DOI: 10.4274/TurkJOrthod.2022.2022.48

TURKISH JOURNAL of ORTHODONTICS

Original Article

Apical Root Resorption of Endodontically Treated Teeth after Orthodontic Treatment: A Split-mouth Study

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Cite this article as: Seker ED, Dincer AN, Kaya N. Apical Root Resorption of Endodontically Treated Teeth after Orthodontic Treatment: A Split-mouth Design Study. *Turk J Orthod.* 2023; 36(1): 15-21

Main Points

- The endodontic treatment did not increase the apical root resorption.
- Orthodontic treatment with extraction increased the apical root resorption in vital teeth unlike endodontically treated teeth.
- The quality of the root canal treatment had no critial effects on root resorption.

ABSTRACT

Objective: The influence of pulp status on orthodontically induced root resorption has attracted attention. The purpose of this study was to compare orthodontically induced root resorption in endodontically treated teeth and their contralateral vital teeth in a split-mouth design.

Methods: The sample included 173 patients who had at least one endodontically treated tooth, and their vital contralateral teeth served as the control group before the completion of orthodontic treatment. Apical root resorption measurements were performed by the comparison of digital panoramic X-ray images obtained at the beginning and at the end of the orthodontic treatment. Kruskal-Wallis, Mann-Whitney U, and Wilcoxon tests were used for statistical analysis.

Results: There was no statistically significant difference in apical root resorption between the endodontically treated teeth and the contralateral teeth ($p>0.05$). Sex and tooth type had no effect on apical root resorption both in the endodontically treated teeth and the contralateral vital teeth ($p>0.05$). Orthodontic treatment with extraction caused more apical root resorption in the vital teeth than in the endodontically treated teeth ($p<0.05$). The quality of the endodontic treatment had no significant influence on apical root resorption ($p>0.05$).

Conclusion: Endodontic treatment does not produce greater apical root resorption compared with the vital teeth.

Keywords: Apical root resorption, orthodontic treatment, root canal treatment, endodontic treatment

INTRODUCTION

Apical root resorption may occur because of mechanical or chemical stimuli including various etiological factors such as infection, trauma, pressure, or orthodontic treatment.[1] Orthodontically induced root resorption has been accepted as a serious complication for a long time.[2] Apical root resorption during active orthodontic treatment was shown in 1927.[3] After that, many studies have revealed the correlation between orthodontic treatment and resorption. In these studies, it was stated that age, sex, orthodontic treatment time, amount of the orthodontic forces, and type of tooth movement (with/without extraction) may have a role in apical root resorption.[4-8]

In addition to numerous studies examining the relationship between root resorption and orthodontic treatment, the influence of pulp status on resorption has attracted attention. However, there are contradictory results

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Received: March 27, 2022
Accepted: October 1, 2022
Epub: March 06, 2023
Publication Date: March 21, 2023

regarding apical root resorption due to orthodontic forces in teeth which are treated endodontically. It is still unclear whether endodontically treated teeth (ETT) differ in terms of resorption compared to vital teeth after exposure to orthodontic forces. Some studies have shown no significant differences in root resorption between vital and root-filled teeth.[9-12] There are also studies reporting that endodontically treated teeth are associated with less root resorption than contralateral teeth with vital pulp.[13-15] Moreover, an animal model study reported that ETT showed greater cement loss than vital teeth after tooth movement.[16]

This split-mouth study compared root resorption associated with orthodontic treatment in teeth with root canal filling and contralateral teeth with vital pulp. The null hypothesis was that there is no difference between ETT and contralateral vital teeth (CVT) in terms of apical root resorption.

METHODS

This split-mouth study was approved by the Non-Interventional Research Ethics Committee of the Bezmialem Vakif University (19/363). Informed consent was received from the patients for their orthodontic treatments.

The patients were selected after a review of 1780 patient records from the archive of the Bezmialem Vakif University Faculty of Dentistry, Department of Orthodontics. The sample was selected from among patients in the archives who were treated from 2010 to 2019.

The following inclusion and exclusion criteria were applied during the examination of the radiography images of 1780 patients. Two hundred and sixty-three patients were excluded from the study because their duration of orthodontic treatment had not yet exceeded 1 year. Among the remaining 1517 patients, 204 had endodontically treated and CVT. Thirteen patients were excluded from the study because they did not comply with the periapical index scoring system that was used in the study, which is the system that was introduced by Ørstavik et al.[17] This scoring system allows the recording of apical periodontitis on radiographs. The system also provides a 5-point ordinal scale ranging from 1 (healthy) to 5 (severe periodontitis with exacerbating features). Furthermore, 8 patients were excluded due to noticeable incisal/occlusal changes, and 10 patients did not have panoramic radiographs that allowed precise measurements. The sample size calculation was performed using the data of a study comparing the amount of root resorption between endodontically treated and vital teeth.[15] That previous study indicated that the amounts of mean apical root resorption were 0.47 ± 0.53 mm and 1.40 ± 1.19 mm for endodontically treated and vital teeth, respectively.[15] G*Power (version 3.0.10) was used to calculate sample size. Accordingly, we estimated that a minimum sample size of 44 subjects was required for detecting statistically significant differences in the orthodontically induced root resorption, to reach a 90% power at the 5% level of significance. More patients than the initially estimated number of patients were included in this study to increase the power of the study and obtain more precise results. Therefore, 110 female (18.78 ± 6.55 years) and 63 male (18.03 ± 4.83 years) patients with a mean age of 18.5 ± 5.98 years were included in this study. The mean orthodontic treatment duration of the patients was 27.87 ± 9.2 months (Table 1). All 173 patients were treated using fixed conventional brackets (Roth prescription, 0.018-inch slot) and general archwire sequences of 0.016-inch nickel-titanium to 0.016x0.022-inch stainless steel (G&H Orthodontics, Franklin, IN, USA). The inclusion and exclusion criteria were as follows.

Inclusion criteria: (1) patients treated using only fixed orthodontic appliances, (2) presence of a tooth subjected to root canal treatment before orthodontic treatment, (3) orthodontic treatment continued for at least 1 year, (4) presence of contralateral teeth that had radiographically normal periapical anatomical structures (intact lamina dura and periodontal ligament space) and had never undergone invasive pulp treatment, (5) good-quality panoramic radiographs before and after orthodontic treatment.

Exclusion criteria: (1) ETT with periapical indices 3, 4, and 5 scores in pretreatment radiography, (2) ETT with excessive root resorption, (3) atypical dental morphology, (4) teeth with noticeable incisal/occlusal edge changes, (5) cleft lip and palate patients, (6) history of orthognathic surgery, (7) systemic or metabolic diseases.

Digital panoramic X-ray images (Planmeca Promax Digital Panoramic X-Ray Unit, Planmeca Inc, Helsinki, Finland) were obtained at the beginning of the treatment (T0) and at the end of the treatment (T1) and used to define apical root resorption. Digital images were obtained using the Dimaxis Pro 3.1.1 program (Planmeca Inc). The ImageJ software (ImageJ software, 1.37, National Institutes of Health, Bethesda, Maryland, USA) was used for measuring apical root resorption. Scale setting was performed based on changing the known distance in pixels to a distance known in millimeters (16.4 pixels/mm).

The lengths of 237 permanent teeth, including the upper central incisors, upper and lower premolars and molars, were quantitatively measured at T0 and T1. The distal and mesial root lengths were measured for the mandibular molars, and the buccal roots were measured for the maxillary molars and premolars. The crown and root lengths in the panoramic radiographs were calculated at T0 and T1 in the ETT and their contralateral teeth as described in previous studies.[18-20]

1. The distance from the incisal or occlusal edge to the root apex was measured in both ETT and CVT on pre-treatment radiographs (a = initial total length).

2. To obtain intra-patient standardization and exclude any possible distortion of panoramic radiographs at T0 and T1, the distance from the incisal or occlusal edge to the cementoenamel junction was measured in both endodontically treated and contralateral teeth (b = pre-treatment, c = post-treatment).

3. Then, the differences (x = expected total length) were calculated as a factor of foreshortening/elongation used in the measurement of the inciso/occluso-apical length of the tooth.

4. The difference between the expected total length and the final root length (d) was accepted as apical root resorption (Figure 1).[18-20]

Statistical Analysis

Thirty panoramic X-ray images were randomly selected after 2 weeks and re-analyzed to assess intra-examiner agreement. The intraclass correlation coefficient (ICC) was used to assess intra-observer reliability. The mean intra-observer ICC was 0.979 (0.950-0.993), which indicated high levels of agreement between the two measurements.

SPSS (version 15.0; SPSS, Chicago, Ill) was used for the statistical analyses, and the level of statistical significance was set at $p<0.05$. The data were tested for normal distribution by using the Shapiro-Wilk test. Sex, treatment type, and quality of root canal treatment were compared between groups with the Mann-Whitney U test. The Kruskal-Wallis test was performed to detect the differences based on tooth type. The comparison of the panoramic radiographs was performed with the Wilcoxon test.

RESULTS

A total of 346 digital panoramic radiographs from 173 patients were analyzed. The demographic data of the patients at the beginning of the treatment are presented in Table 1.

When the T0 and T1 panoramic radiographs were compared, statistically significant apical root resorption differences were observed in both groups ($p<0.05$) (Table 2).

No statistically significant difference in terms of apical root resorption was found between the ETT and the contralateral teeth ($p>0.05$) (Table 3).

Table 1. Demographic characteristics of the patients

Gender (n)	Male	63
	Female	110
Age (Years; Mean ± SD)	Male	18.03±4.83
	Female	18.78±3.55
	Total	18.5±3.98
Treatment type (n)	With extraction	43
	No extraction	130
Tooth type (n)	Maxillary central	11
	Maxillary molar	54
	Maxillary premolar	35
	Mandibular premolar	20
	Mandibular molar	113
Treatment duration (Months; Mean ± SD)	Male	28.01±10.51
	Female	27.79±8.41
	Total	27.87±9.2

SD, standard deviation.

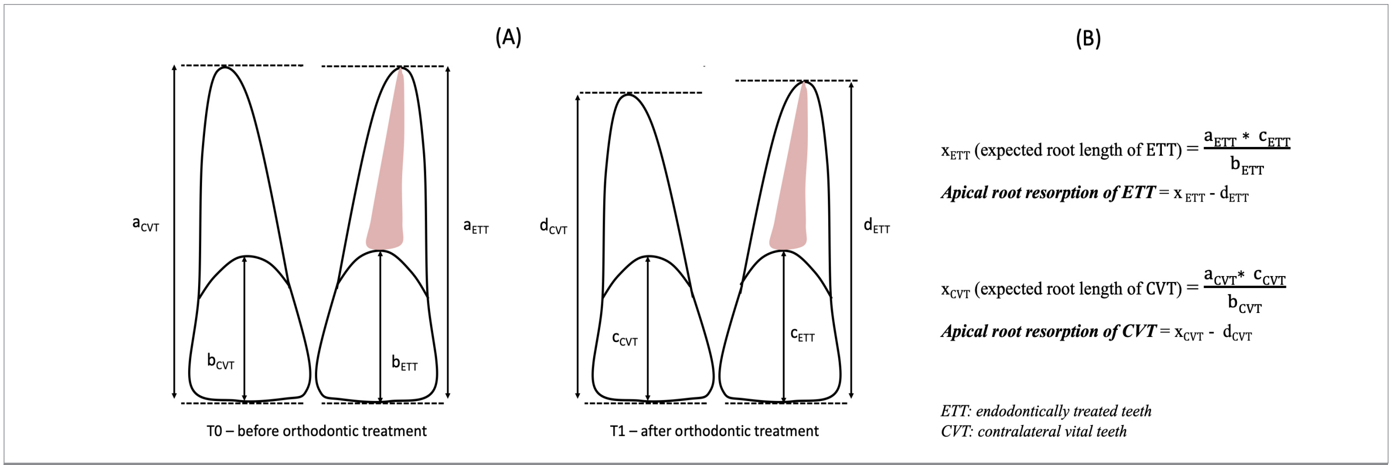

Figure 1. (A) Reference points and lines for measurement (B) Calculation of apical root resorption

While orthodontic treatment with extraction did not have a significant effect on the ETT in terms of resorption, it caused more resorption in the contralateral teeth ($p<0.05$) (Table 4).

Tooth type or sex had no statistically significant effect on the resorption of the endodontically treated or contralateral teeth ($p>0.05$) (Table 4). Moreover, there was no statistically significant difference between poor and good quality root canal treatments in terms of the amounts of apical root resorption ($p>0.05$).

DISCUSSION

A total of 1780 were examined, and 173 of them were included based on the inclusion and exclusion criteria in this split-mouth retrospective study. In studies evaluating orthodontically-induced apical root resorption, digital panoramic radiography, intraoral periapical radiography, and cone-beam computed tomography (CBCT) have been preferred to quantify the degree of root resorption.[10,11,21] Digital panoramic X-ray images were used in this study because of their advantages such as viewing the entire dental arch and their inexpensive and easy to use nature.[22] They also have disadvantages such as errors due to the magnification and superposition of dental structures that may cause the incorrect interpretation of resorption.[22] Moreover, periapical and panoramic radiographs, which allow two-dimensional imaging, can have limitations in terms of the accuracy of apical root resorption measurements.[23] To overcome distortion limitations and standardize the measurements on the digital panoramic radiographs in this study, in the measurement of the closest linear distance from the center of the incisal edge or the cusp tip to the root apex of the teeth, the greatest distance from the incisal/occlusal edge to the cementoenamel junction was also measured to determine the corrected root length. Furthermore, digital panoramic radiographs were preferred in this study since they are the most frequently used method in

Table 2. Comparison of root length before and after orthodontic treatment with Wilcoxon test

	T0	T1	p value
	Mean ± SD	Mean ± SD	
Root length of ETT (mm)	14.7±1.9	13.9±2	<0.001*
Root length of CVT (mm)	15±1.7	14.2±1.8	<0.001*

SD, standard deviation; ETT, endodontically treated teeth; CVT, contralateral vital teeth, *p<0.05.

Table 3. Comparison of apical root resorption values between endodontically treated and contralateral vital teeth with Mann-Whitney U test

ARR in ETT (mm)		ARR in CVT (mm)		p value
Mean ± SD	Median (Min./Max.)	Mean ± SD	Median (Min./Max.)	
-0.73±1.02	-0.7 (-4.8/2.94)	-0.78±1.11	-0.65 (-4.13/1.85)	0.89

SD, standard deviation; ETT, endodontically treated teeth; CVT, contralateral vital teeth; ARR, apical root resorption, Min./Max., minimum/maximum.

Table 4. Summary of independent variables

		ARR in ETT	ARR in CVT
		Mean ± SD	Mean ± SD
Gender	Male	-0.86±1	-0.9±1
	Female	-0.66±0.99	-0.71±1.1
	p value (Mann-Whitney U Test)	0.09	0.06
Treatment type	Extraction	-0.68±1.04	-0.72±1.09
	Nonextraction	-0.92±0.93	-0.96±1.16
	p value (Mann-Whitney U Test)	0.091	0.046*
Tooth type	Maxillary incisors	-1.18±1.3	-1.5±1.16
	Maxillary premolar	-0.48±0.86	-0.78±1.04
	Maxillary molar	-0.64±1.1	-0.78±1.17
	Mandibular premolar	-1.04±1.19	-0.83±1.1
	Mandibular molar	-0.76±0.93	-0.74±1.08
	p value Kruskal Wallis Test	0.25	0.08
Quality of endodontic treatment	Poor	-0.74±1.04	
	Proper	-0.73±1.01	
	p value (Mann-Whitney U Test)	0.84	

*Statistically significant difference, ETT, endodontically treated teeth; CVT, contralateral vital teeth; ARR, apical root resorption, * p<0.05.

the follow-ups of orthodontic treatment, and they have a more acceptable radiation dose than CBCT based on the "as low as reasonably achievable" principle regarding protection against radiation exposure.

For measurements on panoramic radiographs, such as root resorption, where the degree of reproducibility is important, it was suggested that the palatal root of the upper first molar should be considered unreliable, whereas the buccal roots of the upper first molar were reproducible.[24] Besides, more resorption in the distal root was reported in the lower molars.[25] Therefore, the buccal roots of the maxillary molar and the distal roots of the mandibular molar teeth were included in this study. The measurements were performed by one operator, and the ImageJ software, which depends on pixel-based calculation and is commonly used for digitized data analysis, was used.[19]

It has been shown in both histological and radiological studies that resorption occurs with orthodontic treatment, which is usually less than 2.5 mm. A resorption of more than 4 mm was considered as severe resorption.[26,27] In this study, resorption was observed significantly after orthodontic treatment in both the ETT and their contralateral teeth. There was a significant amount of resorption after the treatment compared to the pre-treatment values, and the mean amount of resorption was 0.73 mm for the ETT and 0.78 mm for the CVT. However, no significant difference was observed in the apical root resorption measurements from T0 to T1 between the ETT and the contralateral teeth. In consistency with our findings, Esteves et al.[11] reported that although the mean amount of apical root resorption in vital teeth was slightly greater, there was no significant difference between endodontically treated and vital incisors. However, Wickwire et al.[28] showed that ETT had a higher frequency of root resorption than the control group. Nevertheless, in their studies, most patients had experienced traumatic injuries before their orthodontic treatments, which could have contributed to the resorption process. Another study revealed that vital pulps were resorbed to a significantly greater degree than incisors that had been endodontically treated. Although statistically significant differences were represented, the clinical significance of these differences was minimal.[18]

There is a positive correlation between root resorption and increased treatment duration,[15] and it was stated that the amount of root resorption increases significantly when 12 weeks of force application is reached.[26] In this study, patients whose orthodontic treatment lasted more than a year were included, and their mean treatment duration was 27.87 months. It was stated that the extraction pattern is a critical factor in root resorption. In one study, patients who received 4 first premolar extraction treatments had more resorption than those who were treated without extraction.[29] In accordance with the results of our study, another study demonstrated that orthodontic treatment with extractions represented greater root resorption in vital teeth than in patients without extractions but not on a statistically significant level.[14] It was claimed that orthodontic treatment with extraction compared to non-extraction treatment may cause more irritation in the pulp tissue, more irritation will release more factors that cause resorption, and therefore, less resorption may be observed in patients with ETT since these factors will be released less.[14]

The etiology of resorption is multifactorial and related to orthodontic treatment, as well as individual variables.[27] A study evaluating the effects of sex on external root resorption stated that the amount of root resorption occurring in female patients was greater than that in male patients, but the difference was not statistically significant.[8] In this study, whether the patient was male or female had no effect on resorption in both the ETT and the contralateral teeth. Moreover, the age distribution was limited in this study to better evaluate the effects of endodontically treated and vital teeth on resorption. Since the age distribution of the patients in the study was limited, the effects of age on resorption could not be evaluated. Furthermore, the amount of root resorption varies according to the type of teeth, and this variable was included in this study. It was reported that the maxillary incisors exhibit resorption most frequently, followed by the mandibular incisors and first molars.[27,30] Sharpe et al.[31] suggested that the maxillary central incisors experienced a high incidence of root resorption, followed by molar teeth. Our findings are in accordance with the results of the abovementioned studies.

Kurnaz and Buyukcavus[15] reported that ETT were more resistant to external root resorption than their contralateral vital tooth. In contrast, Huettner and Young[32] revealed that the amount of resorption observed in canal treatment performed under aseptic conditions was not significantly different from that of vital teeth. This study also supported the findings of Huettner and Young[32] in comparisons of the effects of endodontic treatment quality on root resorption, no statistically significant difference was observed between the poor-quality and good-quality root canal treatments. In this study, root canal treatment quality was accepted as good by the following criteria: obturation length (0-2 mm short of length from the radiographic apex) and uniform tapering and density (absence of voids) of root canal filling. Additionally, the data showing scores of 3 or above in the periapical index were excluded. Although the root canal filling was poor, the absence of those with a score of 3 or above according to their periapical index values may have led to the absence of a significant difference between the poor-quality and good-quality root canal treatments. More comprehensive studies are needed to evaluate the effects of the quality of root canal treatment on resorption.

Study Limitations

This retrospective split-mouth study had some limitations highlighted and need to be improved in further studies. Two-dimensional digital panoramic radiographs with less sensitivity than three-dimensional imaging methods were used to measure resorption. The effects of factors such as age and treatment time on root resorption could not be evaluated in detail due to the sample distribution.

CONCLUSION

Within the limitations, the conclusion that may be drawn from this study is that endodontic treatment does not increase apical root resorption. Further studies are needed to evaluate the factors that may cause apical root resorption in ETT and vital teeth after orthodontic treatment.

Ethics Committee Approval: This split-mouth study was approved by the Non-Interventional Research Ethics Committee of the Bezmialem Vakif University (19/363)

Informed Consent: Informed consent was received from the patients for their orthodontic treatments.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - E.D.Ş.; Design - E.D.Ş.; Supervision - E.D.Ş.; Materials - E.D.Ş., A.N.D., N.K.; Data Collection and/or Processing - A.N.D., N.K.; Analysis and/or Interpretation - E.D.Ş., A.N.D., N.K.; Literature Review - E.D.Ş., A.N.D., N.K.; Writing - E.D.Ş., A.N.D.; Critical Review - E.D.Ş., A.N.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

1. Ahangari Z, Nasser M, Mahdian M, Fedorowicz Z, Marchesan MA. Interventions for the management of external root resorption. *Cochrane Database Syst Rev*. 2015;24(11):CD008003. [CrossRef]
2. Andreasen J. External root resorption: its implication in dental traumatology, paedodontics, periodontics, orthodontics and endodontics. *Int Endod J*. 1985;18(2):109-118. [CrossRef]
3. Ketcham AH. A preliminary report of an investigation of apical root resorption of permanent teeth. *Int J Orthod Oral Surg Radiograph*. 1927;13(2):97-127. [CrossRef]
4. Krishnan V. Critical issues concerning root resorption: a contemporary review. *World J Orthod*. 2005;6(1):30-40.[CrossRef]
5. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. *Am J Orthod Dentofacial Orthop*. 1993;103(2):138-146. [CrossRef]
6. Kurol J, Owman-Moll P, Lundgren D. Time-related root resorption after application of a controlled continuous orthodontic force. *Am J Orthod Dentofacial Orthop*. 1996;110(3):303-310. [CrossRef]
7. Paetyangkul A, Türk T, Elekdağ-Türk S et al. Physical properties of root cementum: Part 16. Comparisons of root resorption and resorption craters after the application of light and heavy continuous and controlled orthodontic forces for 4, 8, and 12 weeks. *Am J Orthod Dentofacial Orthop*. 2011;139(3):279-284. [CrossRef]
8. Guo Y, He S, Gu T, Liu Y, Chen S. Genetic and clinical risk factors of root resorption associated with orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 2016;150(2):283-289. [CrossRef]
9. Llamas-Carreras JM, Amarilla A, Solano E, Velasco-Ortega E, Rodríguez-Varo L, Segura-Egea JJ. Study of external root resorption during orthodontic treatment in root filled teeth compared with their contralateral teeth with vital pulps. *Int Endod J*. 2010;43(8):654-662. [CrossRef]
10. Castro I, Valladares-Neto J, Estrela C. Contribution of cone beam computed tomography to the detection of apical root resorption after orthodontic treatment in root-filled and vital teeth. *Angle Orthod*. 2015;85(5):771-776. [CrossRef]
11. Esteves T, Ramos AL, Pereira CM, Hidalgo MM. Orthodontic root resorption of endodontically treated teeth. *J Endod*. 2007;33(2):119-122. [CrossRef]
12. Yang L, Tiwari SK, Peng L. Differences in root resorption between root canal treated and contralateral vital tooth during orthodontic tooth movement: a systematic review. *Orthod J Nepal*. 2016;6(1):41-44. [CrossRef]
13. Mirabella AD, Årtun J. Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. *Eur J Orthod*. 1995;17(2):93-99. [CrossRef]
14. 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]
15. Kurnaz S, Buyukcavus MH. External root resorption in root-filled and vital teeth after extraction and non-extraction orthodontic treatments: a split-mouth retrospective study. *Acta Odontol Scan*. 2021;79(4):282-288. [CrossRef]
16. Mah R, Holland G, Pehowich E. Periapical changes after orthodontic movement of root-filled ferret canines. *J Endod*. 1996;22(6):298-303.
17. Ørstavik D, Kerekes K, Eriksen HM. The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endod Dent Traumatol*. 1986;2(1):20-34. [CrossRef]
18. Spurrier SW, Hall SH, Joondeph DR, Shapiro PA, Riedel RA. A comparison of apical root resorption during orthodontic treatment in endodontically treated and vital teeth. *Am J Orthod Dentofacial Orthop*. 1990;97(2):130-134. [CrossRef]
19. Seker ED, Yagci A, Kurt Demirsoy K. Dental root development associated with treatments by rapid maxillary expansion/reverse headgear and slow maxillary expansion. *Eur J Orthod*. 2019;41(5):544-550. [CrossRef]
20. 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]
21. Qin F, Zhou Y. The influence of bracket type on the external apical root resorption in class I extraction patients-a retrospective study. *BMC Oral Health*. 2019;19(1):53. [CrossRef]
22. Marinescu IR, Bănică AC, Mercuţ V et al. Root Resorption Diagnostic: Role of Digital Panoramic Radiography. *Curr Health Sci J*. 2019;45(2):156-166. [CrossRef]
23. Li Y, Deng S, Mei L et al. Prevalence and severity of apical root resorption during orthodontic treatment with clear aligners and fixed appliances: a cone beam computed tomography study. *Prog Orthod*. 2020;21(1):1. [CrossRef]
24. 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]
25. Beck BW, Harris EF. Apical root resorption in orthodontically treated subjects: analysis of edgewise and light wire mechanics. *Am J Orthod Dentofacial Orthop*. 1994;105(104):350-361. [CrossRef]
26. Roscoe MG, Meira JB, Cattaneo PM. Association of orthodontic force system and root resorption: a systematic review. *Am J Orthod Dentofacial Orthop*. 2015;147(5):610-626. [CrossRef]
27. Weltman B, Vig KW, Fields HW, Shanker S, Kaizar EE. Root resorption associated with orthodontic tooth movement: a systematic review. *Am J Orthod Dentofacial Orthop*. 2010;137(4):462-476. [CrossRef]
28. Wickwire NA, Mc Neil MH, Norton LA, Duell RC. The effects of tooth movement upon endodontically treated teeth. *Angle Orthod*. 1974;44(3):235-242. [CrossRef]

29. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part II. Treatment factors. *Am J Orthod Dentofacial Orthop*. 2001;119(5):511-515. [CrossRef]

30. Remington DN, Joondeph DR, Årtun J, Riedel RA, Chapko MK. Long-term evaluation of root resorption occurring during orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 1989;96(1):43-46. [CrossRef]

31. Sharpe W, Reed B, Subtelny JD, Polson A. Orthodontic relapse, apical root resorption, and crestal alveolar bone levels. *Am J Orthod Dentofacial Orthop*. 1987;91(3):252-258. [CrossRef]

32. Huettner RJ, Young RW. The movability of vital and devitalized teeth in the Macacus rhesus monkey. *Oral Surg Oral Med Oral Pathol*. 1955;8(2):189-197. [CrossRef]