DOI: 10.4274/TurkJOrthod.2024.2024.25

TURKISH JOURNAL OF
ORTHODONTICS

Original Article

External Apical Root Resorption in Endodontically Treated and Vital Teeth after Orthodontic Treatment: A Retrospective Study

Elchin Karimzada[1], Elçin Esenlik[1], Kürşat Er[2]

Akdeniz University Faculty of Dentistry, Department of Orthodontics, Antalya, Turkey
Akdeniz University Faculty of Dentistry, Department of Endodontics, Antalya, Turkey

Cite this article as: Karimzada E, Esenlik E, Er K. External Apical Root Resorption in Endodontically Treated and Vital Teeth after Orthodontic Treatment: A Retrospective Study. *Turk J Orthod.* 2024; 37(4): 249-256

Main Points

- Long treatment duration and extraction treatment were significantly associated with external apical root resorption (EARR).
- The presence of endodontically treated teeth (ETT) did not increase an individual's risk of EARR.
- ETT is more resistant to EARR than contralateral vital pulp.

ABSTRACT

Objective: This retrospective study aimed to assess the presence and amount of external apical root resorption (EARR) in endodontically treated teeth (ETT) and contralateral teeth with vital pulp (VPT) following orthodontic treatment.

Methods: The study sample included panoramic radiographs of 503 patients (314 females and 189 males; 16.29 years±3.98) with 620 ETT and 580 VPT. The tooth length was measured on digital panoramic radiographs, which were collected at the beginning and end of the orthodontic therapy for each subject. The pre- and post-orthodontic treatment radiographic evaluation included the percentage of EARR in ETT and contralateral VPT for all tooth types. Any relationship between EARR and orthodontic treatment type (one- and two-phase; extraction and non-extraction), duration, and patients' age and gender were investigated. Mann-Whitney U, Wilcoxon signed rank, Kruskal-Wallis and Spearman correlation tests were applied for comparisons and to test the correlations.

Results: A statistically significant difference was observed in all orthodontic treatment groups when ETT and VPT were compared in terms of EARR ($p<0.05$). EARR was positively correlated with orthodontic treatment duration and type ($p<0.05$) but was not influenced by patient age or gender. Statistically significant EARR was observed in the two-phase extraction orthodontic treatment group for both ETT and VPT. In VPT, a statistically significant EARR was found in the one-phase extraction treatment group compared with the non-extraction treatment group, whereas no significant difference was found in ETT.

Conclusion: ETT showed significantly lower EARR than VPT. ETT can therefore be moved safely during orthodontic treatment.

Keywords: External root resorption, orthodontic treatment, endodontics, root canal treatment

INTRODUCTION

Tooth root resorption is a complicated and unpredictable pathological condition that affects the cementum, root dentin, and apex and can lead to the irreversible loss of tooth structure.[1] Higher levels of root resorption have been observed during orthodontic tooth movement compared with the natural root resorption process in humans.[2] When orthodontic stresses are applied to teeth, blood flow in the periodontal ligament changes,

Corresponding author: Elchin Karimzada, **e-mail:** ekarimzada@gmail.com
Received: February 19, 2024 **Accepted:** July 24, 2024 **Publication Date:** 31 December, 2024

and a local inflammatory response is created to aid tooth movement.[3] External apical root resorption (EARR) is an undesirable condition that may also be a possible pathological consequence of orthodontic tooth movement. Orthodontically induced EARR is a condition in which the root surface is eroded, leading to the loss of cementum. Once the dentin is affected, this erosion becomes permanent and cannot be reversed.[3] Since orthodontically induced EARR is considered irreversible when it affects the dentin, it is crucial to identify factors that may predispose individuals to clinically significant EARR.[4] Several factors are potential risk factors and induce EARR during orthodontic treatment, including patient age, gender, nutrition, genetics, type of orthodontic appliance, magnitude of applied force, treatment type, treatment duration, and the amount of tooth movement.[5,6]

The possibility of experiencing endodontically treated teeth (ETT) has become even more frequent, with the expanded request for orthodontic treatment among adults. Therefore, predicting the prognosis of ETT after orthodontic treatment and their resistance to EARR is even more important for clinicians in their orthodontic planning. In the literature, the results of studies on whether ETT differs in resorption compared with contralateral teeth with vital pulp (VPT) after orthodontic treatment have been controversial. It has been considered that ETT may be more resistant to EARR than VPT.[7-10] On the contrary, Mah et al.[11] Reported higher EARR in ETT. Some studies have also found no difference in the amount of EARR observed between ETT and contralateral VPT.[12-14] The reasons for these controversial results could be due to the differences in the types of teeth included in the studies, the absence of evaluation of orthodontic treatment types in some studies, or the small sample size of patients and teeth included.

To the best of our knowledge, no previous study has evaluated the EARR resulting from one-phase and two-phase orthodontic treatments in all tooth types and compared their effects on root resorption in both ETT and VPT. Hence, our primary purpose was to assess the presence of EARR resulting from orthodontic treatment in ETT and to compare it with that of contralateral VPT. Second, the relationship between EARR levels and possible predisposing factors, such as treatment type and duration and patient age and sex, was also evaluated in the present study. The first null hypothesis tested was that orthodontic treatments applied to ETT and contralateral VPT did not result in root resorption. The second hypothesis was that the treatment type did not alter the degree of root resorption in ETT and VPT.

METHODS

Sample Selection

Ethical approval for this retrospective study was obtained from the Clinical Research Ethics Committee of Akdeniz University Faculty of Medicine (approval no.: 164, dated: 4 April 2022). The study materials were selected from the archives of Akdeniz University Faculty of Dentistry, Department of Orthodontics.

The records of 4673 patients who were treated from 2012 to 2023 were examined. The analysis focused on the pre- and post-treatment panoramic radiographs of 503 patients (314 females and 189 males; mean age 16.29 years ± 3.98) and 620 teeth (395 belonging to females and 225 belonging to males) that matched the following inclusion criteria: (1) the presence of anamnestic records, treatment planning, and clinical notes in patients' files; (2) high-quality pre-treatment and post-treatment panoramic radiographs; (3) at least one tooth that had been root-filled pre-orthodontically; and (4) teeth without fractures on their incisal or occlusal surfaces.

The quality of the root canal filling was evaluated based on the density of the filling, the taper of the filling, and the distance from the end of the filling to the radiographic apex.[15] The criteria used in this study to evaluate the technical quality of the filling were as follows: (1) length, root canal filling 0-2 mm from the radiographic apex; (2) homogeneity, homogeneous root canal filling, good condensation with no visible voids; and (3) tapering, steady and uniform tapering from the coronal to the apical region, reflecting the canal's original shape.

The exclusion criteria were as follows: (1) individuals with craniofacial anomalies, systemic disorders, or parafunctional habits like bruxism; (2) subjects who underwent endodontic treatment during orthodontic treatment; (3) patients with incomplete orthodontic treatment; and (4) ETT extraction during orthodontic treatment.

The distribution of the ETT based on the tooth number is shown in Figure 1. Out of 620 ETTs, 40 did not exhibit contralateral VPT. The sample was accepted as 580 when comparing the contralateral side to the ETT. In total, 620 ETT and 580 VPT were used to assess the association between EARR percentage and sex, age, treatment duration, and treatment type, whereas 580 ETT and contralateral VPT were compared in terms of the percentage of EARR according to treatment type.

According to the post-hoc power analysis, a Cohen's d of 0.85 was calculated from the comparison of the percentage of EARR in ETT between the one- and two-phase groups in the extraction treatment. The statistical power of the study was 99% with a margin of error of 0.05 given n1=166 and n2=46. The sample size was estimated using the G*Power 3.1.9.2 software.

All orthodontic treatments were performed by a team of residents under the supervision of a single expert. The patients were treated with two different modalities: the "one-phase orthodontic treatment", where patients received only fixed orthodontic treatment and the "two-phase orthodontic treatment", where the first phase involved various orthodontic appliances (monoblock, twin-block, Teuscher, face mask, chin cap and maxillary expansion appliances) followed by fixed orthodontic treatment. For all patients, the fixed orthodontic appliances were conventional Roth systems with a slot size of

	Right upper quadrant							Left upper quadrant						
N	5	72	14	7	1	13	31	27	17	1	12	13	93	5
Tooth number	7	6	5	4	3	2	1	1	2	3	4	5	6	7
	7	6	5	4	3	2	1	1	2	3	4	5	6	7
N	16	126	8	2	0	2	2	0	0	0	2	11	129	11
	Right lower quadrant							Left lower quadrant						

Figure 1. The chart, representing the distribution of ETTs based on the tooth number
N, Sample of the ETT

0.018 inches. The standard archwire sequences ranged from 0.014-inch nickel-titanium to 0.016x0.022-inch stainless steel.

The effect of orthodontic treatment type on the level of EARR was evaluated based on the application of orthopedic and fixed orthodontic treatment together (two-phase) or fixed orthodontic treatment alone (one-phase). Second, the effect of extraction- or non-extraction-fixed orthodontic treatment was assessed. The one- and two-phase treatment groups according to the extraction decision was performed and the extraction and non-extraction treatment groups were then compared based on the treatment phases. Age at the initiation of treatment, treatment duration, and percentage of EARR in ETT and VPT were also evaluated. Moreover, ETT and contralateral VPT were compared with each other in terms of the percentage of EARR according to the treatment phase and extraction decision.

Radiological Assessment

In this study, measurements were made on digital panoramic radiographs taken at the beginning (T0) and end of treatment (T1). Panoramic radiographs were obtained using a Planmeca ProMax panoramic device (Planmeca, Helsinki, Finland) for all patients. The positioning light guides incorporated into the machine were used to standardize the position of the head. The images were obtained using the Planmeca Romexis Viewer program (v.2.7.0.R; Planmeca, Finland).

The lengths of the crowns and roots of the teeth were measured using the Planmeca Romexis Viewer program to determine the amount of EARR occurring between T0 and T1 according to the method described by Linge and Linge.[12] The reference points and lines for the pre- and post-orthodontic treatment measurements are shown in Figure 2. The cementoenamel junction (CEJ) was initially identified as a linear connection between two specific locations, specifically the mesial and distal CEJs. The crown lengths on the pre- and post-treatment radiographs were then determined in ETT and contralateral VPT by measuring the longest distance from the incisal or occlusal edge to the CEJ. The root lengths on the pre- and posttreatment radiographs were also calculated in the ETT and

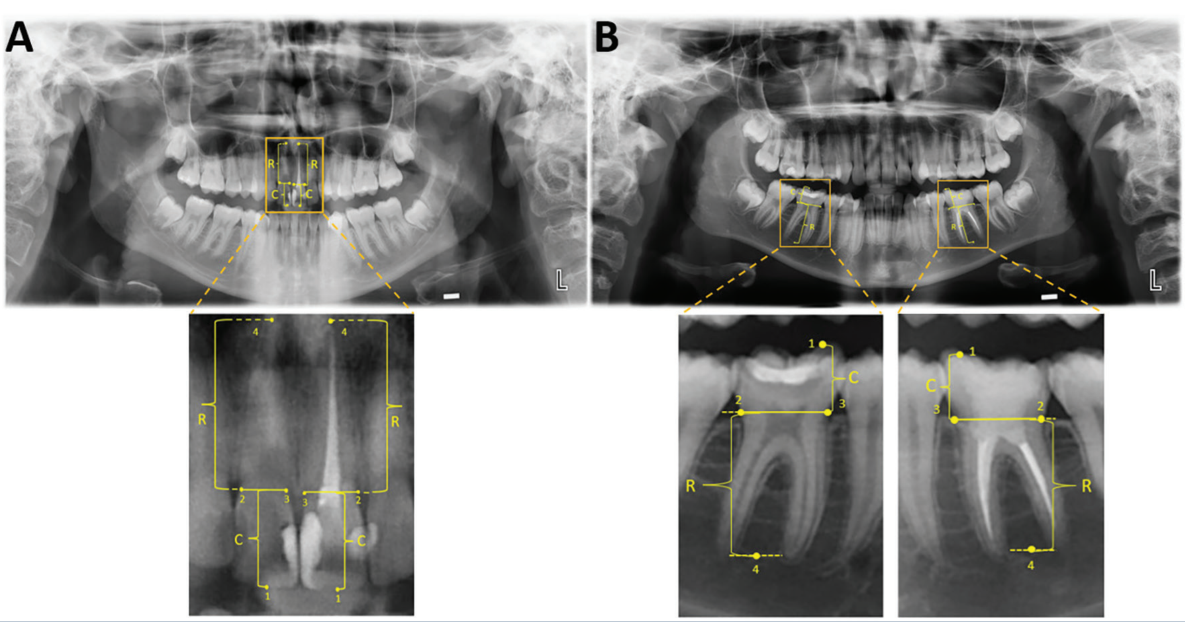

Figure 2. Measurements of crown and root lengths of single-rooted **(A)** and multiple-rooted teeth **(B)**
1-incisal or occlusal edge; 2-distal CEJ; 3-mesial CEJ; 4-iroot apex; R-root length; C-crown length

Turk J Orthod 2024; 37(4): 249-256

contralateral VPT by measuring the distance from the CEJ to the root apices. The root lengths of teeth with multiple roots were calculated by measuring the distance from the CEJ to the midpoint on the line between the root apexes. The buccal roots of the upper and premolars were measured.

First, the amount of EARR was calculated in millimeters as follows: root length pre-orthodontic treatment (R1) root length post-orthodontic treatment (R2) × (crown length before orthodontic treatment/crown length after orthodontic treatment).[12] Then, EARR was defined as the percentage shortening per tooth as follows: EARR×100/R1. Using percentage values is a more efficient approach for conducting comparisons because individual discrepancies in tooth root length can diminish the significance of millimeter-based comparisons of root resorption values.

Statistical Analysis

Analyses were performed using SPSS 23.0 software (SPSS Inc., Chicago, Illinois, USA). To determine the method error, 60 patients were randomly selected and measured by the same researcher within a 2-week interval. The intraclass correlation coefficient was used to assess intraobserver reliability and was found to be 0.98. The assumption of normality was evaluated by using the Shapiro-Wilk test. The Mann-Whitney U test was used for intragroup comparison of pre-treatment age, treatment duration, and percentage of patients with EARR. The same test was used for gender comparison. The Wilcoxon signed rank test was used for the intergroup comparison of the percentage of EARR. Statistically significant cases were defined as those with a $p<0.05$. The Spearman correlation test was used to evaluate the correlation between pre-treatment age, treatment duration, and the percentage of patients with EARR.

RESULTS

The data include information on characteristics such as age at the beginning of treatment, treatment duration, treatment type, number of teeth, tooth group, and percentage of EARR in ETT and VPT. Table 1 presents both the comparison of the one- and two-phase orthodontic treatment groups regarding whether teeth were extracted or not, and the results of the compared extraction and non-extraction groups in the one- and two-phase treatment. Differences were observed in the age at the beginning of treatment, treatment duration, and percentage of EARR in ETT and VPT between the one-phase and two-phase extraction treatment groups. In the one-phase extraction group, the age at the beginning of treatments was higher, whereas the duration of treatment and the percentage of EARR in both ETT and VPT were lower ($p<0.05$).Differences were also observed in the age at the beginning of treatment, treatment duration, and the percentage of EARR in ETT and VPT between the one-phase and two-phase groups in the non-extraction treatment. The age at the beginning of treatment, treatment duration, and percentage of EARR in both ETT and VPT were reduced in the one-phase group compared with the two-phase group in the non-extraction treatment. Significant differences were observed in the age at the beginning of treatment, treatment duration, and percentage of EARR in ETT and VPT between the extraction and non-extraction groups in the one-phase treatment ($p<0.05$). These values were higher in the extraction group than in the non-extraction group. The percentage of EARR in ETT and VPT between the extraction and non-extraction groups in the two-phase treatment was found to be different ($p<0.05$). These values were higher in the extracted group than in the non-extracted group.

Comparisons of the percentage of EARR in ETT and VPT between the one- and two-phase treatment groups are presented in Table 2. The percentage of EARR was significantly higher in VPT than in ETT in both the one- and two-phase treatment groups.

Comparisons of the percentage of EARR in ETT and VPT between the extraction and non-extraction treatment groups are presented in Table 3. Similar to the findings in the phase comparison, the percentage of EARR was higher in the VPT group than in the ETT group in both the extraction and non-extraction treatment groups.

Treatment duration showed a statistically significant, positive but weak correlation with EARR in ETT and VPT ($p<0.001$; $r=0.19$ and $r=0.226$, respectively). Patient age was not significantly correlated with EARR on ETT and VPT (Table 4).

Table 5 presents the comparison of the EARR percentage according to the tooth group in the ETT and VPT. The tooth group significantly impacted apical root resorption in ETT ($p<0.05$), but it did not affect vital teeth ($p>0.05$).

Gender had no statistically significant effect on the percentage of EARR in ETT and VPT.

DISCUSSION

A total of 503 patients, including 620 ETT and 580 VPT, were included in the study based on the specified inclusion and exclusion criteria. This study assessed the differences in tooth lengths of all tooth types in ETT and contralateral VPT before and after orthodontic treatment using digital panoramic radiography. The results from both the one- and two-phase, as well as the extraction and non-extraction treatment groups, were compared within each group and between groups. The present study revealed that the EARR was significantly greater in VPT than in ETT. As a result, the first hypothesis was rejected. Additionally, the amount of EARR was partially influenced by the treatment type in both ETT and VPT; thus, the second hypothesis was partially supported.

Previous studies[7-10] have examined the assessment of root resorption during orthodontic treatment and compared ETT and VPT results. Lee and Lee[7], in their retrospective study reviewing different teeth in 35 patients and reported significantly less EARR in ETT compared with the contralateral VPT. Kurnaz and Buyukcavus[8] examined the mandibular molars

Table 1. Comparison of the one- and two-phase treatment groups based on the extraction and the extraction and non-extraction treatment groups based on the treatment phase

	Treatment phase	Extraction orthodontic treatment				Non-extraction orthodontic treatment				Treatment type	One-phase orthodontic treatment				Two-phase orthodontic treatment			
		n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value		n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
Pre-treatment age (year)	One	166	17.65±5.04	16.49 (14.89-18.08)	**<0.001**	282	16.33±3.6	16.03 (14.48-17.41)	**<0.001**	Ext	166	17.65±5.04	16.49 (14.89-18.08)	**0.002**	46	15.11±3.88	14.5 (13.24-15.41)	0.767
	Two	46	15.11±3.88	14.5 (13.24-15.41)		126	14.83±2.33	14.26 (13.59-15.73)		Non-ext	282	16.33±3.6	16.03 (14.48-17.41)		126	14.83±2.33	14,26 (13.59-15.73)	
Treatment duration (months)	One	166	28.39±9.85	27.8 (22.07-34.53)	**0.01**	282	20.99±10.06	20.03 (12.93-27.07)	**<0.001**	Ext	166	28.39±9.85	27.8 (22.07-34.53)	**<0.001**	46	34.98±10.21	33.95 (24.93-41.83)	0.08
	Two	46	34.98±10.21	33.95 (24.93-41.83)		126	31.69±10.86	30.55 (22.2-40.33)		Non-ext	282	20.99±10.06	20.03 (12.93-27.07)		126	31.69±10.86	30.55 (22.2-40.33)	
ETT: T0-T1 (%)	One	166	4.92±3.99	4.48 (1.77-7.06)	**0.002**	282	4.75±4.27	3.75 (1.78-6.76)	0.547	Ext	166	4.92±3.99	4.48 (1.77-7.06)	0.55	46	7.26±4.99	6.39 (4.27-9.81)	**0.003**
	Two	46	7.26±4.99	6.39 (4.27-9.81)		126	5.45±5.39	3.88 (1.88-7.08)		Non-ext	282	4.75±4.27	3.75 (1.78-6.76)		126	5.45±5.39	3.88 (1.88-7.08)	
VPT: T0-T1 (%)	One	159	7.06±4.6	6.78 (3.26-10.16)	**0.006**	264	5.87±4.34	5.27 (2.45-7.84)	0.196	Ext	159	7.06±4.6	6.78 (3.26-10.16)	**0.005**	42	9.49±5.27	9.11 (5.96-12.43)	**<0.001**
	Two	42	9.49±5.27	9.11 (5.96-12.43)		115	6.68±5.18	5.53 (2.87-8.59)		Non-ext	264	5.87±4.34	5.27 (2.45-7.84)		115	6.68±5.18	5.53 (2.87-8.59)	

SD: Standard deviation; The statistical significance level was $p<0.05$ p: Intragroup comparison (Comparison of One and Two phase groups in Extraction treatment; Comparison of One and Two phase groups in Non-extraction treatment; Comparison Extraction and Non-extraction groups in One phase treatment; Comparison Extraction and Non-extraction groups in Two phase treatment): Mann-Whitney U test. Significant differences are indicated in bold ($p<0.05$). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

of 69 patients and observed more root resorption in vital molars than in endodontically treated molars post orthodontically. In addition, Grissom et al.[9] conducted a study to evaluate the amount of root resorption in 76 (38 endodontically-treated and 38 vital contralateral) teeth with CBCT and found that ETT was more resistant to external root resorption than their contralateral VPT. In another study, Kolcuoglu and Oz[10] evaluated the difference in root resorption between endodontically treated and vital premolars in premolar-extracted orthodontic treatment using micro-CT and reported that ETT was less susceptible to root resorption than VPT. The findings of the present study were in accordance with the abovementioned results. However, some studies[12-16] reported no significant differences in root resorption between ETT and contralateral VPT. The disagreement in the results between previous findings and the current study may be attributed to the inclusion of different types of teeth and study samples, such as incisors and molars. To the best of our knowledge, all types of teeth were included in the present study, and the total sample size was the largest of all similar studies. Moreover, the outcomes of two-phase orthodontic treatment, which includes orthopedic treatment and one-phase orthodontic treatment with only fixed appliances, were investigated.

The mechanism and role of pulp tissue have been researched histologically by some researchers, but it is still complicated. Kaku et al.[17] found that injured and stretched pulp cells express receptor activator of nuclear factor kappa-B ligand (RANKL), macrophage colony stimulating factor (M-CSF), and inflammatory cytokines; thereby, odontoblastic activity starts and inflammatory apical root resorption occurs. They assumed that tensile forces on the pulp cells through the apical foramen induced by orthodontic tooth movement cause an increase in the expression of these factors, which may lead to inflammatory root resorption. Bender et al.[18] suggested that the absence of neuropeptide release from the removed pulp leads to a decrease in CGRP-IR fibers and less resorption in ETT. In addition, calcium hydroxide-based root canal materials have been reported to have a positive effect on the healing process of periapical tissue and the repair of orthodontic root resorption in endodontically treated dog teeth.[19] These factors may explain the lower EARR observed in ETT in those studies.

Previous studies[7,8,20] in the literature have indicated a positive correlation between EARR and the type and duration of orthodontic treatment. It was reported that there was no significant difference between extraction and non-extraction treatment protocols in terms of resorption in ETT, while more resorption was observed in VPT in treatment protocols involving extraction.[7,8,21] Only one study[22] reported that both VPT and ETT showed more resorption in non-extraction cases than in extraction cases. According to the results of our study, orthodontic treatment involving extractions resulted in greater EARR in VPT patients compared with patients without extractions, which is consistent with previous studies.[7,8,21]

Very few studies[20,23,24] have compared one- and two-phase treatment protocols in terms of root resorption. Seker et al.[24] reported a significant increase in the incidence of EARR in patients treated with two-phase treatment compared to those treated

Table 2. Comparison of the EARR percentage in the one- and two-phase orthodontic treatment groups of ETT and VPT groups

Percentage of the EARR	One-phase orthodontic treatment				Two-phase orthodontic treatment			
	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
ETT:T0-T1 (%)	423	4.92±4.24	4.31 (1.77-7.09)	**<0.001**	157	6.25±5.44	4.76 (2.26-7.99)	**0.001**
VPT:T0-T1 (%)	423	6.32±4.47	5.61 (2.73-8.71)		157	7.43± 5.33	6.54 (3.61-9.58)	

SD: Standard deviation; The statistical significance level was p<0.05; p: Intergroup comparison (Comparison of EARR level of ETT and VPT in One phase treatment; Comparison of EARR level of ETT and VPT in Two phase treatment): Wilcoxon signed rank test. Significant differences are indicated in bold (p<0.05).
ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 3. Comparison of the EARR percentage in the extraction and non-extraction orthodontic treatment groups for ETT and VPT

Percentage of EARR	Extraction orthodontic treatment				Non-extraction orthodontic treatment			
	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
ETT:T0-T1 (%)	201	5.56±4.38	5.1 (2.05-7.69)	**<0.001**	379	5.13±4.76	4.07 (1.84-7.09)	**<0.001**
VPT:T0-T1 (%)	201	7.57±4.84	6.93 (3.7-10.56)		379	6.12±4.62	5.34 (2.72-8.09)	

SD: Standard deviation; The statistical significance level was p<0.05; p: Intergroup comparison (Comparison of EARR level of ETT and VPT in Extraction treatment; Comparison of EARR level of ETT and VPT in Non-extraction treatment): Wilcoxon signed rank test. Significant differences are indicated in bold (p<0.05). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 4. Correlation of pre-treatment age and treatment duration with EARR percentage in ETT and VPT

	Correlation	VPT T0-T1 (%)	Pre-treatment age	Treatment duration (months)
ETT:T0-T1 (%) n=620	r	0.245	-0.011	0.190
	p	**<0.001**	0.784	**<0.001**
VPT:T0-T1 (%) n=580	r		-0.047	0.226
	p		0.258	**<0.001**

Spearman Correlation Test. Significant differences are indicated in bold (p<0.05). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 5. Comparison of the EARR percentage according to the tooth group during ETT and VPT

Tooth group	ETT T0-T1 (%)		VPT T0-T1 (%)	
	n (teeth)	Median (Q1-Q3)	n (teeth)	Median (Q1-Q3)
Maxillary anterior	90	5.25 (2.32-8.67)	85	7.52 (4.04-10.39)
Maxillary premolar	46	4.35 (1.34-6.64)	46	6.86 (3.63-11.57)
Maxillary molar	175	4.27 (2.04-7.41)	175	5.3 (2.42-8.49)
Mandibular anterior	4	13.14 (8.37-15.22)	4	7.9 (3.94-8.93)
Mandibular premolar	23	2.59 (0.75-4.86)	23	5.65 (4.65-10.29)
Mandibular molar	282	4.02 (1.8-6.67)	247	5.61 (2.84-8.22)
p		**0.002**		0.077

Kruskal-Wallis test. Significant differences are indicated in bold (p<0.05); ETT, endodontically treated teeth; VPT, contralateral teeth with vital pulp

with fixed appliances alone. However, Faxén Sepanian and Sonnesen[23] found that the one-phase treatment group showed significantly higher EARR than the two-phase treatment group. On the other hand, no significant differences were reported between two-phase and one-phase treatment protocols regarding the incidence of EARR.[20] In the present study, the EARR incidence for both ETT and VPT in the two-phase extraction treatment group was statistically significant when compared with that of one-phase extraction. The longer treatment period in the two-phase treatment group was probably associated with increased root resorption, which in turn could be attributed to greater teeth movements during orthodontic extraction therapy and variations in the level of orthodontic forces utilized in the orthopedic treatment.

A possible relationship between sex and root resorption in both ETT and VPT was also evaluated in the present study; the amount of EARR did not show any significant difference with sex in accordance with previous studies.[7,21] On the contrary, only one study found the EARR to be more frequent in males than females.[20] This result was attributed to the longer treatment duration in male patients. Another possible factor affecting the level of EARR, chronological age, was also investigated. In the current study, the age range was 8.9-43.9 years and the sample was substantial. There was no correlation between age and EARR level, however, similar to previous studies.[20,25] In contrast, Lee and Lee[7] reported a positive correlation between age and root resorption in ETT but not in VPT. This result can be attributed to the sample size. Moreover, the extent of root resorption varied among the tooth groups; this variable was incorporated into the study analysis. Previous studies[20,25] have indicated that maxillary incisors exhibit the highest frequency of resorption, followed by mandibular incisors. McFadden et al.[26] reported that mandibular incisors are more susceptible to root resorption following intrusion movements than maxillary incisors. In our study, the greatest amount of EARR in both the ETT and VPT was observed first in the mandibular anterior teeth, followed by the maxillary anterior teeth. This outcome may be attributed to several factors, including the cortical bone of the socket, alveolar bone on the buccal surface, intrusion movements, and unequal distribution of teeth among the tooth groups.

Digital panoramic radiographs, intraoral periapical radiographs, and three-dimensional images (cone beam computed tomography, CBCT) are commonly used to evaluate EARR following orthodontic treatment.[9,14,21] Three-dimensional imaging has been shown to have greater accuracy and repeatability in evaluating EARR than two dimensional images.[27,28] Despite its accuracy, the use of CBCT for routine orthodontic records has been contested because of the higher radiation dose.[4] Periapical films have been accepted as superior to panoramic images because of the lesser image distortion and greater detail resolution.[29] However, it has been reported that the effective radiation dose of panoramic radiography is lower than that of traditional full-mouth periapical radiography.[30] Apajalahti and Peltola[25] also evaluated root length changes using panoramic radiographs, as periapical radiographs are not routinely taken during orthodontic treatment, and panoramic images provide high-quality results. Root resorption is usually diagnosed on panoramic radiography due to advantages such as low radiation exposure, view of the entire dental arch, and low cost.[31] In the present study, tooth length was measured using digital panoramic radiography. This is because serial periapical radiographs and three-dimensional imaging are not routinely performed during orthodontic treatment. Instead, panoramic radiographs are more routinely used in orthodontic records and are easily accessible for retrospective analysis.[4,25]

For measurements on panoramic radiographs, like root resorption, where reproducibility is crucial, the palatal root of the maxillary first molars was found to be unreliable, whereas the maxillary first molar buccal roots were reproducible on panoramic radiographs.[32] Therefore, the buccal roots of the maxillary molar and premolar teeth were included in this study, similar to previous studies.[21] Common errors in panoramic radiography are generally caused by head positioning. Stramotas et al.[33] reported that linear measurements on panoramic radiographs acquired at different times are sufficiently accurate if the occlusal plane is positioned similarly on both occasions and the extent of tilting does not exceed 10°. In the present study, the same panoramic machine and guide lights were used for all radiographs of each patient to reduce head positioning errors. Moreover, the objective was to compare the EARR on pre- and post-treatment radiographs instead of determining the exact values of root loss.

In this study, care was taken to ensure that root canal treatments were of a certain quality, and teeth that did not meet the specified criteria were excluded from the study because cases with unsuccessful root canal treatment (such as a short root canal filling, lack of filling homogeneity) had a risk of affecting the objectives of our study. In future studies, such cases and the results of orthodontic treatment can be compared retrospectively.

Study Limitations

Our study has some notable strengths that set it apart from other studies in the existing literature. First, a large sample size was evaluated comprehensively in this retrospective study. It is important to note the challenge of identifying a large sample size including ETT in orthodontic patients. Second, the amount of EARR was assessed in different types of orthodontic treatment modalities together with the treatment duration (extraction vs. non-extraction; one-phase vs. two-phase). Nevertheless, the main limitation of this study was the utilization of two-dimensional digital panoramic radiographs, which have lower sensitivity compared with three-dimensional imaging techniques. While prior research[7,8,21,22] has utilized panoramic radiographs to assess EARR, it would be advantageous to perform future investigations using three-dimensional imaging.

CONCLUSION

The findings of the present study indicate that ETT is less susceptible to EARR than VPT. When the pre- and post-orthodontic treatment panoramic radiographs were compared, different EARR values were observed in all teeth. Significantly associated risk factors were long treatment durations and extraction treatment. This study concluded that the potential complications of EARR in ETT might not be a factor to consider when planning orthodontic treatment.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Clinical Research Ethics Committee of Akdeniz University Faculty of Medicine (approval no.: 164, date: 4 April 2022).

Informed Consent: Informed consent was obtained from all patients who were treated, and the patients' individual materials were used in these consent forms.

Footnotes

Author Contributions: Concept - E.E., K.E.; Design - E.E., K.E.; Data Collection and/or Processing - E.K.; Analysis and/or Interpretation - E.K., E.E., K.E.; Literature Search - E.K.; Writing - E.K., E.E.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declare that this study has received no financial support.

REFERENCES

1. Zhao D, Xue K, Meng J, Hu M, Bi F, Tan X. Orthodontically induced external apical root resorption considerations of root-filled teeth vs vital pulp teeth: a systematic review and meta-analysis. *BMC Oral Health*. 2023;23(1):241. [CrossRef]
2. Ito K, Kurasawa M, Sugimori T et al. Risk assessment of external apical root resorption associated with orthodontic treatment using computed tomography texture analysis. *Oral Radiol*. 2023;39(1):75-82. [CrossRef]
3. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part I: the basic science aspects. *Angle Orthod*. 2002;72(2):175-179. [CrossRef]
4. Walker SL, Tieu LD, Flores-Mir C. Radiographic comparison of the extent of orthodontically induced external apical root resorption in vital and root-filled teeth: a systematic review. *Eur J Orthod*. 2013;35(6):796-802. [CrossRef]
5. Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. *Am J Orthod Dentofacial Orthop*. 1996;110(3):311-320. [CrossRef]
6. Jiang RP, McDonald J, Fu MK. Root resorption before and after orthodontic treatment: a clinical study of contributory factors. *Eur J Orthod*. 2010;32(6):693-697. [CrossRef]
7. Lee YJ, Lee TY. External root resorption during orthodontic treatment in root-filled teeth and contralateral teeth with vital pulp: A clinical study of contributing factors. *Am J Orthod Dentofacial Orthop*. 2016;149(1):84-91. [CrossRef]
8. Kurnaz S, Buyukcavus MH. External root resorption in root-filled and vital teeth after dental extraction and non-extraction: A split-mouth retrospective study. *Acta Odontol Scand*. 2021;79(4):282-288. [CrossRef]
9. Grissom AC, Cozad BE, Makins SR, Silva RM, English JD, Kirkpatrick TC. Root surface changes in endodontically treated teeth following orthodontic movement. *J Endod*. 2022;48(11):1361-1366. [CrossRef]
10. Kolcuoğlu K, Oz, A.Z. Comparison of root resorption between root-filled and vital teeth using micro-computed tomography. *Angle Orthod*. 2020;90(1):56-62. [CrossRef]
11. Mah R, Holland G, Pehowich E. Periapical changes after the orthodontic movement of root-filled ferret canines. *J Endod*. 1996;22(6):298-303. [CrossRef]
12. Esteves T, Ramos AL, Pereira CM, Hidalgo MM. Orthodontic root resorption in endodontically treated teeth. *J Endod*. 2007;33(2):119-122. [CrossRef]
13. Llamas-Carreras JM, Amarilla A, Espinar-Escalona E et al. External apical root resorption in maxillary root-filled incisors after orthodontic treatment: a split-mouth design study. *Med Oral Patol Oral Cir Bucal*. 2012;17:e523-527. [CrossRef]
14. Esteves T, Ramos AL, Hidalgo MM. Apical root resorption of vital and endodontically treated teeth after orthodontic treatment: a radiographic evaluation. *Dental Press Endod*. 2013;3(3):69-73. [CrossRef]
15. Tchorz JP, Ganter PA, Woelber JP, Stampf S, Hellwig E, Altenburger MJ. Evaluation of an improved endodontic teaching model: does preclinical exercises influence the technical quality of root canal treatments? *Int Endod J*. 2014;47:410-415. [CrossRef]
16. Linge L, Linge BO. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 1991;99(1):35-43. [CrossRef]
17. Kaku M, Sumi H, Shikata H et al. Effects of pulpectomy on root resorption in orthodontic tooth movement. *J Endod*. 2014;40(3):372-378. [CrossRef]
18. Bender I, Byers MR, Mori K. Periapical replacement resorption of permanent, vital, endodontically treated incisors after orthodontic movement: A report of two cases. *J Endod*. 1997;23(12):768-773. [CrossRef]
19. De Souza RS, De Souza V, Holland R, Gomes-Filho JE, Murata SS, Sonoda CK. Effects of calcium hydroxide-based materials on the periapical tissue healing and orthodontic root resorption of endodontically treated teeth in dogs. *Dent Traumatol*. 2009;25(2):213-218. [CrossRef]
20. Bayir F, Gumus EB. External apical root resorption after orthodontic treatment: incidence, severity and risk factors. *J Dent Res Dent Clin Dent Prospects*. 2021;15(2):100-105. [CrossRef]
21. Şeker ED, Dinçer AN, Kaya N. Apical root resorption of endodontically treated teeth after orthodontic treatment: a split-mouth study. *Turk J Orthod*. 2023;36(1):15-21. [CrossRef]
22. Khan AR, Fida M, Shaikh A. Evaluation of apical root resorption in endodontically treated and vital teeth in adult orthodontic subjects. *J Ayub Med Coll Abbottabad*. 2018;30(4):506-510. [CrossRef]
23. Faxén Sepanian V, Sonnesen L. Incisor root resorption in Class II division 2 patients in relation to orthodontic treatment. *Eur J Orthod*. 2018;40(3):337-342. [CrossRef]
24. Seker ED, Yilmaz BS, Yagci A. Evaluation of apical root resorption in Class III patients who received one-or two-phase orthodontic treatment. *APOS Trends Orthod*. 2021;11(2):123-131. [CrossRef]
25. Apajalahti S, Peltola JS. Apical root resorption after orthodontic treatment-a retrospective study. *Eur J Orthod*. 2007;29(4):408-412. [CrossRef]
26. McFadden WM, Engstrom C, Engstrom H, Anholm JM. A study of the relationship between incisor intrusion and root shortening. *Am J Orthod Dentofacial Orthop*. 1989;96(5):390-396. [CrossRef]
27. Dudic A, Giannopoulou C, Leuzinger M, Kiliaridis S. Detection of apical root resorption after orthodontic treatment using panoramic radiography and cone-beam computed tomography of super-high resolution. *Am J Orthod Dentofacial Orthop*. 2009;135(4):434-437. [CrossRef]
28. Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography in an in vivo investigation. *Int Endod J*. 2009;42(9):831-838. [CrossRef]
29. Pepelassi EA, Diamanti-Kipioti A. Selection of the most accurate conventional radiography method for the assessment of periodontal osseous destruction. *J Clin Periodontol*. 1997;24(8):557-567. [CrossRef]
30. Choi J-W. Assessment of panoramic radiography as a national oral examination tool: review of the literature. *Imaging Sci Dent*. 2011;41(1):1-6. [CrossRef]
31. Marinescu IR, Bănică AC, Mercuţ V et al. Root resorption diagnosis: role of digital panoramic radiography. *Curr Health Sci J*. 2019;45(2):156-166. [CrossRef]
32. Thanyakarn C, Hansen K, Rohlin M, Akesson L. Measurements of tooth length in panoramic radiographs. 1. The use of indicators. *Dentomaxillofac Radiol*. 1992;21(1):26-30. [CrossRef]
33. Stramotas S, Geenty JP, Petocz P, Darendeliler MA. Accuracy of linear and angular measurements on panoramic radiographs taken at various positions in vitro. *Eur J Orthod*. 2002;24(1):43-52. [CrossRef]