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POSSIBLE CAUSES OF ROOT RESORPTION IN ORTHODONTIC TREATMENT*
ORTODONTİK TEDAVİDE KÖK REZORPSİYONUNUN OLASI NEDENLERİ

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ABSTRACT

In this study, the presence and possible causes of external root resorption were investigated by comparing pre- and post-treatment panoramic radiographs. Also, degrees of root resorption were investigated. In this study, external root resorption and its degree were examined in panoramic radiographs of patients who had fixed orthodontic treatment between January 2015 and March 2020. Root resorption was determined in only post treatment panoramic radiographs by comparing pretreatment panoramic radiograph. Anterior and posterior region resorption score of both jaws was calculated for each individual. The relationship between root resorption, age, gender, duration of treatment, types of treatment and malocclusion has been investigated. 560 patients (358 females and 202 males) were included in the study and the average age was 14.2. Root resorption scores of mandibular teeth were higher in males ($p<0.01$). A positive correlation was found between the treatment duration and root resorption scores of maxillary anterior teeth ($p<0.01$). Root resorption scores of all regions were higher in orthodontic treatment with extraction ($p<0.01$). There was no significant relationship between age and root resorption score ($p>0.05$). Long-term orthodontic treatment and orthodontic treatment with extraction increase the prevalence of root resorption. Panoramic radiograph is an important diagnostic tool in the detection of root resorption due to orthodontic treatment.

Keywords: Orthodontic treatment, panoramic radiography, root resorption.

ÖZ

Bu çalışmada eksternal kök rezorpsiyonunun olası nedenleri, tedavi öncesi ve sonrası panoramic radyograflar karşılaştırılarak araştırılmıştır. Ayrıca kök rezorpsiyonunun derecesi de incelenmiştir. Bu çalışmada, Ocak 2015 ile Mart 2020 yılları arasında sabit ortodontik tedavi gören hastalarda eksternal kök rezorpsiyonu ve derecesi incelenmiştir. Kök rezorpsiyonu, tedavi sonrası panoramic radyografın tedavi öncesi panoramic radyografla karşılaştırılması ile belirlenmiştir. Her hasta için iki çenede ön ve arka gruptaki dişler için rezorpsiyon skoru hesaplanmıştır. Kök rezorpsiyonuyla yaş, cinsiyet, tedavi süresi, tedavi tipi ve maloklüzyon tipi ile arasındaki ilişki araştırılmıştır. Yaş ortalaması 14.2 olan 560 hasta (358 kadın ve 202 erkek) çalışmaya dahil edilmiştir. Erkeklerin mandibular ön dişlerinin kök rezorpsiyon skoru daha yüksektir ($p<0.01$). Maksiller ön dişlerin rezorpsiyon skoru ile tedavi süresi arasında pozitif korelasyon vardır ($p<0.01$). Çekimli ortodontik tedavi gören hastalarda tüm bölgelerde rezorpsiyon skoru daha fazladır ($p<0.01$). Yaş ve rezorpsiyon skoru arasında anlamlı ilişki bulunmamıştır ($p>0.05$). Uzun süren ortodontik tedavilerde ve çekimli ortodontik tedavilerde kök rezorpsiyon sıklığı artmaktadır. Panoramik radyograflar ortodontik tedavi nedeniyle oluşan kök rezorpsiyonlarının teşhisinde önemli bir tanı aracıdır.

Anahtar kelimeler: Ortodontik tedavi, panoramik radyografi, kök rezorpsiyonu.

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INTRODUCTION

External root resorption is one of the most important and common side effects of orthodontic treatment.[1]During orthodontic tooth movement, inflammatory cytokines stimulate many migrating cells as well as bone cells to make bone resorption and construction in the alveolar bone as a result of a series of external forces.[2]At this stage, root resorption or root shortening can be observed.[3]Periapical and periodontal infections, trauma, nutrition and systemic disorders can cause external root resorption.[3-5] Mostly, the origin and pathogenesis of root resorption are still uncertain.[3,6]It is hard to predict root resorption during orthodontic treatment. But in the scientific literature, some factors are seemed to be suspicious. The extraction pattern and treatment duration can be important factors for root resorption. While root resorption is commonly found in mandibular anterior teeth because of contact with cortical bone, in treatments with extraction, upper incisors and upper and lower molars has lower incidence of root resorption. External root resorption induced by orthodontic forces differs from other etiologic factors. The treatment period, magnitude and type of functional force, direction and amount of tooth movement, type of treatment and biologic features can be related with to the root resorption during orthodontic treatment.[4,5]In orthodontic cases, root resorption is usually sterile, asymptomatic and clinically insignificant.[4,7,8] Severe root resorption that causes mobility or lost of teeth and weakening the dental arc hamper the success of orthodontic treatment.[8,9]

Panoramic radiographs are routinely used for pretreatment planning and evaluation of the current teeth.[1,10] Although panoramic radiographs enable to visualize all teeth with periapical tissues, it has some disadvantages such as magnification, superimposition and ghost images of compact tissues, making it challenging to evaluate.[11] So, it may lead to confusion or misdiagnosis while examining root resorption in panoramic radiograph. In these cases, consultation with an oral radiologist and examination of periapical radiographs of suspected teeth can be helpful. Periapical radiographs have higher resolution with accuracy of fine details and lower distortion compared with panoramic radiographs, allowing better precision in root resorption.[1]

Determining the reasons of root resorption related to orthodontic treatment may cause changes in the treatment method and duration. The aim of the present study was to identify the relationship between age, gender, type of skeletal and dental malocclusion, treatment duration, presence of extraction and root resorption related with orthodontic treatment.

MATERIAL AND METHODS

In this retrospective study, we investigated root resorption in890 records from patients aged 10-24 years who underwent orthodontic treatment between 2015 and 2020. Overall 560patients (358 women, 202 men) were included according to exclusion/inclusion criteria. The exclusion criteria included non-compliance to appointments, systemic illnesses effecting bone metabolism, craniofacial syndromes, cleft palate or lip, impacted or missing teeth, phase I orthodontic treatment, surgical orthodontic treatment, use of temporary anchorage devices and molar protraction during orthodontic treatment. From the database of department, panoramic radiographs obtained before and after orthodontic treatment without any technical errors and distortion were included the study. All panoramic radiographs were achieved using Planmeca Promax, (Planmeca, Helsinki, Finland, 66 kV, 6 mA, 16 s).

In addition, data regarding date of birth, gender, date of beginning and finish of treatment, appointment schedules, and types of treatment (presence of any tooth extraction) as well as pretreatment lateral cephalometric radiographs and intraoral photographs were included. The total treatment duration was calculated as time from the day of attachment brackets and settlement of arch wire to the removal of all orthodontic usages. Only roth bracket system with 22th sloth width were included the present study. Angle classification was defined according to the pretreatment intraoral photographs as follows: Class I, Class II (division 1 and 2) and Class III. Lateral cephalometric radiographs were used to define the type of vertical growth pattern and skeletal malocclusion. ANB (A Point-Nasion-B Point) angle was calculated for sagittal plane jaw relationship (Class I: 0° <ANB < 4°, Class II: ANB > 4°, Class III ANB < 0°).

Presence and degree of root resorption were investigated in post-treatment panoramic radiographs comparing with pre-treatment panoramic radiographs. The modified root resorption classification technique described by Sharpe et al.[12]was used in the evaluation of resorption levels. According to this technique, the resorption level was rated as follows: 0, no resorption; 1, root resorption within 1-2 mm of the root tip; 2, root resorption with a level greater than 1-2 mm but less than one-third of the root length marked; and a root resorption level exceeding one-third of the root length marked as score of "3" (Figure 1). In 560 patients, panoramic radiographs were examined and teeth 16-46 were evaluated according to Sharpe et al.[12]classification of apical root resorption. Modified root resorption scores (MRRS) were calculated for posterior and anterior teeth in both jaws. MRRS is calculated by the ratio of total score of examined teeth to total number of examined teeth.

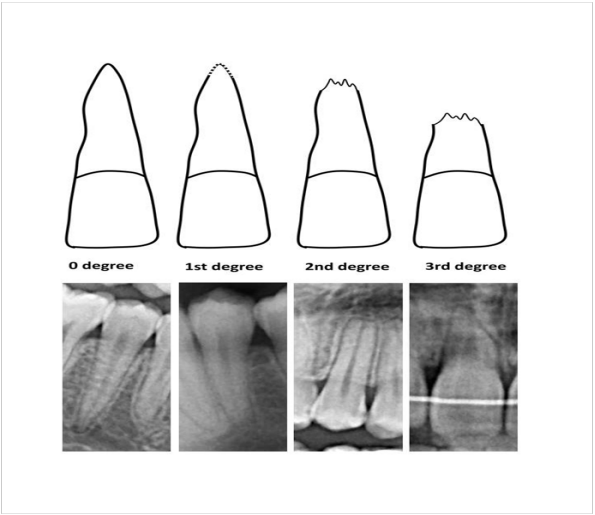

Figure 1. Schematic views and degrees of root resorption with the examples from cropped panoramic radiographs.

Statistical Analysis

Each variable was described using percentage, frequency, mean and standard deviation. The predictor variables of interest included. While gender, type of skeletal and dental malocclusion, MRRS and extraction type were used as categorical variables; age and treatment duration was used as continuous variables. MRRS was compared with overall orthodontic treatment duration by adjusted for potential confounding variables and using a linear regression model. A t-test was made between the MRRS of genders, and extraction/non-extraction groups. Multifactorial regression analysis was performed for the MRRS, age and gender. Radiologic examination was performed by two observers. The inter-class and intra-class correlation coefficients were calculated to evaluate the reliability of measurement. The inter-observer difference was found to be insignificant. All correlation tests were two-sided. p-value is less than 0.05, it is considered as significant. All statistical analyses were done with SPSS software (Statistical Package for Social Science V22.0, Chicago, Illinois, USA).

RESULTS

The study included panoramic radiographs from the 560 patients (358 women and 202 men). The mean age and mean treatment duration were 14.2 years and 25.6 months, respectively. Overall, 12553 teeth were examined from 560 panoramic radiographs. Table 1 presents the distribution of all patients according to evaluated parameters.

The highest MRSS percent was observed in maxillary central incisors; followed by maxillary lateral incisors. Ratios and degrees of root resorption of each tooth were presented in Table 2.

Bivariate correlation analysis

Bivariate correlation analysis was shown at the Table 3. No correlation was found between age and MRRS or between age and extraction according to bivariate analysis.

Table 1. Demographics of the subjects enrolled in the study

Variables		Occurence (n)	Percentage (%)
Gender	Male	202	36.1
	Female	358	63.9
Type of dental malocclusion	Class I	281	50.2
	Class II	267	47.7
	Class III	12	2.1
Skeletal classification	Class I	311	55.5
	Class II	234	41.8
	Class III	15	2.7
Extraction or non-extraction	Extraction	310	55.4
	Non-extraction	250	44.6
		Mean ± Standard deviation	
Age (years)		14.26 ± 1.89	
Treatment duration (months)		25.59 ± 8.73	

Table 2. Prevalence of external root resorption according to each tooth

Tooth Number	Degree 0		Degree 1		Degree 2		Degree 3		Total	
	n	(%)	n	(%)	N	(%)	n	(%)	n	(%)
11	321	57.3	211	37.7	25	4.5	3	0.5	560	100
12	351	63.8	174	31.6	25	4.5	0	0	550	100
13	500	89.3	56	10	4	0.7	0	0	560	100
14	249	91.9	20	7.4	2	0.7	0	0	271	100
15	518	92.5	32	5.7	10	1.8	0	0	560	100
16	548	97.9	10	1.8	2	0.4	0	0	560	100
21	335	59.8	202	36.1	22	3.9	1	0.2	560	100
22	341	61.5	185	33.3	26	4.7	2	0.4	554	100
23	485	86.6	72	12.9	3	0.5	0	0	560	100
24	260	97	8	3	0	0	0	0	268	100
25	520	92.9	30	5.4	10	1.8	0	0	560	100
26	545	97.3	7	1.3	8	1.4	0	0	560	100
31	477	85.2	81	14.5	2	0.4	0	0	560	100
32	475	84.8	79	14.1	6	1.1	0	0	560	100
33	472	84.6	86	15.4	0	0	0	0	558	100
34	398	93	30	7	0	0	0	0	428	100
35	498	89.2	60	10.7	0	0	0	0	558	100
36	455	82.1	75	13.5	26	4.7	0	0	554	100
41	471	84.1	87	15.5	2	0.4	0	0	560	100
42	467	83.4	87	15.5	6	1.1	0	0	560	100
43	488	87.1	72	12.9	0	0	0	0	560	100
44	401	95.5	17	3.3	0	0	2	0.5	420	100
45	514	92.8	36	6.5	6	1.1	0	0	554	100
46	492	88.1	40	7.2	26	4.6	0	0	558	100

Table 3. Correlation coefficients of the bivariate correlation analysis between age, treatment duration, extraction, dental classification, skeletal classification and mean root resorption score (MRRS) after treatment for the maxillary and mandibular anterior and

Correlation coefficients	MRRS Maxillary posterior	MRRS Maxillary anterior	MRRS Mandibular posterior	MRRS mandibular anterior	Age	Treatment duration	Extraction	Dental classification	Skeletal classification
Age	-0.075	0.046	-0.033	0.002	1.000	-0.024 -0.059		-0.023	0.032
Treatment duration	0.043	0.136**	0.076	0.052	-0.024	1.000	0.246**	0.191**	0.004
Extraction	0.250**	0.096*	0.256**	0.100*	-0.06	0.246**	1.000	0.325**	0.070
Dental classification	0.053	0.006	-0.142**	0.051	-0.023	0.191**	0.325**	1.000	0.257**
Skeletal classification	-0.016	-0.070	-0.089*	0.020	0.032	0.004	0.077	0.257**	1.000

MRRS: mean root resorption score *P<0.05, **P<0.01.

The correlation coefficient between treatment duration and extraction was 0.25 (P<0.01), hence in extraction cases treatment duration was longer. There was a positive relationship between treatment duration and dental classification (P<0.01). With the exception of the maxillary anterior teeth (P<0.01), no statistically significant relationship was found between treatment duration and root resorption.

All regions had higher MRSS in orthodontic treatment with extractions, the correlation coefficients ranging from 0.09 to 0.26 (P<0.01; P<0.05). Extractions had significantly positively correlated with dental classification (P<0.01).

There was a significant negative correlation between MRRS of mandibular posterior teeth and dental classification as well as skeletal classification, the correlation coefficient was -0.14 (P<0.01) and -0.09 (P<0.05), respectively.

Multiple regression analysis

While age, gender, treatment duration, extraction, dental and skeletal classification were used as the independent variables, MRRS were used as the dependent variable (Table 4). The gender had a statistically significant correlation with root resorption at mandibular anterior and posterior teeth (-0.15; -0.13). Female patients had more root resorption at mandibular anterior and posterior teeth than male patients. The age and skeletal classification had no significant correlation. The patients with Class I and Class III dental malocclusion had greater root resorption at mandibular posterior teeth than patients with Class II dental malocclusion (-0.26). Extractions had a statistically significant correlation with root resorption in posterior parts of the maxillary and mandibular dentition (0.26; 0.34). A statistically significant correlation was found between treatment duration and root resorption of the maxillary anterior teeth (0.12).

DISCUSSION

Root resorption is one of the important and unpredictable side effects of orthodontic treatment. Although most of cases were clinically asymptomatic and insignificant, identification of root resorption at the accurate time may help clinicians to limit the degree of resorption by changing the treatment method. A lot of factors may cause to root resorption during orthodontic treatment.[4-8] It is important to determine the most suspicious conditions for the root resorption. So, the present study was conducted with a large sample for contribution to scientific literature.

Periapical radiographs, lateral cephalometric projections, panoramic radiographs and cone beam computed tomography have been used to determine the root resorption in the literature. Cone beam computed tomography is the most reliable method for the evaluation of apical root resorption.[13,14] However, routine use is not possible due to high cost and radiation dose. A single panoramic radiograph is more practical than multiple periapical radiographs because it provides comprehensive information on all teeth and both jaws in a single image. Therefore, panoramic radiography was used for the present study. Also, radiographs in which root apex cannot be clearly traced was excluded from the study.

It seems that the classification described by Sharpe et al.[12] is preferred more commonly for the evaluation of external root resorption on panoramic radiographs.[4,15] Therefore, Sharpe et al.[12] resorption classification system was used in the present study.

When the rate of relationship between treatment type and resorption frequency was examined, it was seen that root resorption is observed quite frequently in patients having fixed orthodontic treatment.[16,17] Therefore, only patients having fixed orthodontic treatment were examined instead of those having treatment with removable appliances while selecting the material of the study.

It has been proposed that maxillary incisors are the first teeth to be exposed to constant treatment forces, and therefore are the most commonly reported site of resorption activity.[18,19] In terms of resorption frequency, maxillary central and lateral incisors were found to be the most affected teeth in the present study similarly to the results of the literature.

We found that female patients had more root resorption

Table 4. Multiple regression analysis of mean root resorption score (MRRS)

Variables	MRRS											
	Maxillary Posterior			Maxillary anterior			Mandibular posterior			Mandibular anterior		
	Esti-mate	95% CI	*p* value	Estimate	95% CI	*p* value	Estimate	95% CI	*p* value	Estimate	95% CI	*p* value
Gender: male	-0.05	(-0.18, 0.05)	0.271	-0.02	(-0.11, 0.64)	0.599	-0.13**	(-0.22, -0.05)	0.001	-0.15***	(-0.15, -0.43)	0.000
Age (year)	-0.06	(-0.05, 0.01)	0.120	0.06	(-0.01, 0.04)	0.183	-0.03	(-0.03, 0.01)	0.328	-0.01	(-0.01, 0.01)	0.925
Class II dental malocclusion:	-0.02	(-0.16, 0.09)	0.589	-0.01	(-0.11, 0.08)	0.786	-0.26**	(-0.35, -0.18)	0.000	0.02	(-0.04, 0.07)	0.697
Class III dental malocclusion:	0.01	(-0.43, 0.44)	0.982	-0.03	(-0.42, 0.22)	0.541	-0.05	(-0.46, 0.14)	0.283	0.01	(-0.17, 0.21)	0.820
Skeletal classification (ANB): Class II	-0.01	(-0.14, 0.10)	0.743	-0.06	(-0.15, 0.03)	0.194	-0.02	(-0.10, 0.06)	0.601	0.04	(-0.03, 0.07)	0.395
Skeletal classification (ANB): Class III	-0.03	(-0.52, 0.26)	0.514	-0.05	(-0.44, 0.13)	0.280	-0.06	(-0.45, 0.08)	0.177	-0.02	(-0.21, 0.13)	0.618
Treatment duration	-0.02	(-0.01, 0.01)	0.709	0.12**	(0.00, 0.01)	0.006	0.05	(-0.00, 0.01)	0.228	0.03	(-0.00, 0.01)	0.453
Extraction/non-extraction	0.26***	(0.24, 0.49)	0.000	0.08	(-0.01, 0.17)	0.083	0.34***	(0.26, 0.43)	0.000	0.08	(-0.00, 0.11)	0.056
Adjusted R-square		5.7%			1.9%			13.7%			2.2%	

ANB: A Point-Nasion-B Point Mean MRRS values were used as the dependent variable. *P<0.05; **P<0.01; ***P<0.001.

at mandibular anterior and posterior teeth than male patients. Hormonal difference between genders may be a factor causing this result. Because estrogen inhibits bone resorption by suppressing the number of osteoclasts in women while testosterone reduces bone resorption in men. Testosterone also stimulates bone formation in males and females, and can be altered to estrogen to prevent bone resorption.[20] Estrogen suppresses bone resorption by inhibiting osteoclastic and cementoclastic activities. In an animal study, it was reported that, female sex hormones decrease orthodontically induced root resorption and may decelerate the speed of tooth movement. This is contrary to the studies of Sameshima et al.[21] and Linge et al.[17] who reported no significant difference in external root resorption between genders but is in agreement with some previous research.[22,23] We think that the difference with previous studies is caused by the differences in number of individuals and distribution of individuals according to gender.

It was found that there was no correlation between age and root resorption. This is contrary to the findings of Jiang et al. who found a strong correlation between root resorption and age and reported that the older patients were prone to severe root resorption.[4] This contradictory result may be due to younger age in the present study population. Generally, elderly and middle-aged individuals have more complex orthodontic treatment than adolescents and young adults because periodontal structure is different in adult patients with higher likelihood of periodontal problems. Sameshima et al.[21] reported no correlation was found between there sorption of maxillary anterior teeth and age, but they also found that adults had significantly more resorption in their mandibular anterior teeth. Similar to our results; Pastro et al. concluded that no significant relationship was found between age and apical root resorption[24].

In all regions, MRSS were higher in orthodontic treatment with extractions. Extractions had a statistically significant correlation with root resorption only in the posterior parts of the maxillary and mandibular dentition in the present study. This revealed that extraction, among the other factors such as age, gender, treatment duration, skeletal and dental malocclusion type, was less important for maxillary and mandibular anterior root resorption than previously believed. This may be due to the difference about the amount of tooth movement between anterior and posterior teeth. Previous researchers also found more root resorption in cases with premolar extraction due to greater amount of tooth movement.[14,17] Sameshima et al.[21] also stated that the most root resorption was seen in individuals who had 4 premolar teeth extracted for orthodontic purposes. It was also found that treatment duration and extraction had a statistically significant correlation in the present study. Furthermore, treatment duration had a statistically significant relationship with maxillary anterior root resorption.

A statistically significant correlation was found between maxillary anterior root resorption and treatment duration in the present study. Therefore, it was considered that an increase in treatment duration might lead an increase in maxillary anterior root resorption because of continuous stimulus to the root. This result was compatible with other studies indicating that long-term orthodontic treatment increased the possibility of external root resorption.[6,17, 25, 26] Segal et al.[27] reported that as the duration of orthodontic force increases, the inflammatory response in the surrounding tissues of the tooth increases. The increase in inflammation also causes an increase in root resorption.

Patients with Class III and Class I dental malocclusion had more root resorption at mandibular posterior teeth than patients with Class II dental malocclusion in the present study. This result may be due to more movement of mandibular molar teeth in patients with Class III and Class I dental malocclusion. There may be more maxillary incisor retraction instead of mandibular posterior movement in Class II dental occlusion due to increased over jet. Brin et al.[25] that maxillary incisors demonstrated more apical root resorption following Class II treatment.

This study has some limitations including its retrospective design, application of different treatment techniques and different orthodontic forces. Another limitation is detection of root resorption by panoramic radiographs instead of cone beam computed tomography because of high exposure dose. Further prospective studies may be useful to understand the relationship between fixed orthodontic treatment and apical root resorption. In the future studies, comparing the fixed orthodontic treatment and clear aligners is also helpful. Nevertheless, the results of the present study provide important information about the reasons of root resorption. Clinicians should be aware of these reasons and make some changes in treatment protocols to prevent possible root resorptions.

CONCLUSIONS

No relationship was found between patient age and MRSS in patients underwent fixed orthodontic treatment. Orthodontic treatment with extraction increased root resorption in our study population. Patients treated with extractions may have more root resorption and the impact of extraction on root resorption may be a consequence of increased tooth movement.

The possible effects of orthodontic treatments and orthodontic forces on teeth should not be ignored in terms of maintaining dental health. The duration of treatment may be longer in treatments with extractions, and therefore the likelihood of apical root resorption occurring may be increased. The risk factors for root resorption should be carefully evaluated in the patients when making the decision of extractions.

Ethics Committee Approval: Approval was received for this study from Aydın Adnan Menderes University Faculty of Dentistry Clinical Research Ethics Committee (Date: 2021/17, Issue: 02).

Informed Consent: Since it was a retrospective study, no consent was obtained.

Peer Review: Externally independent.

Author Contributions: Concept - EK; Design-YAU, EK; Supervision EK, YAU; Sources-YAU, Materials-YAU, UT; Data Collection and/or processing-YAU, UT; Analysis and/or interpretation-EK, YAU; Literature review-EK, UT; Written by - EK, YAU; Critical review-EK, YAU.

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REFERENCES

1. Maués CP, do Nascimento RR, Vilella Ode V. Severe root resorption resulting from orthodontic treatment: prevalence and risk factors. *Dental Press J Orthod.* 2015;20(1):52-58. doi:10.1590/2176-9451.20.1.052-058.oar.
2. Kaur H, El-Bialy T. Shortening of Overall Orthodontic Treatment Duration with Low-Intensity Pulsed Ultrasound. *J Clin Med*. 2020;9(5):1303. doi:10.3390/jcm9051303.
3. 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):462-76. doi:10.1016/j.ajodo.2009.06.021.
4. Jiang RP, McDonald JP, Fu MK. Root resorption before and after orthodontic treatment: a clinical study of contributory factors. *Eur J Orthod.* 2010;32 (6):693-697. doi:10.1093/ejo/cjp165.
5. Motokawa M, Sasamoto T, Kaku M, et al. Association between root resorption incident to orthodontic treatment and treatment factors. *Eur J Orthod.* 2012;34(3):350-356. doi:10.1093/ejo/cjr018.
6. 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. doi:10.1016/j.ajodo.2014.12.026.
7. Hartsfield JK Jr, Everett ET, Al-Qawasmi RA. Genetic factors in external apical root resorption and orthodontic treatment.*Crit Rev Oral Biol Med*. 2004;15(2):115-122. doi:10.1177/154411130401500205.
8. Lopatiene K, Dumbravaite A. Risk factors of root resorption after orthodontic treatment. *Stomatologija.* 2008;10(3):89-95. PMID: 19001842.
9. Travess H, Roberts-Harry D, Sandy J. Orthodontics. Part 6: Risks in orthodontic treatment. *Br Dent J.* 2004;196(2):71-77. doi:10.1038/sj.bdj.4810891.
10. Sameshima GT, Asgarifar KO. Assessment of root resorption and root shape: periapical vs panoramic films. *Angle Orthod.* 2001;71(3):185-189. doi:10.1043/00033219(2001)071<0185:AORRAR>2.0.CO;2.
11. Ridao-Sacie C, Segura-Egea JJ, Fernández-Palacín A, Bullón-Fernández P, Ríos-Santos JV. Radiological assessment of periapical status using the periapical index: comparison of periapical radiography and digital panoramic radiography. *Int Endod J.* 2007;40(6):433-440. doi:10.1111/j.1365-2591.2007.01233.x.
12. 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. doi:10.1016/0889-5406(87)90455-0.
13. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 1. Literature review. *Am J Orthod Dentofacial Orthop.* 1993;103(1):62-66. doi:10.1016/S0889-5406(05)81763-9.
14. Apajalahti S, Peltola JS. Apical root resorption after orthodontic treatment -- a retrospective study. *Eur J Orthod.* 2007;29(4):408-412. doi:10.1093/ejo/cjm016.
15. Ruoping J, Ding Z, Minkui F. *A clinical study of root resorption before and after orthodontic treatmen.t Eur J Orthod.* 2010;32(6):693-697. doi:10.1093/ejo/cjp165.
16. Levander E, Malmgren O, Stenback K. Apical root resorption during orthodontic treatment of patients with multiple aplasia: a study of maxillary incisors. *Eur J Orthod.* 1998;20(4):427-434. doi:10.1093/ejo/20.4.427.
17. 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. doi:10.1016/S0889-5406(05)81678-6.
18. Janson GR, De Luca Canto G, Martins DR, Henriques JF, De Freitas MR. A radiographic comparison of apical root resorption after orthodontic treatment with 3 different fixed appliance techniques. *Am J Orthod Dentofacial Orthop.* 2000;118(3):262-273. doi:10.1067/mod.2000.99136.
19. Remington DN, Joondeph DR, Artun 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. doi:10.1016/0889-5406(89)90227-8.
20. Masella RS, Meister M. Current concepts in the biology of orthodontic tooth movement. *Am J Orthod Dentofacial Orthop.* 2006;129(4):458-468. doi:10.1016/j.ajodo.2005.12.013.
21. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part I. Diagnostic factors. *Am J Orthod Dentofacial Orthop.* 2001;119(5):505-510. doi:10.1067/mod.2001.113409.
22. Kjaer I. Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. *Eur J Orthod.* 1995;17(1):25-34. doi:10.1093/ejo/17.1.25.
23. 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. doi:10.1016/0889-5406(90)70086-R.
24. Pastro JDV, Nogueira ACA, Salvatore de Freitas KMS, et al. Factors Associated to Apical Root Resorption after Orthodontic Treatment. *Open Dent J.* 2018;12:331-339. PMID: 29875885.
25. Brin I, Tulloch JF, Koroluk L, Philips C. External apical root resorption in Class II malocclusion: a retrospective review of 1-versus 2-phase treatment. *Am J Orthod Dentofacial Orthop.* 2003;124 (2):151-156. doi:10.1016/S0889-5406(03)00166-5.
26. Mavragani M, Vergari A, Selliseth NJ, Bøe OE, Wisth PL. A radiographic comparison of apical root resorption after orthodontic treatment with a standard edgewise and a straight-wire edgewise technique. *Eur J Orthod.* 2000;22(6):665-674. doi:10.1093/ejo/22.6.665.
27. Segal GR, Schiffman PH, Tuncay OC. Meta analysis of the treatment-related factors of external apical root resorption. *Orthod Craniofac Res.* 2004;7 (2):71-78. doi:10.1111/j.1601-6343.2004.00286.x.