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ORIGINAL ARTICLE

A 22-year follow-up cross-sectional study on periapical health in relation to the quality of root canal treatment in a Belgian population

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Abstract

Aim: To investigate the prevalence of apical periodontitis (AP) and the technical standard of root canal treatment in a Belgian population, assess the association of different variables with periapical status, and compare the results to a similar study conducted 22 years previously.

Methodology: In this cross-sectional study, 614 panoramic radiographs of first-time adult attendees at the Dental School of the University Hospital of Ghent were examined. Recorded patient-level parameters included gender, age, number of teeth, number of root filled teeth, presence of any AP lesion, and number of implants. The following tooth-level data were collected: tooth presence, coronal status, quality of coronal restoration, post presence, type of root-filling material, length and density of root filling, root-end filling material, presence of AP, and adjacent implant. Multivariable multilevel binary logistic regression was used to explore the association between patient and tooth characteristics and AP prevalence. Risk differences and confidence intervals were calculated to compare the present with the previous study.

Results: The prevalence of AP at patient and tooth level was 46.9% and 5.6%, respectively. Fifty-one per cent of the 614 patients had at least one root filled tooth, and 5.9% of the 14 655 teeth studied were root filled. AP was found in 45% of root filled teeth. Fifty-four per cent of the root-filled teeth were rated as inadequate. Multivariable multilevel logistic regression revealed that more teeth, more implants, fewer root-filled teeth, adequate density, adequate coronal restoration, and no caries reduced the likelihood of AP. There were no statistically significant differences between the two studies regarding the prevalence of root-filled teeth or AP and the technical quality of root canal treatment.

Conclusions: The prevalence of AP and the technical quality of root canal treatment in Belgium have not substantially changed over the last 22 years, despite the technological advancements and continuing education in the field.

KEYWORDS

apical periodontitis, prevalence, repeated cross-sectional study, root canal treatment

INTRODUCTION

Apical periodontitis (AP) is an inflammatory response of the periapical tissues to the presence of microorganisms and/or their toxins within the root canal system (Kakehashi et al., 1965). As AP is mostly asymptomatic, diagnosis is based on radiographic examination, including periapical and panoramic radiographs or cone-beam computed tomography (CBCT). Alternative diagnostic methods like ultrasound real-time imaging and magnetic resonance imaging (MRI) have also been described (Cotti & Schirru, 2022). Because AP contributes to the inflammatory burden of the human body (Georgiou et al., 2019; Gomes et al., 2013) and may affect the general health of the individual (Jakovljevic, Duncan, et al., 2020; Jakovljevic, Nikolic, et al., 2020; Khalighinejad et al., 2016), treatment is indicated.

The management of AP includes root canal treatment and retreatment or surgical endodontic intervention in case of a root-filled tooth (Duncan et al., 2023). These clinical procedures include cleaning and disinfection of the root canal system, thereby eliminating or significantly reducing the infectious load, followed by placement of a root canal filling and adequate coronal restoration to prevent bacterial recontamination.

When executed according to recommended standards (ESE, 2006), root canal treatment of periapically involved teeth has a high clinical success rates (Ng et al., 2011). However, cross-sectional studies have reported a high prevalence of poor quality root fillings and high levels of AP in root filled teeth. In a recent systematic review, (Tibúrcio-Machado et al., 2021), the prevalence of AP in root-filled teeth was found to be 39%. This is in contrast to AP prevalence of 3% in non-treated teeth. All in all, the global prevalence of AP was found to be 52% at the individual level and 5% at the tooth level.

The study of AP prevalence in a population provides an indication of the populations treatment needs and provides decision-makers with a basis for more effective use of resources for the prevention and treatment of endodontic disease. In addition, the high prevalence of AP in root filled teeth warrants the analysis of root filled teeth prevalence in a population, especially in ageing cohorts where the increase of tooth retention may raise the proportion of root fillings (Kirkevang, 2018). It has been recommended that research on the prevalence of AP should provide information at both the tooth and individual levels, which is more relevant for researchers, dental practitioners, and policymakers (Tibúrcio-Machado et al., 2021).

The prevalence of AP and root filled teeth has been evaluated in many countries. Some studies used periapical radiographs (Georgopoulou et al., 2005; Jiménez-Pinzón et al., 2004; Kirkevang et al., 2001a, 2001b; Özbaş et al., 2011). Other studies used either panoramic radiographs (De Moor et al., 2000; Di Filippo et al., 2014; Gulsahi et al., 2008; Gumru et al., 2011; Huumonen et al., 2017; Kabak & Abbott, 2005; Loftus et al., 2005; Lupi-Pegurier et al., 2002; Mukhaimer et al., 2012; Peters et al., 2011; Sunay et al., 2007), both periapical and panoramic images (Dugas et al., 2003; Gencoglu et al., 2010) or used CBCT scans (Baruwa et al., 2022; Meirinhos et al., 2020; Van der Veken et al., 2017).

Only two studies on periapical health in adults have been conducted in Belgium: one using panoramic radiographs (De Moor et al., 2000) and one using CBCT (Van der Veken et al., 2017). De Moor et al. evaluated 206 radiographs and 4617 teeth, finding that 6.6% of all teeth and 40.4% of the endodontically treated teeth had periapical radiolucencies. Additionally, they found that more than half of the root-filled teeth (56.7%) were classified as technically inadequate (De Moor et al., 2000).

Van der Veken et al. (2017) evaluated 639 CBCT scans and 11 117 teeth. AP was found in 2.2% of the non-root filled teeth and 32.7% of the root filled teeth. Approximately half (49.3%) of the root filled teeth were of inadequate quality. The prevalence of AP was 22.8% when the root filling was adequate but increased to 41% when it was inadequate. However, the diagnostic accuracy of CBCT with regards to root filled teeth has been shown to be significantly lower than for non-root filled teeth, and there may be a significant risk of overdiagnosis of AP (Kruse et al., 2019). Panoramic radiographs, on the other hand, have high specificity and good diagnostic accuracy (Cotti & Schirru, 2022; Nardi et al., 2018), but may underestimate the disease due to their low sensitivity.

Over the last 2 decades, significant changes have taken place in the Belgian dental field with regards to endodontics, such as the increased use of rubber dam and NiTi mechanical instrumentation (including implementation of mechanical instrumentation in the undergraduate curricula), increased appeal for endodontic referral, and a trend towards more contemporary treatment protocols (Neukermans et al., 2015). Whether this has lead to improvement of the technical quality of root canal treatment, and/or a change in AP prevalence is unclear. Monitoring of disease prevalence within a given population over time might provide useful information regarding future health care need, provide feedback regarding health care developments during that time, and could also impact the development of undergraduate and postgraduate education (Kirkevang et al., 2001a, 2001b).

Follow-up cross-sectional studies investigating similar patient cohorts at different points in time may help understand future needs. To our knowledge, only

3 studies have investigated trends of AP prevalence in time: in Denmark, the Netherlands, and Germany (Connert et al., 2019; Kirkevang et al., 2001a, 2001b; Peters et al., 2011), but information on the Belgian situation is lacking.

Therefore, the aim of this follow-up cross-sectional study is to investigate the prevalence of AP and the technical standard of root canal treatment in Belgium, to assess the association of certain variables with periapical status, and to compare the results to a similar study conducted in Belgium 22 years previously.

MATERIALS AND METHODS

The study followed the Preferred Reporting items for Observational studies in Endodontics (PROBE) guidelines (Nagendrababu, Duncan, Fouad, Kirkevang, Parashos, Pigg, Vaeth, Jayaraman, Suresh, Arias, et al., 2023; Nagendrababu, Duncan, Fouad, Kirkevang, Parashos, Pigg, Vaeth, Jayaraman, Suresh, Jakovljevic, & Dummer, 2023). This cross-sectional study was approved by the Ethics Commission of Ghent University (THE-2022-0024). The requirement for obtaining informed consent was waived because of the retrospective nature of the study.

Study design and population

The sample size was calculated using the following formula (Pourhoseingholi et al., 2013):

$$n = \frac{Z^2 \mathrm{P}(1-\mathrm{P})}{e2}$$

The prevalence (P) of AP was estimated at (52%) (Tibúrcio-Machado et al., 2021). The precision level (e) was determined at 0.05, and the Z value was 1.96 for a 95% confidence interval. From the above formula, the minimum sample size required was 384 patients.

This cross-sectional study included a convenience sample from the adult Belgian population. All the panoramic X-rays taken on adult patients consulting the Ghent University Hospital Dental Clinic during 2019 were screened. These radiographs were taken with a Planmeca ProMax 2D X-ray unit (Planmeca, Helsinki, Finland). Exclusion criteria were then applied to the sample as follows:

- Patients not attending for the first time;
- Edentulous patients;
- Radiographs of inadequate quality (inability to obtain accurate data of all present teeth due to blurry or distorted images, incomplete coverage, poor contrast, over- or underexposure, or presence of large artefacts).

Evaluation of radiographs

Two evaluators were trained in scoring of the different variables on the panoramic radiographs (Table 1). For calibration, the evaluators scored 30 panoramic radiographs, which were not part of the present research material. After 3 months, the same set of radiographs was rescored. Cohen's kappa was determined to measure inter- and intra-examiner agreement on various factors, including the presence of AP, coronal status, quality of coronal restoration, length and density of root filling, and presence of implants (Hunt, 1986; Valachovic et al., 1986). To ensure consistency, 30 new panoramic radiographs were evaluated for inter-examiner calibration 3 months after the initial calibration. Based on almost perfect inter- and

TABLE 1 The recorded tooth-level variables.

Tooth number	Length of root filling
• FDI notation	• Root canal filling 0–2 mm short of the radiographic apex
Coronal status	• Root canal filling >2 mm short of the radiographic apex
• Intact	• Root canal filling extruded beyond the radiographic apex (sealer is excluded)
• Primary caries	Density of root filling
• Non-metallic direct restoration	• Homogenous: root filling with uniform density and without voids or space between the filling and root canal wall, from its most coronal extent to its most apical extent
• Metallic direct restoration	• Non homogenous: when any of the above criteria were not met
• Indirect restoration	Root-end filling material
Quality of coronal restoration	• Nil
• Adequate	• Non-metallic
• Inadequate	• Metallic
Post	Periapical Status
• None	• AP
• Direct post	• No AP
• Cast post	Adjacent implant
Root-filling status	• Yes
• None	• No
• GP	
• Paste	
• Silver point	
• Material in the pulp chamber	

Abbreviation: GP, gutta-percha.

intra-examiner agreement scores in the two sets, it was reasonable to use the scores of one researcher for further assessment of the radiographic findings.

The digital radiographs were displayed on a 19′ Plug and Play model monitor using an NVIDIA Riva TNT 2 model 64 graphic card with 32-bit quality colour and 1280 × 1024 pixels resolution in a room with subdued lighting. The observers were free to use any image enhancement tool (adjusting properties such as contrast, density, brightness, and sharpness), provided by the computer software (Mediadent V8, Corilus SA/NV, Ghent, Belgium) in order to facilitate the diagnosis of periradicular pathosis and the tooth-related parameters (Folk et al., 2005; Huumonen & Ørstavik, 2002).

Variables

On each panoramic radiograph, both patient-level and tooth-level data were collected. All patient records were de-identified by assigning codes to maintain anonymity during the study. Patient-level parameters included gender, age, number of teeth, number of root filled teeth, presence of AP lesion, and number of implants. Per radiograph, the following tooth-level data were collected: tooth presence, coronal status, quality of the coronal restoration, presence and type of post, type of root-filling material, length of the root filling, density of the root filling, presence of a root-end filling material, presence of AP, and presence of an adjacent implant (Table 1). Third molars were excluded.

Root-filling status

Endodontically treated teeth were defined as those with radiopaque material in the pulp chamber and/or root canal(s). All other teeth were categorized as non-endodontically treated.

Periapical status

AP was defined as the widening of the periodontal ligament to more than twice the width of the lateral periodontal ligament space (De Moor et al., 2000).

Coronal status

Caries was defined as a localized radiolucency into the dentine of the crown. Restorations of the coronal part of the tooth, either direct and appearing to be plastic (non-metallic) or metallic, based on the radiopacity, or indirect, were noted.

The quality of the coronal restoration was assessed as follows (Siqueira et al., 2005): adequate: any restoration that appeared radiographically intact; inadequate: any restoration with detectable radiographic signs of open margins, overhangs, or caries in relation to the restoration.

Based on the root-filling length and root-filling density, a new variable, 'quality of root canal treatment', was calculated (ESE, 2006):

- Adequate: root-filling ending no more than 2 mm from the radiographic apex and without visible voids.
- Inadequate: root filling more than 2 mm short of, or beyond the radiographic apex, or containing voids.

Teeth with multiple roots were classified according to the root with the worst periapical status. Similarly, root filled teeth with multiple roots were classified according to the root with the poorest quality of root filling. All patient and tooth level data were entered into a spreadsheet (Microsoft Excel, Microsoft, Redmond, WA, USA).

Data analysis

Descriptive analysis of tooth- and patient-level variables

Means were calculated for continuous and discrete variables; frequencies and percentages were used to report the different categorical variables.

Association between patient and tooth characteristics and AP prevalence

Two separate multivariable multilevel binary logistic regressions were conducted to investigate the association of periapical status with several patient- and tooth-level characteristics. The first analysis comprised the teeth of all patients (614 patients, 14 645 teeth). In the second analysis, only root filled teeth were included, yielding 312 patients with 856 endodontically treated teeth. A varying-intercept model with the following variables was used in both regression analyses:

- at the patient level: gender, age, number of teeth, number of root-filled teeth, and number of implants;
- at the tooth level: coronal status, quality of coronal restoration, post, root-filling material, root-filling length, density, root-filling quality, treatment quality, and adjacent implant.

TABLE 2 Dichotomised parameters used in the second analysis.

Coronal status	Root-filling status
• Caries	• GP
• Non-metallic direct	• Other
• Metallic direct	Length of root filling
• Indirect	• Adequate
Quality of coronal restoration	• Inadequate
• Adequate	Density of root filling
• Inadequate	• Adequate
Post	• Inadequate
• Yes	Adjacent implant
• No	• Yes
	• No

For the second analysis, tooth-related variables with more than two categories were converted into binary variables to simplify interpretation (Table 2). This was done for all variables except for coronal status, where parameters were maintained as originally recorded.

Age and number of teeth were logarithmically transformed for having a wider 'dynamic range' (Gelman & Hill, 2007). In this case, their regression coefficient (after exponentiation) is interpreted as the proportional change in the odds of presenting AP per proportional increase in age and the number of teeth, respectively (Gelman & Hill, 2007).

Both models encountered convergence issues: this was the case for several tooth-related variables in the first analysis (i.e., coronal status, post, root-filling material, root-filling length, and density) and for the odds ratio of the absence of coronal restoration versus adequate coronal restoration in the second analysis. Hence, the corresponding odds ratios of these variables were not estimated. We considered a significance level of 5% to infer statistical significance corresponding to a 95% CI for the odds ratio that excludes the null value (i.e., odds ratio equal to 1).

Comparison of the results with the study of De Moor et al. (2000)

The results of the present study were compared to those of a similar study in Belgium that was conducted 22 years ago (De Moor et al., 2000). To this end, risk differences with 95% confidence interval (CI) were calculated for each tooth and characteristic (Figure 4). A positive risk difference indicated a higher risk of the investigated characteristic in the present study than in De Moor et al., 2000. If the 95% CI included the zero value, the corresponding results were considered statistically non-significant; otherwise, they were statistically significant (see Figures S1–S3).

For the comparison of the present study with the De Moor study regarding the distribution of root-filling length (Table 6), a binomial logistic regression was performed. A 95% CI that excludes an odds ratio equal to one coincides with a *p*-value less than .05.

Statistical software

Analyses were implemented in the statistical software R (version 4.3.0) (R Core Team, 2023). The figures were created using the R package ggplot2 (Wickham, 2009). R package lme4 was used to conduct multilevel logistic regression (Bates et al., 2015) and the Nelder–Mead for optimisation method.

RESULTS

Participants

Of the initial sample of 1411 panoramic X-rays, 797 were excluded due to inadequate quality ($n=140$), previous dental treatment at the hospital (not presenting for the first time) ($n=645$), and edentulous patients ($n=12$). The remaining 614 patients were included in the study; patient- and tooth-level data were extracted (Figure 1).

Calibration

Cohen's kappa was almost perfect for all variables, with a slightly lower agreement for the coronal status and the quality of coronal restorations (Table 3).

Patient-level data

The 614 OPGs included recordings for 314 male and 300 female individuals with a total of 14 655 teeth. Figure 2 graphically displays the distribution of age and gender amongst the patients.

The patients had a mean age of 41.5 years and a mean number of 25.1 teeth. The most commonly missing teeth were the mandibular first molars, with 34% of patients missing the left and 34.4% missing the right. On average, each patient had 1.36 root-filled teeth, and slightly over half of the patients (51%) had at least one root filled tooth. Nearly half (46.9%) of the patients had one or more teeth with AP, as shown in Figure 3. A small proportion of the

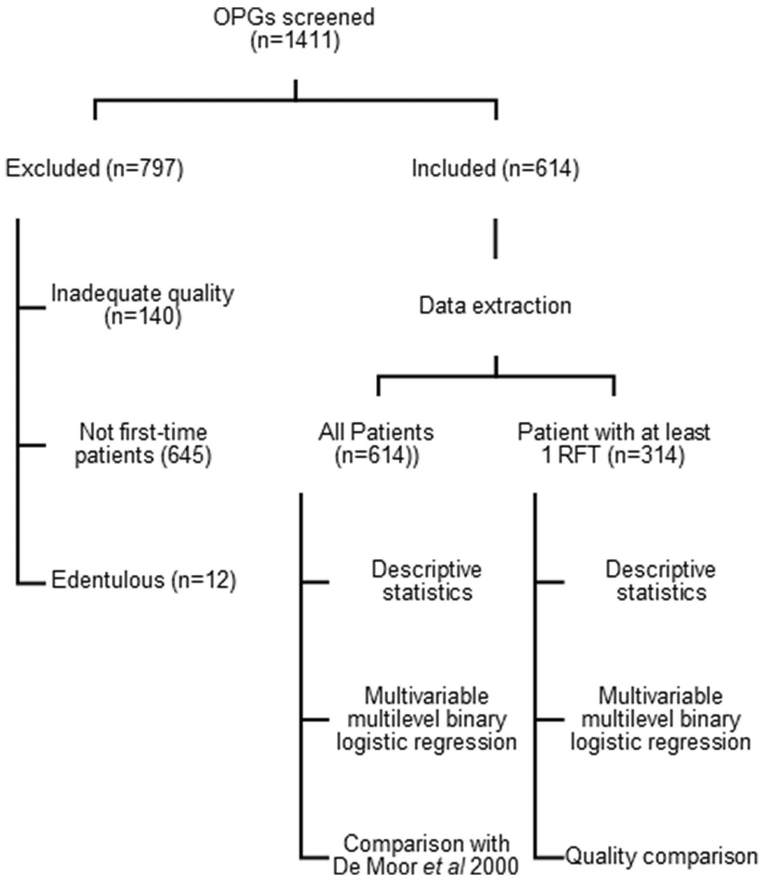

FIGURE 1 PROBE flowchart of the study, from screening of OPGs to statistical analysis.

TABLE 3 Inter- and intraobserver agreement.

	Inter-observer agreement 1		Inter-observer agreement 2[a]		Intra-observer agreement	
	Cohen's κ	ASE	Cohen's κ	ASE	Cohen's κ	ASE
AP patient level	1	—	1	—	1	—
AP tooth level	0.912	0.018	0.915	0.016	0.955	0.013
Length RF	1	—	0.95	0.012	0.975	0.01
Density RF	1	—	0.943	0.013	0.98	0.009
CS	0.813	0.017	0.883	0.014	0.877	0.014
CR quality	0.808	0.018	0.859	0.016	0.909	0.013
Adjacent implant	1	—	1	—	1	—

Abbreviations: AP, apical periodontitis; ASE, asymptotic standard error; CR, coronal restoration; CS, coronal status; RF, root filling.

[a]3 months later.

sample (4.4%) had at least one dental implant, with 27 patients falling into this category.

Tooth-level data

This study included 14655 teeth, and Figure 4 displays the distribution of teeth according to coronal (presence and type of restoration, presence of caries), root canal (untreated or root filled), and periapical status (presence of AP), presented per tooth number.

Coronal status

Of 14655 teeth examined, 10655 (73%) had no restorations. 914 teeth (6.2%) had primary caries. 3998 teeth (27.3%) had coronal restorations, of which 89.5% (3580 teeth) were deemed adequate. Direct restorations were present in 3540 (24.2%) teeth, indirect restorations were

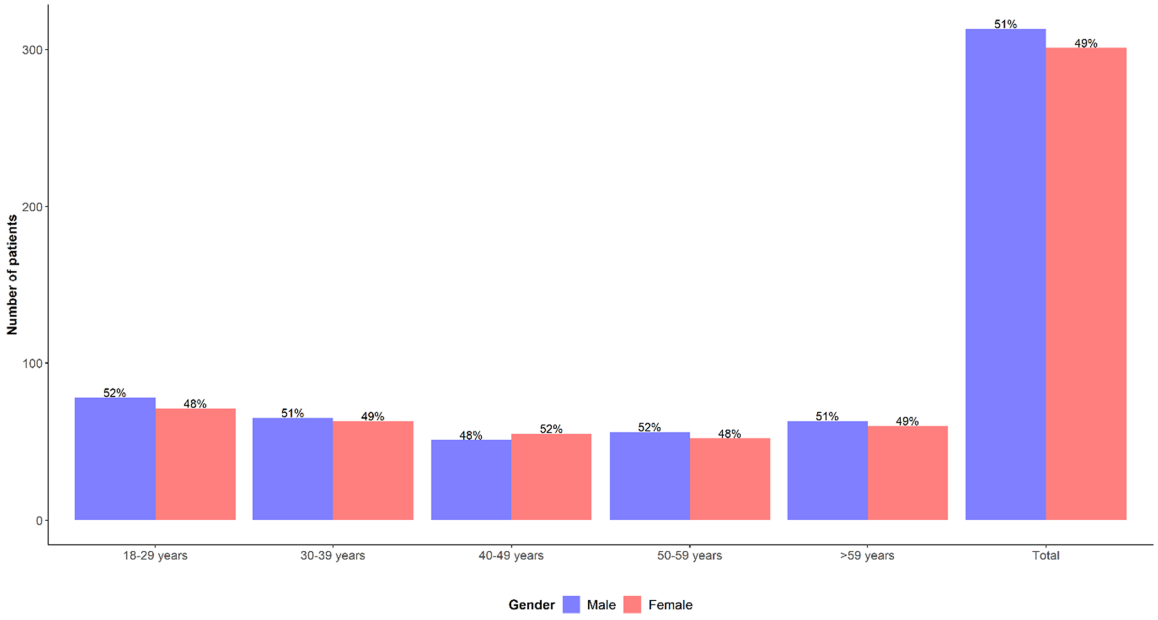

FIGURE 2 Bar plot depicting the distribution of age and gender among the included patients ($n = 614$).

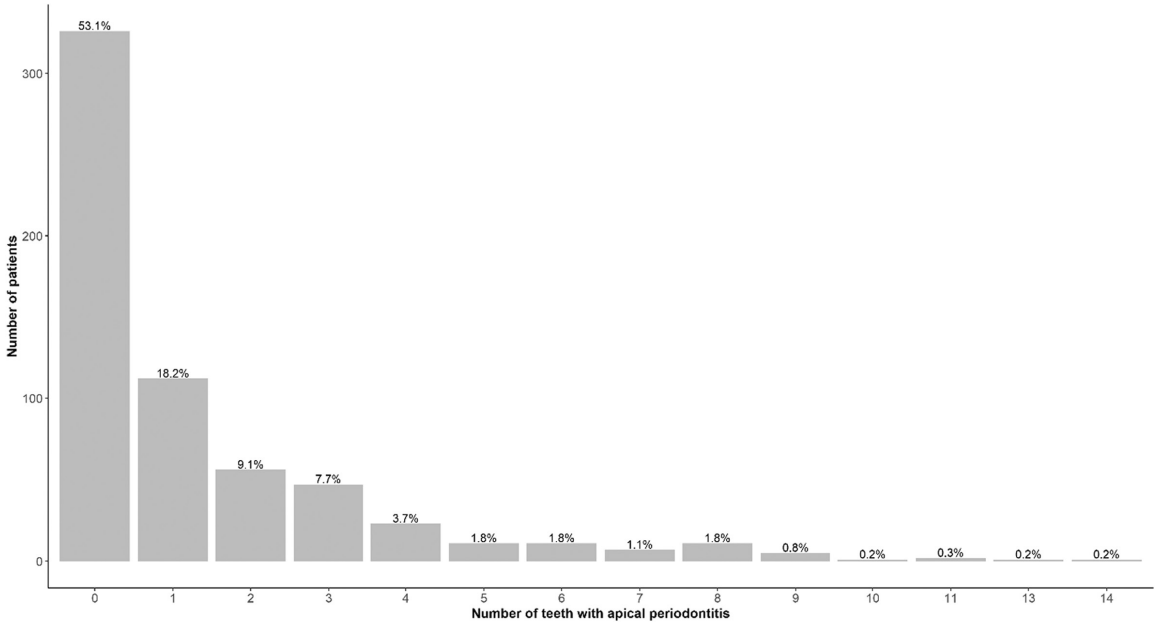

FIGURE 3 Distribution of patients ($n = 614$) according to the number of teeth with apical periodontitis per individual.

present in 3.1% (458 teeth), whilst 1% (155 teeth) had a post.

Root canal status

Of the 14655 teeth examined, 858 (5.8%) had been root filled. Amongst these, 419 (49%) had an inadequate root-filling length, 389 (45%) had an inadequate root-filling density, and 460 (54%) were of inadequate quality (inadequate root-filling length and/or inadequate root-filling density). Twenty-five (2.9%) teeth had a silver point, 7 (0.8%) teeth had a root-end filling material. The upper left first molar had the highest prevalence of root filling (11.8%).

Periapical status

Of the 14655 teeth examined, 819 (5.6%) had AP. The prevalence of AP in root-filled teeth was 45% (385 teeth). The first upper left molar had the highest prevalence of AP (13.6%), followed by the first lower left molar (12.1%) and the first upper right molar (12%).

Tooth	Observed teeth	Missing teeth	Endodontically treated teeth	Apical periodontitis	No coronal restoration -ca	No coronal restoration +ca	Filling -ca	Filling +ca	Crown -ca	Crown +ca
11	559 (91.0)	55 (9.0)	36 (6.4)	27 (4.8)	381 (68.2)	31 (5.5)	105 (18.8)	12 (2.1)	30 (5.4)	0 (0.0)
12	550 (89.6)	64 (10.4)	34 (6.2)	28 (5.1)	392 (71.3)	31 (5.6)	81 (14.7)	16 (2.9)	30 (5.5)	0 (0.0)
13	557 (90.7)	57 (9.3)	29 (5.2)	19 (3.4)	436 (78.3)	33 (5.9)	55 (9.9)	8 (1.4)	22 (3.9)	3 (0.5)
14	463 (75.4)	151 (24.6)	43 (9.3)	35 (7.6)	280 (60.5)	34 (7.3)	121 (26.1)	9 (1.9)	16 (3.5)	3 (0.6)
15	469 (76.4)	145 (23.6)	49 (10.4)	46 (9.8)	238 (50.7)	46 (9.8)	139 (29.6)	21 (4.5)	22 (4.7)	3 (0.6)
16	484 (78.8)	130 (21.2)	51 (10.5)	58 (12.0)	151 (31.2)	38 (7.9)	245 (50.6)	27 (5.6)	20 (4.1)	3 (0.6)
17	498 (81.1)	116 (18.9)	25 (5.0)	38 (7.6)	223 (44.8)	46 (9.2)	199 (40.0)	17 (3.4)	12 (2.4)	1 (0.2)
21	560 (91.2)	54 (8.8)	38 (6.8)	24 (4.3)	392 (70.0)	28 (5.0)	100 (17.9)	8 (1.4)	30 (5.4)	2 (0.4)
22	546 (88.9)	68 (11.1)	34 (6.2)	26 (4.8)	377 (69.0)	43 (7.9)	91 (16.7)	12 (2.2)	23 (4.2)	0 (0.0)
23	567 (92.3)	47 (7.7)	29 (5.1)	19 (3.4)	440 (77.6)	27 (4.8)	56 (9.9)	12 (2.1)	30 (5.3)	2 (0.4)
24	496 (80.8)	118 (19.2)	38 (7.7)	22 (4.4)	314 (63.3)	36 (7.3)	121 (24.4)	10 (2.0)	14 (2.8)	1 (0.2)
25	463 (75.4)	151 (24.6)	45 (9.7)	32 (6.9)	256 (55.3)	31 (6.7)	136 (29.4)	12 (2.6)	26 (5.6)	2 (0.4)
26	484 (78.8)	130 (21.2)	57 (11.8)	66 (13.6)	166 (34.3)	46 (9.5)	228 (47.1)	26 (5.4)	14 (2.9)	4 (0.8)
27	492 (80.1)	122 (19.9)	30 (6.1)	33 (6.7)	242 (49.2)	39 (7.9)	180 (36.6)	19 (3.9)	10 (2.0)	1 (0.2)
31	580 (94.5)	34 (5.5)	8 (1.4)	6 (1.0)	553 (95.3)	8 (1.4)	13 (2.2)	3 (0.5)	3 (0.5)	0 (0.0)
32	591 (96.3)	23 (3.7)	2 (0.3)	8 (1.4)	555 (93.9)	12 (2.0)	14 (2.4)	1 (0.2)	9 (1.5)	0 (0.0)
33	598 (97.4)	16 (2.6)	7 (1.2)	8 (1.3)	528 (88.3)	25 (4.2)	29 (4.8)	3 (0.5)	10 (1.7)	3 (0.5)
34	560 (91.2)	54 (8.8)	23 (4.1)	22 (3.9)	425 (75.9)	35 (6.2)	79 (14.1)	10 (1.8)	10 (1.8)	1 (0.2)
35	511 (83.2)	103 (16.8)	40 (7.8)	30 (5.9)	315 (61.6)	36 (7.0)	126 (24.7)	15 (2.9)	18 (3.5)	1 (0.2)
36	405 (66.0)	209 (34.0)	41 (10.1)	49 (12.1)	136 (33.6)	37 (9.1)	197 (48.6)	30 (7.4)	4 (1.0)	1 (0.2)
37	491 (80.0)	123 (20.0)	33 (6.7)	52 (10.6)	206 (42.0)	52 (10.6)	193 (39.3)	33 (6.7)	6 (1.2)	1 (0.2)
41	589 (95.9)	25 (4.1)	8 (1.4)	8 (1.4)	557 (94.6)	10 (1.7)	15 (2.5)	1 (0.2)	6 (1.0)	0 (0.0)
42	593 (96.6)	21 (3.4)	6 (1.0)	8 (1.3)	555 (93.6)	10 (1.7)	19 (3.2)	1 (0.2)	8 (1.3)	0 (0.0)
43	595 (96.9)	19 (3.1)	9 (1.5)	14 (2.4)	545 (91.6)	16 (2.7)	20 (3.4)	4 (0.7)	8 (1.3)	2 (0.3)
44	555 (90.4)	59 (9.6)	27 (4.9)	14 (2.5)	437 (78.7)	26 (4.7)	73 (13.2)	8 (1.4)	10 (1.8)	1 (0.2)
45	512 (83.4)	102 (16.6)	44 (8.6)	29 (5.7)	312 (60.9)	30 (5.9)	137 (26.8)	14 (2.7)	16 (3.1)	3 (0.6)
46	403 (65.6)	211 (34.4)	41 (10.2)	46 (11.4)	129 (32.0)	52 (12.9)	195 (48.4)	19 (4.7)	4 (1.0)	3 (0.7)
47	484 (78.8)	130 (21.2)	31 (6.4)	52 (10.7)	200 (41.3)	56 (11.6)	196 (40.5)	26 (5.4)	6 (1.2)	0 (0.0)
Total	14655	2537	858 (5.9)	819 (5.6)	9741 (66.5)	914 (6.2)	3163 (21.6)	377 (2.6)	417 (2.8)	41 (0.3)

FIGURE 4 Distribution of coronal status, root canal status and periapical status according to tooth type ($n = 14\,655$). Each cell presents the absolute count and relative frequency (in parenthesis) for each characteristic. Highlighted cells indicate statistically significant differences ($p < .05$) for the corresponding proportional differences between the present article and De Moor and colleagues. (−ca, free of caries; +ca, with caries).

Association between patient and tooth characteristics and AP prevalence

The results of the multivariable multilevel binary logistic regressions are summarized in Tables 4 and 5. Regarding patient-level characteristics (Table 4), a patient with more teeth was less likely to exhibit AP than a patient with less teeth (OR: 0.31 with 95% Cl: 0.18–0.56). A patient with more root-filled teeth was slightly more likely to display AP than a patient with less root-filled teeth (OR: 1.14 with 95% CI: 1.06–1.23). A patient with more implants was less likely to present with AP compared to a patient with less implants (OR: 0.71 with 95% CI: 0.53–0.94). At the tooth level, teeth with an inadequate coronal restoration were more likely to display AP than those with an adequate coronal restoration (OR: 5.56, 95% CI: 3.70–8.33). There was no statistically significant association between the following parameters and AP prevalence: gender (OR: 0.72, 95% CI: 0.51–1.01) and age (OR: 1.06, 95% CI: 0.63–1.79).

At the tooth level (Table 5), root-filled teeth with an indirect, direct non-metallic, and direct metallic restoration were less likely to show AP when compared to those who had no restoration but had caries (OR: 0.31 with 95% CI: 0.14 to 0.73, 0.24 with 95% CI: 0.12 to 0.51, and 0.17 with 95% CI: 0.07 to 0.40, respectively). Root-filled teeth with an inadequate coronal restoration were more likely to display AP than those with an adequate coronal restoration (OR: 1.96 with 95% CI: 1.10 to 3.52). Root-filled teeth with inadequate root-filling density were more likely to present AP than those with adequate root-filling density (OR: 6.86 with 95% CI: 3.53 to 13.34). There was no statistically significant association between the following parameters and the prevalence of AP: the type of coronal restoration, presence of a post, type of root-filling material, root-filling length, treatment quality, and adjacent implant (Table 5).

Comparison with the study of De Moor et al. (2000)

The orange cells in Figure 4 highlight statistically significant differences between the present data and the earlier study by De Moor et al. (2000). The previous study had a higher proportion of teeth with caries, with or without a filling (5.5% and 7.9%, respectively, compared to 2.6% and 6.2%, respectively). The present study found a greater proportion of teeth without any coronal restoration (66.5%) compared to the previous study (61.7%), and this

TABLE 4 Multilevel multivariable logistic regression for the association of apical periodontitis with several characteristics (613 patients, 14645 teeth).

	Apical periodontitis	Odds ratio (95% CI)
Patient characteristic		
Age[a,b]	44 (18, 82)	1.06 (0.63, 1.79)
Gender[c]		
Female	369/7053 (5%)	0.72 (0.51, 1.01)
Male	448/7592 (6%)	#
Number of teeth[a,b]	24 (4, 28)	**0.31 (0.18, 0.56)**
Number of root-filled teeth[a]	2 (0, 16)	**1.14 (1.06, 1.23)**
Number of implants[a]	0 (0, 8)	**0.71 (0.53, 0.94)**
Tooth characteristic		
Coronal restoration quality		
Inadequate	161/416 (39%)	**5.56 (3.70, 8.33)**
Adequate	242/3573 (7%)	#
Adjacent implant		
With	8/66 (12%)	2.38 (0.63, 8.99)
Without	809/14579 (6%)	#

Note: Statistically significant results are indicated in bold.

Abbreviations: #, reference category; CI, confidence interval.

[a]Median and range (minimum, maximum).

[b]Included in the model after log-transformation.

[c]Number of cases with apical periodontitis out of the total number of cases in the investigated category.

difference was statistically significant ($p < .05$) (Figure 4). More detailed information is provided in Figure S3. There was no statistically significant difference in the overall prevalence of AP or the prevalence of root-filled teeth. Regarding the quality of root canal treatment, a root filled tooth was slightly more likely to have an adequate root-filling length in the present study compared to the De Moor study (OR: 1.16, 95% CI: 0.86 to 1.55), but the difference was not statistically significant (Table 6).

DISCUSSION

Observational studies, in which investigators do not randomly allocate an intervention or use no comparison group, are ranked lower than analytical studies in the hierarchy of evidence (Forrest, 2009). Despite this, cross-sectional studies can provide useful insights into hypotheses or research questions to be addressed in the randomized clinical trials (Gilmartin-Thomas et al., 2018). This study design has a number of advantages in comparison with the randomized controlled trials, including cost-effectiveness, a faster and simpler implementation, as well as the ability to address factors which cannot be randomized ethically, such as the correlation between poor root-filling quality and AP or poor coronal restoration and AP. Cross-sectional studies are useful for providing information regarding the distribution and prevalence of a disease in a population, as well as the associated risk factors (Eriksen et al., 2002). A recognized drawback of cross-sectional studies is the inability to ascertain whether an AP lesion is healing or advancing. Petersson et al. (1991) revealed that after a 10-year period the number of healed periapical lesions equalled the number of newly developed lesions, suggesting that the outcomes of cross-sectional studies remain valid. Importantly, the focus of this study was on aspects related to the prevalence of AP in a specific population and not on the outcome of endodontic treatment. Since the present study is cross-sectional, a statistically significant result does not confirm any causal effect, which is the case in a randomized controlled study; it merely indicates a statistical association between the investigated variables. Furthermore, a statistically non-significant result is not evidence of no association between the investigated variables.

This study used a cross-sectional approach based on existing panoramic radiographs, constituting a convenience sample rather than a random selection of the Belgian population. The 614 patient records available for the study exceeded the minimal 384 necessary in order to obtain statistically significant results. Although it is more scientifically robust to draw a random sample from the general population and invite these patients to undergo a radiographic (or even clinical) screening, there are some ethical considerations regarding inviting people and taking radiographs for epidemiological

TABLE 5 Multilevel multivariable logistic regression for the association of apical periodontitis with several tooth-level characteristics (312 patients, 856 teeth).

Tooth characteristic (95% CI)	Apical periodontitis[a] (%) ratio	Odds
Coronal status[b]		
Indirect	91/205 (44%)	**0.31 (0.14, 0.73)**
Non-metallic direct	170/426 (40%)	**0.24 (0.12, 0.51)**
Metallic direct	42/109 (39%)	**0.17 (0.07, 0.40)**
Caries	82/116 (71%)	#
Non-metallic direct		0.77 (0.42, 1.43)
Metallic direct		0.53 (0.24, 1.15)
Indirect		#
Non-metallic direct		1.45 (0.77, 2.73)
Metallic direct		#
Coronal restoration quality		
Inadequate	107/162 (66%)	**1.96 (1.10, 3.52)**
Adequate	196/578 (34%)	#
Post		
With	67/142 (47%)	1.87 (0.99, 3.54)
Without	318/714 (45%)	#
Root-filling material		
Other	34/55 (62%)	1.94 (0.77, 4.88)
Gutta-percha	351/801 (44%)	#
Root-filling length		
Inadequate	318/419 (76%)	1.68 (0.70, 4.04)
Adequate	67/437 (15%)	#
Density		
Inadequate	312/389 (80%)	**6.86 (3.53, 13.34)**
Adequate	73/467 (16%)	#
Root-filling quality		
Inadequate	339/460 (74%)	2.42 (0.73, 7.98)
Adequate	46/396 (12%)	#
Treatment quality		
Inadequate	360/539 (67%)	1.44 (0.60, 3.48)
Adequate	25/317 (8%)	#
Adjacent implant		
With	4/17 (24%)	0.44 (0.08, 2.54)
Without	381/839 (45%)	#

Note: Statistically significant results are indicated in bold.

Abbreviations: #, reference category; CI, confidence interval.

[a]Number of cases with apical periodontitis out of the total number of cases in the investigated category.

[b]All six possible pairwise comparisons among the categories of coronal status are presented.

TABLE 6 Comparison of the quality of the root canal treatment between the two studies (length of the root-filling material).

Length of the root filling	Present study	De Moor	
0–2 mm short of the radiographic apex	437 (51.1)	109 (47.4)	OR: 1.16, 95% CI: 0.86 to 1.55
>2 mm short of the radiographic apex	411 (48.0)	115 (50.0)	
extrusion beyond the radiographic apex	8 (0.9)	6 (2.6)	

reasons. Many other studies used a similar convenience sample (Kielbassa et al., 2017; Nascimento et al., 2018; Song et al., 2014; Timmerman et al., 2017; Van der Veken et al., 2017). Furthermore, the demographic distribution of the present cohort (age and gender) is similar to that of the Belgian population (Statbel, 2023) and to the population of the previous study (De Moor et al., 2000) The Figures S1–S3 depict the differences in the distribution of missing teeth, coronal status, root canal status, and periapical status according to tooth type between the two studies. In addition, the cost of dental care at dental schools in Belgium does not differ significantly compared to that charged in private practices, so this should not influence the socio-economic constitution of the sample either. Nevertheless, caution should be exercised when extrapolating the findings to the general population.

Whilst histological examination is the gold standard for confirming the presence of AP (de Paula-Silva et al., 2009; Dutta et al., 2014), panoramic radiographs were used in the present study, for a variety of reasons. First, we aimed to compare our results with the findings of the first study on the prevalence of AP in Belgium (De Moor et al., 2000), which also utilized panoramic radiographs. Secondly, this study only evaluated the presence, not the degree, of AP. Panoramic radiographs can be used for the basic detection of AP (Cotti & Schirru, 2022). If a study aims to apply a quantitative measurement approach of AP, then another radiographic method should be used (Kirkevang et al., 2001a, 2001b). Thirdly, we needed full-mouth data in order to perform an analysis at both the patient and tooth level. At the Ghent University Hospital Dental Clinic, full-mouth surveys using periapical radiographs are only taken for patients with periodontal disease, thus introducing a selection bias when basing a study on full-mouth periapical surveys. Similarly, in our dental clinic, CBCT scans are only conducted for specific diagnostic purposes and never routinely conform the position statement of ESE (ESE, 2014). However, a panoramic radiograph is taken for every new patient presenting at the dental school. Thus, full-mouth data, while maintaining the sample size as representative as possible, was only achievable with the use of panoramic radiographs.

The use of panoramic radiographs could result in an underestimation of the disease because of their low sensitivity, even though they may have high specificity and good diagnostic accuracy (Cotti & Schirru, 2022; Nardi et al., 2018). In a study about the future of imaging techniques for the detection of periapical lesions, Cotti and Schirru (2022) concluded that dental panoramic tomography is still considered a useful exam for the basic diagnosis of AP, which is important for epidemiological studies. Some researchers have proposed that the greater accuracy of cone-beam computed tomography (CBCT) scans could improve the reliability of prevalence studies on AP (Di Filippo et al., 2014; Peters et al., 2011). Yet, more recent studies have indicated that CBCT can increase the probability of false-positive and false-negative diagnoses, particularly in root-filled teeth (Kruse et al., 2019). Moreover, it is known that 42% of the cases where a periapical inflammatory lesion could be detected based on a CBCT scan, display no inflammation histologically and therefore no need for intervention (Kruse et al., 2017). Moreover, guidelines have advised the use of CBCT for strictly specific indications and not for routine diagnostic imaging (ESE, 2014). A recent systematic review and meta-analysis on the global prevalence of AP (Tibúrcio-Machado et al., 2021), considering the ALARA and ALADA principles, concluded that CBCT should not be the method of choice for AP diagnosis in epidemiological studies.

Numerous cross-sectional studies have utilized panoramic radiographs due to their convenience and the validity in diagnosing AP in epidemiological research (Da Silva et al., 2009; Kayahan et al., 2008; Loftus et al., 2005).

Several epidemiological studies have examined the prevalence of AP in different populations, with results at the tooth level ranging from 1.5% to 15%. In the present study, the prevalence of AP was found to be 46.9% among all patients and 5.6% among all teeth examined. Previous research conducted in Belgium, reported the prevalence of AP amongst teeth to be 6.6% and 5.9% respectively (De Moor et al., 2000; Van der Veken et al., 2017). The present results also align with the global prevalence of AP, which was determined to be 52% at the individual level and 5% at the tooth level in a recent systematic review (Tibúrcio-Machado et al., 2021). Root fillings were found in 51.1% of patients and 5.9% of teeth, slightly lower than the global averages of 55.7% and 8.2%, respectively. (León-López et al., 2022). Of the root-filled teeth, 45% had AP, aligning with other studies. De Moor et al., 2000 (40.4%), Van der Veken et al., 2017 (32.7%), Dugas et al., 2003 (45.4%), Kabak & Abbott, 2005 (45.2%), Tsuneishi et al., 2005 (40%), and Eriksen et al., 2002 (42.6%).

When assessing the relationship between the recorded patient-level and tooth-level variables and AP prevalence, a number of factors were found to impact AP prevalence. A statistically significant association was found between the patient's number of teeth and the likelihood of presenting AP, with patients who had more teeth being less likely to exhibit AP. Missing teeth can be attributed to various patient factors, including high caries activity, social risk factors, and poor oral hygiene, as well as dentist-related factors such as poor quality restorative treatments and the use of more invasive treatment methods. Regardless of

the cause, it is not unexpected to find an increased prevalence of AP in the remaining teeth (Lambert et al., 2018; Ramsay et al., 2018).

A statistically significant association was also found between the patient's number of root-filled teeth and the likelihood of presenting AP, with patients having more root-filled teeth being more likely to present with AP. This is a logical consequence of the high rate of AP in root-filled teeth.

When evaluating the influence of the number of implants, patients with a greater number of implants had lower odds of AP. The presence of implants suggests that these patients are motivated to have teeth replaced and demonstrates access to high levels of dental care, and dental mindedness of these patients. Another explanation is that teeth with AP in these patients have been extracted and replaced by implants instead of opting for primary or secondary treatment or surgical endodontics. The necessity of establishing a healthy dentition prior to implant placement could also be the case.

The patient's gender was not found to be a statistically significant factor in our study. These results are consistent with previous studies that found no statistically significant gender-based differences (Boucher et al., 2002; Jiménez-Pinzón et al., 2004; Kirkevang et al., 2001a, 2001b), but contradict some other studies who found that AP was more prevalent in men than in women (Huumonen et al., 2017). Our findings, in line with Kirkevang et al., 2004, associate inadequate coronal restorations and caries to a higher risk of AP prevalence. Adequate restorations and any other coronal status (indirect, non-metallic, or metallic) were associated with lower AP prevalence. However, relying solely on radiographs to rate the quality of the coronal restoration has limitations due to weak correlation with the clinical findings (Dugas et al., 2003; Hommez et al., 2002).

Accurate assessment requires both clinical and radiographic examination. De Moor et al., 2000 evaluated the quality of root canal treatment based only on the length of the root-filling material. In the present study, treatment quality was assessed not only by the length of the root-filling material but also by its density, which was found to be a statistically significant factor associated with the prevalence of AP. In order to compare the quality of treatment between the two studies, we analysed solely the root-filling length data in our dataset, as outlined in Table 6. The results suggest that there is no statistically significant difference in the quality of root filling between the two studies. This aligns with the findings of Peters et al. (2011) who found that the periapical status in an Amsterdam subpopulation showed no improvement over nearly 2 decades. However, this conclusion differs from the results obtained by Kirkevang et al. (2001a, 2001b) who reported an improvement in the technical quality of endodontic treatment over the last 24 years, although the prevalence of AP did not decrease. Connert et al. (2019) found an improvement in AP prevalence and the quality of root canal treatment after 20 years in a German population. AP prevalence in the 1993 sample was 3.37%, whilst in the 2013 sample, it was 2%. Although this is considered an improvement, no statistical analysis is mentioned for the comparison of these numbers.

Our study compared the 6.6% prevalence of AP in the study by De Moor with the 5.6% prevalence observed in the present study. Based on the risk difference and the confidence intervals, this difference was not statistically significant. Considering the lack of consensus in the endodontic literature regarding what constitutes a 'clinically significant difference' in AP prevalence, our study relied on the statistically significant difference to draw conclusions. However, it is known that clinical and statistical differences do not always align (Kang et al., 2017).

In the same study (Connert et al., 2019), the number of acceptable root filled teeth in 1993 was 14.4% and improved to 34.7% after 20 years. These percentages differ from the percentages of acceptable root fillings in our study, which were significantly higher (47.4% in the study of De Moor, and 51.1% after 22 years). So although in the study by Connert et al., 2019 a considerable improvement was defined, the increased percentage of 34.7% was still 12.7% below the reference percentage from our first study. In addition, no statistical analysis for the comparison of these numbers is mentioned by Connert et al., 2019. In our study, the difference between the two values was not statistically significant according to the binomial analysis that was performed.

It is important to note that the assessment of root-filling density through two-dimensional panoramic radiographs has limitations as it may not accurately reflect the true homogeneity of the root filling in all planes, which could lead to an underestimation of inadequate root fillings. Thus, only root fillings that were significantly inadequate in terms of density were probably identified.

Numerous studies have indicated that the presence of technically inadequate root fillings is associated with increased AP prevalence (Chala et al., 2011; De Moor et al., 2000; Dugas et al., 2003; Huumonen et al., 2012, 2017; Kabak & Abbott, 2005; Kirkevang et al., 2001a, 2001b; Loftus et al., 2005; Lupi-Pegurier et al., 2002; Özbaş et al., 2011; Peters et al., 2011; Segura-Egea et al., 2004; Sjögren et al., 1990; Sunay et al., 2007; Van der Veken et al., 2017). The present results suggest otherwise, as no statistically significant association of root-filling quality or length with respect to the prevalence of AP was found. One of the explanations for this difference could lie in the statistical analysis used in our study, which was a multilevel multivariable binary logistic regression. This

analysis considers multiple predictors and their complex interactions that might be missed in simpler analyses like univariate logistic regression or analyses without predictor clustering. It controls for potential confounders and handles nested data structures accurately. The present findings are, however, consistent with the findings of Zhong et al. (2008), who, in a sample of 609 root filled teeth, found no statistically significant association between root-filling length and AP prevalence, but higher AP prevalence in cases with poor root-filling density. The latter was also observed in our findings, with the odds of AP in case of poor root-filling density being almost 7 times higher than in cases of adequate root-filling density.

Regarding the assessment of root-filling length, divergent standards have been observed in different studies regarding the permissible extent of root filling in relation to the apex. A 2 mm distance has been proposed by the European Society of Endodontology (2006), while other studies (Huumonen et al., 2012, 2017; Kirkevang et al., 2001a, 2001b; Segura-Egea et al., 2004) have recommended a 3 mm distance. For the present study, the 2 mm distance was adopted as the threshold value.

According to the present results, there has not been any substantial change in the prevalence of AP nor the quality of root canal treatment over the last 22 years. The number of teeth with an adequate root-filling quality remains unacceptably low, which is in accordance with other studies (Peters et al., 2011; Timmerman et al., 2017), despite the 22 years of technological advancement in the field and continued undergraduate and postgraduate educational efforts in Belgium. Despite being amongst the wealthiest nations globally, the prevalence of AP remains disappointingly high, and the quality of root canal treatment poor. This calls for strategic action in the field.

CONCLUSION

The prevalence of AP at patient and tooth level was 46.9% and 5.6%, respectively. AP prevalence in root filled teeth was 45%, and 54% of the root fillings were of poor quality. At patient level more teeth, more implants and less RCT teeth were linked with lower AP prevalence. At the tooth level, presence of caries, inadequate root-filling density, and inadequate quality of the coronal restoration were associated with higher AP prevalence. No considerable change in the prevalence of AP or technical quality of root canal treatment over the last 22 years was observed.

AUTHOR CONTRIBUTIONS

Georgios Keratiotis, Mieke De Bruyne, Roeland De Moor, and Maarten Meire: conceptualization and design. Georgios Keratiotis: patient data retrieval, assessment of the radiographs, and data registration. Georgios Keratiotis, Loukia Spineli, and Maarten Meire: data management, analysis, and interpretation. Georgios Keratiotis, Loukia Spineli, and Maarten Meire: writing and managing the manuscript.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasheets of the study are available after communication with the corresponding author.

ETHICS STATEMENT

This study has been independently reviewed and approved by an ethical board, the ethics commission of Ghent University (Registration number: THE-2022-0024). This research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version 2008) and the requirements of Belgium where the research has been carried out. All data were handled and evaluated according to the above-mentioned principles.

PATIENT CONSENT STATEMENT

The requirement for obtaining informed consent was waived because of the retrospective nature of the study.

REPORTING GUIDELINES

This study has been conducted in accordance with the reporting guidelines by PROBE 2023 for observational studies in endodontics and the recommended checklist is enclosed.

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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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