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ORIGINAL ARTICLE

External root resorption in root-filled and vital teeth after extraction and non-extraction orthodontic treatments: a split-mouth retrospective study

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ABSTRACT

Objective: This study aimed to compare the amounts of external root resorption (ERR) during different modalities of orthodontic treatment (OT) in root-filled teeth (RFT) and their contralateral teeth with vital pulp (VPT) in the same patient.

Material and methods: The study sample consisted of 69 patients in two groups: 35 patients in the non-extraction group (18 female, 17 male; 18.16 ± 3.79 years), and 34 patients in the extraction group (19 female, 15 male; 17.72 ± 2.78 years). Digital panoramic radiographs of each patient taken before and after OT were used to measure the tooth length and root surface area. The amounts of ERR in RFT and contralateral VPT were evaluated pre- and post-OT in mandibular molars. The data were statistically analyzed with the paired *t*-test, independent *t*-test, and analysis of covariance (ANCOVA) ($p < .05$).

Results: A statistically significant difference was observed in both the orthodontic treatment groups when RFT and VPT were compared in terms of ERR ($p < .05$). A significant difference was observed between RFT and VPT in extraction treatments when the reduction in the root area between the two sides in the groups was compared ($p < .05$).

Conclusions: RFT are more resistant to ERR than VPT. The ERR in RFT may not be a significant matter for the planning of OT.

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Endodontics; external root resorption; orthodontic treatment; root canal treatment; vital teeth

Introduction

External root resorption (ERR) is considered a side effect of orthodontic tooth movement and is an undesirable, irreversible, complex pathological process. This type of root resorption affects the cementum and root dentine as well as causes permanent damage to the root structure [1,2]. The teeth involved in orthodontic treatment (OT) may be exposed to ERR, and many published articles have confirmed the relationship between OT and ERR [3,4].

ERR can begin in the early levelling stages of OT [5]. Many factors may influence the degree and severity of ERR during OT, and factors such as age, sex, genetics, tooth extraction, type of orthodontic appliance, duration of treatment, the distance of tooth movement, and the type and magnitude of orthodontic forces play an essential role [6,7]. Massler and Malone [8] observed ERR in 86.4% of orthodontic patients, and histological studies reported that root resorption occurs in 90% of orthodontically moved teeth [9,10].

Surface resorption (also called repair-related resorption) is a type of ERR caused by damage to cementum as a result of orthodontic forces, surgical procedures, mechanical dental trauma, or excessive pressure of impacted tooth or tumours [11]. ERR occurs from all directions, including both sides of the root and the apical region [12]. If the trauma and/or pressure are/is stopped, spontaneous healing occurs, and osteoclasts and macrophages remove the injured root surface, which is then repaired by the formation of new cementum and periodontal ligament fibres [11,13].

The studies have reported controversial findings of root-filled teeth (RFT) involved in OT. In animal studies, Mattison et al. [14] and Mah et al. [15] reported no significant differences between the ERR of RFT and teeth with vital pulp (VPT) when both were subjected to orthodontic forces. In addition, Esteves et al. [16] and Llamas-Carreras et al. [17] showed similar results with these animal studies in their clinical studies and reported that there was no significant difference between RFT and VPT in terms of ERR. However, some authors found that RFT are more susceptible to ERR than are VPT during OT [18–20]. On the contrary, other authors reported less ERR with RFT [21,22]. According to these controversial results, the ERR of RFT and VPT, when involved in OT, remains a problem that needs to be investigated in an evidence-based manner [23].

To our knowledge, in the literature, when determining the amount of ERR, except for *in vitro* studies, linear measurements are generally preferred, and apical resorption has been more studied. Thus, the aim of this study—which we designed by considering the deficiencies in the literature—

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was to compare ERR associated with OT in RFT and contralateral VPT in the same patient both linearly and areally. The study's first hypothesis was that there is no difference between root resorption in RFT and the control VPT. The second hypothesis was that the modality of fixed OT does not change the amount of root resorption in RFT and VPT.

Materials and methods

This split-mouth design study is a retrospective clinical one. Ethical approval was obtained from the Clinical Research Ethics Committee of Kutahya Health Sciences University, Kutahya, Turkey (reference number: 2020/02–07). In addition, written informed consent was obtained from patients and their parents who received OT.

The sample size was calculated using a power analysis (G*Power v.3.0.10; Kiel, Germany) for apical root resorption in endodontically treated teeth at an alpha error probability of 0.05 and a power of 90% to detect a clinically meaningful difference of 0.95 mm (±1.15 mm) for the amount of ERR between the groups [22]. The power analysis showed that a minimum of 21 patients was required for each group. More patients were included in the study to increase the power of the study.

The radiographs of patients treated in our orthodontic clinic between June 2018 and June 2020 were divided into two groups—extraction and non-extraction OT—and were selected for assessment according to the following inclusion criteria:

1. Panoramic films that have been standardized and have a high image quality in order to determine the landmarks correctly;
2. Pre-OT, patients without any periapical pathology and endodontically treated mandibular molars at least 1 year ago and contralateral VPT; and
3. Patients without known parafunctional habits, such as bruxism and clenching.
4. For the extraction OT group, moderate anchorage cases with the four first premolar extractions were selected. At the beginning and end of the treatment, equal amounts of mesialization were compared between the right and left sides.
5. Attention was paid to the same bracket system and the same amount of tooth movement (anchorage amount).

The study excluded patients who underwent endodontic treatment during OT, had teeth with anomalies in size and position, had a contralateral nonvital tooth, were treated with a history of trauma, had missing treatment records, or were extracted for OT (except mandibular first premolar teeth). Since it may affect the calculation of total root and tooth length, the amount of tipping in the molars was also examined on panoramic radiographs. Patients with tipping in their mandibular molars were excluded from the study. Both researchers evaluated and ensured that the examined teeth of the patients had a closed root apex.

Thirty-five (18 female; 17 male) patients (mean age: 18.16 ± 3.79 years) who underwent non-extraction OT and met the inclusion criteria among 367 patients who completed their treatment were included in the non-extraction group. Thirty-four (19 female; 15 male) patients (mean age: 17.72 ± 2.78 years) who received OT with first premolar extraction were included in the extraction group. Root-canal filled teeth were on the right side in 19 patients and on the left in 16 patients in the non-extraction OT group; in the extraction OT group, it was found on the right side in 17 patients and on the left side in 17 patients. Table 1 presents the descriptive data of the patients included in the study.

All 69 patients were treated with conventional brackets (Roth prescription and a slot size of 0.018 inches). When all the patients' records were examined, it was evident that their OTs were performed with a general archwire sequence ranging from 0.014-inch nickel-titanium to 0.017 × 0.025-inch stainless steel. The mean duration of treatment was 1.53 ± 0.64 years in the non-extraction OT group, whereas it was 2.07 ± 0.72 years in the extraction OT group.

Image analysis

In both groups, the amount of ERR in RFT and contralateral VPT was evaluated pre-and post-OT in mandibular molars. In our study, measurements were made on digital panoramic radiographs taken just before treatment and immediately after debonding. These radiographs were obtained using a Planmeca ProMax X-ray machine (Planmeca, Helsinki, Finland). They were taken in our faculty. The position of the head was standardized while the radiographs were taken.

The crown length and root length measurements were analyzed by Planmeca Romexis Viewer (v.5.4.1.R; Planmeca, Italy) according to the method prescribed by Linge and Linge [3] (Figure 1). The reference points and measurements used pre- and post-OT are shown in Figure 1. While making measurements, first, the cementoenamel junction (CEJ) was determined as a straight line between two points, namely mesial and distal CEJs. The crown lengths on the initial and final radiographs were then calculated in RFT and contralateral VPT, measuring the longest distance from the incisal or occlusal edge to the CEJ. The root lengths pre- and post-OT were generally calculated in RFT and contralateral VPT by measuring the distance from the CEJ to the root apexes. Because the mandibular molars in our study had two roots, the root lengths were calculated by measuring the distance from the CEJ to the midpoint on the line between the root apexes.

The calculation of the amount of ERR and the proportions are shown in Figure 2. The amount of ERR was calculated in millimetres. The root length difference between pre- and post-treatment was calculated. Then, the ratio of the pre-treatment crown length to the post-treatment crown length was calculated, and the two values found were multiplied. The proportion of the root resorption in RFT was calculated by proportioning to the root resorption in VPT.

Digital area measurements were also made to support the linear measurements we used in our study (Figure 3). The area measurements were performed on digital panoramic radiographs after digital calibration, using the SketchAndCalc

Table 1. Comparison of the chronological ages, gender distributions, tooth type distributions, and treatment durations between the groups.

	Non-extraction Orthodontic Treatment Mean ± SD	Extraction Orthodontic Treatment Mean ± SD	*p*
Chronological Age (years)[a]	18.16 ± 3.79	17.72 ± 2.78	NS
Gender[b]	18 Female 17 Male	19 Female 15 Male	NS
Tooth Type[b] **(*n*)**	36 - *n* = 12 46 - *n* = 16 37 - *n* = 4 47 - *n* = 3	36 - *n* = 10 46 - *n* = 13 37 - *n* = 7 47 - *n* = 4	NS
Treatment Duration[a] **(years)**	1.53 ± 0.64	2.07 ± 0.72	***

[a]Independent *t*-test for the difference between intergroup changes. [b]Pearson chi-square test for distribution, SD: standard deviation; NS: not-significant ($p > .05$); ***$p < .001$.

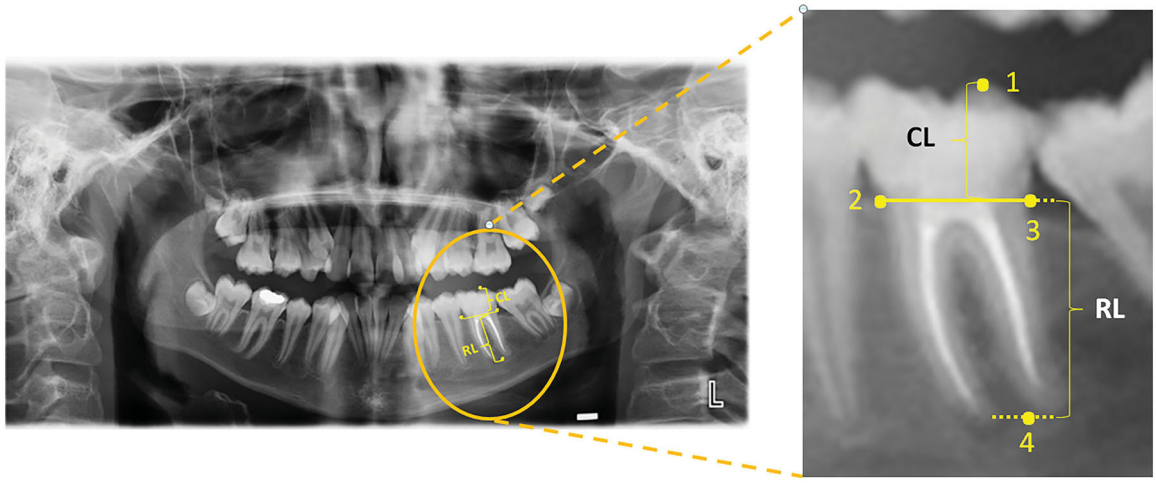

Figure 1. Measurement of crown and root lengths used in the study on panoramic radiographs.

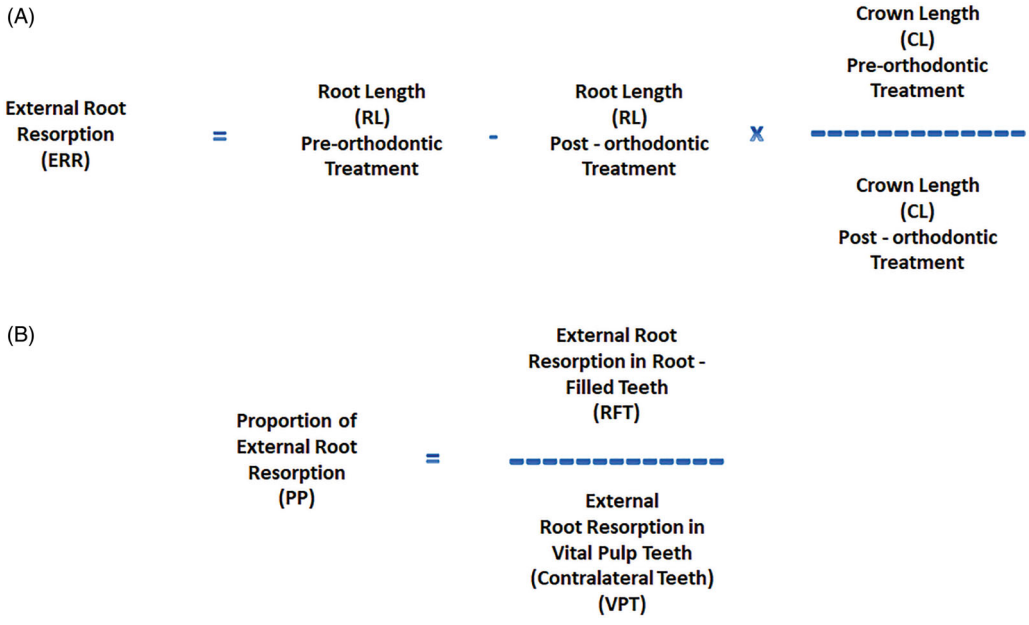

Figure 2. Calculation of the amount of ERR (A) and the proportions (B).

area calculation software program (Axiom Welldone, https://www.sketchandcalc.com/).

Statistical analysis

In order to determine reliability, ten patients were randomly selected, and 20 panoramic radiographs pre- and post-orthodontic treatment were measured by the same researcher after two weeks interval. The intraclass correlation coefficient between the two measurements was 0.942 (0.904–0.981). The difference between the first and second measurements was not significant. The Kolmogorov–Smirnov test was used to assess the normality of our data. Parametric tests were used because the data showed a normal distribution.

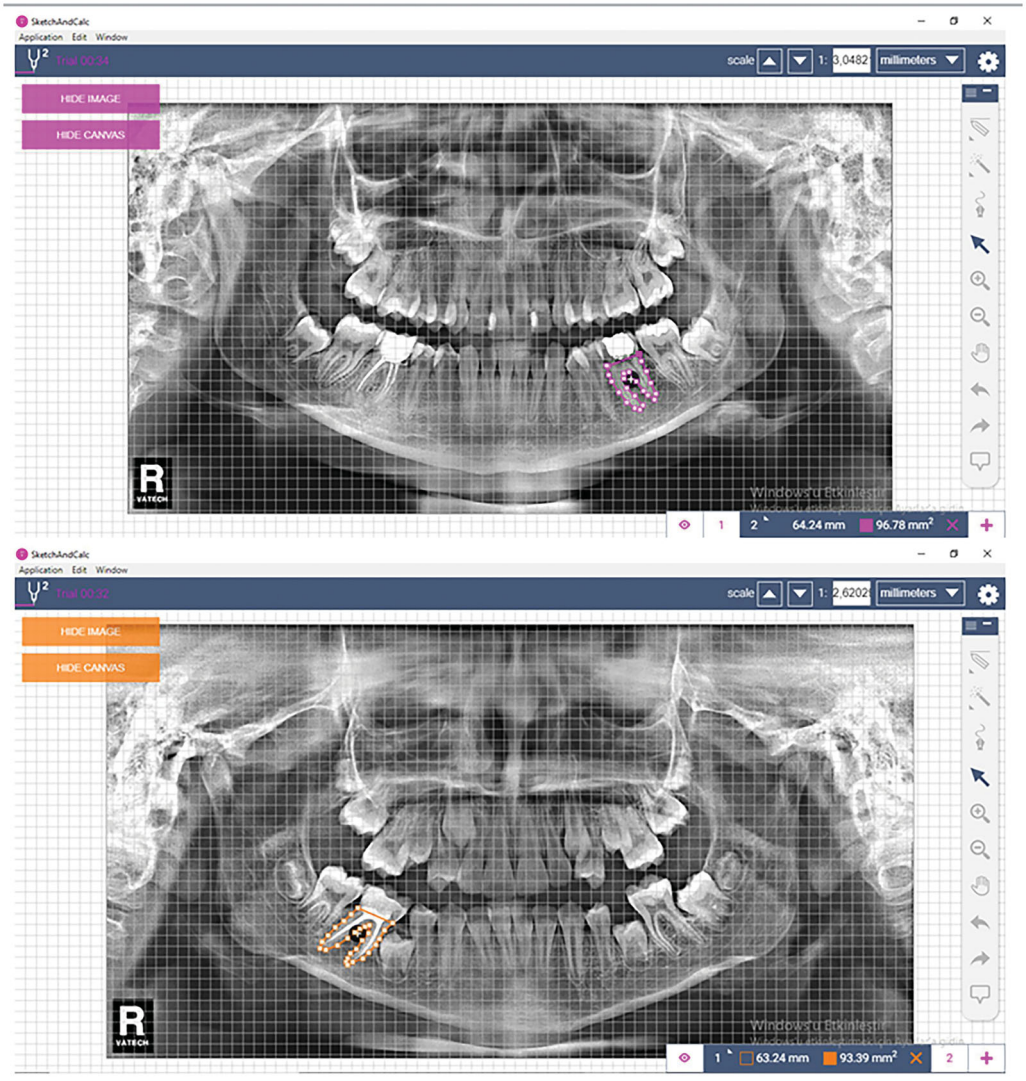

Figure 3. Area measurement of roots used in the study on panoramic radiographs.

The Pearson correlation test was used for the patients' gender distribution and the distribution of the types of teeth. The paired *t*-test was used to determine changes in the groups with treatment within themselves. The independent *t*-test was used to compare the mean age and duration of treatment in the groups as well as compare the amount of ERR in VPT with RFT. In the evaluation of the effect of orthodontic treatment modalities on the amount of ERR, an analysis of covariance (ANCOVA) was performed by taking initial tooth length measurements and initial root surface areas as a covariant in order to compare the two groups ($p < .05$). SPSS package program (for Windows, v.20.0; SPSS Inc., Chicago, IL) was used to analyze the data. The results were considered statistically significant at the $p < .05$ significance level.

Results

No statistically significant differences were found in the gender distribution and chronological age tested by the Pearson chi-squared test and student *t*-test, respectively ($p > .05$). The duration of treatment was found to be statistically significantly higher in the extraction OT group (2.07 ± 0.72 years; $p < .05$) (Table 1).

A comparison of the mean amount of ERR and proportion in the groups is provided in Table 2. A statistically significant difference was found between the RFT and VPT in both the orthodontic treatment groups in terms of ERR ($p < .05$). Taking the initial tooth length values as covariant (initial tooth length [RFT] = 16.3 mm), as a result of the evaluation of the ERR in RFT and proportion with ANCOVA, it was seen that the differences between the means of ERR in the extraction and non-extraction OT groups were not statistically significant ($p > .05$). The difference between both sides and the amount of ERR in the VPT were found to be statistically significant when the groups were compared ($p < .05$).

A comparison of the mean root areas and treatment changes of RFT and VPT in the groups is given in Table 3. In the study, the change of root areas in all the teeth of both groups was statistically significant ($p < .05$). Taking the initial root surface areas as covariant (initial root surface areas [RFT] = 107.13 mm^3), as a result of the evaluation of the ERR with ANCOVA; the decrease in the root area in RFT was not significant between the two groups ($p > .05$), whereas the

Table 2. Mean values and statistical comparison of ERR in RFT, ERR in VPT, and proportion (PP) in groups.

	Non-extraction Orthodontic Treatment Mean ± SD	P^1	Extraction Orthodontic Treatment Mean ± SD	P^1	P^2
ERR in root-filled teeth (mm)	0.47 ± 0.53	**	0.49 ± 0.52	**	NS
ERR in vital pulp teeth (Contralateral) (mm)	1.40 ± 1.19		1.47 ± 1.18		***
Difference	−0.93 ± 1.21	–	−0.98 ± 1.18	–	***
Proportion (PP)	0.53 ± 0.52	–	0.54 ± 0.47	–	NS

P^1: Independent t test for difference between RFT and VPT; P^2: P values of ANCOVA, [Covariant (mm) Initial Tooth Length (RFT): 16.3 mm] for the difference between intergroup changes,.
SD: standard deviation; NS: not-significant ($p > .05$); ** $p < .01$, *** $p < .001$.

Table 3. Mean values and statistical comparison of root areas in groups.

	Non-extraction Orthodontic Treatment Mean ± SD				Extraction Orthodontic Treatment Mean ± SD				
	Pre-Treatment T0	Post-Treatment T1	Difference	P^1	Pre-Treatment T0	Post-Treatment T1	Difference	P^1	P^3
Root-filled teeth root area (mm^2)	105.45 ± 17.38	103.55 ± 16.45	−1.91 ± 2.89	.000	106.49 ± 19.53	104.09 ± 19.07	−2.39 ± 1.08	.000	NS
Vital pulp teeth (contralateral) root area (mm^2)	107.13 ± 20.92	104.73 ± 20.74	−2.39 ± 1.51	.000	106.79 ± 18.11	103.22 ± 18.22	−3.56 ± 3.21	.000	***
P^2		NS				**			

P^1: Paired t-test for intra-group changes, P^2: Independent t-test for the difference between intergroup changes, P^2: Independent t-test for difference between RFT and VPT; P^3: p values of ANCOVA, [Covariant (mm^3) Initial Root Surface Area (RFT): 107.13 mm^3] for the difference between intergroup changes.
SD: standard deviation; NS: not-significant ($p > .05$); **$p < .01$, ***$p < .001$.

decrease in the root area in VPT was significant ($p < .05$). When the decrease in the root area between the two sides in the groups was compared, the difference between RFT and VPT was not significant in non-extraction treatments ($p > .05$). In contrast, there was a significant difference between RFT and VPT in extraction treatments ($p < .05$).

Discussion

This study evaluated the pre- and post-OT difference of the tooth lengths and the root surface areas in mandibular molars using digital panoramic radiographs. The results obtained from the extraction and non-extraction OT groups were compared both within and among the groups. Our study's findings demonstrated that the ERR was significantly higher in VPT than in RFT in both linear and area measurements. Therefore, the first hypothesis was rejected. Also, the amount of ERR was not affected by the modality of treatment (extraction or non-extraction OT) only in RFT; therefore, our second hypothesis was partially accepted.

When pre- and post-treatment radiographs were examined, it was observed that all teeth showed some degree of ERR in both groups, and this difference was statistically significant. These results are in line with the results of the studies by Spurrier et al. [19], Esteves et al. [16], and Mirabella and Artun [21], who observed significant differences in the occurrence of ERR because of OT. However, Castro et al. [24] reported that the level of ERR was not statistically significant in root lengths pre- or post-OT between RFT and VPT. The disparity between our study may be due to the investigated differences in the type of teeth. It may also be caused by the millimetre measurements of the other study. Conversely, in our study, they were calculated as root surface areas.

The measurement of root resorption during OT and a comparison between RFT and VPT results have been studied previously. In a retrospective study, Esteves et al. [16] reviewed 32 (16 endodontically treated and 16 contralateral vital maxillary central incisors) teeth of 16 patients, and they reported no statistically significant ERR between RFT and VPT. Also, Llamas-Carreras et al. [25] supported this study and reported no significant differences in the severity of ERR between RFT and contralateral VPT during OT. However, our results showed that VPT were more affected by ERR than were RFT. In previous studies, it has been reported that root resorption occurring during OT shows different results between different tooth groups [25]. The difference between those studies and our current one could be attributed to the type of teeth included in the study; their studies evaluated maxillary incisors, whereas ours evaluated molars.

Spurrier et al. [19] reviewed maxillary incisors of 43 patients in their retrospective study and reported that the vital incisors were significantly more resorbed than were the root-filled incisors post-OT. In addition, Mirabella and Artun [21] examined the maxillary anterior teeth of 36 patients, and they also observed significantly less ERR in RFT than in VPT. In another study, Lee and Lee [22] examined different types of teeth of 35 patients undergoing OT pre- and post-treatment, and they observed significantly less ERR in RFT when compared with contralateral VPT. Also, in a meta-analysis [26], it was indicated that ERR was less in RFT than in their contralateral VPT. In addition, Lee and Lee [22] suggested that if severe root resorption occurs during OT, endodontic treatment might be considered to decrease or stop ERR during OT. The findings of our study are in accordance with these studies. The newest studies in the literature also support our findings. Kolcuoglu and Oz [27] examined the amount of root resorption in the premolars extracted for OT with micro-CT, and they found less root resorption in RFT in their study.

It was reported that the movement of VPT during OT might cause neurovascular disturbances with inflammatory changes and probable degenerative changes in the pulp. The previous trauma, caries, restorations, or periodontal disease history of pulpal stimulation and the magnitude, direction, and duration of orthodontic forces affect the severity of orthodontic force on the pulp tissues [28]. It was reported that injured and stretched pulp cells express inflammatory

cytokines, macrophage colony-stimulating factor (M-CSF), and receptor activator of NF-κB ligand (RANKL), thereby initiating odontoclastic activity. Tensile forces through the apical foramen to the pulp cells during endodontic treatment increase the expression of these factors, and apical root resorption may occur [29]. In RFT, these factors would not be secreted without the pulp, and these pulp tissue alterations might explain the increased ERR in VPT.

In the literature, studies have shown an association between ERR and the type and duration of OT [4]. Lee and Lee [22] observed that the type of treatment was statistically significantly correlated with ERR. Similar results were obtained in our study. According to the results of this study, the amount of root resorption was affected by the modality of treatment (non-extraction or extraction OT) in VPT; however, this difference was not statistically significant in RFT. In this study, extraction OT showed a statistically-significant longer duration of treatment than non-extraction OT, and extraction OT resulted in more ERR than in teeth without extractions. Previous studies also support the importance of an extended duration of treatment as the cause of root resorption [30]. This finding may be explained by the observation that prolonged treatment causes prolonged orthodontic forces and, as a result, causes more pulp irritation; thus, more factors causing ERR can be secreted [31]. These results are also in accordance with previous studies [32].

In this study, the measurement of tooth lengths and the calculation of root surface area were performed on digital panoramic radiographs. Previous studies have also used panoramic radiographs for evaluating ERR during OT [17,22,25]. Also, periapical radiographs and three-dimensional imaging (cone beam computed tomography, CBCT) can be used to evaluate root resorption [24,33]. In general, extraoral radiographs are considered less accurate when examining the ERR's extent than periapical radiographs. The use of panoramic films to measure pre- and post-treatment root resorption may overestimate [34] or underestimated [35] the amount of root loss after orthodontic tooth movement. Because the periapical films have less image distortion and greater resolution of fine details, they were considered superior to panoramic images [36]. However, the validity of periapical films to accurately depict ERR has been questioned due to errors caused by variabilities in teeth shape [37]. Three-dimensional imaging has been shown to have higher accuracy and repeatability than two-dimensional imaging in assessing ERR [38]. However, CBCT images are associated with a higher radiation dose than are other radiographic techniques [33]. In the present study, comparisons of root length between the pre- and post-treatment radiographs were evaluated using panoramic radiographs. This is because the serial periapical radiographs and three-dimensional imaging are not routinely taken during OT, and panoramic radiographs are routinely more used for orthodontic records than are other radiographs, and readily available for retrospective analysis [4,33]. However, in the current study, the degree of root resorption and surface area differences were evaluated by comparing the pre- and post-treatment radiographs instead of measuring the exact values. Stramotes et al. [39] reported that if the occlusal plane is positioned similarly on both conditions and if the extent of tilting does not exceed 10 degrees, the linear measurements using panoramic radiographs taken at different times show sufficiently accurate results. In this study, two radiology assistants took digital panoramic radiographs using the same panoramic machine to minimize such errors. In order to standardize the position of the head, a positioning light incorporated into the machine was used.

There are several strengths that distinguish our study from the studies in the literature: First, a sufficiently large sample size was recruited. The sample size is pertinent to identify the clinical and statistical significance. Second, in this study, root surface areas were examined along with ERR and proportions, and our linear measurements supported the area measurements. Third, the amount of root resorption in different modalities (extraction vs. non-extraction) of OT were both examined in the same study. Additionally, while only incisors or all types of teeth were simultaneously evaluated in the literature, mandibular molars were preferred in our study both for standardization and because of the limited number of studies studying only molars.

This study suggests that the possible complication of ERR in RFT may not be an important consideration in OT planning. Moreover, it has been shown that root canal treatment seems to protect teeth from external root resorption. If the tooth is indicated for root canal treatment and will be involved in the orthodontic movement, these results should encourage clinicians to perform root canal treatment. In addition, root canal treatment can be considered to decrease or stop ERR when severe resorption occurs during OT. However, the pieces of evidence are not strong. Further retrospective and prospective studies with larger sample sizes using different imaging techniques such as CBCT are required to confirm the results.

Conclusions

According to the results of this study, RFT are more resistant to ERR than are their contralateral VPT. Comparing the radiographs taken pre- and post-treatment, different levels of ERR were observed in all teeth. As the duration of OT prolonged, the amount of ERR increased. Clinicians should consider orthodontic tooth movement of RFT as a relatively safe clinical procedure, and no change in OT planning is required to move RFT.

Disclosure statement

The authors deny any conflicts of interest related to this study.

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

We declare that all authors have contributed significantly to this study and that all authors are in agreement with the manuscript.

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