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Prevalence of apical periodontitis and its association with previous root canal treatment, root canal filling length and type of coronal restoration – a cross-sectional study

J. Meirinhos[1], J. N. R. Martins[1], B. Pereira[1], A. Baruwa[1], J. Gouveia[1], S. A. Quaresma[1], A. Monroe[2] & A. Ginjeira[1]

[1]Department of Endodontics, Faculdade de Medicina Dentária, Universidade de Lisboa, Lisbon, Portugal; and [2]Private Practice, San Diego, CA, USA

Abstract

Meirinhos J, Martins JNR, Pereira B, Baruwa A, Gouveia J, Quaresma SA, Monroe A, Ginjeira A. Prevalence of apical periodontitis and its association with previous root canal treatment, root canal filling length and type of coronal restoration – a cross-sectional study. *International Endodontic Journal*.

Aim To analyse the prevalence of periapical lesions and their association with previous root canal treatment, root canal filling length and type of coronal restoration using *in vivo* cone-beam computed tomographic (CBCT) assessment.

Methodology A global sample of 20 836 teeth, with a combined total of 27 046 roots, from 1160 patients, was analysed via CBCT assessment in eight health centres. Each tooth was evaluated by one out of five examiners after having performed a defined calibration procedure on the basis of 319 teeth. Intra- and inter-rater reliability tests were performed. Each tooth was classified according the tooth number, presence/absence of periapical lesions, presence/absence of previous root canal treatment, length of root canal filling (short, good or overfilling) and type of coronal restoration. The *z*-test for proportions was used to analyse differences between tooth subgroups, and an odds ratio was determined in order to analyse the association between treatment status and periapical lesions. A $P < 0.05$ was considered significant.

Results At a tooth level, the overall prevalence of periapical lesions in the sample was 10.4%. Maxillary teeth were associated with a significantly larger percentage of lesions (13.1%), whilst maxillary first molars had the greater proportion of lesions (21.2%). The prevalence of periapical lesions was significantly larger in root filled teeth (55.5%), short root canal fillings (72.7%) and in teeth restored with crowns (46.1%). At a root level, the mesiobuccal roots of both maxillary first molars had a tendency for a larger percentage of periapical lesions.

Conclusion History of root canal treatment, root canal filling length and type of coronal restoration influenced the presence of periapical lesions. Molars were more commonly associated with periapical lesions on root filled teeth, particularly those with short root fillings and those with crowns.

Keywords: apical periodontitis, cone-beam computed tomography, cross section study, diagnostic imaging, endodontically treated teeth, outcome measure.

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Correspondence: Jorge N. R. Martins, Faculdade de Medicina Dentária da Universidade de Lisboa, Cidade Universitária, 1649-003 Lisboa, Portugal (e-mail: jnr_martins@yahoo.com.br).

Introduction

Apical periodontitis is a local inflammatory response due to the presence of microorganisms within an infected root canal system (Abbott 2004). Populations of microorganisms within the canal system are the main cause of post-treatment endodontic disease, which is most often revealed upon radiographic examination (Estrela *et al.* 2008a).

Contamination of the root canal system may arise in teeth with or without previous root canal treatment (Van der Veken *et al.* 2016). However, several authors (Saunders *et al.* 1997, De Moor *et al.* 2000, López-López *et al.* 2012) have reported that apical periodontitis is more prevalent in root filled teeth. In these cases, the treatment outcome may be influenced by characteristics of the root filling such as poor condensation, short root fillings or extrusion of material into the periapical tissues (Ray & Trope 1995, Sjögren *et al.* 1997, Riccucci *et al.* 2011, Fernández *et al.* 2017). Further studies have suggested that a high-quality coronal restoration helps to prevent root canal re-infection, and crown cuspal coverage significantly improves the prognosis for teeth following root canal treatment (Imura *et al.* 2007, Ng *et al.* 2010, Chala *et al.* 2011, Landys Borén *et al.* 2015). Post-treatment endodontic disease appears to be associated with many factors (Byström *et al.* 1987). A systematic review by Ng *et al.* (2008) concluded that four factors were associated with better outcomes following root canal treatment: preoperative absence of periapical radiolucency, root canal filling extending to 2 mm within the radiographic apex, root canal filling with no voids and a satisfactory coronal restoration.

Imaging techniques used to evaluate the presence of periapical lesions include periapical radiographs, panoramic radiographs and cone-beam computed tomography (CBCT). CBCT is able to provide a three-dimensional view of the area of interest and appears to be the most accurate technique when trying to detect these types of lesions (Estrela *et al.* 2008a, Patel *et al.* 2012a, Weissman *et al.* 2015, Karabucak *et al.* 2016). Therefore, it follows that CBCT assessment of periradicular tissues may help to predict tooth prognosis and long-term survival.

Although several studies have performed assessments on the association of periapical lesions with many different factors, including multi-rooted teeth, the direct study of each particular root, in multi-rooted teeth, has yet to be fully addressed. Each root of a multi-rooted tooth may have a separate outcome. Therefore, the aim of this study was to analyse, in both teeth and individual roots, the prevalence of periapical lesions according to several factors, including the presence of a previous root canal treatment, apical extension of root canal filling and type of coronal restoration *in vivo* using CBCT assessment. The null hypotheses to be tested was there is no difference in the prevalence of periapical lesions in each tooth type or each particular root regarding the following variables: (i) presence/absence of previous root filling, (ii) apical extension of root canal filling and (iii) type of coronal restoration.

Material and methods

Cone-beam computed tomography examinations from 1160 patients, 497 males and 663 females with an average age of 48.4 years, were collected from databases in eight health centres. The metropolitan areas of Lisbon, Oporto, Espinho, Moita and Maia, were selected in order to include the main population regions throughout Portugal. All the CBCT examinations available on those centres were analysed. Each scan was evaluated on-site using the same step-by-step screening protocol by one of five independent examiners after calibration through intra- and inter-rater reliability tests (see statistical analysis). The screening protocol included an initial tooth/root selection, followed by a mandatory root alignment in the three planes (coronal, sagittal and axial) in order to have a centred view in the three planes, which was followed by the tooth/root classification according to the parameters to be assessed that were analysed always following the same order (see below the parameter to be classified). This study was built on a convenience sample, and the observers performed an analysis of all the data available at each source location. All available CBCT scans were collected from existing image databases and were performed between 2012 and 2018 for several diagnostic reasons, but not for the purpose of the present study. The CBCT devices varied in brand and model depending on location, however, the inclusion criteria required that only full-arch scans with voxel sizes equal to or less than 200 μm would be eligible for the study. Table 1 summarizes the CBCT characteristics and settings used. The specific visualization programmes varied depending on location, however, all software had similar functionalities to allow for a consistent assessment methodology. All samples were analysed in the coronal, sagittal and axial planes, and a noise reduction filter was applied if necessary. Third molars, unrestorable root fragments, impacted teeth, deciduous or permanent teeth with immature apices were excluded. Teeth that could not be measured due to image artefacts were also excluded and represented less than 1.0% of the overall assessed teeth sample. Moreover, 3.0% of the analysed patients were not included in the study mainly due to severe metal artefacts coming from large restorations or implants that made the analysis of the majority of the teeth/roots present impossible. The data assessment was performed between January and December 2018 and followed the 'strengthening the reporting of observational studies in epidemiology' (STROBE statement) after the study approval by the ethics commission of Faculdade de Medicina Dentária da Universidade de Lisboa.

A total of 20 836 teeth and 27 046 roots were included. Root-by-root assessments were performed on molars exclusively.

Each tooth, and root, was classified according to the following parameters:

- Tooth (or root) number
- Presence/absence of periapical radiolucency according to CBCT periapical index score proposed by Estrela *et al.* (2008b). Absence was define according to score 0 (intact periapical bone structures) and presence according to scores 1 to 5 (diameter of periapical radiolucency above 0.5 mm)
- Presence/absence of previous root filling
- Length of root filling (classified as follows: 'Short' when 2 mm short of the radiographic apex; 'Good' when filled to within 0–2 mm of the radiographic apex; and 'Overfilling' when past the radiographic apex). The alignment of the three planes was performed in the step-by-step screening method and allowed a double-check of the length measurements in both coronal and sagittal views. Since these two views may present small variations due to the root canal morphology in the apical area, the longer length (worst scenario) was the one to be considered.
- Presence/absence of lateral radiolucency.
- Presence/absence of root resorption.
- Type of coronal restoration (intact tooth, unrestored/cavitated, intracoronal restoration, crown and abutment).

Table 2 summarizes the sample characteristics.

Statistical analysis

A sample size calculation was conducted taking into consideration the data collected in the initial 6 months of the project, and, based on those initial outcomes, it was concluded that at least 61 teeth were required in both groups of short and good root filling length to identify a significant difference regarding the presence of periapical lesions, with an alpha type error of 0.05, a power of 0.80 and an effect of 24.0%.

In order to determine the individual and group reliability of assessment, intra- and inter-reliability tests were conducted. The individual reliability was calculated using Cohen's kappa test after all observers performed the assessment of periapical health status, presence of a previous root filling and type of coronal restoration on the initial 319 teeth twice with one-month interval between assessments. The group reliability was determined by calculating the interclass correlation coefficient (ICC) on those same 319 teeth. The observers and the group were considered reliable for both inter- and intra-rater reliability tests if the kappa coefficient of agreement and ICC value were equal or superior to 0.61. Table 3 summarizes the reliability test results.

All collected data were introduced into SPSS software (version 24; IBM SPSS Statistics, Chicago, IL, USA). The primary outcome was the prevalence of

Table 1 Geographic location and cone-beam computed tomographic characteristics

Location	District	CBCT Model	Brand	Voxel Size (μm)	FOV (Small/Full Arch)	Observer
Espinho	Aveiro	Hyperion x5	My Ray, Imola, Italy	80	Full	J.Me.
Lisbon	Lisbon	Rayscan α+	Ray, Gyeonggi-do, Korea	180	Full	A.B.
Lisbon	Lisbon	R100	Morita, Kyoto, Japan	125	Full	A.B.
Lisbon	Lisbon	I-Max Touch	Owandy, Croissy-Beaubourg, France	185	Full	J.G.
Lisbon	Lisbon	Promax 3D	Planmeca, Helsinki, Finland	200	Full	J.Ma.
Maia	Oporto	Vistavox	Durr Dental, Gechingen, Germany	120	Full	J.Me.
Moita	Setúbal	NewTom Giano	NewTom, Verona, Italy	75	Full	B.P.
Oporto	Oporto	Orthophos Xg 3D	Sirona, Bensheim, Germany	160	Full	J.Me.

Table 2 Sample charactistics

Factors evaluated	Roots, *n* (%)	Teeth, *n* (%)
Sample characterization		
Gender		
Female	15 214 (56.3%)	11 828 (56.8%)
Male	11 832 (43.7%)	9008 (43.2%)
Age		
≤40	10 242 (37.9%)	7521 (36.1%)
>40	16 804 (62.1%)	13 315 (63.9%)
Tooth type		
Anterior teeth	10 455	10 455
Premolars	5768	5768
Molars	10 823	4613
Tooth location		
Maxilla	14 297	10 067
Mandible	12 749	10 769
Sample clinical conditions		
Periapical lesion		
Yes	2913 (10.8%)	2177 (10.4%)
No	24 133 (89.2%)	18 659 (89.6%)
Lateral radiolucency		
Yes	127 (0.5%)	98 (0.5%)
No	26 919 (99.5%)	20 738 (99.5%)
Root resorption		
Yes	258 (1.0%)	236 (1.1%)
No	26 788 (99.0%)	20 600 (98.9%)
Previous root canal treatment		
Yes	3281 (12.1%)	2305 (11.1%)
No	23 765 (87.9%)	18 531 (88.9%)
Missed canals		
Yes	297 (1.1%)	276 (1.3%)
No	2984 (11.0%)	2029 (9.7%)
Length root canal obturation		
Short > 2 mm	1181 (4.4%)	832 (4.0%)
Good 0–2 mm	1636 (6.0%)	1114 (5.3%)
Overfilling	463 (1.7%)	359 (1.7%)

periapical lesions, whereas the predictive variables were the tooth numbers, history of root canal treatment, length of root canal filling and the presence/absence of a coronal restoration. The prevalence for each group was calculated as well as the lower and upper limits of the 95% confidence intervals (CI). The z test for proportions was used to analyse differences between groups of teeth, and an odds ratio was determined. For all compared groups, a P value of < 0.05 was considered significant.

Results

Tooth analysis

The prevalence of periapical lesions in maxillary teeth was largest in first molars (21.2% [18.9%–23.6% CI 95%]) and was significantly greater ($P < 0.05$) than the percentage on both maxillary incisors and canines. The maxillary lateral incisors (9.2% [7.8%–10.6% CI 95%]) and canines (8.1% [6.8%–9.4% CI 95]) had lower percentages with no significant difference between them ($P > 0.05$). In mandibular teeth, first molars had the largest prevalence of periapical lesions (18.8% [16.3%–21.3% CI 95%]), which was significantly greater when compared to all other mandibular teeth ($P < 0.05$), except for the mandibular second molar ($P > 0.05$). The mandibular lateral incisors (5.5% [4.5%–6.6% CI 95%]) and canines (4.2% [3.3%–5.1% CI 95%]) had a significantly lower prevalence ($P < 0.05$), with no difference between them ($P > 0.05$). There was also no significant difference in lesion prevalence between maxillary and mandibular first molars ($P > 0.05$). Table 4 presents a descriptive analysis of the results according to tooth group.

The overall prevalence of periapical lesions was 10.4%. The proportion of lesions was significantly larger ($P < 0.05$) in maxillary teeth (13.1% [12.44%–13.76% CI 95%]) when compared to mandibular teeth (8.0% [7.5%–8.5% CI 95%]). Root filled teeth had a 24.5 higher odds of being associated with periapical lesions versus nonroot filled teeth. Teeth with short root fillings had a 3.1 higher odds of being associated with periapical lesions when compared to teeth with good root filling length. Good fillings and overfillings were not significantly different ($P > 0.05$) and both had a significantly lower prevalence when compared to short root fillings ($P < 0.05$; Fig. 1). Intact teeth had significantly less ($P < 0.05$) prevalence of periapical lesion (2.8% [2.5%–3.1% CI 95%]) when compared with unrestored/cavitated teeth, or those with intracoronal restoration, crown or bridge abutments. There was no significant difference ($P > 0.05$) between teeth restored with crowns (46.1% [42.6%–49.6% CI 95%]) or teeth acting as bridge abutments (45.5% [40.8%–50.2%]), and however, both had a significantly greater ($P < 0.05$) proportion of periapical lesions when compared to all other groups (Fig. 2). Table 5 presents a descriptive analysis of the overall results and according to dental arch.

Root analysis

The prevalence of periapical lesions amongst different roots of the same tooth group was very similar. However, there was a tendency for greater percentages on mesiobuccal roots of maxillary molars and mesial roots of mandibular molars. The mesiobuccal root

Table 3 Intra- and inter-rater reliability test value

Factors evaluated	Observers Teeth evaluated twice	A Intra-reliability test values[a]	B Intra-reliability test values[a]	C Intra-reliability test values[a]	D Intra-reliability test values[a]	E Intra-reliability test values[a]	Inter-reliability test value[b]
Apical periodontitis	319	0.610	0.818	0.774	0.951	0.737	0.915
Previous root canal treatment	319	1.00	1.00	1.00	0.982	1.00	0.935
Coronal restoration	319	1.00	0.678	1.00	0.838	0.734	0.938

[a]Cohen kappa.
[b]Interclass correlation coefficient.

was 10% more likely to be associated with a periapical lesion when compared to distobuccal and palatal roots in previously treated maxillary first and second molars. Table 6 presents a descriptive analysis of the results according to molar root group.

Discussion

Prognostic factors for the outcome of root canal treatment include the following: presence of preoperative periapical lesions (Ng *et al.* 2011), rubber dam use (Ahmad 2009, Lin *et al.* 2014), density/extent of root canal filling (Ng *et al.* 2008, Riccucci *et al.* 2011) and quality of coronal restorations (Ray & Trope 1995). Additional important prognostic factors for tooth retention include the following: age (Imura *et al.* 2007, Landys Borén *et al.* 2015), tooth type (Imura *et al.* 2007, Ng *et al.* 2010), presence of mesial/distal contacts (Ng *et al.* 2010) and post-treatment type of coronal restoration (Ng *et al.* 2008, Landys Borén *et al.* 2015). Several studies from different research groups unanimously highlight the high prevalence of periapical periodontitis associated with poor-quality root fillings (Boucher *et al.* 2002, Segura-Egea *et al.* 2004, Georgopoulou *et al.* 2005, Kabak & Abbott 2005, Chala *et al.* 2011, Paes da Silva Ramos Fernandes *et al.* 2013, Dutta *et al.* 2014, Van der Veken *et al.* 2016, Huumonen *et al.* 2017).

Previous studies have documented that CBCT imaging, as a radiological technique, is better able to detect periradicular changes versus conventional radiography (Estrela *et al.* 2008a, Ordinola-Zapata *et al.* 2011, Patel *et al.* 2012b). According to Estrela *et al.* (2008a), who analysed the same 1425 endodontically treated teeth using three different imaging techniques, the percentage of identified periapical lesion was 17.6%, 35.3% and 63.3% for panoramic radiographs, periapical radiographs and CBCT, respectively. These differences were considered statistically significant. The authors concluded that the CBCT technique had a higher sensibility to identify periapical lesions and that conventional radiographs tend to underestimate the prevalence of lesions mostly due to false-negative cases. One factor that might partially justify these results is the fact that approximately 30%–50% mineral bone loss is required for the lesion to be identified by conventional radiographs (Estrela *et al.* 2008a). In addition, a three-dimensional assessment allows a more reliable analysis of many other dependent variables such as root filling length or crown and intracoronal restorations, when compared to two-dimensional analysis. However, it is important to note also that overdiagnosis of periapical periodontitis in previous root canal treated teeth assessed by CBCT has also been reported (Kruse *et al.* 2019).

Moreover, inter-observer reliability tests demonstrate that CBCT assessment is a reliable and reproducible method to study the prevalence of periapical lesions. However, it is important to be aware that beam hardening artefacts, caused by radiopaque materials such as metal posts, metal restorations and root filling materials, may reduce imaging quality and represent a limitation of CBCT assessment (Estrela *et al.* 2008b).

The overall prevalence of periapical lesions detected in the present study was 10.4%, which is within the range (1.4%–15.1%) found in previous studies using panoramic radiographs (De Moor *et al.* 2000, Kabak & Abbott 2005, Al-Omari *et al.* 2011) or CBCT imaging (Paes da Silva Ramos Fernandes *et al.* 2013, Dutta *et al.* 2014). The maxilla (13.1%) was more commonly affected than the mandible (8.0%), and molars had a significantly greater prevalence ($P < 0.05$; Table 5), which is in agreement with a previous study (Paes da Silva Ramos Fernandes *et al.*

Table 4 Prevalence of periapical lesion according to tooth and previous root filling treatment, root filling length and type of coronal restoration

Factors evaluated	Periapical lesion	Central incisor	Lateral incisor	Canine	First premolar	Second premolar	First molar	Second molar
Maxillary teeth								
Periapical lesion	Presence	191 (11.3%)	150 (9.2%)	136 (8.1%)	217 (16.7%)	186 (15.0%)	246 (21.2%)	194 (14.4%)
Previous root canal treatment								
Yes	Presence	116 (49.4%)	96 (51.6%)	74 (36.1%)	141 (60.3%)	136 (54.0%)	167 (72.6%)	105 (67.7%)
	Absence	119 (50.6%)	90 (48.4%)	131 (63.9%)	93 (39.7%)	116 (46.0%)	63 (27.4%)	50 (32.3%)
No	Presence	75 (5.1%)	54 (3.7%)	62 (4.2%)	76 (7.1%)	50 (5.1%)	79 (8.5%)	89 (7.5%)
	Absence	1383 (94.9%)	1397 (96.3%)	1419 (95.8%)	991 (92.9%)	939 (94.9%)	854 (91.5%)	1102 (92.5%)
Length root canal filling								
Short> 2 mm	Presence	24 (63.2%)	28 (73.7%)	28 (50.0%)	72 (74.2%)	61 (74.4%)	104 (81.3%)	55 (79.7%)
	Absence	14 (36.8%)	10 (26.3%)	28 (50.0%)	25 (25.8%)	21 (25.6%)	24 (18.8%)	14 (20.3%)
Good 0–2 mm	Presence	74 (46.8%)	48 (42.5%)	38 (33.9%)	57 (54.3%)	66 (46.8%)	42 (61.8%)	34 (61.8%)
	Absence	84 (53.2%)	65 (57.5%)	74 (66.1%)	48 (45.7%)	75 (53.2%)	26 (38.2%)	21 (38.2%)
Overfilling	Presence	18 (46.2%)	20 (57.1%)	8 (21.6%)	12 (37.5%)	9 (31.0%)	21 (61.8%)	16 (51.6%)
	Absence	21 (53.8%)	15 (42.9%)	29 (78.4%)	20 (62.5%)	20 (69.0%)	13 (38.2%)	15 (48.4%)
Coronal restoration								
Intact tooth	Presence	44 (4.3%)	28 (2.8%)	20 (1.9%)	16 (2.5%)	9 (1.6%)	12 (3.4%)	23 (4.1%)
	Absence	983 (95.7%)	982 (97.2%)	1050 (98.1%)	612 (97.5%)	568 (98.4%)	338 (96.6%)	535 (95.9%)
Nonrestored/cavitated	Presence	7 (10.0%)	9 (10.0%)	15 (14.7%)	24 (42.9%)	25 (49.0%)	16 (47.1%)	17 (41.5%)
	Absence	63 (90.0%)	81 (90.0%)	87 (85.3%)	32 (57.1%)	26 (51.0%)	18 (52.9%)	24 (58.5%)
Filling	Presence	65 (15.3%)	50 (12.5%)	62 (16.5%)	118 (23.8%)	80 (16.6%)	161 (23.3%)	121 (18.1%)
	Absence	359 (84.7%)	351 (87.5%)	313 (83.5%)	378 (76.2%)	402 (83.4%)	529 (76.7%)	547 (81.9%)
Crown	Presence	60 (40.0%)	55 (45.1%)	21 (30.0%)	37 (48.7%)	38 (45.2%)	34 (77.3%)	23 (57.5%)
	Absence	90 (60.0%)	67 (54.9%)	49 (70.0%)	39 (51.3%)	46 (54.8%)	10 (22.7%)	17 (42.5%)
Bridge Abutment	Presence	15 (68.2%)	8 (57.1%)	18 (26.1%)	22 (48.9%)	34 (72.3%)	23 (51.1%)	10 (25.6%)
	Absence	7 (31.8%)	6 (42.9%)	51 (73.9%)	23 (51.1%)	13 (27.7%)	22 (48.9%)	29 (74.4%)
Mandibular teeth								
Periapical lesion	Presence	126 (7.0%)	99 (5.5%)	78 (4.2%)	99 (5.8%)	133 (8.8%)	171 (18.8%)	151 (12.7%)
Previous root canal treatment								
Yes	Presence	27 (65.9%)	33 (71.7%)	32 (53.3%)	52 (42.3%)	80 (37.7%)	119 (66.5%)	102 (69.4%)
	Absence	14 (34.1%)	13 (28.3%)	28 (46.7%)	71 (57.7%)	132 (62.3%)	60 (33.5%)	45 (30.6%)
No	Presence	99 (5.7%)	66 (3.7%)	46 (2.6%)	47 (3.0%)	53 (4.1%)	52 (7.1%)	49 (4.7%)
	Absence	1648 (94.3%)	1699 (96.3%)	1734 (97.4%)	1545 (97.0%)	1246 (95.9%)	680 (92.9%)	997 (95.3%)
Length root canal filling								
Short> 2 mm	Presence	7 (87.5%)	12 (92.3%)	16 (59.3%)	23 (60.5%)	36 (50.0%)	77 (88.5%)	62 (78.5%)
	Absence	1 (12.5%)	1 (7.7%)	11 (40.7%)	15 (39.5%)	36 (50.0%)	10 (11.5%)	17 (21.5%)
Good 0–2 mm	Presence	13 (61.9%)	10 (52.6%)	13 (48.1%)	21 (32.8%)	37 (32.5%)	32 (45.7%)	27 (57.4%)
	Absence	8 (38.1%)	9 (47.4%)	14 (51.9%)	43 (67.2%)	77 (67.5%)	38 (54.3%)	20 (42.6%)
Overfilling	Presence	7 (58.3%)	11 (78.6%)	3 (50.0%)	8 (38.1%)	7 (26.9%)	10 (45.5%)	13 (61.9%)
	Absence	5 (41.7%)	3 (21.4%)	3 (50.0%)	13 (61.9%)	19 (73.1%)	12 (54.5%)	8 (38.1%)

Table 4 Continued

Factors evaluated	Periapical lesion	Central incisor	Lateral incisor	Canine	First premolar	Second premolar	First molar	Second molar
Coronal restoration								
Intact tooth	Presence	78 (4.9%)	48 (3.0%)	32 (2.1%)	22 (1.8%)	21 (2.5%)	2 (0.7%)	6 (1.2%)
	Absence	1506 (95.1%)	1529 (97.0%)	1460 (97.9%)	1175 (98.2%)	835 (97.5%)	304 (99.3%)	475 (98.8%)
Nonrestored/cavitated	Presence	3 (37.5%)	6 (23.1%)	6 (7.3%)	5 (5.6%)	20 (33.3%)	18 (52.9%)	10 (40.0%)
	Absence	5 (62.5%)	20 (76.9%)	76 (92.7%)	85 (94.4%)	40 (66.7%)	16 (47.1%)	15 (60.0%)
Filling	Presence	38 (21.7%)	38 (19.9%)	28 (12.4%)	43 (11.7%)	56 (11.3%)	110 (21.7%)	98 (15.8%)
	Absence	137 (78.3%)	153 (80.1%)	198 (87.6%)	326 (88.3%)	438 (88.7%)	397 (78.3%)	522 (84.2%)
Crown	Presence	3 (23.1%)	3 (25.0%)	5 (33.3%)	17 (48.6%)	20 (36.4%)	35 (63.6%)	17 (60.7%)
	Absence	10 (76.9%)	9 (75.0%)	10 (66.7%)	18 (51.4%)	35 (63.6%)	20 (36.4%)	11 (39.3%)
Bridge abutment	Presence	4 (50.0%)	4 (80.0%)	7 (28.0%)	12 (50.0%)	16 (34.8%)	6 (66.7%)	20 (51.3%)
	Absence	4 (50.0%)	1 (20.0%)	18 (72.0%)	12 (50.0%)	30 (65.2%)	3 (33.3%)	19 (48.7%)

2013). This finding may be related to the greater risk of dental caries due to plaque accumulation in difficult to access areas. Also, the inherent anatomical complexity of molar teeth may result in improper root canal debridement, disinfection and root filling (Al-Omari *et al.* 2011). The greater percentages of periapical lesions associated with the mesiobuccal root of the maxillary first molar versus the distobuccal and palatal roots might be related to a greater prevalence of missed canals in the mesiobuccal root, particularly a missed second mesiobuccal canal (Huumonen *et al.* 2006, Costa *et al.* 2018).

Root fillings were present in 2305 teeth in the sample (11.1%). This high percentage of root filled teeth may be explained by an increased dental awareness together with a growing elderly population (Schulte *et al.* 1998). Some studies have shown an association between root filled teeth and apical periodontitis (Kabak & Abbott 2005, Al-Omari *et al.* 2011, López-López *et al.* 2012). The present study found 55.5% of root filled teeth were associated with periapical periodontitis, which is in agreement with the study from Karabucak *et al.* (2016). In addition, the present study revealed a significantly greater prevalence of periapical lesions on root filled teeth when compared with teeth with no root canal treatment. Therefore, the first null hypothesis was rejected.

The results revealed a greater prevalence of periapical lesions (73.2% maxillary teeth and 71.9% mandibular teeth) in teeth and roots with short root fillings (>2mm from the radiographic apex) (Table 5). These results are in accordance with several previous studies (Kirkevang *et al.* 2007, Paes da Silva Ramos Fernandes *et al.* 2013, De Sousa Gomide Guimarães *et al.* 2019). Possible reasons for this finding might include inadequate negotiation, debridement and disinfection of the apical portion of the root canal system and the lack of an adequate apical seal, allowing for the proliferation of apical bacteria and increasing the prevalence of apical periodontitis. Good root filling length (which was defined, in the present study, within 0–2 mm from the radiographic apex in order to match with the same interval assessed by Ng *et al.* (2008) in their review) was associated with a lower prevalence of periapical lesions, which is in line with the results reported in Sjögren *et al.* (1990) using the same radiographic reference. One other study using different root filling length intervals concluded the prevalence of periapical radiolucency was lower in roots filled within 1–2mm short from the apex, followed by 0 mm from the apex and only then more

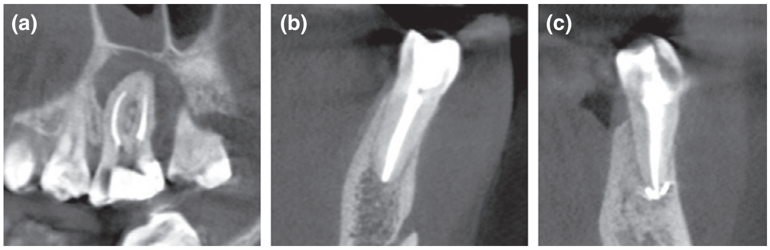

Figure 1 CBCT assessment of root canal filling length: (a) sagittal slice of a maxillary first molar with 'short' root canal fillings and an associated periapical lesion; (b) coronal slice of a mandibular premolar with a 'good' root canal filling length; and (c) coronal slice of a mandibular premolar with an 'overfilling'.

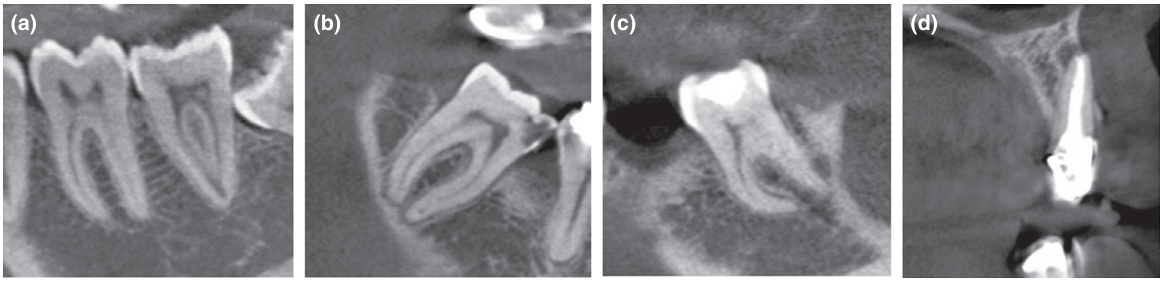

Figure 2 CBCT assessment regarding the type of coronal restoration: (a) sagittal slice of intact mandibular molars; (b) sagittal slice of a unrestored mandibular first molar and an associated periapical lesion; (c) sagittal slice of a mandibular first molar restored with an occlusal restoration; and (d) coronal slice of a maxillary lateral incisor with a history of root canal treatment and crown, with an associated periapical lesion.

than 2 mm shorter from the apex (De Sousa Gomide Guimarães *et al.* 2019). That same study reported the prevalence of periapical lesions was greater on molars, a result that corroborates with the present study. There was a similar prevalence of periapical lesions when comparing good root filling (46.0%) and overfilled (45.4%) canals (Table 5). A previous study (De Sousa Gomide Guimarães *et al.* 2019) found that the extrusion of materials (sealer or Gutta-percha) did not improve the healing of the periapical tissues (Schaeffer *et al.* 2005, Schilder 2006). It has been stated that overfilling may be responsible for irritation and the recruitment of inflammatory cells into the periapical tissues (Ricucci & Langeland 1998), especially when using sealers containing formaldehyde (Riccuci 2002, Dahl 2005). However, in the present study no differences were noted between adequately filled and overfilled canal systems, a finding which contrasts with the classic study of Sjögren *et al.* (1990). Possible explanations for this lack of agreement might include differences in clinical protocols, three-dimensional versus two-dimensional assessment, and limitations when interpreting radiographic images due to interference of the extruded root filling material. Regardless, there was a significant difference when comparing short fills to good fills or overfills, and therefore, the second null hypothesis was also rejected.

When considering the long-term success of root canal treatment, coronal leakage may play an important role, perhaps as important as any aspect or step of the root canal treatment itself (Ray & Trope 1995). Unfortunately, the quality of coronal restorations, although considered relevant (Restrepo-Restrepo *et al.* 2019), is difficult to assess on CBCT scans due to several types of image artefacts. Clinical examination and intraoral radiographs may be more reliable methods of evaluating the quality of coronal restorations (Tyndall & Rathore 2008) than CBCT imaging. In the present study design, it was decided to evaluate only the type of restoration not its integrity. The present study revealed that intact teeth had fewer periapical lesions (2.8%), data which are in agreement with a previous research (Paes da Silva Ramos Fernandes *et al.* 2013). A larger prevalence of periapical lesions was found in teeth restored with either single unit crowns or crowns serving as bridge abutments (46.1% and 45.5%, respectively; Table 5), results

Table 5 Prevalence of periapical lesions according to maxillary and mandibular arches

Factors evaluated	Periapical lesion	Maxillary teeth	Mandibular teeth	Overall
Periapical lesion	Presence	1320 (13.1%)	857 (8.0%)	2177 (10.4%)
Previous root canal treatment				
Yes	Presence	835 (55.8%)	445 (55.1%)	1280 (55.5%)
	Absence	662 (44.2%)	363 (44.9%)	1025 (44.5%)
No	Presence	485 (5.7%)	412 (4.1%)	897 (4.8%)
	Absence	8085 (94.3%)	9549 (95.9%)	17634 (95.2%)
Length root canal filling				
Short> 2 mm	Presence	372 (73.2%)	233 (71.9%)	605 (72.7%)
	Absence	136 (26.8%)	91 (28.1%)	227 (27.3%)
Good 0–2 mm	Presence	359 (47.7%)	153 (42.3%)	512 (46.0%)
	Absence	393 (52.3%)	209 (57.7%)	602 (54.0%)
Overfilling	Presence	104 (43.9%)	59 (48.4%)	163 (45.4%)
	Absence	133 (56.1%)	63 (51.6%)	196 (54.6%)
Coronal restoration				
Intact tooth	Presence	152 (2.9%)	209 (2.8%)	361 (2.8%)
	Absence	5068 (97.1%)	7284 (97.2%)	12352 (97.2%)
Non restored/cavitated	Presence	113 (25.5%)	68 (20.9%)	181 (23.5%)
	Absence	331 (74.5%)	257 (79.1%)	588 (76.5%)
Filling	Presence	657 (18.6%)	411 (15.9%)	1068 (17.5%)
	Absence	2879 (81.4%)	2171 (84.1%)	5050 (82.5%)
Crown	Presence	268 (45.7%)	100 (46.9%)	368 (46.1%)
	Absence	318 (54.3%)	113 (53.1%)	431 (53.9%)
Bridge abutment	Presence	130 (46.3%)	69 (44.2%)	199 (45.5%)
	Absence	151 (53.7%)	87 (55.8%)	238 (54.5%)

which corroborate with Dutta *et al.* (2014). Intracoronal restorations were associated with fewer periapical lesions (17.5%) when compared to full crowns, a fact that might be related to the tooth preoperative status. Teeth restored with full crowns were likely more structurally compromised prior to the root canal treatment and crown placement, factors which may influence the presence of periapical lesions at the time of the CBCT assessment. Therefore, the third null hypothesis was also rejected.

A limitation of cross-sectional studies is the impossibility to determine whether a periapical lesion is healing or progressing (Costa *et al.* 2018). Moreover, this type of data analysis, using a one-point-in-time assessment, does not take into account all causal factors that may affect the outcome or progression of periapical healing. Such factors may include the treatment date and specific clinical procedures (Costa *et al.* 2018), as well as the clinician skills and qualifications (Burry *et al.* 2016). The convenience sample used in the present study represented a sample of the population that attended 8 different health centres, and consequently, it was not possible to adequately judge the quality of the treatment protocols (Paes da Silva Ramos Fernandes *et al.* 2013). Other limitations of the present study were the exclusion of some specimens due to immature apices or the presence of imaging artefacts that interfered with assessment (Estrela *et al.* 2008b).

CBCT is a very helpful clinical tool when assessing the presence of periapical lesions (Peters & Peters 2012), as it provides three-dimensional information and has a greater sensitivity for diagnosis of hard tissue changes (Huumonen *et al.* 2006) when compared to radiographs. In the present study, the axial, sagittal and coronal slices of each tooth were examined to increase the reliability of the assessment, and all scans were taken for clinical reasons other than for the present research in order to avoid the unnecessary exposure of patients to radiation. Moreover, only full-arch examinations were considered in the present study in order to avoid possible bias from small FOV scans. The latter are acquired mostly for endodontic reasons and might therefore be associated with a higher probability of revealing endodontic complications and periapical lesions than full-arch scans. Although the present findings were based on the analysis of a convenience sample, such data provide useful information about the prevalence of periapical lesions in a real clinical practice environment. This increases the study's external validity and may help to define new strategies for prevention, treatment and

Table 6 Prevalence of periapical lesions on each root of multi-rooted molars

		Molar Roots									
		Maxillary teeth[a]						Mandibular teeth[b]			
		First molar			Second molar			First molar		Second molar	
Factors evaluated	Periapical lesion	Mesiobuccal	Distobuccal	Palatal	Mesiobuccal	Distobuccal	Palatal	Mesial	Distal	Mesial	Distal
Periapical lesion	Presence	188 (18.2%)	159 (15.4%)	158 (15.3%)	101 (11.3%)	89 (9.9%)	85 (9.5%)	159 (17.5%)	141 (15.5%)	131 (12.3%)	126 (11.8%)
Previous root canal treatment											
Yes	Presence	130 (65.3%)	107 (53.8%)	105 (52.8%)	57 (55.9%)	46 (45.1%)	44 (43.1%)	112 (62.9%)	102 (57.3%)	88 (65.2%)	85 (63.0%)
	Absence	69 (34.7%)	92 (46.2%)	94 (47.2%)	45 (44.1%)	56 (54.9%)	58 (56.9%)	66 (37.1%)	76 (42.7%)	47 (34.8%)	50 (37.0%)
No	Presence	58 (6.9%)	52 (6.2%)	53 (6.3%)	44 (5.5%)	43 (5.4%)	41 (5.2%)	47 (6.4%)	39 (5.3%)	43 (4.6%)	41 (4.4%)
	Absence	778 (93.1%)	784 (93.8%)	783 (93.7%)	749 (94.5%)	750 (94.6%)	752 (94.8%)	682 (93.6%)	690 (94.7%)	886 (95.4%)	888 (95.6%)
Length root canal filling											
Short> 2 mm	Presence	79 (73.1%)	54 (74.0%)	57 (72.2%)	29 (80.6%)	20 (60.6%)	17 (63.0%)	68 (86.1%)	56 (80.0%)	54 (78.3%)	46 (70.8%)
	Absence	29 (26.9%)	19 (26.0%)	22 (27.8%)	7 (19.4%)	13 (39.4%)	10 (37.0%)	11 (13.9%)	14 (20.0%)	15 (21.7%)	19 (29.2%)
Good 0–2 mm	Presence	39 (55.7%)	42 (42.0%)	41 (41.0%)	21 (40.4%)	20 (37.0%)	20 (35.7%)	34 (42.5%)	38 (42.2%)	26 (51.0%)	28 (56.0%)
	Absence	31 (44.3%)	58 (58.0%)	59 (59.0%)	31 (59.6%)	34 (63.0%)	36 (64.3%)	46 (57.5%)	52 (57.8%)	25 (49.0%)	22 (44.0%)
Overfilling	Presence	12 (57.1%)	11 (44.0%)	7 (35.0%)	7 (50.0%)	6 (40.0%)	7 (36.8%)	10 (52.6%)	8 (44.4%)	8 (53.3%)	11 (55.0%)
	Absence	9 (42.9%)	14 (56.0%)	13 (65.0%)	7 (50.0%)	9 (60.0%)	12 (63.2%)	9 (47.4%)	10 (55.6%)	7 (46.7%)	9 (45.0%)

[a]Only at least 3-rooted maxillary molars (8 teeth had a radix, which was not taken into account for this table).
[b]Only at least 2-rooted mandibular molars (8 teeth had a radix, which was not taken into account for this table).

monitoring of periapical disease. The association between CBCT and histologic findings is still lacking in the literature, and therefore, further longitudinal studies on this topic are recommended.

Conclusions

Root filled teeth and teeth restored with crowns were associated with a significantly greater prevalence of periapical lesions. Short root fillings also had a significant impact on the presence of periapical lesions. Molar teeth were most likely to be associated with periapical lesions, and the mesiobuccal roots of maxillary first molars had periapical lesions more often than any other type of root. Extra care should be taken when controlling apical length during root canal treatment, and teeth with root fillings and crowns should be regularly monitored.

Conflict of Interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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