	2012	Palestine	13.2 (12.4–14.0)	Not provided
Kalender et al.	2013	Turkey	8.9 (8.5–9.3)	64.0
Ureyen Kaya et al.	2013	Turkey	2.6 (2.4–2.8)	Not provided
Archana et al.	2015	India	4.1 (3.9–4.3)	Not provided
Alrahabi et al.	2016	Saudi Arabia	6.4 (6.0–6.7)	52.8
Hussein et al.	2016	Malaysia	0.7 (0.5–0.9)	Not provided
Europe				
Allard et al.	1986	Sweden	17.6 (16.1–19.1)	97.3
Petersson et al.	1986	Sweden	13.0 (12.1–14.0)	Not provided
Bergström et al.	1987	Sweden	6.5 (5.9–7.1)	Not provided
Eckerbom et al.	1988	Sweden	13.0 (12.1–14.0)	Not provided
Eriksen et al.	1988	Sweden	3.4 (2.8–4.0)	53.2
Petersson et al.	1989	Sweden	22.2 (21.4–22.9)	93.0
Odesjo et al.	1990	Sweden	8.6 (8.1–9.0)	Not provided
Eriksen et al.	1991	Norway	6.0 (5.1–6.8)	56.0
Imfeld et al.	1991	Switzerland	20.3 (18.5–22.0)	77.6
De Cleen et al.	1993	Netherlands	2.3 (1.9–2.8)	Not provided
Ainamo et al.	1994	Finland	21.0 (19.4–22.7)	76.0
Eriksen et al.	1995	Norway	1.3 (0.9–1.7)	24.0

(Continues)

TABLE 2 (Continued)

Authors	Year	Country	Prevalence of RFT (%; 95% CI)	Percentage of people with at least one RFT (95% CI)
Soikonen et al.	1995	Finland	21.5 (19.9–23.2)	Not provided
Weiger et al.	1997	Germany	2.7 (2.3–3.0)	Not provided
Marques et al.	1998	Portugal	1.6 (1.2–1.9)	22.0
Sidaravicius et al.	1999	Lithuania	8.2 (7.4–9.1)	64.6
De Moor et al.	2000	Belgium	6.8 (6.0–7.5)	Not provided
Narhi et al.	2000	Finland	21.1(18.6–23.6)	Not provided
Kirkevang et al.	2001	Denmark	4.8 (4.5–5.2)	52.0
Boucher et al.	2002	France	19.1 (18.0–20.1)	Not provided
Lupi-Pegurier et al.	2002	France	18.9 (18.0–19.8)	Not provided
Jimenez-Pinzon et al.	2004	Spain	2.1 (1.7–2.5)	Not provided
Georgopoulou et al.	2005	Greece	8.9 (8.2–9.5)	65.6
Kabak et al.	2005	Belarus	20.3 (19.9–20.8)	Not provided
Loftus et al.	2005	Ireland	2.0 (1.7–2.4)	31.8
Kirkevang et al.	2006	Denmark	5.7 (5.2–6.1)	58.8
Skudutyte-Rysstad et al.	2006	Norway	1.5 (1.2–1.9)	23.0
Frisk et al.	2008	Sweden	5.5 (5.1–5.9)	Not provided
Segura-Egea et al.	2008	Spain	2.1 (1.7–2.5)	41.0
Covello et al.	2010	Italy	11.4 (10.8–12.1)	Not provided
Kamberi et al.	2011	Kosovo	2.3 (1.8–2.8)	Not provided
Matijevic et al.	2011	Croatia	8.5 (8.3–8.8)	75.9
Peters et al.	2011	Netherlands	4.9 (4.3–5.5)	Not provided
Huumonen et al.	2012	Finland	7.3 (7.2–7.5)	61.3
López-López et al.	2012	Spain	6.4 (5.9–6.9)	Not provided
Rocha et al.	2012	Portugal	3.9 (3.4–4.4)	Not provided
Jersa et al.	2013	Latvia	17.8 (16.9–18.7)	87.0
Di Filippo et al.	2014	UK	3.4 (2.8–4.0)	Not provided
Dutta et al.	2014	Scotland	4.8 (4.1–5.5)	Not provided
Lemagner et al.	2015	France	18.2 (16.6–19.8)	Not provided
Huumonen et al.	2017	Finland	6.6 (6.5–6.8)	58.0
Kielbassa et al.	2017	Austria	11.1 (10.7–11.5)	Not provided
Van der Veken et al.	2017	Belgium	12.2 (11.6–12.8)	70.2
Vengerfeldt et al.	2017	Estonia	6.9 (6.8–7.1)	58.2
Bürklein et al.	2019	Germany	8.2 (7.6–8.8)	Not provided
Meirinhos et al.	2020	Portugal	11.1 (10.6–11.5)	Not provided
Oceania				
Punch	1997	Australia	2.4 (2.0–2.8)	Not provided
Da Silva et al.	2009	Australia	8.8 (8.1–9.5)	Not provided
Timmerman et al.	2017	Australia	1.7 (1.5–1.9)	19.9

Note: The studies have been ordered by continents and countries.

Subgroup analysis: Type of radiographic diagnosis

Another analysis of subgroup was made comparing the prevalence of RFT depending on the radiographic method of diagnosis. Studies were grouped according to the radiographic method used: periapical radiograph ($n = 21$), cone beam computed tomography (CBCT) ($n = 6$) and panoramic radiograph ($n = 38$). Studies that used more than one radiographic method for diagnosis were excluded.

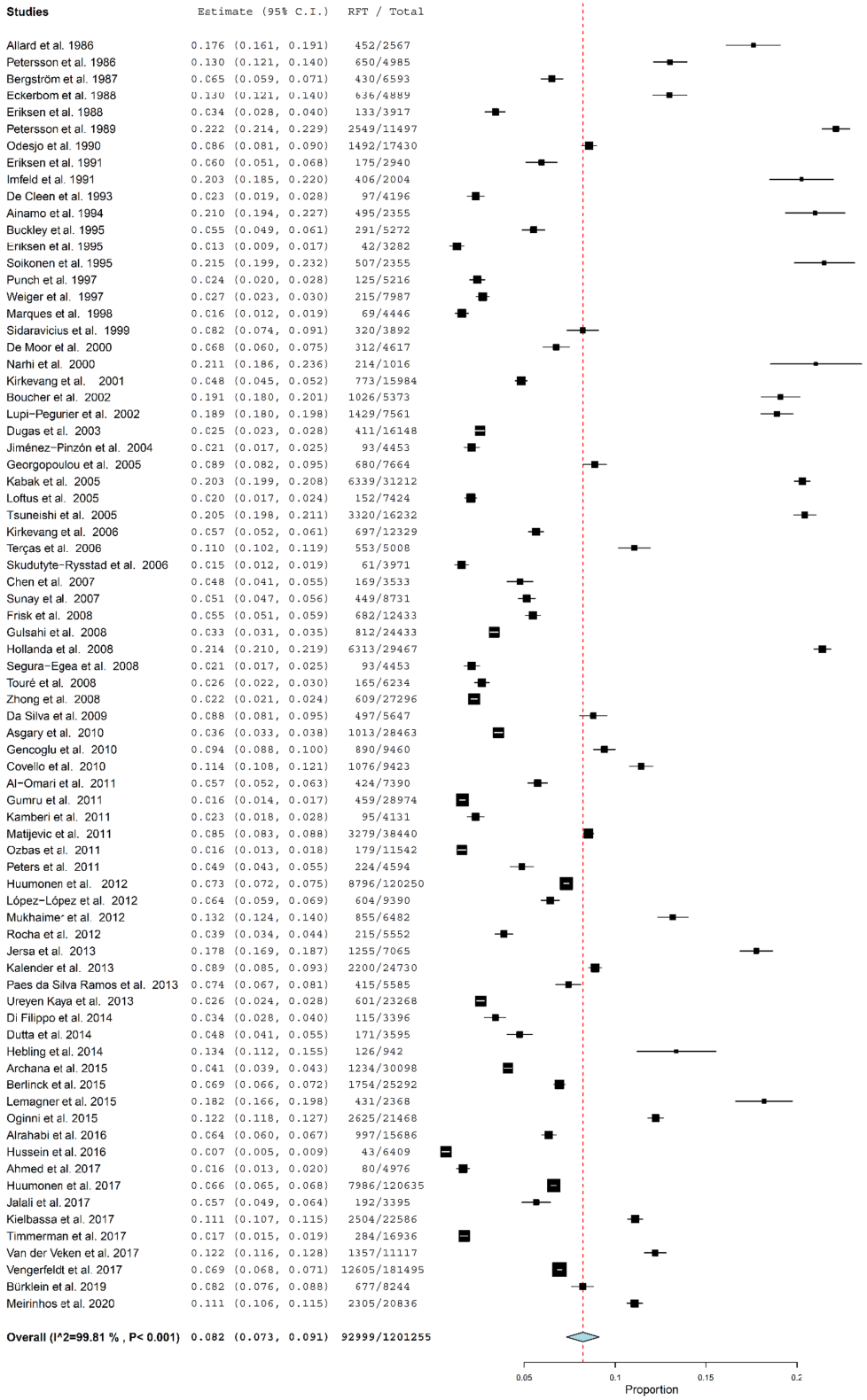

FIGURE 2 Forest plot of the prevalence of root filled teeth (RFT) in all the included studies.

The forest plot of these subgroups of studies is shown in Figure 6.

The prevalence of RFT in the studies that used periapical radiographs was 9.5% (95% CI = 7.4%–11.6%). The heterogeneity was $I^2 = 99.8\%$ ($p < .001$). The calculated prevalence of RFT for the studies that used panoramic radiographs was 7.2% (95% CI = 6.0%–8.5%), being the heterogeneity value $I^2 = 99.9\%$ ($p < .001$). Only six of the included studies used CBCT for radiographic diagnosis (Bürklein et al., 2020; da Paes Silva Ramos Fernandes et al., 2013; Dutta et al., 2014;

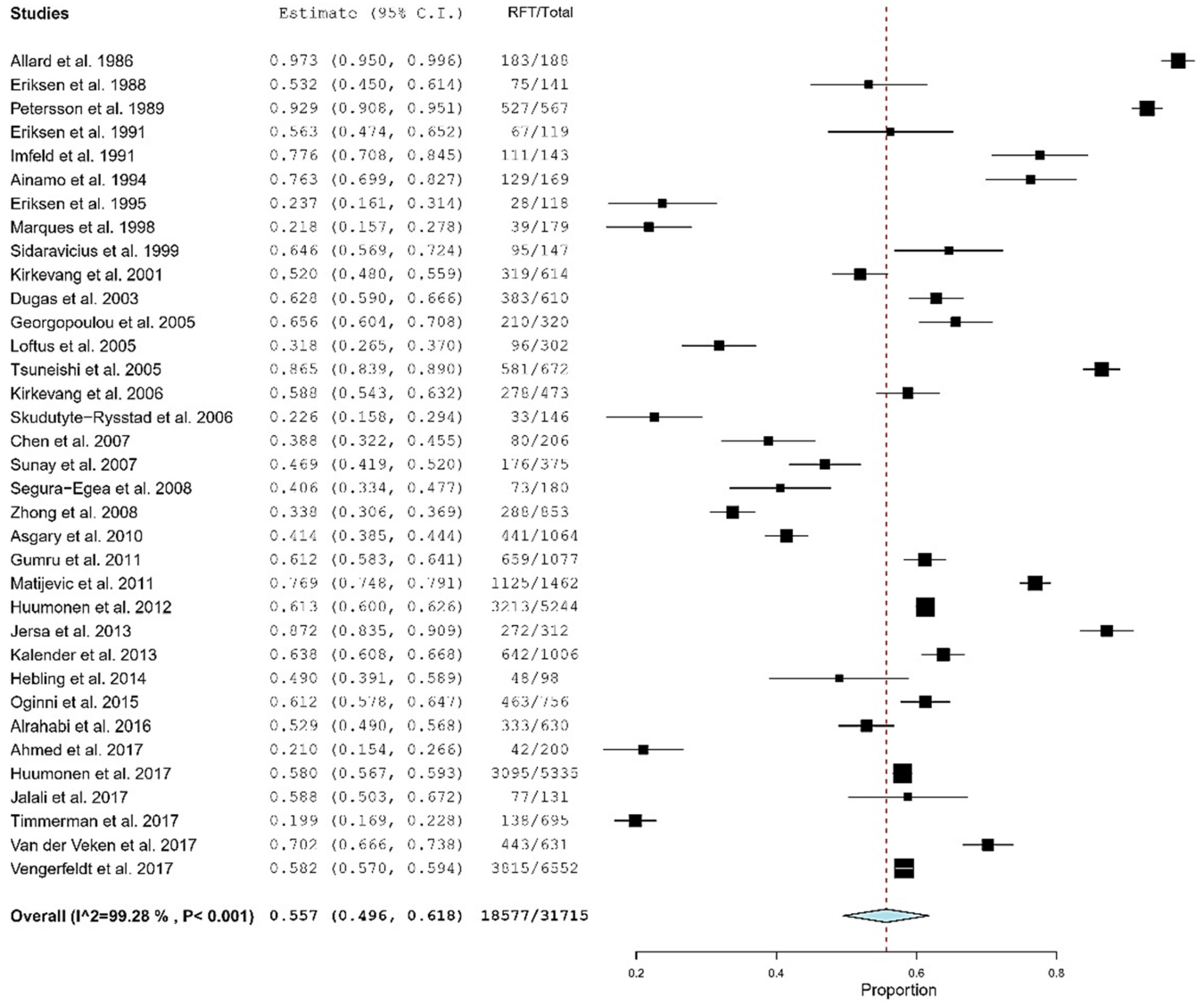

FIGURE 3 Forest plot of the studies that have calculated the percentage of people with at least one root filled teeth (RFT) in the total sample.

Lemagner et al., 2015; Meirinhos et al., 2020; Van der Veken et al., 2017). The prevalence of RFT calculated for CBCT studies was 10.3% (95% CI = 7.7%–12.8%), being the heterogeneity 99.0% ($p < .001$).

Quality assessment

Study quality was assessed to determine the risk of bias. For each study, data are showed in Table S3. Twenty-nine studies were classified as high risk of bias (Ainamo et al., 1994; Allard & Palmqvist, 1986; Bergström et al., 1987; Berlinck et al., 2015; Boucher et al., 2002; Buckley & Spangberg, 1995; Chen et al., 2007; Covello et al., 2010; Dutta et al., 2014; Eckerbom et al., 1987; Eriksen, 1995; Eriksen et al., 1988; Eriksen & Bjertness, 1991; Frisk et al., 2008; Gumru et al., 2011; Hollanda et al., 2008; Jalali et al., 2017; Jersa & Kundzina, 2013; Loftus et al., 2005; López-López et al., 2012; Meirinhos et al., 2020; Närhi et al., 2000; Oginni et al., 2015; Petersson et al., 1986; Punch, 1997; Soikkonen, 1995; Sunay et al., 2007; Vengerfeldt et al., 2017; Weiger et al., 1997). Forty-five studies were classified as moderate risk of bias (Ahmed et al., 2017; Al-Omari et al., 2011; Alrahabi & Younes, 2016; Archana et al., 2015; Asgary et al., 2010; Bürklein et al., 2020; da Paes Silva Ramos Fernandes et al., 2013; Da Silva et al., 2009; De Cleen et al., 1993; De Moor et al., 2000; Di Filippo et al., 2014; Dugas et al., 2003; Gencoglu et al., 2010; Georgopoulou et al., 2005; Gulsahi et al., 2008; Hebling et al., 2014; Hussein et al., 2016; Huumonen et al., 2012; Imfeld, 1991; Jersa & Kundzina, 2013; Jiménez-Pinzón et al., 2004; Kabak & Abbott, 2005; Kalender et al., 2013; Kamberi et al., 2011;

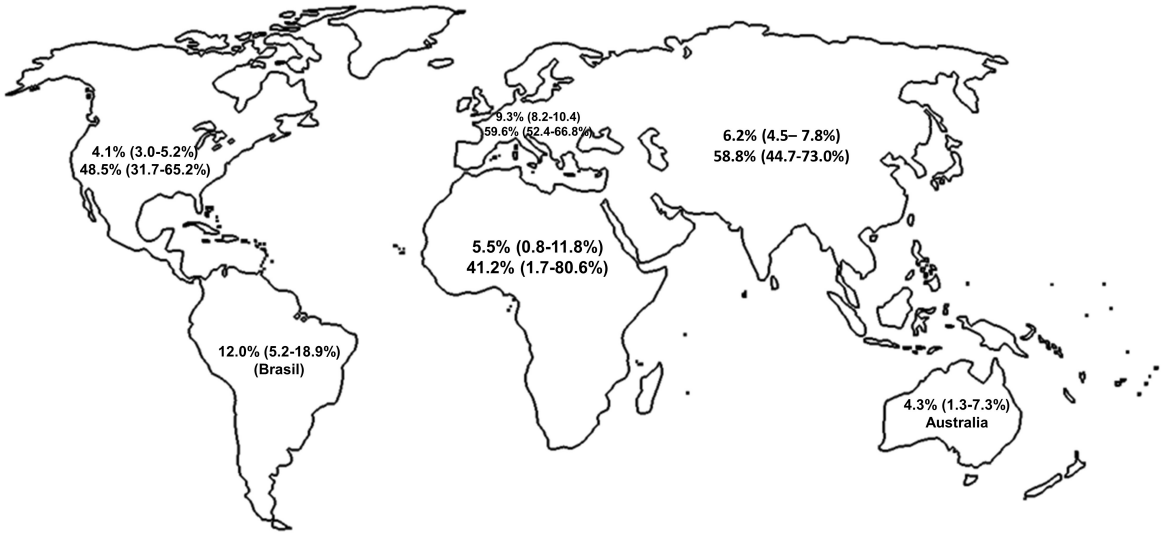

FIGURE 4 World map showing the prevalence of root filled teeth (RFT) (up) and the percentage of people with at least one RFT (down) calculated in the forest plots of the studies carried out in each continent. The values of South America are only from Brazil.

Kielbassa et al., 2017; Kirkevang et al., 2001, 2006; Lemagner et al., 2015; Lupi-Pegurier et al., 2002; Marques et al., 1998; Matijević et al., 2011; Mukhaimer et al., 2012; Özbaş et al., 2011; Peters et al., 2011; Petersson et al., 1989; Rocha et al., 2012; Segura-Egea et al., 2008; Sidaravicius et al., 1999; Skudutyte-Rysstad & Eriksen, 2006; Terças et al., 2006; Timmerman et al., 2017; Touré et al., 2008; Tsuneishi et al., 2005; Ureyen Kaya et al., 2013; Van der Veken et al., 2017; Zhong et al., 2008), and only two of the 74 included studies were classified as low risk of bias (Huumonen et al., 2017; Ödesjö et al., 1990).

DISCUSSION

The aim of this systematic review has been to analyse the worldwide prevalence of RCT. Based on raw data from the primary study, it can be concluded that globally, 8.2% of teeth have been endodontically treated, and 55.7% of adults over the age of 18 have at least one RFT. In short, more than half of the world's population has had at least one RCT. The data provided by this systematic review can be considered the first scientific approximation to the prevalence of RCT worldwide.

Prevalence and incidence systematic review and meta-analysis is an emerging methodology in the field of evidence synthesis. These reviews can provide useful information for healthcare professionals and policymakers on the burden of diseases, conditions or therapies, showing their geographical distribution and their changes and trends over time (Munn et al., 2015). Taking into account that the traditional PICO approach to inclusion criteria used in systematic reviews of effects evidently does not align with questions relating to prevalence, the CoCoPop mnemonic (condition, context, and population) approach has been used (Munn et al., 2015).

The high frequency of RFT showed in this study, together with the previously high prevalence of AP found in the world population, 52% of people and 5% of teeth (Tibúrcio-Machado et al., 2021), place endodontic disease and RCT as one of the most frequent and important health problems in the world population. The high prevalence of AP (Tibúrcio-Machado et al., 2021) and RCT should be taken into account by those responsible for health policies and the medical and dental communities, in view of the distribution of dental resources. Likewise, the academic authorities and the universities should also value the need to give the necessary extension to endodontics in the training curriculum of dentists.

The databases search provided nearly 2000 articles that, applying the inclusion criteria, resulted in a systematic review of 74 full-text articles analysed. All the studies investigated the prevalence of RFT in a certain population of patients over 18 years of age using different diagnostic radiographic methods.

Both cross-sectional and longitudinal studies were included in the present review. In the included longitudinal studies in which various stages of follow-up are reported (Eriksen et al., 1988; Frisk et al., 2008; Kirkevang et al., 2006), only the most recent data have been taken into account.

Articles that studied the prevalence of RFT in people with systemic disease were excluded. Both the prevalence of AP (Katz & Rotstein, 2021; Liljestrand et al., 2016; Segura-Egea et al., 2015) and RFT (Caplan et al., 2009; Gomes et al., 2016; Meurman et al., 2017) are influenced by the systemic status of the patient, so including these studies in the review would have altered the results by introducing confounding factors.

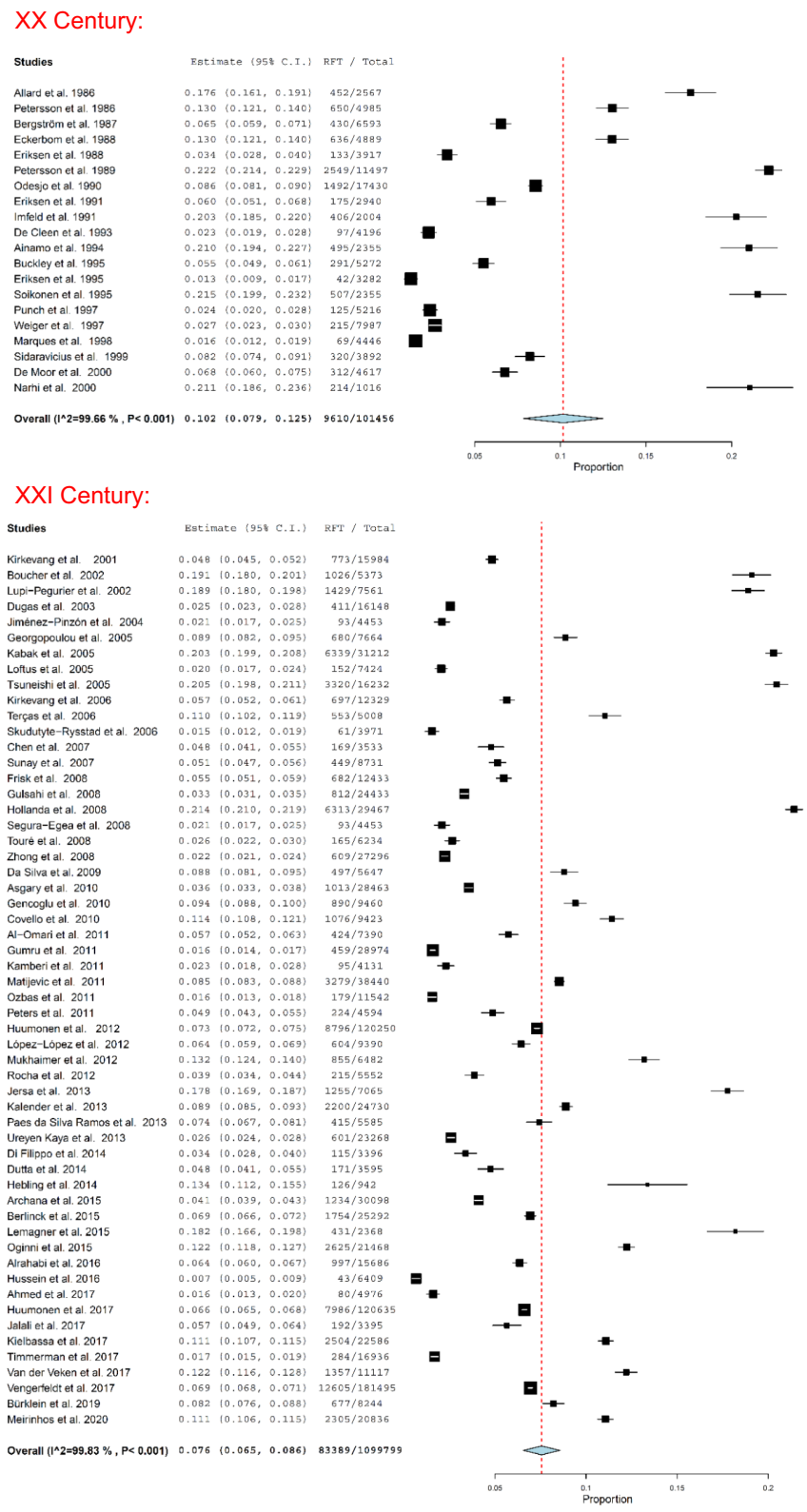

FIGURE 5 Forest plot of the prevalence of root filled teeth (RFT) in the studies carried out in the 20th and 21st centuries.

Subgroup analysis: Geographical distribution

When the studies included in this systematic review are classified geographically, the results show that the prevalence of RFT is very different from one country to another. Furthermore, different studies in the same country provide very different data. This is the case of Finland, where the prevalence of RCT ranges from 6.6% (Huumonen et al., 2012, 2017) to 21.5% (Ainamo et al., 1994; Närhi et al., 2000; Soikkonen, 1995). This variability, rather than by geographical factors, may be caused by an important confounding factor that must be taken into account when

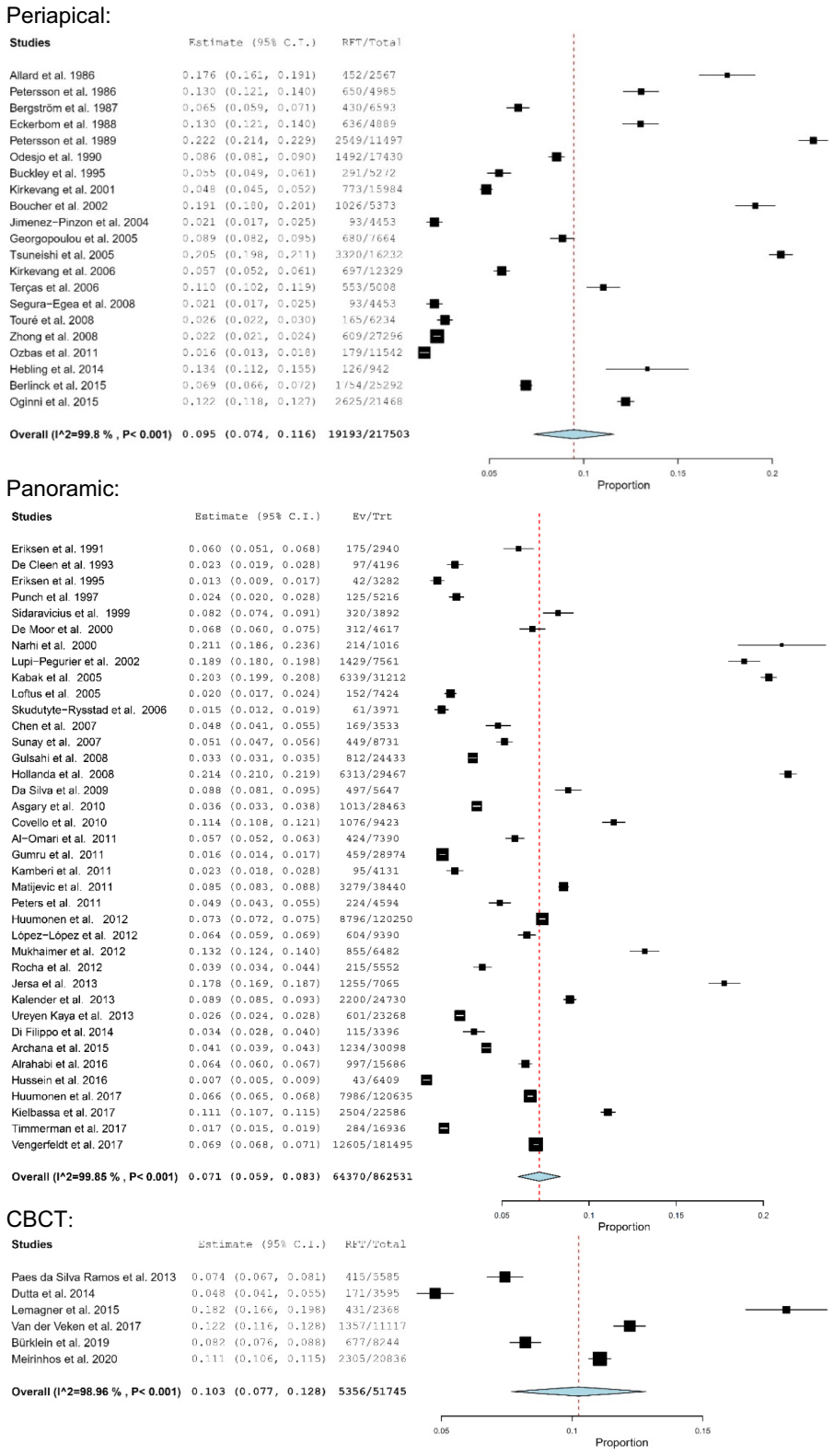

FIGURE 6 Forest plots of subgroups analysis according to the type of radiographic diagnosis: Periapical radiographs (up), panoramic radiographs (middle) and cone beam computed tomography (CBCT) (down).

assessing the results of this study: age. Since RCT is the treatment for endodontic disease and it develops throughout life, older people, logically, have a higher frequency of RCT. For this reason, studies in which the sample is made up of elderly people (Ainamo et al., 1994, Närhi et al., 2000, Soikkonen, 1995) show a higher prevalence of RCT compared to studies in which the sample consisted of younger people (Huumonen et al., 2012, 2017). Something

similar occurs with the data reported by the Swedish studies. However, almost none of the studies provided detailed information on the distribution by age or gender of the patients included in the sample.

Grouping the studies by continents, Europe and South America are the ones that show the highest prevalence of RFT. However, the data for South America come from studies carried out in a single country, Brazil, as well as the data for Oceania (only Australia). In the case of Brazil, the high frequency of RFT found may be a reflection of the fact that there are more studies on this subject in this country.

The African population shows the lowest prevalence of RFT. The differences in the age of the populations (Jiang et al., 2021), the different level of economic development (Bas & Azogui-Lévy, 2022; Listl et al., 2015), and the different access to dental health services (Kodama et al., 2021) can explain the differences observed between continents. The highest levels of per capita dental expenditures has been found for High-Income North America, Australasia, Western Europe, High-Income Asia Pacific, and East Asia (Righolt et al., 2018).

Subgroup analysis: Year of publication

In the forest plot including the studies conducted in the 20th century the calculated prevalence of RFT was 10.2% (95% CI = 7.9%–12.5%), substantially higher than calculated for studies conducted in the 21st century 7.6% (95% CI = 6.5%–8.6%).

A possible explanation would be the improvement in oral health quality devoted to greater prevention, together with minimal intervention in operative dentistry (Mount, 2007). The increase in the standard of living that has been taking place in the last 50 year (Akachi & Canning, 2015), could have facilitated access to dental care, reducing the incidence of caries (Whelton et al., 2019), with the consequent reduction in the incidence of pulpitis and apical periodontitis around the world, thus explaining a progressive decrease in the prevalence of RFT.

On the contrary, another possible explanation could be the increase in dental implant treatments that has taken place in the last three decades (Elani et al., 2018). Dentists and patients could have chosen to extract the teeth affected by irreversible pulpitis and/or apical periodontitis and place dental implants, rather than perform RCT.

And yet there may still be another explanation. Dentists may be changing their prescription habits for RCT, reserving it only for cases of apical periodontitis. The impact that the development of minimally invasive dentistry has undoubtedly had on the practice of endodontics (Wolters et al., 2017), may have caused a reduction in the number of RCT performed in recent years. During the second half of the 20th century, and even during the first decade of the present century, RCT was still indicated by some endodontic societies (American Association of Endodontists, 2009) as the treatment of choice, not only for the treatment of apical periodontitis but also for irreversible pulpitis, diagnosed by the presence of spontaneous pain (American Association of Endodontists, 2020). This could have produced an endodontic overtreatment that would be reflected in a high prevalence of RFT (Crespo-Gallardo et al., 2019). However, since the end of the 20th century and, especially in the past two decades, numerous studies (Careddu & Duncan, 2021; Duncan et al., 2021) have been demonstrating that spontaneous pain is not always indicative of irreversible pulpitis and that more conservative and less invasive therapeutic options, such as pulpotomy, could resolve, in many cases, supposedly irreversible pulpitis (Asgary et al., 2018; Marending et al., 2016). This change in therapeutic approaches has been able to influence the results of the most recent studies, in which lower RCT prevalence are found.

Subgroup analysis: Type of radiographic diagnosis

The radiographic method used in each study for the diagnosis of RFT was different. Most of the studies (36) used panoramic, 21 used periapical radiographs, and only six, all published after 2013, used CBCT. Although it might be thought that the detection of RFT can be performed with the same precision with any of the three methods, the studies using CBCT reported the highest prevalence of RFT (10.3%), followed by those using periapical radiographs (9.5%) and, finally, the studies using panoramic radiographs (7.1%). The results seem to indicate that, in addition to the publication date, the result of each study may be influenced by the radiographic method used for diagnosis. CBCT gives a three-dimensional image of the entire root canal system making it easier to know the root anatomy. This three-dimensional image helps to find supernumerary canals and roots, making easier the diagnosis of RFT (Liang et al., 2013; Nekoofar et al., 2006; Segato et al., 2018). The fact that studies in which CBCT is used provide the highest prevalence of RFT, all of them being carried out in the 21st century, in which the prevalence of RFT tends to decrease, indicates that, certainly, CBCT detects RFT with greater precision.

Implications for clinical practice and research

The progressive reduction of the prevalence of RFT showed in the present systematic review can be interpreted as a

reflection of the impact that minimally invasive dentistry and endodontics (Wolters et al., 2017), and the new recommendations on the more conservative treatment of deep caries lesions (Duncan et al., 2021; Innes et al., 2016; Schwendicke et al., 2016) are having throughout the world (Machiulskiene et al., 2020).

Determining the real effect that the recommendations of international societies (Duncan et al., 2021; Innes et al., 2016) based on scientific evidence have on dental practice is very complex. For decades, pulpal conditions that could have been treated by vital pulp therapy procedures have been diagnosed as irreversible pulpitis based on the existence of spontaneous pain (American Association of Endodontists, 2009). On the contrary, this diagnosis, in many cases erroneous, has led to hundreds of teeth undergoing RCT unnecessarily (Crespo-Gallardo et al. 2019). Scientific certainty that spontaneous pain does not always imply irreversible pulpitis has resulted in an increase in vital pulp therapy procedures within endodontic practice (Asgary et al., 2014; Careddu & Duncan, 2021). Added to this fact are the advances in the field of preventive dentistry, dental materials, and conservative dentistry, now focused on minimally invasive dentistry. In short, the results of this study show that the paradigm can be finally changing: the focus of endodontic practice may be shifting towards less invasive therapies, such as pulpotomy, pulp capping and dental pulp regenerative procedures.

Quality assessment

More than half of the studies were classified as moderate risk of bias and only two studies as low risk of bias (Huumonen et al., 2017; Ödesjö et al., 1990). The main drawbacks of the studies were from the sample selection, since most of the studies considered a selected group of patients, without taking into account the random sampling. Only five included studies calculated the sample size needed to improve the representativeness of the studied population (Bürklein et al., 2020; Hussein et al., 2016; Huumonen et al., 2017; Kirkevang et al., 2001; Timmerman et al., 2017). Then, a limitation of this systematic review is that, in most of the studies, the samples were drawn from patients seen in university dental clinics and are not representative of the general population. Similar limitation has been found in a previous systematic review analysing the prevalence of AP (Tibúrcio-Machado et al., 2021). However, the large sample size of the analysis may, at least in part, compensate for this limitation.

Given the very low proportion of RCTs performed on third molars, whether or not the third molar was included in the study does not represent a major limitation. So, low risk of bias was considered if the third molar was included in the total sample. Similarly, if edentulous patients were not included in the total patient sample, low risk of bias was also considered. On the contrary, when the study did not specify whether it included edentulous patients in the total sample, it was considered to be a very high risk of bias.

Strength and limitations

As previously considered, the results of the present systematic review should be evaluated with caution, since the samples of the different studies are not representative of the general population. On the contrary, the large number of studies included in the systematic review, 76 can be considered a strength and compensate, at least partially, for the limitation of non-random sampling.

CONCLUSIONS

Root canal treatment is a very common therapy throughout the world. More than half of the studied population have at least one RFT. The percentage of RFT worldwide is, on average, greater than 8%. When studies conducted in the 20th century are compared with those of the 21st century, a decrease in the prevalence of RFT is observed, which could indicate a change in the therapeutic attitudes of dentists in the management of endodontic diseases.

AUTHOR CONTRIBUTIONS

Conceptualization, D.C.-B. & J.J.S.-E.; Methodology and Software, D.C.-B. & M.L.-L.; Validation, J.J.S.-E., J.M.-G., D.C.-B. & P.M.-M.; Formal Analysis P.M.-M. & D.C.-B.; Investigation M.L.-L., J.J.S.-M., P.M.-M., J.M.-G., D.C.-B. & J.J.S.-E.; Data Curation J.J.S.-E., M.L.-L. & D.C.-B.; Writing – Original Draft Preparation J.J.S.-E., M.L.-L., P.M-M., & D.C.-B.; Writing – Review & Editing, D.C.-B., J.M.-G. & J.J.S.-E.; Visualization P.M.-M., J.J.S.-M., J.M.-G. & J.J.S.-E.; Supervision J.J.S.-E. & D.C.-B. All authors have reviewed and approved the submitted version. All authors developed the idea and contributed to the final version of the manuscript equally.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

ETHICS STATEMENT

This systematic review did not need the Ethics Committee Approval due to the absence of research with patients.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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