RSBO

ISSN:
Electronic version: 1984-5685
RSBO. 2023 Jul-Dec;20(2):275-86

Original Research Article

Evaluation of external apical radicular reabsortion in the upper and lower teeth in orthodontic treatment

Aline Xavier Ferraz[1]
Julia da Silva Germiniani[1]
Gabrielly Aparecida Eulálio dos Santos[1]
Cristiano Miranda de Araújo[1]
Camila Paiva Perin Mattos[1]
Bianca Simone Zeigelboim[1]
Flávio Ricardo Manzi[2]
Ângela Graciela Deliga Schröder[1, 2]

Corresponding author:
Ângela Graciela Deliga Schröder
Universidade Tuiuti do Paraná
Rua Padre Ladislau Kula, n. 395 – Santo Inácio
CEP 82010-210 – Curitiba – PR – Brasil
E-mail: angela.schroder@utp.br

[1] University of Tuiuti of Paraná – Curitiba – PR – Brazil.
[2] Pontifical Catholic University of Minas Gerais – Belo Horizonte – MG – Brazil.

Received for publication: April 4, 2023. Accepted for publication: May 10, 2023.

Keywords:
root reabsorption;
digital dental radiography;
orthodontics.

Abstract

Objective: The aim of this study was to evaluate external apical root resorption in the upper and lower teeth during orthodontic treatment. **Material and methods:** Periapical radiographs of 37 patients (22.05 years) of both sexes were evaluated by two radiologists at the beginning of orthodontic treatment, after the alignment and leveling phase, and at the end of orthodontic treatment, and classified according to the severity of root resorption. **Results:** The results indicated that root resorption was present in most of the dental groups evaluated at the end of treatment ($p < 0.05$), with a relationship to malocclusion type, root shape, and apical shape, while treatment time affect the process of root resorption in some dental groups evaluated. It was observed that the greater the degree of dental crowding at the beginning of treatment, the higher the incidence of root resorption at the end. **Conclusion:** Based on the results of this study, it is concluded that there is a need for a radiographic protocol involving all teeth before and after the alignment and leveling phase.

Introduction

Root resorption is one of the possible, undesirable occurrences of orthodontic treatments, having a multifactorial etiology resulting from a complex interaction between individual biology and the effect of mechanical forces [2]. There is a consensus among the authors [1, 2, 8, 10, 11, 30, 37] that almost all orthodontic activity produces a certain degree of tooth resorption, and there is a general agreement that the presence of pre-existing root resorption increases the risk factor [3, 29].

The frequency of root resorption in orthodontically treated patients is high [7], but the loss of up to three millimeters in the apical third should not be a cause for special care [15]. Nevertheless, extreme and irreversible damage to the dental root, such as severe root resorption, can result in up to 20% [5] of orthodontic treatments. Several factors are involved in the mechanism of apical external resorption, such as genetics, systemic factors, gender, force magnitude, type of movement [2-5, 9], duration, and type of orthodontic force [2, 3, 5, 9].

Radiography is the diagnostic method most commonly used to detect the presence of external apical root resorption [2]. The technique of image subtraction comparing periapical radiographs obtained before and after orthodontic treatment is effective in quantifying apical external root resorption [14]. With the appearance of digital radiographs, great expectations were developed to improve the radiodiagnosis of small external root resorptions, which cannot be diagnosed by conventional radiographs. This is justified by the possibility of utilizing the tools available in the software [38] to process digital radiographic images. Digital radiographic systems exhibit high accuracy in the measurement of tooth length with external apical root resorption, which is superior to conventional films [38].

The objective of this study was to evaluate the degree of root resorption in all groups of teeth in two moments – after the leveling and alignment phase, and at the end of the orthodontic treatment by means of periapical radiographs – and determine the association between the level of root resorption and the root shape, apical shape, age, gender, type of malocclusion, amount of initial dental unevenness, and time of treatment.

Material and methods

The sample of the present study consisted of 74 teeth from each dental group (central incisors, lateral incisors, canines, first premolars, second premolars, and first and upper molars) of 37 patients with a mean age of 22.05 years (12 to 40 years), 15 in the growth phase (under 15 years) and 22 adults (over 15 years). Scanning of the initial periapical radiographs and after alignment and dental leveling were performed using a transparency scanner (HP 4050, Palo Alto, CA, USA). Patients were consecutively selected from the same dental office in order to meet the following inclusion criteria (convenience sample): they had not previously been treated orthodontically; all permanent teeth had erupted (except for third molars); absence of exodontia, agenesis, malformation, or defect in the teeth; supernumerary teeth; endodontic treatment; and impacted incisors.

All patients were treated by the same orthodontist using the Straight Wire technique, with slot 0.22 "x0.028" (Abzil, 3M, São José do Rio Preto, Brazil) using the yarn sequence (Abzil, 3M, São José do Rio Preto, Brazil): 0.014 "NiTi, 0.018" SS, 0.017x0.025 "SS, 0.014." NiTi wire remained for one month in the arc and the other wires remained on average for two months. Exclusion criteria during treatment were: history of trauma and alteration in the incisal portion of the crown of the incisors (wear and tear) during orthodontic treatment.

All the periapical radiographs were acquired by the parallelism technique, and were performed by the same professional. The time interval between the initial and post-leveling radiographs was from six to 12 months, with an average time of nine months. This period was variable due to the amount of movement required to perform the dental alignment and leveling. The same Heliodent 70 Dental X-Ray (Sirona – The Dental Company, Bensheim, Germany), 70 kVp and 10 mA X-ray apparatus was used to obtain all X-rays using Kodak Insight film (Eastman Kodak Co, Rochester, NY, USA).

The evaluation of the digital images was performed by two dental radiology specialists, after training and calibration of the same. The Kappa test was applied to verify the level of intra- and inter-examiner agreement, obtaining a level of agreement between 0.85-0.92.

After the training, the periapical radiographs of the lower central incisors at the beginning of treatment and after the alignment and leveling phase were evaluated by each examiner. The total longitudinal length of the tooth in the radiographic image was obtained using the program Adobe Photoshop CS3, using the measurement of the distance of the incisal points coronary (CI) and the root apex (RA). The IC point was obtained by the midpoint of the mesio-distal length of the incisal edge of the incisors, while the AR point was located in the most apical portion of the root apex (figure 1). For teeth with two or three roots, the following distances were utilized: the apex to the tip of the most prominent cusp in the premolar, the apex to the tip of the palatal cusp in the upper molars, and tip of the mesial cusp to the apex in the lower molars. These measurements were performed twice for each tooth, by two evaluators.

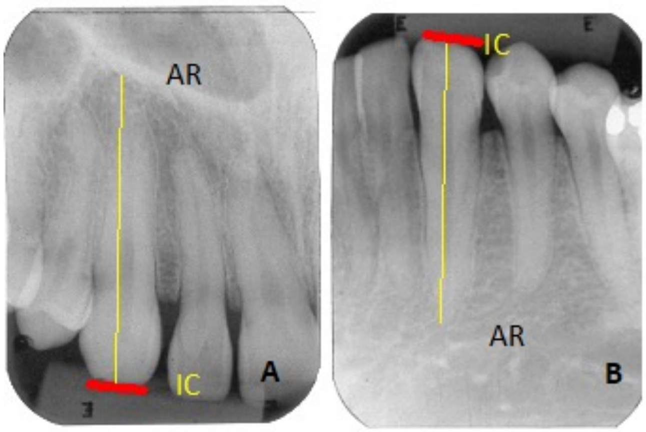

Figure 1 (A and B) – Points and lines used to standardize the measurement of tooth length in digital radiographic images. IC: Coronary incisal point. AR: Root apex point.

The roots were classified according to the root morphology, using triangular, rhomboid, and square, and apical morphology was classified by normal, pipette, and with laceration [15]. The classification of the severity of root resorption by Levander and Malmgren [15] was used, where: degree 0 = no root resorption; grade 1 = irregular contour up to 1 mm resorption; grade 2 = root resorption between 1 and 2 mm; grade 3 = root resorption between 2 and 3 mm; grade 4 = root resorption greater than 3 mm.

The Irregularity Index by Little [21] was used to determine the degree of initial dental unevenness. The patients were classified into four intervals according to the degree of unevenness obtained in the initial gypsum models: 1 to 3 mm; 4 to 6 mm; 7 to 9 mm; and 10 mm or more.

For cases in which root resorption greater than 2 mm was observed in the intermediate phase, a norm was adopted to reduce the applied force by half, increase the interval between the application of the force, and perform periapical radiographs at intervals of three months. Root resorption of less than 2 mm was followed with the same methodology until the end of treatment.

Calibration of the magnification between the radiographs was also performed, as they were obtained at various times and could contain some distortion. In order to standardize the measurements without stretching or root shortening, the distance between the cementoenamel junction and the incisal edge of tooth 41 was measured, and the linear correction between the two moments was performed through a simple rule of three, with only the mean measures calibrated.

After tabulations of the data, they were submitted to the statistical treatment Q-Square and Fisher's Exact, with a significance level of 5%.

Results

At the end of the radiographic evaluations, the averages were obtained between the measurements performed by the evaluators for each of the 888 teeth evaluated in the 37 patients and in the three phases of the work, i.e., after the alignment and leveling phase and at the end of the orthodontic treatment. Of the 37 patients evaluated, all had root resorption in at least one tooth during a phase of the orthodontic treatment.

The presence of apical external root resorption (RR) was related to several factors, such as gender, age, malocclusion, root shape, apical shape, treatment time, initial tooth level, and treatment time. Data were statistically submitted to chi-square test and / or Fisher's exact test for comparison of means ($p < 0.05$).

When the presence of root resorption was related to the genus, a statistical association of the presence of this condition was observed, with the gender between the beginning of the treatment and the end of the alignment and leveling phase (intermediate phase) only in the lower first molars. However, the root resorption was present with statistical significance in the majority of dental groups in the third evaluation (between the initial and final radiography).

Table I – Relationship between root resorption and gender

	RR quantity observed in the first evaluation (between the initial and intermediate radiography)				RR quantity observed in the second evaluation (between the intermediate and final radiography)				RR quantity observed in the third evaluation (between the initial and final radiography)			
	MEN		WOMEN		MEN		WOMEN		MEN		WOMEN	
	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR
11/21	5	21	17	31	9	17	20	28	9	17	8	40
12/22	12	14	18	30	9	17	16	32	9*	17*	4*	44*
13/23	13	13	19	29	10	16	23	25	10*	16*	6*	42*
14/24	16	10	22	26	11	15	39	19	13*	13*	10*	38*
15/25	9	17	19	29	13	13	35	13	13*	13*	8*	40*
16/26	12	14	27	21	12	14	22	26	12*	14*	8*	40*
31/41	12	14	21	27	14	12	28	20	14*	12*	11*	37*
32/42	16	10	30	18	12	14	24	24	12	14	14	34
33/43	18	8	26	22	16	10	26	22	16*	10*	12*	36*
34/44	17	9	28	20	14	12	26	22	16*	10*	10*	38*
35/45	17	9	31	17	11	15	27	21	11	15	16	32
36/46	8*	18*	30*	18*	15	11	26	22	15*	11*	14*	34*

* There was a statistical difference.

Chi-square, p <0.05; Fisher's exact, p <0.05.

S / RR – absence of external root apex resorption; C / RR – presence of external root apex resorption.

Regarding age, there was a statistical relationship between the presence of RR and age (age 1 – growing patients, age 2 – adult patients) between the initial period and the intermediate period (p <0.05) only for the lateral incisors, while there was no such relationship between the intermediate and final periods (p> 0.05). In the third evaluation, a positive relationship was observed with root resorption for the first and second lower premolars (table II).

Table II – Relationship between root resorption and age range

	RR quantity observed in the first evaluation (between the initial and intermediate radiography)				RR quantity observed in the second evaluation (between the intermediate and final radiography)				RR quantity observed in the third evaluation (between the initial and final radiography)			
	AGE 1		AGE 2		AGE 1		AGE 2		AGE 1		AGE 2	
	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR
11/21	10	20	12	32	10	20	19	25	3	27	6	38
12/22	11	19	19	25	10	20	15	29	2	28	4	40
13/23	14	16	18	26	15	15	18	26	4	26	5	39
14/24	16	14	22	22	15	15	25	19	7	23	19	25
15/25	12	18	16	30	19	11	29	15	4	26	5	39
16/26	15	15	24	20	13	17	21	23	3	27	9	35
31/41	17	13	16	28	16	14	26	18	7	23	8	36
32/42	25*	5*	21*	23*	16	14	20	24	11	19	8	36
33/43	20	10	24	20	16	14	26	18	9	21	12	32
34/44	22	8	23	21	17	13	23	21	11*	19*	8*	36*

To be continued...

Continuation of table II

	RR quantity observed in the first evaluation (between the initial and intermediate radiography)				RR quantity observed in the second evaluation (between the intermediate and final radiography)				RR quantity observed in the third evaluation (between the initial and final radiography)			
	AGE 1		AGE 2		AGE 1		AGE 2		AGE 1		AGE 2	
	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR
35/45	23	7	25	19	18	12	20	24	15*	15*	7*	37*
36/46	16	14	22	22	16	14	25	19	7	23	13	31

* There was a statistical difference.

Chi-square, p <0.05; Fisher's exact, p <0.05.

S / RR – absence of external root apex resorption; C / RR – presence of external root apex resorption.

Regarding malocclusion, there was a statistical relationship between the presence of root resorption with malocclusion between the initial period and the intermediate period ($p < 0.05$) in the upper and lower lateral incisors and lower first molars, while this relationship continued between the intermediate period and the final maxillary lateral incisors ($p < 0.05$). Statistical relationship was also observed in all phases of the orthodontic treatment for the first lower molars (table III).

Table III – Relationship between root resorption and malocclusion

	RR quantity observed in the first evaluation (between the initial and intermediate radiography)						RR quantity observed in the second evaluation (between the intermediate and final radiography)						RR quantity observed in the third evaluation (between the initial and final radiography)					
	Class I		Class II		Class III		Class I		Class II		Class III		Class I		Class II		Class III	
	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR	S/RR	C/RR
11/21	9	13	8	28	5	11	7	15	16	20	6	10	4	18	3	33	2	14
12/22	15*	7*	8	28	7	9	3	19	18*	18*	4*	12*	3	19	3	33	0	16
13/23	11	11	13	23	8	8	10	12	19	17	4	12	4	18	4	32	2	14
14/24	15	7	13	23	10	6	13	9	19	17	8	8	5	17	5	31	4	12
15/25	10	12	10	26	8	8	14	8	25	11	9	7	1	21	8	28	2	14
16/26	14	8	20	16	5	11	11	11	13	23	10	6	5	17	4	32	4	12
31/41	9	13	19	17	5	11	16	6	16	20	10	6	6	16	6	30	3	13
32/42	11*	11*	28	8	7	9	10	12	17	19	9	7	5	17	10	26	4	12
33/43	14	8	20	16	10	6	16	6	17	19	9	7	8	14	8	28	5	11
34/44	12	10	23	13	10	6	10	12	20	16	10	6	3	19	9	27	5	11
35/45	13	9	25	11	10	6	12	10	18	18	8	8	8	14	9	27	5	11
36/46	13*	9*	21	15	4*	12*	16	6	18	18	7	9	9*	13*	11*	25*	0*	16*

* There was a statistical difference.

Chi-square, p <0.05; Fisher's exact, p <0.05

S / RR – absence of external root apex resorption; C / RR – presence of external root apex resorption.

There is a positive statistical relationship between root resorption and root shape of the teeth in the initial and intermediate period only for upper incisors with triangular and rhomboid root shapes. The same condition can also be observed in the third evaluation, i.e., between the initial and final period for the same group, teeth with triangular and rhomboid forms ($p < 0.05$) (table IV).

Table IV – Relationship between root resorption and root shape

	Initial and intermediate difference						**Intermediate and final difference**						**Initial and final difference**					
	TRIAN		RHOM		SQUA		TRIAN		RHOM		SQUA		TRIAN		RHOM		SQUA	
	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR
11/21	13*	17*	9*	35*	0	0	14	16	15	29	0	0	7*	23*	2*	42*	0	0
12/22	9	13	21	31	0	0	11	11	14	38	0	0	3	19	3	49	0	0
13/23	5	7	27	35	0	0	6	6	27	35	0	0	1	11	8	54	0	0
14/24	2	4	36	32	0	0	4	2	36	32	0	0	1	5	23	45	0	0
15/25	1	4	27	42	0	0	5	0	43	26	0	0	1	4	9	60	0	0
16/26	0	1	39	34	0	0	0	1	34	39	0	0	0	1	12	61	0	0
31/41	30	33	3	8	0	0	37	26	5	6	0	0	15	48	0	11	0	0
32/42	34	22	12	6	0	0	29	27	7	11	0	0	17	39	3	15	0	0
33/43	4	2	40	28	0	0	3	3	39	29	0	0	2	4	19	49	0	0
34/44	5	1	40	28	0	0	3	3	37	31	0	0	2	4	20	48	0	0
35/45	7	3	41	23	0	0	3	7	35	29	0	0	3	7	19	45	0	0
36/46	1	1	37	35	0	0	0	2	41	31	0	0	1	1	19	53	0	0

* There was a statistical difference.

Chi-square, $p < 0.05$; Fisher's exact, $p < 0.05$.

TRIAN = triangular; RHOM = rhomboid; SQUA = square; SRR = without root resorption; CRR = with root resorption.

When assessing the relationship between root resorption and the apical form of the teeth, a positive statistical relationship was observed in the initial-intermediate period for the lower central incisors with normal apical form and in pipette for the first lower premolars with normal apical form and with laceration. This same condition was also found in the third evaluation, i.e., between the initial and final period, for the same group of incisors and premolars with the normal apical form. The first lower premolars exhibited a positive association in the third evaluation for the form with dilaceration, which had not been observed before (table V).

Table V – Relationship between root resorption and apical shape

	Initial and intermediate difference						**Intermediate and final difference**						**Initial and final difference**					
	NORMAL		PIPE		TORN		NORMAL		PIPE		TORN		NORMAL		PIPE		TORN	
	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR
11/21	19	47	3	3	0	2	24	42	4	2	1	1	9	57	1	5	1	1
12/22	21	30	0	2	9	12	17	34	2	0	6	15	5	46	0	2	2	19
13/23	29	34	1	4	2	4	27	36	3	2	3	3	8	55	0	5	1	5
14/24	35	29	1	2	2	5	32	32	3	0	5	2	22	42	1	2	1	6
15/25	23	33	1	3	4	10	36	20	4	0	8	6	19	37	0	4	2	12
16/26	35	32	0	0	4	3	30	37	0	0	4	3	10	57	0	0	3	4
31/41	17*	34*	13*	4*	3	3	30	21	8	9	4	2	7*	44*	5	12	3	3
32/42	33	26	4	0	9	2	30	29	2	2	4	7	13	46	3*	1*	3	8
33/43	41	28	3	1	0	1	39	30	3	1	0	1	19	50	2	2	0	1
34/44	34*	28*	2	0	9*	1*	34	28	0	2	6	4	17*	45*	0	2	5*	5*
35/45	42	23	2	0	4	3	34	31	1	1	3	4	19	46	1	1	2	5
36/46	33	32	0	0	5	4	35	30	0	0	6	3	19	46	0	0	1	8

* There was a statistical difference.

Chi-square, $p < 0.05$; Fisher's exact, $p < 0.05$.

PIPE = pipette; SRR = no root resorption; CRR = with root resorption.

A correlation was also noted with the evolution of orthodontic treatment, i.e., how teeth presented evidence of root resorption in the intermediate phase. The results show that there was only a positive association for the second upper premolars, i.e., those with root resorption will continue to reabsorb, and those that did not present root resorption in the first evaluation will continue to exhibit said condition until the end of the treatment. This same association was not found in the other dental groups (table VI).

Table VI – Evolution of root resorption

	RR quantity observed in the first evaluation (between the initial and intermediate radiography)		**RR quantity observed in the second evaluation (between the intermediate and final radiography)**	
	SRR	CRR	SRR	CRR
11/21	22	52	29	45
12/22	30	44	25	49
13/23	32	42	33	41
14/24	38	36	40	34
15/25	28*	46*	48*	26*
16/26	39	35	34	40
31/41	33	41	42	32
32/42	46	28	36	38
33/43	44	30	42	32
34/44	45	29	40	34
35/45	48	26	38	36
36/46	38	36	41	33

* There was a statistical difference.

Chi-square, $p < 0.05$; Fisher's exact, $p < 0.05$.

SRR = no root resorption; CRR = with root resorption.

The treatment time did not present a statistically significant relationship in any of the three ranges evaluated for any tooth group when only the presence or absence of root resorption was analyzed, as shown in table VII.

Table VII – Relationship between root resorption and treatment time

Initial/final	**Within 18 months**		**19-24 months**		**25-36 months**	
	SRR	CRR	SRR	CRR	SRR	CRR
11/21	5	15	2	30	2	20
12/22	2	18	3	29	1	21
13/23	8	12	7	25	6	16
14/24	6	14	8	24	3	19
15/25	3	17	4	28	3	19
16/26	3	17	6	26	3	19
31/41	6	14	10	22	4	18
32/42	6	14	8	24	4	18
33/43	9	11	7	25	6	16
34/44	5	15	8	24	9	13
35/45	3	17	11	21	9	13
36/46	5	15	8	24	3	19

Chi-square, $p < 0.05$; Fisher's exact, $p < 0.05$.

SRR= without root resorption; CRR = with root resorption.

In relation to the degree of dental unevenness and its relationship with the root resorption of the incisors and lower canines, the higher the degree of dental unevenness at the beginning of the orthodontic treatment, the greater the incidence of root resorption in the incisors and lower canines at the end of the treatment. Furthermore, even the group with the lowest initial slope resorption was present at the end of the treatment (table VIII).

Table VIII – Relationship between root resorption and degree of initial tooth unevenness (Little Irregularity Index)

	Initial to intermediate period								**Initial to final period**							
Little	1-3mm		4-6mm		7-9mm		10mm or +		1-3mm		4-6mm		7-9mm		10mm or +	
	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR	SRR	CRR
Lower incisors	19*	25*	28*	16*	10*	18*	21*	11*	15*	29*	12*	32*	2*	26*	5*	27*
Lower canines	15	7	12	10	6	8	10	6	9*	13*	3*	19*	3*	11*	6*	10*

* There was a statistical difference.

Chi-square, $p < 0.05$; Fisher's exact, $p < 0.05$.

SRR = without root resorption; CRR = with root resorption.

Discussion

It is difficult to establish comparisons between the results and conclusions of the vast majority of studies on root resorption due to methodological differences between the studies. This challenge is markedly present with regard to the classification of external root resorption, which can be done subjectively, as observed in some studies [12, 13, 22, 23, 25], or objectively [15, 24].

Even among radiographic studies, comparisons are limited due to the different radiographic techniques used in the studies: periapical intra-oral radiography [8, 10, 11, 15-17, 19, 22, 24, 26, 34], panoramic radiography [13, 22], teleradiography [12], periapical intraoral radiography, teleradiography [35], and computed tomography of the cone beam [28]. The periapical technique has been shown to be superior to that of the diagnosis of external root resorption [33], which has shown that panoramic radiographic images can overestimate 20% or more the amount of root loss after orthodontic movement, compared to images from periapical radiography.

All permanent teeth are subject to presenting clinically irreversible microscopic evidence of root resorption that is not radiographically detectable. As a rule, reabsorption does not compromise the tooth's functional capacity or longevity [3, 15, 22, 29]. Many authors [1, 15, 20, 31] consider root resorption to be a common consequence in orthodontic treatments. These findings are confirmed by the results of this study, as all the patients had at least one tooth with some degree of root resorption during the orthodontic treatment.

It is not possible to predict the risk of root resorption before orthodontic treatment. Patients at risk should be identified by radiographic controls during treatment [2, 3, 6, 15, 18]. According to Levander and Malmgren [15], the diagnosis of apical external root resorption can be made after six months of treatment, which has also been recommended by other authors [2, 3, 16, 18].

Treatment time

Some authors have affirmed that the increase in the period of orthodontic movement determines a greater tendency towards root resorption [1, 2, 32]. However, other authors [23, 29] have reported no root resorption as a consequence of increased treatment time.

In human radiological studies, Baumrind *et al.* [1] reported treatment time as a determinant factor in root resorption, although extreme resorptions believed to be related to systemic factors, as opposed to time.

Levander and Malmgren [15] found 34% of the teeth examined with root resorption after six to nine months of treatment, whereas at the end of the active treatment, which was carried out over 19 months, root resorption increased to 56%.

In the present study, with regard to the treatment time and its influence on root resorption, there were 15 cases of root resorption within 18 months of treatment, 30 cases between 19 and 24 months, and 20 cases between 25 and 36 months. Statistically, the treatment time factor only showed a positive statistical association for upper central incisors, lower central incisors, lower lateral incisors, lower canines, and lower second premolars. When reabsorption occurred, the positive association was for grade 1 in the lower central incisors, lower canines, and lower second premolars, but not at all time intervals.

Age

In 1954, Massler and Malone [24] had reported that, even in the absence of orthodontic treatment, the incidence of root resorptions exacerbates with age. Factors such as periodontal ligament characteristics and muscular adaptation to occlusal changes may be more favorable in young patients [19].

All tissues involved in the root resorption process undergo changes with age. The periodontal membrane becomes less vascularized, bones become more dense, avascular, and lose elasticity, and the cement becomes thicker. These changes reflect the greater susceptibility to root resorption observed in adults [20, 34, 36]. Teeth with open apex would be less susceptible to resorption, due to the likelihood of better nutrition, greater cellularity of the apical area, and a more effective muscular adaptation towards occlusal changes. The early approach aimed at correcting maxillary mandibular relationships would be based on teeth not susceptible to reabsorption. However, other studies [1, 12, 15, 22] have affirmed that there is no association between age and predisposition to develop apical external root resorption.

Linge and Linge [20] found that the maxillary incisors were reabsorbed less frequently in patients younger than 11 years of age with periapical radiographs, and that in the first study, root radicular shortening was found to be twice as high in older patients when compared with younger ones. However, other authors [1, 12, 15] have verified a null association between age and root resorption. In this study, age was only associated with root resorption for the lower lateral incisors in the first evaluation, and for the lower premolars in the final evaluation.

Sexual dimorphism

Not conclusively, women may be considered more predisposed to root resorption, since some studies [20, 36] have suggested that the inter-sex difference is not related to hormonal factors, but rather to the stage of root development at the same age or orthodontic age. Thus, the roots of men's teeth would be more immature and, thus, less predisposed to resorption. This could be taken into account in this study if the sample consisted of all growing patients, but it was divided into growing patients and adult patients. The higher frequency of external apical root resorption in women was also found in the works of Levander and Malmgren [15] and Kjaer [13].

However, contrary to the results above, Baumrind, Korn, and Boyd [1] found an average of 1.2 mm more of external apical root resorption in men than in women. This result is compatible with the findings of this study, because although women present a higher frequency, when men develop external apical root resorption, it tends to present a higher degree of severity. The women presented a lower frequency of root resorption when compared to men only for the lower molars in the first evaluation (between the initial and intermediate radiography).

Maloclusion

In association with Angle's classification, only Kalley and Phillips [12] found a significant incidence of root resorption in patients with Angle Class III malocclusion. However, Mirabela and Artun [26] and Baumrind *et al.* [1] reported no significant differences between Angle Classes I, II, and III. These results were compatible with those found in this study, as the type of malocclusion presented a positive co-association with the frequency and / or degree of root resorption only for the upper lateral incisors, lower lateral incisors and lower molars in the initial-intermediate phase. During the intermediate phase, a co-association was observed for the upper lateral incisors in patients with Angle Class II and III malocclusion and Angle Class I malocclusion for the lower molars.

When the dental groups were analyzed separately, only the upper lateral incisors exhibited a positive association between root resorption and type of malocclusion at all time intervals. The lower lateral incisors and lower molars were positively associated with resorption only in the first evaluation. Thus, the co-association between root resorption and type of malocclusion may be related to the severity of the malocclusion as a consequence of the required mechanical resources and the long treatment time [26, 27].

Radicular form

Several authors have stated that the region of the anterior teeth, especially the upper incisors, is the most vulnerable to root resorption [12, 15, 17, 26, 35]. For other authors [13, 15, 19, 24, 34], the lower incisors constitute the group of teeth that present a higher frequency in the development of external apical root resorption. It is not difficult to understand this frequency, since they are unirradiculate teeth with conical shape, and they transmit the force applied on the crown directly to the apex during movement.

When the degree of root resorption and the shape of the root (triangular, rhomboid, or square) were associated, most of the teeth presented a rhomboid root shape. Only the central and lateral inferior incisors and half of the upper central incisors presented a triangular radicular form; only in these teeth, i.e., the superior incisors, was a statistically significant association observed between the radicular form and root resorption in the initial and intermediate and initial and final periods (Chi-square, $p > 0.05$). This result is in agreement with the studies by Kjaer [13], but diverges from Levander and Malmgren [15], who observed that the degree of root resorption in teeth with lofted apex was higher than that observed in normal roots.

Apical form

When analyzing the apical anatomy of the root, studies [3, 13, 15, 17, 18, 26, 28, 33-36] have shown that the apical pipetted form is the most susceptible to developing apical external root resorption. In this study, when the root resorption and the apical form were related, a statistically significant association was only observed in the initial-intermediate period for the lower incisors with normal shape and in pipette. In the first lower premolars with normal and torn in the initial-final period, a positive association was only found in the lower lateral incisors with normal root and pipette, and in the first lower premolars with apical normal and torn form (chi-square, $p > 0.05$).

The teeth that presented the highest frequency of root laceration were the upper lateral incisors (28.3%), second upper premolars (20.2%), lower lateral incisors (17.5%), and lower first premolars (14.8%).

Dental disnivelation quantity

Regarding the degree of dental unevenness and its association with the root resorption of the incisors and lower canines, the higher the degree of unevenness exhibited at the beginning of the orthodontic treatment, the greater the incidence of root resorption in the incisors and lower canines at the end of the treatment. It was also observed that, even in the group with the lowest initial level, reabsorption was present at the end of treatment, i.e., regardless of the degree of dental unevenness, it is positively associated with the presence of root resorption at the end of the orthodontic treatment in the aforementioned teeth. This may be explained by the radicular shape that they present, and because they are teeth that perform the greatest movements during orthodontic treatment [18, 27].

Conclusion

Based on the results of this study, it may be suggested that it is necessary to have as a protocol to radiograph all teeth before and after the alignment and leveling phase. Only then will the evolution of root resorption be known for each individual, thus providing individualization of the orthodontic treatment, with respect to the forces applied in the different dental groups.

References

1. Baumrind S, Korn EL, Boyd RL, Francisco S, Emeritus P. Apical root resorption in orthodontically treated adults. Am J Orthod Dentofac Orthop. 1996;110(3):311-20.

2. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: part 1. Literature review. Am J Orthod Dentofac Orthop. 1993;103(1):62-6.

3. Brezniak N, Wassersteln A, Tel Aviv D. Root resorption after orthodontic treatment: part 2. Literature review. Am J Orthod Dentofac Orthop. 1993;103(2):138-46.

4. Brito LS, Santos DCL, Negrete D, Flaiban E, Santos RL. Reabsorção radicular diante das forças ortodônticas. Rev Odontol Univ Cid São Paulo. 2019 Apr-Jun;31(2):177-86.

5. Casa MA, Faltin RM, Faltin K, Sander FG, Arana-Chavez VE. Root resorptions in upper first premolars after application of continuous torque moment. Intra-individual study. J Orofac Orthop. 2001;62(4):285-95.

6. Chapnick L, Endo D. External root resorption: an experimental radiographic evaluation. Oral Surg Oral Med Oral Pathol. 1989;67:578-82.

7. Chiqueto K, Martins DR, Janson G. Effects of accentuated and reversed curve of Spee on apical root resorption. Am J Orthod Dentofac Orthop. 2008;133(2):261-8.

8. DeShields RW. A study of root resorption in treated class II, division I malocclusions. Angle Orthod. 1969;39(4):231-45.

9. Faltin RM, Arana-Chavez VE, Faltin K, Sander FG, Wichelhaus A. Root resorptions in upper first premolars after application of continuous intrusive forces. Intra-individual study. J Orofac Orthop. 1998;59(4):208-19.

10. Goldson L, Henrikson CO. Root resorption during Begg treatment: a longitudinal roentgenologic study. Am J Orthod. 1975;68(1):55-66.

11. Janson GRP, de Luca Canto G, Rodrigues Martins D, Castanha Henriquesand JF, de Freitas MR. A radiographic comparison of apical root resorption after orthodontic treatment with 3 different fixed appliance techniques. Am J Orthod Dentofac Orthop. 2000;118(3):262-73.

12. Kaley J, Phillips C. Factors related to root resorption in edgewise practice. Angle Orthod. 1991;61(2):125-32.

13. Kjaer I. Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. Eur J Orthod. 1995;17(1):25-34.

14. Kreich EM, Chibinski AC, Coelho U, Wambier LS, Zedebski RAM, Moraes MEL et al. A posteriori registration and subtraction of periapical radiographs for the evaluation of external apical root resorption after orthodontic treatment. Imaging Sci Dent. 2016;46(1):17-24.

15. Levander E, Malmgren O. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. Eur J Orthod. 1988;10(1):30-8.

16. Levander E, Malmgren O, Eliasson S. Evaluation of root resorption in relation to two orthodontic treatment regimes. A clinical experimental study. Eur J Orthod. 1994;16(3):223-8.

17. Levander E, Malmgren A, Stenback K. Apical root resorption during orthodontic treatment of patients with multiple aplasia: a study of maxillary incisors. Eur J Orthod. 1998;20(4):427-34.

18. Levander E, Bajka R, Malmgren O. Early radiographic diagnosis of apical root resorption during orthodontic treatment: a study of maxillary incisors. Eur J Orthod. 1998;20(1):57-63.

19. Linge L, Linge BO, Skien D. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. Am J Orthod Dentofac Orthop. 1991;99(1):35-43.

20. Linge BO, Linge L. Apical root resorption in upper anterior teeth. Eur J Orthod. 1983;5(3):173-83.

21. Little RM. Stability and relapse of mandibular anterior alignment: University of Washington studies. Semin Orthod. 1999;5(3):191-204.

22. Lupi JE, Handelman CS, Sadowsky C. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. Am J Orthod Dentofac Orthop. 1996;109(1):28-37.

23. Malmgren O, Goldson L, Hill C, Orwin A, Petrini L, Lundberg M. Root resorption after orthodontic treatment of traumatized teeth. Am J Orthod. 1982;82(6):487-91.

24. Massler M, Malone AJ. Root resorption in human permanent teeth. Am J Orthod. 1954;40(8):619-33.

25. McNab S, Battistutta D, Taverne A, Symons AL. External apical root resorption following orthodontic treatment. Angle Orthod. 2000;70(3):227-32.

26. Mirabella AD, Artun J. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. Am J Orthod Dentofac Orthop. 1995;108(1):48-55.

27. Parker RJ, Harris EF. Directions of orthodontic tooth movements associated with external apical root resorption of the maxillary central incisor. Am J Orthod Dentofac Orthop. 1998;114(6):677-83.

28. Kim SY, Lim SH, Gang SN, Kim HJ. Crown and root lengths of incisors, canines, and premolars measured by cone-beam computed tomography in patients with malocclusions. Korean J Orthod. 2013;43(6):271-8.

29. Perona G, Wenzel A. Radiographic evaluation of the effect of orthodontic retraction on the root of the maxillary canine. Dentomaxillofacial Radiol. 1996;25(4):179-85.

30. Pinheiro BC, Fernandes KGC. Reabsorção radicular em tratamento ortodôntico. Rease. 2022;8(10):1302-17.

31. 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):43-6.

32. Reitan K. Initial tissue behaviour during apical root resorption. Angle Orthod. 1974;44(1):68-82.

33. Sameshima GT, Asgarifar KO. Assessment of root resorption and root shape: periapical vs panoramic films. Angle Orthod. 2001;71(3):185-9.

34. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: part I. Diagnostic factors. Am J Orthod Dentofac Orthop. 2001;119(5):505-10.

35. Taithongchai R, Sookkorn K, Killiany DM. Facial and dentoalveolar structure of apical root shortening and the prediction. Am J Orthod Dentofac Orthop. 1996;110(3):296-302.

36. Thongudomporn U, Freer TJ. Anomalous dental morphology and root resorption during orthodontic treatment: a pilot study. Aust Orthod J. 1998;40(8):629-33.

37. Trevisan IC, Postingher T, Conde A, Pigozzi LB, Bellan MC, Paulus M. Reabsorção radicular interna de incisivos superiores permanentes tratados endodonticamente. Rev Odontol Araçatuba. 2021;42(2):9-17.

38. Westphalen VPD, Moraes IG, Westphalen FH, Martins WD, Souza PHC. Conventional and digital radiographic methods in the detection of simulated external root resorptions: a comparative study. Dentomaxillofacial Radiol. 2004;33(4):233-5.