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ORIGINAL ARTICLE

Factors that may increase the risk of external apical root resorption during orthodontic treatment

Retrospective clinical investigation

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Abstract

Purpose To determine the correlation between external apical root resorption and malocclusion-related variables in patients treated with fixed orthodontic appliances.

Methods In all, 103 patients aged 12–15 years and treated with edge-wise appliances either without extractions or with four premolar extractions were included in this retrospective cohort study. External apical root resorption was assessed in the pre- and posttreatment panoramic radiographs of these patients for incisors, canines, premolars, and first molars. A total of 2332 teeth were evaluated in 206 panoramic radiographs obtained from 103 patients. The gender of the patients, duration of orthodontic treatments, presence of premolar extractions, Angle classification, overbite, overjet and amount of crowding were assessed. Wilcoxon signed-rank test, Mann–Whitney U test, and Kruskal–Wallis test were used for statistical analysis of the data.

Results Statistically significant ($p<0.001$) root resorption occurred in all examined teeth during orthodontic treatment. The degree of root resorption observed in the premolars was significantly greater in premolar extraction cases than in nonextraction cases. Statistically significant negative correlations were found between the degree of root resorption of the maxillary lateral teeth and between the maxillary first premolar teeth and the amount of maxillary crowding.

Conclusions The orthodontic treatment protocols and the amount of tooth movements achieved were shown to be dependent on the severity of dental malocclusions and they have an influence on the amount of external apical root resorption that occurs during the course of orthodontic treatment.

Keywords Treatment duration · Malocclusion · Tooth crowding · Angle classification · Tooth extraction

Faktoren, die das Risiko für eine externe apikale Wurzelresorption während einer kieferorthopädischen Behandlung erhöhen können

Eine retrospektive klinische Untersuchung

Zusammenfassung

Zielsetzung Ermittelt werden sollte der Zusammenhang zwischen externer apikaler Wurzelresorption und malokklusionsbezogenen Variablen bei mit festsitzenden kieferorthopädischen Apparaturen behandelten Patienten.

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Methoden Insgesamt 103 Patienten im Alter von 12-15 Jahren, die entweder ohne Extraktionen oder mit Extraktionen von 4 Prämolaren mit Edge-Wise-Apparaturen behandelt wurden, nahmen an dieser retrospektiven Kohortenstudie teil. Die externe apikale Wurzelresorption wurde vor und nach der Behandlung auf den Panoramaröntgenbildern dieser Patienten für Schneidezähne, Eckzähne, Prämolaren und erste Molaren beurteilt. Insgesamt wurden 2332 Zähne auf 206 Panoramaröntgenbildern von 103 Patienten untersucht. Dabei wurden das Geschlecht der Patienten, die Dauer der kieferorthopädischen Behandlungen, das Vorhandensein von Prämolarextraktionen, die Angle-Klassifikationen, Overbite, Overjet und das Ausmaß des Engstandes berücksichtigt. Für die statistische Analyse der Daten wurden der Wilcoxon-Signed-Rank-Test, der Mann-Whitney-U-Test und der Kruskal-Wallis-Test verwendet.

Ergebnisse Bei allen untersuchten Zähnen trat während der kieferorthopädischen Behandlung eine statistisch signifikante ($p < 0{,}001$) Wurzelresorption auf. Das Ausmaß der Wurzelresorption bei den Prämolaren war in Fällen, in denen die Prämolaren extrahiert wurden, signifikant größer als in Fällen ohne Extraktion. Es wurden statistisch signifikante negative Korrelationen zwischen dem Grad der Wurzelresorption der Oberkieferseitenzähne und zwischen den ersten Prämolaren des Oberkiefers und dem Ausmaß des Engstandes im Oberkiefer festgestellt.

Schlussfolgerungen Es hat sich gezeigt, dass die kieferorthopädischen Behandlungsprotokolle und das Ausmaß der erreichten Zahnbewegungen vom Schweregrad der Zahnfehlstellungen abhängen und einen Einfluss auf den Grad der externen apikalen Wurzelresorption haben, die im Verlauf der kieferorthopädischen Behandlung auftritt.

Schlüsselwörter Behandlungsdauer · Malokklusion · Engstand · Angle-Klassifizierung · Zahnextraktion

Introduction

External apical root resorption (EARR) is a side effect which is frequently observed after orthodontic treatment [4]. Studies have shown that a resorption lacunae occurs on the pressure side of the tooth surface after application of an orthodontic force [14, 22, 25, 29]. The lacunae starts at the periphery of the hyalinized area and may even extend into the pulp canal without being detected on radiographs. Luckily, severe root resorption that shortens the lifetime of a tooth or hinders orthodontic treatment is rarely observed [27]. However, general dentists and other dental specialists usually assume that root resorption is preventable and blame the orthodontists when it occurs during orthodontic treatment [30]. Thus, there is no doubt that orthodontists and other dentists have to investigate the factors contributing to external apical root resorption and understand the mechanism of this problem to avoid it or to minimize its detrimental effects [27, 30].

Numerous clinical and laboratory studies examining EARR have been reported in the literature [1–30]. Nevertheless, the interaction between orthodontic treatment and root resorption is still controversial. Various factors have been associated with root resorption such as individual predisposition, systemic factors, genetic background, gender, age, root morphology, duration of orthodontic treatment, magnitude of orthodontic forces, direction of orthodontic tooth movement, amount of apical displacement, type of malocclusion, treatment technique, and trauma [2, 4, 9, 11, 13, 15, 18, 21, 23, 26, 27, 29, 30]. However, the contributions of each factor are conflicting due to the different methodologies and heterogeneous patient samples used in the studies [18].

The aim of this study was to determine the correlation between EARR and malocclusion-related variables in a homogeneous patient sample treated with fixed orthodontic appliances. The variables examined were gender, duration of orthodontic treatment, extraction of premolars, Angle classification, overbite, overjet, maxillary crowding, and mandibular crowding. The H_0 hypothesis was that similar degrees of root resorption occur during orthodontic treatment realized with different treatment protocols in different malocclusions, whereas the H_1 hypothesis was that malocclusion type and the related treatment protocol affects the degree of root resorption that occurs during orthodontic treatment.

Materials and methods

The records of patients treated with fixed orthodontic appliances in the Orthodontics Department of Başkent University (Ankara, Türkiye) between 2013 and 2020 were retrospectively examined. Başkent University Institutional Review Board and Ethics Committee (project number D-KA20/97) approved the retrospective study protocol and consent procedure. Written informed consent was obtained from all patients and their parents/guardians for the use of their orthodontic data for research at the beginning of their orthodontic treatment. A power analysis was performed to calculate the sample size required for this retrospective study. The power analysis revealed that a sample size of 96 was needed to detect statistically significant differences with a power of 85% at 0.05 significance level. The correlation coefficient for the H_0 hypothesis was accepted as 0.00, which shows no correlation between the degrees of root

resorption and the tested variables. On the other hand, the correlation coefficient for the H_1 hypothesis was accepted if ≥ 0.30, which shows a moderate correlation between the degrees of root resorption and the tested variables. Therefore, a correlation coefficient of 0.30 was considered a statistically significant difference between the H_0 and H_1 hypothesis using a two-sided hypothesis test, and the moderate correlation value of 0.30 was taken from the literature [8]. Sample size estimation was performed by using PASS software (Number Cruncher Statistical System, Version 2000, Kaysville, UT, USA).

Patients with medical history of systemic diseases, maxillofacial trauma (involving teeth, jaws or facial structures, reported by the patient/parent anytime before or during treatment), endodontic treatment, orthognathic surgery, previous orthodontic treatment, dental anomalies of number, impacted teeth except for third molars, malformed roots (number, length, shape abnormalities of the root such as dilacerations, taurodontism), incomplete root formation (young/newly erupted permanent tooth with incomplete root apex formation), harmful habits (bruxism, thumb sucking, nail biting), radiographic signs of pathologies, and poor quality radiographs were excluded. Of the remaining patients, 103 patients who were aged 12–15 years, having excellent-quality panoramic radiographs and treated with 0.018 × 0.025 inch slot edge-wise appliances either without extractions or with four premolar extractions from each half jaw, were included in the study. All patients were Caucasians. The digital panoramic radiographs were acquired with the same orthopantomograph (Planmeca, PM 2002 cc; Proline, Helsinki, Finland) at pre- (T1) and posttreatment (T2) stages in all patients.

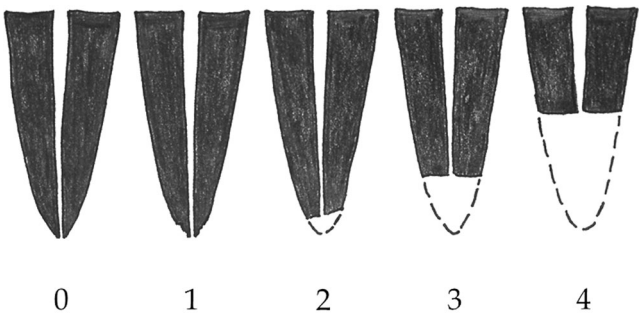

Fig. 1 Scores used for classification of root resorption. *0*: no root resorption, *1*: mild resorption with root of normal length and irregular contour only, *2*: moderate resorption with small areas of root loss and apex having an almost straight contour, *3*: severe resorption with loss of almost one third of root length, *4*: extreme resorption with loss of more than one third of root length. (Modified from Levander and Malgrem [15]; with kind permission © Oxford University Press, all rights reserved)

Abb. 1 Scores zur Klassifizierung von Wurzelresorption. *0*: Keine Wurzelresorption, *1*: leichte Resorption mit einer Wurzel von normaler Länge und nur unregelmäßiger Kontur, *2*: mäßige Resorption mit kleinen Bereichen von Wurzelverlust und Apex mit fast gerader Kontur, *3*: starke Resorption mit Verlust von fast einem Drittel der Wurzellänge, *4*: extreme Resorption mit Verlust von mehr als einem Drittel der Wurzellänge. (Mod. aus Levander und Malgrem [15]; mit freundl. Genehmigung © Oxford University Press, alle Rechte vorbehalten)

The gender of the patients, duration of orthodontic treatment, presence of premolar extractions, Angle classification, overbite, overjet, and amount of crowding were noted. EARR in the pre- and posttreatment panoramic radiographs was assessed by two calibrated examiners for incisors, canines, premolars, and first molars. The scoring system of Levander and Malgrem [15] was used for classification of the degree of root resorption (Fig. 1). The scores used for classification and their interpretations are as follows: 0 = no root resorption, 1 = mild resorption with root of normal length and irregular contour only, 2 = moderate resorption with small areas of root loss and apex having an almost straight contour, 3 = severe resorption with loss of almost one third of root length, 4 = extreme resorption with loss of more than one third of root length. A total of 2332 teeth were evaluated in 206 panoramic radiographs obtained from 103 patients.

Statistical analysis

Data analysis was performed by using SPSS for Windows (IBM Corp., version 22, Armonk, NY, USA). Descriptive statistics were calculated for all variables. Continuous or ordinal data were shown as mean and standard deviation, while categorical variables were shown as number of patients and percentages. The statistical differences in the root resorption scores between the pre- and posttreatment radiographs were evaluated by Wilcoxon signed-rank test. The differences between two groups (male/female, extraction/nonextraction) were compared by Mann–Whitney U test, while the differences between more than two groups (Angle class I/II/III) were compared by Kruskal–Wallis test. The degree of association between the root resorption scores and continuous variables (treatment duration, overbite, overjet, maxillary crowding and mandibular crowding) was calculated by Spearman's correlation coefficient. A p value less than 0.05 was considered statistically significant.

Method error was evaluated by reassessment of the pre- and posttreatment panoramic radiographs of 35 randomly selected patients by the same two examiners after an interval of 30 days. Both intra- and interexaminer reliability in scoring root resorption were calculated by intraclass correlation coefficients (ICC) with 95% confidence intervals. The ICC calculated for each tooth ranged between 0.89 and 1.00 for intraexaminer reliability and between 0.78 and 0.93 for interexaminer reliability; thus, the examiners were found to be reliable.

Table 1 Demographic distribution of patients with their malocclusion and treatment characteristics

Tab. 1 Demographische Verteilung der Patienten mit Zahnfehlstellungen und Behandlungsmerkmalen

Variables	*n*	%	Mean	SD
Gender				
Female	63	61.2	–	–
Male	40	38.8	–	–
Extraction status				
Nonextraction	68	66.0	–	–
Four premolar extractions	35	34.0	–	–
Angle relationship				
Class I	56	54.4	–	–
Class II	36	35.0	–	–
Class III	11	10.6	–	–
Overbite, mm	–	–	2.81	2.28
Overjet, mm	–	–	3.64	3.03
Maxillary crowding, mm	–	–	–3.60	4.60
Mandibular crowding, mm	–	–	–2.27	4.01
Treatment duration, months	–	–	27.21	7.63

n number, % percentage, *SD* standard deviation

Table 2 Comparison of pre- (T1) and posttreatment (T2) root resorption scores using the Wilcoxon signed-rank test and the degree of root resorption observed during orthodontic treatment (T2–T1 difference)

Tab. 2 Vergleich der Werte für die Wurzelresorption vor (T1) und nach der Behandlung (T2) anhand des Wilcoxon-Signed-Rank-Tests und des während der kieferorthopädischen Behandlung beobachteten Grads der Wurzelresorption (T2-T1-Differenz)

		Pretreatment (T1)		Posttreatment (T2)		T2–T1 difference		
	n	Mean	SD	Mean	SD	Mean	SD	*p*-value
UR 6	103	0.05	0.31	0.47	0.62	0.41	0.58	*< 0.001* ***
UR 5	78	0.05	0.28	0.69	0.83	0.64	0.80	*< 0.001* ***
UR 4	93	0.08	0.34	1.01	0.94	0.94	0.93	*< 0.001* ***
UR 3	103	0.11	0.37	1.48	0.89	1.37	0.89	*< 0.001* ***
UR 2	103	0.14	0.47	1.87	0.72	1.73	0.79	*< 0.001* ***
UR 1	103	0.12	0.43	1.71	0.69	1.59	0.74	*< 0.001* ***
UL 1	103	0.12	0.44	1.71	0.69	1.59	0.74	*< 0.001* ***
UL 2	103	0.14	0.50	1.87	0.73	1.72	0.80	*< 0.001* ***
UL 3	103	0.13	0.42	1.50	0.88	1.38	0.89	*< 0.001* ***
UL 4	94	0.09	0.35	0.99	0.91	0.90	0.90	*< 0.001* ***
UL 5	77	0.08	0.33	0.70	0.84	0.62	0.81	*< 0.001* ***
UL 6	103	0.05	0.30	0.49	0.65	0.44	0.61	*< 0.001* ***
LR 6	103	0.05	0.31	0.56	0.79	0.51	0.73	*< 0.001* ***
LR 5	78	0.10	0.39	0.78	0.92	0.67	0.86	*< 0.001* ***
LR 4	93	0.12	0.41	1.09	0.94	0.97	0.90	*< 0.001* ***
LR 3	103	0.18	0.54	1.72	0.87	1.54	0.90	*< 0.001* ***
LR 2	103	0.18	0.52	1.95	0.59	1.77	0.72	*< 0.001* ***
LR 1	103	0.19	0.53	2.10	0.63	1.91	0.75	*< 0.001* ***
LL 1	103	0.19	0.52	2.13	0.64	1.94	0.77	*< 0.001* ***
LL 2	103	0.18	0.52	1.97	0.56	1.79	0.70	*< 0.001* ***
LL 3	103	0.18	0.54	1.72	0.85	1.54	0.88	*< 0.001* ***
LL 4	95	0.12	0.41	1.13	0.87	1.01	0.87	*< 0.001* ***
LL 5	76	0.11	0.40	0.86	0.91	0.76	0.86	*< 0.001* ***
LL 6	103	0.07	0.34	0.65	0.79	0.57	0.74	*< 0.001* ***

UR Upper Right, *UL* Upper Left, *LR* Lower Right, *LL* Lower Left, *n* number, *SD* standard deviation
$p < 0.05$: significant, ***$p < 0.001$

Table 3 Comparison of the degree of root resorption observed in females/males and in nonextraction/four premolar extraction cases during orthodontic treatment using Mann–Whitney U test

Tab. 3 Vergleich des Ausmaßes der Wurzelresorption bei weiblichen/männlichen Patienten und bei Patienten ohne Extraktion bzw. mit 4 extrahierten Prämolaren während der kieferorthopädischen Behandlung mittels Mann-Whitney-U-Test

	Female		Male			Nonextraction		4 Premolar extraction		
	Mean	SD	Mean	SD	*p*-value	Mean	SD	Mean	SD	*p*-value
UR 6	0.46	0.57	0.34	0.59	0.239	0.33	0.47	0.58	0.71	0.117
UR 5	0.78	0.82	0.35	0.67	0.069	0.58	0.78	1.50	0.58	*0.037* *
UR 4	1.00	0.90	0.83	0.98	0.327	0.76	0.88	1.24	0.96	*0.020* *
UR 3	1.48	0.85	1.18	0.94	0.147	1.25	0.99	1.59	0.66	0.117
UR 2	1.81	0.74	1.58	0.87	0.247	1.70	0.83	1.77	0.73	0.858
UR 1	1.61	0.69	1.55	0.83	0.952	1.57	0.77	1.63	0.69	0.883
UL 1	1.61	0.69	1.54	0.84	0.886	1.56	0.77	1.63	0.69	0.846
UL 2	1.85	0.73	1.51	0.87	0.075	1.72	0.84	1.74	0.71	0.872
UL 3	1.51	0.83	1.14	0.94	0.080	1.24	0.97	1.62	0.65	0.063
UL 4	1.03	0.91	0.69	0.87	0.066	0.73	0.87	1.25	0.88	*0.006* **
UL 5	0.73	0.82	0.43	0.79	0.117	0.47	0.72	1.63	0.74	*< 0.001* ***
UL 6	0.52	0.65	0.29	0.52	0.064	0.38	0.55	0.55	0.71	0.328
LR 6	0.62	0.77	0.31	0.63	0.078	0.44	0.71	0.63	0.76	0.194
LR 5	0.73	0.82	0.57	0.95	0.274	0.48	0.73	1.33	0.98	*0.002* **
LR 4	1.00	0.85	0.92	1.00	0.586	0.69	0.79	1.44	0.89	*< 0.001* ***
LR 3	1.63	0.89	1.36	0.90	0.172	1.44	0.94	1.71	0.79	0.192
LR 2	1.81	0.67	1.71	0.80	0.639	1.82	0.72	1.68	0.73	0.358
LR 1	2.02	0.68	1.73	0.84	0.091	1.91	0.74	1.91	0.78	0.974
LL 1	2.03	0.69	1.79	0.87	0.182	1.94	0.76	1.94	0.80	0.981
LL 2	1.86	0.64	1.68	0.77	0.325	1.80	0.71	1.77	0.69	0.793
LL 3	1.63	0.87	1.36	0.90	0.188	1.45	0.94	1.69	0.76	0.262
LL 4	1.05	0.82	0.94	0.95	0.570	0.78	0.83	1.40	0.81	*< 0.001* ***
LL 5	0.84	0.85	0.57	0.87	0.185	0.62	0.80	1.29	0.91	*0.013* *
LL 6	0.70	0.77	0.35	0.65	0.081	0.52	0.74	0.68	0.75	0.276

UR Upper Right, *UL* Upper Left, *LR* Lower Right, *LL* Lower Left, *SD* standard deviation
$p \geq 0.05$: not significant; $p < 0.05$: significant, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Results

The demographic distribution of the patients, their malocclusions and treatment characteristics are shown as absolute numbers and percentages for categorical variables, whereas they are shown as mean and standard deviation for continuous or ordinal variables (Table 1).

A significant amount of root resorption occurred in all examined teeth during orthodontic treatment. A statistically significant increase ($p < 0.001$) was observed in the root resorption scores of the posttreatment radiographs, compared to the pretreatment radiographs (Table 2).

The degree of root resorption observed in the females were greater than in the males in all examined teeth. However, the differences observed in the degree of root resorption between the females and males were not statistically significant (Table 3).

The degree of root resorption observed in almost all examined teeth was greater in the premolar extraction cases than in the nonextraction cases. Furthermore, the differences in the degree of root resorption between the premolar extraction and nonextraction cases were statistically significant for all premolar teeth (Table 3). Despite the fact that a smaller number of premolars were evaluated in the premolar extraction cases, the nonparametric Mann–Whitney U test detected significant differences in the degree of root resorption of premolars between the extraction and nonextraction cases.

There was no statistically significant difference in the degree of root resorption among the different Angle classes (Table 4).

The degree of root resorption of the maxillary first premolars and maxillary lateral teeth increased if maxillary crowding decreased, since there were statistically significant negative correlations between these two parameters and maxillary crowding. No statistically significant correlation was observed between the degree of root resorption of other teeth and maxillary crowding. In addition, no statistically significant correlation was observed between the degree of root resorption and other variables such as treat-

Table 4 Comparison of the degree of root resorption observed in Angle class I, II, and III relationships during orthodontic treatment using the Kruskal–Wallis test

Tab. 4 Vergleich des Ausmaßes der Wurzelresorption bei Angle-Klasse-I-, -II- und -III-Beziehungen während der kieferorthopädischen Behandlung mit dem Kruskal-Wallis-Test

	Angle class I		Angle class II		Angle class III		
	Mean	SD	Mean	SD	Mean	SD	*p*-value
UR 6	0.38	0.53	0.45	0.67	0.44	0.53	0.919
UR 5	0.50	0.73	0.91	0.90	0.38	0.52	0.152
UR 4	1.06	0.98	0.85	0.91	0.60	0.70	0.341
UR 3	1.28	0.90	1.52	0.83	1.36	1.03	0.498
UR 2	1.68	0.80	1.81	0.71	1.70	1.06	0.811
UR 1	1.49	0.72	1.75	0.73	1.55	0.82	0.292
UL 1	1.49	0.72	1.74	0.74	1.55	0.82	0.326
UL 2	1.70	0.77	1.77	0.77	1.70	1.06	0.886
UL 3	1.29	0.89	1.52	0.83	1.36	1.03	0.503
UL 4	0.96	0.94	0.88	0.86	0.70	0.95	0.663
UL 5	0.50	0.76	0.88	0.90	0.29	0.49	0.151
UL 6	0.38	0.53	0.52	0.71	0.50	0.71	0.782
LR 6	0.53	0.73	0.50	0.76	0.40	0.70	0.850
LR 5	0.71	0.82	0.70	0.92	0.33	0.82	0.502
LR 4	1.04	0.88	1.00	0.97	0.50	0.71	0.218
LR 3	1.51	0.85	1.60	0.95	1.45	1.04	0.777
LR 2	1.81	0.71	1.81	0.67	1.45	0.93	0.620
LR 1	1.92	0.70	1.94	0.75	1.73	1.01	0.859
LL 1	1.98	0.74	1.94	0.75	1.73	1.01	0.804
LL 2	1.83	0.72	1.78	0.64	1.64	0.81	0.908
LL 3	1.49	0.85	1.66	0.91	1.36	1.03	0.465
LL 4	1.06	0.89	1.00	0.87	0.80	0.79	0.683
LL 5	0.86	0.92	0.70	0.84	0.57	0.79	0.694
LL 6	0.64	0.74	0.50	0.76	0.44	0.73	0.479

UR Upper Right, *UL* Upper Left, *LR* Lower Right, *LL* Lower Left, *SD* standard deviation
$p \geq 0.05$: not significant

ment duration, overbite, overjet, and mandibular crowding for any teeth (Table 5).

Discussion

Factors associated with external apical root resorption were examined in various studies in the orthodontic literature [1–30]. Clinical studies concerning root resorption generally focused on malocclusion characteristics, amount of orthodontic tooth movement or extraction pattern separately [2, 4–6, 8, 9, 11, 13, 14, 16, 18, 20, 21, 23, 24, 26–29]. Nevertheless, most of these studies were conducted only on maxillary anterior teeth, some of them used an non-standardized radiographic technique and some had a small sample size. In addition, none of them evaluated the influence of malocclusion characteristics comprehensively [2, 4, 8, 9, 11, 13, 16, 18, 21, 23, 26–29]. This study aimed to determine the correlation between the amount of EARR and malocclusion type together with the extraction pattern. Thus, it was intended to illustrate the relationship between dentition characteristics and the risk of root resorption for all teeth involved in orthodontic treatment.

This study was conducted on Caucasians aged between 12 and 15 years and treated with 0.018×0.025 inch slot edge-wise appliances. Hence, the study sample was rather homogeneous. However, the patients were treated by various clinicians, which makes consideration of several variables essential. On the other hand, inclusion of patients treated by different clinicians allowed access to a larger study sample. It was also remarked in the literature that treatments performed by various clinicians may prevent a bias related to specific clinical procedures that can systematically influence the treatment outcome [8, 27, 28].

The only methods that give exact results in the evaluation of root resorption are histology or scanning electron microscopy. However, these methods can be performed only on teeth which are experimentally moved and then extracted [7]. Therefore, radiography is the only method which is clinically available to evaluate root resorption.

Table 5 Correlation coefficients calculated between treatment duration, overbite, overjet, maxillary crowding, mandibular crowding, and the degree of root resorption observed during orthodontic treatment using Spearman's correlation coefficient

Tab. 5 Unter Verwendung des Spearman-Korrelationskoeffizienten berechnete Korrelationskoeffizienten zwischen Behandlungsdauer, Overbite, Overjet, Engstand im Ober- und Unterkiefer und dem Grad der während der kieferorthopädischen Behandlung beobachteten Wurzelresorption

	Treatment duration		Overbite		Overjet		Maxillary crowding		Mandibular crowding	
	r-value	*p*-value	r-value	*p*-value	r-value	*p*-value	r-value	*p*-value	r-value	*p*-value
UR 6	–0.056	0.645	–0.126	0.228	–0.136	0.192	–0.108	0.301	–0.113	0.278
UR 5	–0.131	0.404	–0.037	0.776	0.089	0.501	–0.054	0.679	–0.025	0.849
UR 4	0.059	0.629	0.004	0.972	–0.030	0.778	–0.274	*0.008* **	–0.158	0.130
UR 3	0.149	0.219	0.071	0.500	–0.008	0.941	–0.121	0.245	–0.099	0.341
UR 2	0.031	0.796	–0.104	0.309	–0.101	0.321	–0.242	*0.016* *	–0.058	0.566
UR 1	0.072	0.540	–0.071	0.481	–0.082	0.415	–0.050	0.620	0.067	0.506
UL 1	0.069	0.558	–0.080	0.429	–0.089	0.379	–0.053	0.600	0.066	0.518
UL 2	0.095	0.426	–0.081	0.426	–0.091	0.371	–0.246	*0.015* *	–0.094	0.356
UL 3	0.106	0.378	0.119	0.252	0.011	0.913	–0.115	0.263	–0.107	0.298
UL 4	–0.023	0.852	0.052	0.619	0.014	0.897	–0.265	*0.009* **	–0.183	0.077
UL 5	–0.021	0.889	–0.071	0.586	0.116	0.370	–0.047	0.716	0.018	0.886
UL 6	–0.088	0.464	–0.124	0.230	–0.088	0.394	–0.151	0.141	–0.128	0.216
LR 6	–0.112	0.363	–0.052	0.623	–0.107	0.309	–0.007	0.950	0.133	0.204
LR 5	–0.143	0.333	0.038	0.764	–0.064	0.609	0.159	0.200	0.277	0.083
LR 4	0.000	0.998	0.043	0.684	–0.022	0.833	–0.130	0.215	0.005	0.965
LR 3	0.034	0.772	–0.047	0.645	–0.101	0.323	–0.161	0.112	0.002	0.985
LR 2	0.137	0.245	0.065	0.522	–0.015	0.882	–0.062	0.542	0.093	0.358
LR 1	0.086	0.465	0.093	0.359	–0.039	0.701	–0.183	0.069	–0.020	0.845
LL 1	0.107	0.359	0.061	0.545	–0.051	0.615	–0.172	0.085	0.028	0.779
LL 2	0.115	0.325	0.065	0.523	–0.033	0.742	–0.091	0.365	0.085	0.400
LL 3	0.088	0.454	–0.019	0.852	–0.032	0.756	–0.233	0.070	0.037	0.714
LL 4	0.025	0.838	0.019	0.856	–0.030	0.776	–0.190	0.065	0.013	0.900
LL 5	–0.024	0.869	–0.072	0.568	–0.113	0.372	0.021	0.867	0.171	0.170
LL 6	0.003	0.979	–0.053	0.613	–0.127	0.226	–0.034	0.742	0.137	0.188

UR Upper Right, *UL* Upper Left, *LR* Lower Right, *LL* Lower Left
$p \geq 0.05$: not significant; $p < 0.05$: significant, $^{*}p < 0.05$, $^{**}p < 0.01$

Within the radiographic methods, cone beam computed tomography (CBCT) is the most reliable as it provides highly sensitive imaging of the root [2, 7]. Nevertheless, with its high cost and radiation dose, CBCT can not replace routine panoramic radiography for the moment [7, 23]. It is financially not explainable and ethically not appropriate to obtain a CBCT scan especially from young patients both at the beginning and at the end of an orthodontic treatment without having an actual reason to do it. Hence, evaluation of root resorption was performed on panoramic radiographs in this study, since they are the primary imaging modality and are obtained as part of routine orthodontic records at multiple stages of treatment in most dental clinics. Only patients having excellent-quality panoramic radiographs were included in this study to eliminate bias while evaluating root resorption. In addition, the scoring system of Levander and Malgrem [15] was used in this study, as it was found to be reliable and commonly used in root resorption studies [8, 18]. The high intraexaminer and interexaminer ICC scores obtained in this study confirmed that this system is reliable for the evaluation of root resorption. Nevertheless, apparent proclination or uprighting of the incisors and severe changes in the buccal–lingual inclinations of the canines, premolars or molars may influence the assessment of root resorption when using this system, especially if the root length is evaluated alone without examining the changes in contour irregularity, proportion, and shape of the root.

In this study it was observed that a statistically significant ($p < 0.001$) amount of root resorption occurred in all examined teeth during orthodontic treatment. The smallest degree of resorption observed was 0.41 which indicates a very mild resorption with only an apex having irregular contour and a root of normal length. On the other hand, the greatest degree of resorption observed was 1.94 which indicates a moderate resorption with small areas of root loss and an apex having an almost straight contour without showing any clinically obvious changes. The degree of root resorption observed in this study were similar with the studies of Brin and Bollen [4], Freitas et al. [8] and Dudic et al. [7], in which the same root resorption scoring system

was used. On the other hand, Sameshima and Sinclair [28] observed a root resorption of 0.34–1.58 mm, whereas Liou and Chang [16] observed a root resorption of 2.1–2.8 mm by using a different root resorption scoring system. In this study, it was also seen that the smallest amount of resorption occurred in the upper molars, while the greatest amount of resorption occurred in the lower incisors. Nonetheless, unlike our study, Sameshima and Sinclair [27] observed the greatest amount of resorption in the upper incisors. This difference may be related with the variations in the patient samples used in these studies or with possible errors in the evaluation of the length of the incisors which present more apparent proclination or uprighting.

This study demonstrated that greater total amount of root resorption was observed in females compared with males, in all examined teeth. However, the differences observed in the degree of root resorption between the females and males were not statistically significant. In addition, none of the teeth were severely affected by root resorption and no clinically important negative symptoms could be observed during orthodontic treatment. This finding is compatible with the findings presented by Sameshima and Sinclair [27] and by Marques et al. [18], as the amount of root resorption they observed in males and females were similar.

The results of this study revealed that the degree of root resorption observed in the premolar extraction cases were greater compared to the nonextraction cases, in almost all examined teeth. Furthermore, the differences in the degree of root resorption between the premolar extraction and nonextraction cases were also statistically significant in all upper and lower premolars. The only exception was seen in the lower incisors, where very similar amounts of root resorption occurred both in the premolar extraction and nonextraction cases. The reason for this higher incidence of root resorptions observed after treatment with premolar extractions can be the increased movement of the neighboring teeth during the closure of the extraction space. The premolars were shown to be among the most prone teeth to root resorption, as they are adjacent to the extraction space [8, 28]. On the other hand, similar amounts of root resorptions were observed in the lower incisors in the premolar extraction and nonextraction cases. This might be explained with the protrusion of the incisors in the course of nonextraction treatments. This effect is typically more prominent in the mandible, since lateral expansion of the lower dental arch is limited. Our findings are similar with the findings of Sameshima and Sinclair [28] and of Freitas et al. [8]. These authors also observed that the amount of root resorptions in their premolar extraction cases were significantly higher than in nonextraction cases.

In this study it was observed that there were no statistically significant differences in the degree of root resorption of cases having Angle class I, II or III relationship. This result is compatible with the result of Marques et al. [18] who showed that distal occlusion or mesial occlusion did not influence the tendency of root resorption directly. Similarly, no statistically significant correlation was found between the degree of root resorption and other variables related with the dentition such as overbite, overjet, and crowding. The only exception was the statistically significant negative correlation found between the degree of root resorption of teeth UR4, UR2, UL2, UL4, and maxillary crowding. This finding can be attributed to the nonextraction treatment protocol, which is usually preferred in cases with mild/moderate crowding and typically involves an expansion of the dental arches. As a consequence, an increased degree of root resorption was observed in these teeth in patients presenting with less crowded dental arches. Similar with our findings, Sameshima and Sinclair [27], Freitas et al. [8] and Marques et al. [18] observed no correlation between the degree of root resorption and overbite. However, Sameshima and Sinclair [27] and Freitas et al. [8] observed a significant correlation between the degree of root resorption and overjet.

The results of this study revealed no statistically significant correlation between the degree of root resorption and treatment duration. This result is compatible with the findings presented by Freitas et al. [8]; nevertheless it is different from the findings of Liou and Chang [16]. The difference between the results may be related to the variations in patient samples or treatment mechanics used in these studies. All patients included in the study of Liou and Chang [16] were adults and subjected to maxillary premolar extraction followed by *en masse* maxillary anterior retraction and intrusion. These specific tooth movements are likely to be the reason for the increased degree of root resorption observed in that study.

One of the limitations of this study was the small number of premolars evaluated in the premolar extraction cases. The smallest number of teeth evaluated in any tooth category ranged from 8 to 10 for second premolars and from 25 to 27 for first premolars in the premolar extraction cases. Nevertheless, the Mann–Whitney U test was able to detect significant differences in the degree of root resorption of premolars between the extraction and nonextraction cases. With its nonparametric design, this test is applicable in study groups involving a small number of samples. Another limitation of this study was that the patient sample was treated by several clinicians. Thus, the bonding procedures, wire bending technique, and ligation methods may have varied to a certain extent. Although, this composition may have caused orthodontic force levels to vary between the patients, inclusion of patients treated by various clinicians helps to obtain larger study samples and it prevents a bias caused by individual clinical procedures and thus supports generalization of the results [8, 27, 28]. It must also

be kept in mind that the subgroups of the patient sample were not uniform when gender, extraction protocol, or Angle classifications were examined. On the other hand, our results may be another step beyond for both researchers and clinicians to understand several parameters that can influence treatment results more comprehensively.

Conclusions

- Root resorption occurred in all teeth subjected to orthodontic force during orthodontic treatment.
- Greater root resorption occurred in premolar extraction cases compared to nonextraction cases.
- An increase in maxillary crowding resulted in a smaller amount of root resorption in the maxillary laterals and first premolars.
- Gender, Angle classification, overbite, overjet, mandibular crowding, and treatment duration did not influence the degree of root resorption that occurred during orthodontic treatment.
- Severity of dental malocclusion and orthodontic treatment protocol were not independent variables and they both had an influence on the risk of root resorption.
- The H_0 hypothesis had to be rejected and the H_1 hypothesis was accepted.

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Declarations

Conflict of interest B. Kaya, A. Gülşahı and G. Türkyılmaz declare that they have no competing interests.

Ethical standards This retrospective study involving human participants was in accordance with the ethical standards of the institutional and/or national research committee (Başkent University Institutional Review Board and Ethics Committee, project number D-KA20/97) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants or their parents/guardians. This article does not contain any studies with animals performed by any of the authors.

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