Oral Radiology (2022) 38:405–415
https://doi.org/10.1007/s11282-021-00570-2

ORIGINAL ARTICLE

The quality of root canal treatment and periapical status of permanent teeth in Turkish children and teens: a retrospective CBCT study

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Received: 8 May 2021 / Accepted: 16 September 2021 / Published online: 29 October 2021

Abstract

Objective This study aimed to assess the quality of root canal fillings and the prevalence of periapical radiolucencies in the permanent teeth of 6–18 year-old Turkish children.

Methods CBCT images of 150 patients' 235 teeth with a mean age of 16.0 ± 2.06 years were included. Root development stage, quality of root canal filling, the presence and severity of periapical radiolucencies, and their relationship with anatomical structures were recorded. Correlations between the quality of root canal filling, periapical lesion, and lesion size were assessed using regression analyses.

Results A total of 235 teeth (528 root canals) were evaluated. 65.5% of root canals had periapical lesions. Immature roots and mandibular teeth had the highest prevalence and the largest size of periapical radiolucencies ($p < 0.05$). Overfilling ($n = 52$), underfilling ($n = 93$), unfilled ($n = 46$), inhomogeneously filled ($n = 113$) root canals and poor coronal restoration ($n = 85$ teeth) were observed in terms of technical failures of endodontic treatment. The quality of endodontic treatment was associated with the presence of periapical lesion and lesion size ($p < 0.05$). Teeth with under-filled, overfilled or inhomogeneously filled root canals and poor coronal restoration had a periapical lesion larger than 5 mm ($p < 0.05$). Immature teeth were most associated with the presence of lesion (OR = 4.07) and the lesion size > 5 mm (OR = 3.71).

Conclusion The prevalence of periapical radiolucencies in young permanent teeth showed an increase when the tooth was an incisor, had incomplete root development, or the root filling had technical errors.

Keywords Cone beam computed tomography · Periapical lesion · Root canal therapy · Treatment outcome · Children

Introduction

The outcome of endodontic treatment is strongly influenced by the technical quality of the root filling and the coronal restoration, which both should prevent bacterial leakage by providing a hermetic seal [1, 2]. The factor influencing the periapical healing is multifactorial. Pre-operative factors, such as the presence, size and topography of the lesion, and its relationship with anatomic landmarks, also play a key role in the treatment outcome [2, 3]. Intra-operative factors, such as disinfection of the root canal system effectively, homogeneity and length of the root canal filling, quality of coronal restoration, endodontic treatment complications, etc., have been reported to affect the outcome of root canal treatment [2–4]. In children and adolescents, the presence of immature roots and the possible lack of compliance to treatment and radiographic procedures are additional challenges that undermine successful outcomes [5]. Furthermore, periapical defects with radiolucent, radiopaque or mixed radiographic features mimicking periapical lesions of non-endodontic origin, such as odontogenic cysts and tumors [6], nonodontogenic cysts [7], benign fibro-osseous lesions [8], benign nonodontogenic neoplasms [9, 10] and malignant neoplastic lesions [11, 12], may lead to misdiagnosis of previously endodontically treated teeth. In addition to patient-related factors, such as tooth anatomy, medical conditions, such as diabetes [13], compromised immune response [14], gene polymorphisms that alter immune response of the host [15], and bone mineral density [16], may also significantly affect the outcome of endodontic treatment.

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Radiographs play a significant role in the assessment of anatomical features and periapical lesions, determination of working length and the quality of obturation, and evaluation of endodontic treatment outcomes [17, 18]. Most studies evaluating endodontic treatment outcomes have utilized two-dimensional radiography (i.e., periapical radiographs [19, 20] or panoramic radiographs [21, 22]), while only a few have used cone-beam computed tomography (CBCT) [4, 23]. Compared with conventional radiographic methods, CBCT imaging offers significantly better diagnostic accuracy, since it provides a three-dimensional (3D) view along with the relationships to adjacent anatomical structures. Owing to these inherent advantages, more cases of apical periodontitis are likely to be detected with CBCT than with conventional radiographs [24]. However, the significantly higher radiation dose from CBCT imaging justifies the current concerns for its routine use as a replacement to two-dimensional radiographs in children [25].

Various diagnostic indices have been proposed for the radiographic evaluation of root fillings and periapical tissues [26]. The Periapical Index developed by Ørstavik et al. [26] has been widely used in epidemiological studies to determine the periapical status on two-dimensional radiographs. Due to the emerging use of dental 3D imaging, Estrela et al. [23] developed CBCTPAI, a new PAI based on CBCT images. Since both PAI and CBCTPAI only evaluate image sizes and bone expansion or destruction, Venskutonis et al. [4] more recently proposed a new periapical and endodontic status scale (PESS). PESS includes the complex periapical index (COPI) and the endodontically treated tooth index (ETTI). COPI was designed for the identification and classification of periapical bone lesions in apical periodontitis, while ETTI was designed for the evaluation of endodontic treatment quality by CBCT.

There is little information available on the quality of root canal treatment and periapical status of endodontically-treated permanent teeth of young individuals [22, 27]. The aim of this study was to assess the quality of root canal treatment and periapical status of root-filled permanent teeth of Turkish children between 6 and 18 years of age, using the PESS index.

Materials and methods

Sample selection

This retrospective study was approved by the Local Ethics Committee (GO20/828). CBCT images obtained between November 2014 and July 2020 were retrieved from the database of the Hacettepe University, Department of Dentomaxillofacial Radiology. The sample consisted of CBCT images which were taken for any dental reason from patients aged between 6 and 18 years, who had at least one root-filled permanent tooth. A total of 1469 CBCT scans were examined. The exclusion criteria were: scans with insufficient diagnostic quality for endodontic assessment ($n=412$), presence of root fragments or a fractured root, teeth with endodontic–periodontal lesions, intraosseous pathologies ($n=49$), such as cysts in non-periapical locations, tumors, and fibroosseous lesions. Scans with motion or metal artifacts superimposed on the dental arch were also excluded ($n=24$). A final sample of 984 scans were screened and CBCT images of 150 patients (80 males and 70 females, mean age = 16.0 ± 2.06 years) with 235 teeth were included in the study. Of these, 85 were anterior teeth, 43 were premolars and 107 were molars. A total of 528 root canals were evaluated.

Radiographic evaluation

All selected CBCT images were obtained using i-Cat Next Generation device (Imaging Sciences International, Hatfield, PA, USA) with the following parameters: 120 kVp, 3–8 mA, 16 × 6 cm field-of-view, 0.20 mm voxel, and 26 s scan time. The CBCT scans were analyzed separately by two oral radiologists with more than five years of experience on i-CAT Vision software (Imaging Sciences). Prior to the study, the examiners were calibrated with 30 scans (20% of the sample size), which were not included in the present study. Evaluation of each scan was repeated with a 2 week interval. After reaching an intra- and inter-observer reliability greater than 0.80, the examiners proceeded to the main CBCT study.

CBCT images were viewed on a 24-inch LCD monitor with 1920 × 1080 resolution (Dell, Round Rock, TX, USA), in a dimly lit, quiet room [28]. No time restriction was set. Examiners were able to use a zoom tool and brightness/contrast tool and to adjust slice thickness according to their preferences. In cases of disagreement, the image was reviewed by two other experienced authors to obtain a consensus. Assessments were performed on axial, coronal, and sagittal multiplanar reconstruction planes (MPR), along the long axis of each root.

Assessment of the quality of endodontic treatment and periapical status

The quality of endodontic treatment was assessed according to the criteria within the endodontically treated tooth index defined by Venskutonis et al. [4] (Table 1).

In cases of apical pathologies associated with an endodontically treated tooth, the identification and classification of the periapical lesion (PL) were assessed through COPI proposed by Venskutonis et al. [4]. The parameters of periapical status evaluated for each single root (Table 1).

Table 1 New endodontically treated tooth index (L, H, CS, and CF evaluation scale) and complex periapical index (S, R, and D evaluation scale) [4]

- L (length of the root canal filling)[a]
  - L1: 0–2 mm from radiographic apex
  - L2: > 2 mm from radiographic apex
  - L3: overfilling (extrusion of material through the apex)
  - L4: filling material visible only in pulp chamber
  - L5: filled canal of a surgically treated root
- H (homogeneity of the root canal fillings)
  - H1: complete obturation (homogenous appearance of the root canal filling)
  - H2: incomplete obturation (voids and porous appearance of the root canal filling)
- CS (coronal seal)
  - CS1: adequate (coronal restoration appears intact radiographically)
  - CS2: inadequate (detectable radiographic signs of overhangs, open margins, recurrent caries, or lost coronal restoration)
- CF (complications/failures)[b]
  - CF0: no complications
  - CF1: root perforation
  - CF2: root canal not treated/missed
  - CF3: root resorption
  - CF4: root/tooth fracture
  - CF5: endodontically treated root with radiolucency
- S (size of the radiolucent lesion)
  - S0: widening of the periodontal ligament not exceeding 2 times the width of the lateral periodontal ligament
  - S1: the diameter of a small well-defined radiolucency up to 3 mm
  - S2: the diameter of a medium well-defined radiolucency 3–5 mm
  - S3: the diameter of a larger well-defined radiolucency > 5 mm
- R (relationship between root and radiolucent lesion)
  - R0: no radiolucency, when widening of the periodontal ligament not exceeding 2 times the width of the lateral periodontal ligament
  - R1: radiolucent lesion appears on one root
  - R2: radiolucent lesion appears on more than one root
  - R3: radiolucent lesions with involvement of furcation
- D (location of bone destruction)
  - D0: no radiolucency, when widening of the periodontal ligament not exceeding 2 times the width of the lateral periodontal ligament
  - D1: radiolucency around the root
  - D2: radiolucency is in contact with important anatomical structures
  - D3: destruction of cortical bone

[a] L4 and L5 were not evaluated in this study

[b] L, H, and CF were evaluated for each single root canal, while CS was evaluated per tooth. The scores were applied to each root of one particular tooth

Statistical analysis

Statistical analyses were performed using SPSS software version 22.0 (SPSS, Inc., Chicago, IL, USA). The data were expressed in frequency and percentage. Chi-square test was used to assess the significance of differences between categorical variables. Intra- and inter-examiner agreement was calculated using Kappa and weighted Kappa tests. The level of significance was set to $p = 0.05$. Multiple logistic regression analyses (backward multiple regression and multinomial regression analysis) were used to determine whether an independent variable remained statistically significant after controlling for other confounding variables. Based on the results of the univariate analyses, independent variables with p value < 0.2 were included in the regression model [29]. Risk estimates were presented as odds ratios with 95% confidence intervals (CIs).

Results

The intra- and inter-observer Kappa values indicated almost perfect agreement (0.82–0.91 and 0.81–0.87, respectively). A total of 528 root canals were evaluated (85 anterior teeth, 61 premolars, and 382 molars). The frequency and distribution of tooth types (anterior, premolar and molar); the number of root canals according to the localization (maxilla or mandible); the stage of root development (mature or immature) [30]; and endodontic treatment quality index (ETTI; L, H, CS, and CF) are presented in Table 2. In all tooth types, the majority of roots had developed to mature stage. The results of the ETTI showed that L1 (adequate length of the root canal filling, H1 (homogenous appearance of the root canal filling), and CS1 (adequate coronal restoration) were the most frequent findings. As for the status of complications/failures, CF5 (apical radiolucency) was the most observed category in all tooth types with an overall prevalence of 65.5%, while CF1, CF3 were the least observed categories. There were only 158 cases (29.9%) with no complications.

Forty-two of 125 multirooted teeth (33.7%) had at least one missed root canals. More than half of those missed root canals were the mesiobuccal 2 of maxillary first molars and followed by the second distal canal (28.5%) of mandibular first molars. Twenty-nine of 39 maxillary first molars had four canals but only four of them (16.0%) had root filling in all canals. Sixty-nine percent of the missed root canals had apical radiolucency (CF5).

The COPI assessment showed that the most frequent category was S0 among premolars (42.6%) and molars (35.6%) for the lesion size. For anterior teeth, however, the diameter of the lesion was greater than 5 mm (S3) in most cases (32.9%). As for the relationship between root and radiolucent lesion, apical radiolucency was absent (R0) in 182 cases (34.5%). Apical lesions in relation to single root (R1) and more than one root (R2) were present in 154 (29.2%) and 190 (35.9%) cases, respectively. In 72 cases (13,6%), a furcal radiolucency (R3) was apparent, while combining lesions (R2 + R3) were present in 70 cases (13.3%). Apical lesions were located around the root (D1) in 187 cases (35.4%), which was also located near anatomical structures (D1 + D2) in 71 cases (13.4%), and was accompanied by cortical bone destruction (D1 + D2 + D3) in 65 cases (12.3%). Totally, 136 of the periapical lesions (39.3%) were markedly close to important anatomical structures. Figure 1 depicts representative sections of treatment errors and complications.

Apical radiolucency: associated factors and size of the radiolucent lesion

The status of apical radiolucency (CF5) and size of the periapical lesion (S) according to tooth type, stage of root development, localization, length of the root canal filling (L), homogeneity of the root canal filling (H), and coronal seal status are shown in Table 3. The prevalence of apical radiolucency and the S3 category was higher in anterior teeth than in premolars ($p = 0.038$) and molars ($p = 0.047$). The stage of immature root development was associated with the presence of apical radiolucency and categories S0 and S2 ($p = 0.001$ and $p = 0.002$, respectively). Localization (mandible or maxilla) was not significantly associated with periapical status ($p = 0.149$), but root canals in the mandible were significantly associated with the category S3, with regard to the size of the lesion ($p = 0.000$). Parameters L, H, and CS were significantly associated with periapical status, with a significantly higher prevalence of the apical radiolucency in the categories L2–L3, H2, and CS2 compared with categories L1, H1, and CS1 ($p = 0.000$, $p = 0.000$, and $p = 0.028$, respectively). Considering the size of the radiolucent lesion, category S3 was more frequently observed in the categories L2–L3, H2, and CS2 than in categories L1, H1, and CS1 ($p = 0.000$).

Logistic regression analysis of factors associated with apical radiolucency

Univariate analyses showed that anterior teeth (OR: 1.79), immature root stage (OR: 4.23), underfilled root canals (L2;

Table 2 Characteristics of root canal filled permanent teeth and endodontically treated tooth index

Characteristics							Endodontically treated tooth index (ETTI)												
Dental groups	No. of teeth	Localization		No. of canals	RD		L			H		CS		CF					
		Max	Man		Mat	Imm	L1	L2	L3	H1	H2	CS1	CS2	CF0	CF1	CF2	CF3	CF4	CF5
	n	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Anterior	85	73	12	85	63	22	53	12	20	50	35	66	19	12	4	–	13	5	65
Premolar	43	33	10	61[a]	58	3	45	10	3	41	16	32	29	25	0	3	1	–	35
Molar	107	41	66	382[b]	365	17	239	71	29	277	62	70	37	121	3	43	10	–	246
Total	235	147	82	528	486	42	337	93	52	368	113	168	85	158	7	46	24	5	346

Max maxilla; *Man* mandibula; *RD* root development; *Mat* mature; *Imm* immature

[a] Three root canals were untreated

[b] Forty-three root canals were untreated

Fig. 1 Examples of CBCT images demonstrating treatment errors and complications: cross-sectional (**a**) and coronal (**b**) sections showing non-homogenous filling and underfilling in maxillary incisor and premolars with apical radiolucency (AR). Coronal (**c**) and sagittal (**d**) sections showing a maxillary first molar with underfilling and non-homogenous filling. AR associated with distobuccal root canal involving maxillary sinus is also seen. Sagittal view (**e**) showing an overfilled root canal associated with AR in the mandibular second premolar. Cross-sectional view (**f**) showing AR associated with cortical expansion and perforation in a maxillary incisor with extrusion of sealer. Coronal (**g**) and axial (**h**) sections showing a non-filled root canal (mesiobuccal) associated with AR in contact with mandibular canal in the mandibular first molar

OR: 3.13), overfilled root canals (L3; OR: 2.94), canals with non-homogeneous filling (H2; OR: 2.83), and inadequate coronal sealing (CS2; OR: 1.54) contributed to an increased risk for the presence of apical radiolucency ($p < 0.05$, Table 3). All those variables and the ‘localization’ parameter (with an insignificant p value of < 0.20) were included in a multivariate logistic regression model. The results of logistic regression with backward method showed that immature root stage (OR: 4.07), mandible localization (OR: 1.51), underfilling (L2; OR: 2.21), overfilling (L3; OR: 2.75), and non-homogeneous filling (H2; OR: 2.32) were the significant risk factors of apical radiolucency ($p < 0.05$, Table 4).

Logistic regression analysis of factors associated with size of the radiolucent lesion

The results of multinomial logistic regression analysis for the associated factors of the lesion size (S1, S2, and S3) are shown in Table 5. The widening of the periodontal ligament (S0) was considered as the reference category. Taking molars as the reference category, the tooth type assessment showed that anterior teeth had 2.89 times higher risk for a lesion size greater than 5 mm (S3) compared to the reference category (S0). Taking ‘mature’ stage as the reference category, the root development stage assessment showed that the immature root stage had 6.65 times higher risk for a lesion size of 3–5 mm (S2) and 3.71 times higher risk for S3, compared to S0. Finally, taking maxilla as the reference category, the localization assessment showed that mandible had 2.69 times higher risk for S2 compared to S0.

Considering the homogeneity of the root canal filling (H1 = reference category), non-homogeneous filling (H2) had 2.75 times higher risk for S2 and 2.49 times higher risk for S3, compared to S0. With respect to length of the root canal filling (L1 = reference category), underfilled (L2) had 2.26 times higher risk for a lesion size up to 3 mm (S1) and 2.48 times higher risk for S3, while overfilled root filling (L3) had 3.01 times higher risk for S3, compared to S0. As for the coronal seal status (CS1 = reference category), inadequate coronal sealing (CS2) had 2.20 times higher risk for S3 compared to S0.

Discussion

This study evaluated the quality of endodontic treatment, the accompanying technical failures and the prevalence of apical radiolucency in root-filled teeth in a group of children and teens. CBCT images were used, since they offer greater diagnostic sensitivity than periapical radiographs [24, 31].

Table 3 Apical radiolucency and size of the radiolucent lesion according to some characteristics of root canal filling

Characteristics	Apical radiolucency			Size of the radiolucent lesion				
	Absent *n* (%)	Present *n* (%)	*p* value*	S0 *n* (%)	S1 *n* (%)	S2 *n* (%)	S3 *n* (%)	*p* value*
Teeth groups								
Anterior	20 (23.5)	65 (76.5)	**0.038**	20 (23.5)	24 (28.2)	13 (15.3)	28 (32.9)	**0.047**
Premolar	26 (42.6)	35 (57.4)		26 (42.6)	21 (34.4)	7 (11.5)	7 (11.5)	
Molar	136 (35.6)	246 (64.4)		136 (35.6)	101 (26.4)	46 (12.0)	99 (25.9)	
Total	182 (34.5)	346 (65.5)		182 (34.5)	146 (27.7)	66 (12.5)	134 (25.4)	
Root development								
Mature	177 (36.4)	309 (63.6)	**0.001**	177 (36.4)	134 (27.6)	55 (11.3)	120 (24.7)	**0.002**
Immature	5 (11.9)	37 (88.1)		5 (11.9)	12 (28.6)	11 (26.2)	14 (33.3)	
Total	182 (34.5)	346 (65.5)		182 (34.5)	146 (27.7)	66 (12.5)	134 (25.4)	
Location								
Maxilla	103 (37.3)	173 (62.7)	**0.149**	103 (37.3)	95 (34.4)	29 (10.5)	49 (17.8)	**0.000**
Mandible	79 (31.3)	173 (68.7)		79 (31.3)	51 (20.2)	37 (14.7)	85 (33.7)	
Total	182 (34.5)	346 (65.5)		182 (34.5)	146 (27.7)	66 (12.5)	134 (25.4)	
Length of the root canal filling								
L1	139 (41.2)	198 (58.8)	**0.000**	139 (41.2)	91 (27.0)	40 (11.9)	67 (19.9)	**0.000**
L2	17 (18.3)	76 (81.7)		17 (18.3)	29 (31.2)	14 (15.1)	33 (35.5)	
L3	10 (19.2)	42 (80.8)		10 (19.2)	15 (28.8)	9 (17.3)	18 (34.6)	
Total	166 (34.4)	316 (65.6)		166 (34.4)	135 (28.0)	63 (13.1)	118 (24.5)	
Homogeneity of the root canal filling								
H1	145 (39.3)	224 (60.7)	**0.000**	145 (39.3)	103 (27.9)	43 (11.7)	78 (21.1)	**0.000**
H2	21 (18.6)	92 (81.4)		21 (18.6)	32 (28.3)	20 (17.7)	40 (35.4)	
Total	166 (34.4)	316 (65.6)		166 (34.4)	135 (28.0)	63 (13.1)	118 (24.5)	
Coronal seal								
CS1	130 (37.8)	214 (62.2)	**0.028**	130 (37.8)	105 (30.5)	41 (11.9)	68 (19.8)	**0.000**
CS2	52 (28.3)	132 (71.7)		52 (28.3)	41 (22.3)	25 (13.6)	66 (35.9)	
Total	182 (34.5)	346 (65.5)		182 (34.5)	146 (27.7)	66 (12.5)	134 (25.4)	

*Chi-square test

$p < 0.05$

The CBCTPAI index classifies measurements of periapical radiolucency in five scores in addition to codes of cortical bone destruction or expansion [23]. The PESS index utilizes more complex parameters that evaluate all important factors for periapical radiolucency, such as the quality of root filling and restoration, lesion size, number of lesions, and the relation of lesions to anatomical structures [4, 32]. In the present study, the PESS index was used with some limitations. For instance, teeth with L4 (filling material visible only in pulp chamber) were not included in this study, since this can reflect pulpotomy, which does not fall into the scope of root canal filling. Likewise, teeth with L5 (Filled canal of a surgically treated root) were not evaluated due to difficulty in the interpretation of lesion size, teeth. Nevertheless, L5 can be a favorable category for prospective studies. Teeth with CF4 defining the root fracture were also not included since they do not have a conventional root canal treatment. The healing tissue between fragments may be variable, and it may not indicate a lesion.

While age appears to play an important role in the healing of periapical lesions [33], there is little information on the periapical status of root-filled permanent teeth in children, adolescents and teens [27, 34]. A variety of factors including the level of root development, the existence of wider root canals, and the cooperation status can affect the quality of root canal treatment and periapical status in children [27, 35]. Clarke et al. [27] reported that young patients with lower compliance to clinical procedures had lower success rates in the technical quality of endodontic treatment. Obturation of wider root canals requires more time, which is strongly dependent on patient co-operation.

Immature teeth with wide apical foramina or no apical constriction have a higher risk of irrigant extrusion and associated accidents [36]. A study by Kakoli et al. [37] concluded that higher levels and greater depth of bacterial

Table 4 Logistic regression analysis of factors associated with apical radiolucency

Univariate analyses with logistic regression	Odds ratio	95% (CI)	*p* value
Tooth groups			
Anterior	1.79	1.04—3.09	0.034*
Premolar	0.74	0.43—1.28	0.292
Molar	–	–	–
Root development			
Mature	–	–	–
Immature	4.23	1.63—10.98	0.003*
Location			
Maxilla	–	–	–
Mandible	1.30	0.90–1.87	0.150
Length of the root canal filling			
L1	–	–	–
L2	3.13	1.77—5.54	0.000*
L3	2.94	1.43—6.07	0.003*
Homogeneity of the root canal fillings			
H1	–	–	–
H2	2.83	1.68—4.76	0.000*
Coronal seal			
CS1	–	–	–
CS2	1.54	1.04—2.27	0.029*
Multivariate logistic regression model (Backward method[a])			
Root development			
Immature	4.07	1.52—10.85	0.005*
Location			
Mandible	1.51	1.00—2.26	0.045*
Length of the root canal filling			
L2	2.21	1.20—4.06	0.010*
L3	2.75	1.31—5.77	0.007*
Homogeneity of the root canal fillings			
H2	2.32	1.32—4.07	0.003*

[a] Variables with a p value <0.2 from the univariate analyses were included in the multivariate logistic regression model

*$p < 0.05$

invasion in dentinal tubules may explain the common finding of increased periapical irritation and delayed healing in the young age group. Furthermore, dental trauma may result in immature root development and loss of pulp vitality. In such cases, endodontic treatment can be complicated by erroneous working length estimation, overextended obturation due to the lack of apical stop, and increased risk of root fracture due to thin root walls [38]. Together, these reasons justify the need for evaluating the quality of root canal treatment and periapical status, exclusively in children and teens.

Technical factors including the irrigation method, the root canal material, and the root filling technique are well-documented factors that affect the outcome of endodontic treatment in necrotic immature teeth. The use of side-vented irrigation needles, apical negative pressure irrigation, passive ultrasonic irrigation, and sonic irrigation have been have been recommended to provide an effective irrigation, while minimizing the risk for apical extrusion of root canal irrigants [39]. In open-apex necrotic immature teeth, apical barrier techniques using calcium silicate-based biomaterials or the use of regenerative endodontic procedures have been recommended instead of conventional apexification using calcium hydroxide, which might increase the risk of cervical fractures in the long term [40]. It should be noted that the endodontic management of necrotic immature teeth requires both pediatric behavior management skills and technical proficiency in advanced endodontic treatments [27]. Thus, incorporation of advanced preclinical and clinical training in pediatric specialty programs could improve the outcome of root canal treatment in the children and teens.

In the present study, periapical lesions were more frequently observed in mandibular teeth (68.7%) than in maxillary teeth (62.7%) in the lack of statistical significance. Previous work in the adult population has indicated a higher frequency of lesions in maxillary teeth [41], while a search of the literature has not indicated any data with regard to the jaws in young individuals. Demirbuğa et al. [42], have reported that the prevalence of teeth requiring endodontic therapy and root-filled teeth were significantly higher in the mandibular teeth of children. Those findings may suggest that mandibular teeth may be exposed to endodontic treatment need at an earlier stage. From another point of view, maxillary lesions have a faster rate of resolution due to the more extensive vascular network in the maxilla [43]. In the present study, the number of S3 lesions (> 5 mm) was significantly higher in mandibular teeth, anterior teeth, and immature teeth. Periapical health/healing is most adversely influenced by the presence and size of the periapical lesion, especially when the size is 5 mm or greater [2, 4, 44]. The number of bacteria species and their relative abundance is higher in teeth with larger periapical lesions, which are longer standing root canal infections, with a deeper level of bacterial invasion within dentinal tubules [45]. Ridel et al. [35], evaluated 165 root-filled teeth in 129 individuals with a mean age of 16.2 years. Fifty-two of the teeth with at least one-year follow-up after root canal treatment had apical periodontitis. In the present study, a higher prevalence of periapical radiolucency (178, 75.75%) was found in 235 root-filled teeth. Although the indexes and the radiographic methods used for diagnosis are different, the prevalence of lesions in both studies is higher than those reported in adults [35, 41].

In the present study, the prevalence of periapical lesions was significantly higher in anterior teeth than in premolars and molars. Additionally, periapical lesions > 5 mm (S3) were 2.89-fold higher for anterior teeth. In the study of Nascimento et al. [46], both anterior teeth and maxillary

Table 5 Multinominal logistic regression analysis of factors associated with size of the radiolucent lesion

Size of radiolucent lesion (mm)^a									
	S1 (< 3 mm)			S2 (3–5 mm)			S3 (> 5 mm)		
	Odds ratio	95% (CI)	*p* value	Odds ratio	95% (CI)	*p* value	Odds ratio	95% (CI)	*p* value
Teeth groups									
Anterior	1.14	0.55—2.37	0.718	1.69	0.65—4.39	0.278	2.89	1.31—6.36	**0.008***
Premolar	0.98	0.49—1.98	0.967	1.08	0.39—2.94	0.879	0.52	0.19—1.44	0.214
Molar	–	–	–	–	–	–	–	–	–
Root development									
Mature	–	–	–	–	–	–	–	–	–
Immature	2.52	0.83—7.63	0.102	6.65	2.05—21.53	**0.002**	3.71	1.20—11.47	**0.023***
Location									
Maxilla	–	–	–	–	–	–	–	–	–
Mandible	0.78	0.46—1.31	0.353	2.69	1.32—5.48	**0.006**	3.42	1.86—6.28	**0.000***
Length of the root canal filling									
L1	–	–	–	–	–	–	–	–	–
L2	2.26	1.13—4.55	**0.021**	1.77	0.74—4.23	0.198	2.48	1.19—5.16	**0.015***
L3	2.10	0.89—4.97	0.090	2.75	0.99—7.62	0.051	3.01	1.24—7.30	**0.014***
Homogeneity of the root canal filling									
H1	–	–	–	–	–	–	–	–	–
H2	1.64	0.84—3.20	0.143	2.75	1.23—6.12	**0.013**	2.49	1.24—4.99	**0.010***
Coronal seal									
CS1	–	–	–	–	–	–	–	–	–
CS2	0.84	0.49—1.44	0.547	1.32	0.68—2.55	0.398	2.20	1.27—3.81	**0.004***

Bold indicates the significance values

^{a}Reference category is S0 (widening of the periodontal ligament not exceeding 2 times the width of the lateral periodontal ligament

*$p < 0.05$

molars were most related with apical radiolucency. In a study by Ridell et al. [35], the prevalence of periapical lesion in molars was significantly higher than that of anterior teeth. Burklein et al. [41] have also reported that molars were more often related to periapical lesions compared to all other teeth. It is noteworthy to mention that the same study reported a 3.05-fold increase in the risk of periapical lesion for anterior teeth [41]. The authors explained the reason as being increased prevalence of dental trauma to maxillary incisors. It is well known that a majority of traumatic dental injuries occur before the age of 20, and maxillary central incisors are most frequently affected [47]. This might also be the case herein, but cannot be ascertained owing to the retrospective nature of the present study.

It is well known that the quality of the endodontic treatment has a strong impact on the status of the periradicular tissues [2, 48–50]. The failure of endodontic treatment is multifactorial and cannot simply be associated with a single factor. As with previous studies [41, 46], the length and homogeneity of root canal filling and the presence of an adequate coronal restoration were the factors used for evaluating the quality of root canal filling herein. Based on the results of univariate analyses with logistic regression, all those factors were significantly associated with the presence of periapical radiolucency, while for the multivariate logistic regression model, there was no relationship with coronal seal. Immature root stage was the highest risk factor for periapical lesion, followed by overfilling (OR = 2.75), inhomogeneity of root canal filling (OR = 2.32), and short root canal filling more than 2 mm from the apex (OR = 2.21). A root filling 0–2 mm short from the radiographic apex has been defined as "good filling length" or "ideal" in previous studies [27, 51]. The present results also corroborate with those studies, with over-filling and short root canal filling more than 2 mm being associated with the presence of periapical lesions. Moreover, our results indicate a relationship between filling length errors with the lesion size (> 5 mm). The risk of S3 lesion increased by 3.01-, 2.49-, 2.48- and 2.20-fold in the presence of overfilled canals, inhomogeneity of root filling, short root filling and inadequate coronal seal, respectively. To the best of our knowledge, no previous study has evaluated factors that may influence the lesion size. According to multivariate regression analysis herein, many factors that increased the risk of the lesion presence, also increased the severity of the lesions. This is extremely important in that, the larger lesion, the poorer the prognosis for healing [2, 44].

In line with the findings of Karabucak et al. [52], the most frequently missed root canal was the second mesiobuccal canal in maxillary first molars, followed by the second distal canal in mandibular first molars. Although 69.0% of missed root canals had associated periapical radiolucency, this was not statistically significant as with the study of Karabucak et al. [52], here, the high prevalence of missed root canals reiterates the importance of the knowledge of root canal configurations and searching for additional canal orifice(s) under appropriate magnification and illumination [53].

The proximity of periapical lesions to important anatomic structures, such as the maxillary sinus, nasal floor, mandibular canal and mental foramen, can be detected via CBCT. Such anatomical structures are of utmost importance for better treatment planning and safe intervention [54]. Here, 136 of the periapical lesions (39.3%) were markedly close to important anatomical structures, and 65 of them had accompanying cortical bone destruction. The proximity of the periapical lesions to the maxillary sinus may lead to inflammation and localized mucosal thickening; and eventually maxillary sinusitis [32]. Progressive destruction of surrounding bone will compromise future dental implant placement if extraction is planned [55].

CBCT imaging offers an increased sensitivity to determine pathological changes in the periapical region. Torabinejad et al. [56] have observed that teeth that were judged to have a successful endodontic treatment on periapical radiographs had radiolucencies more than 1 mm on CBCT images. While the presence of radiolucencies on CBCT imaging may not necessarily call for further treatment in the absence of clinical symptoms, the presence and severity of periapical lesions in children may be associated with poor quality of root canal treatment and immaturity of root canals, which might require retreatment.

The limitations of this study are the retrospective study design and sample selection bias. Here, the indications for CBCT not only included endodontic treatment, but also surgical and orthodontic reasons. By nature of retrospective study design, other important clinical factors influencing the quality of root canal filling, such as using a rubber dam, providing effective disinfection, and time before coronal filling, were not evaluated herein, since our patient records do not include the use of rubber dam or the endodontic disinfection products. Besides, the distinction cannot be done between a lesion in the process of healing from a previously larger lesion or a progressing one. On the other hand, the large sample size of the present study may decrease sampling error and may reflect the possible associations more closely [57].

Some technical factors, such as the field of view (FOV), voxel size, kilo-voltage-peak (kVp), tube current and number of projections, influence the quality of CBCT images [58]. The main disadvantage of CBCT image is the presence of the artefacts, which occur as a result of dental materials with a high-density and high atomic number. Artefacts may impair detecting of several clinical conditions [59]. Intracanal materials, such as gutta-percha, root canal sealer, and metallic posts, cause artefacts and make complicate endodontic evaluation [60]. In the present study, CBCT images with artefacts impeding the evaluation of root canal filling were not evaluated. All CBCT images were evaluated by two experienced dentists at the same time and high-resolution CBCT images were used. The assessments were performed not only one plane, but also on axial, coronal, and sagittal multi-planar reconstruction planes (MPR). The present study has the major strength of being the first CBCT study evaluating the quality of root canal treatment and its outcomes, as well as the size and anatomical relations of periapical lesions in children. To a lesser extent, another advantage of the present study, owing to the age of patients, is the absence of intracanal metallic posts or crowns which, as in the elderly population, may lead to artifacts in interpretation. Further, the wide root canals of children provided some level of convenience for evaluating the homogeneity of root fillings. Finally, prospective cohort studies including both clinical and imaging variables strongly suggested for evaluating their effects on periapical lesions over time. Comparing the lesions on periapical radiographs and CBCT images can also be done for evaluating the differences, and advantages over each other.

In the presence of an immature root and technical errors, such as overfilling, underfilling and inhomogeneous root filling, a higher prevalence of periapical radiolucencies was observed. Those factors, coupled with poor coronal restorations, were also associated with the larger (> 5 mm) lesions. Periapical lesions close to anatomical structures and cortical destruction were also common in children and teens.

Acknowledgements The authors would like to thank Merve Kasikci from the Department of Biostatistics, Hacettepe University School of Medicine, for her valuable contrubutions to data analysis.

Funding Not applicable.

Declarations

Conflict of interest Elif Ballikaya, Nagihan Koc, Nihal Avcu, and Zafer Cehreli declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human or animal subjects performed by the any of the authors. The Ethics approval was obtained prior to the study (GO20/828).

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