DOI: https://doi.org/10.17921/2447-8938.2019v21n5p494-499

Lower Incisor Root Resorption after Orthodontic Alignment and Leveling

Reabsorção da Raiz Após o Alinhamento e Nivelamento Dentário

Ângela Graciela Deliga Schroder*[a]; Mariana Gonzaga Erthal Ribeiro[a]; Alyssa Sales dos Santos[b]; Amaro Ilidio Vespasiano Silva[c]; Flavio Ricardo Manzi[c]

[a]Pontifícia Universidade Católica do Paraná, Programa de Pós-Graduação em Odontologia, PR, Brasil.
[b]Pontifícia Universidade Católica de Minas Gerais, MG, Brasil.
[c]Pontifícia Universidade Católica de Minas Gerais, Programa de Pós-Graduação em Odontologia, MG, Brasil.
*E-mail: dra.angela@digitalface.com.br
Recebido em: 20/03/2019; Aprovado em: 29/05/2019

Abstract

The objective of this study was to evaluate the external apical root resorption in the lower incisors after orthodontic alignment and leveling using digital periapical radiographs. The sample consisted of periapical radiographs of 90 lower central incisors from 45 patients, 19 men and 26 women aged 12-36 years (mean 22.7 years). All the 90 lower central incisors were performed periapical radiographs in two phases: 1 - initial before orthodontic treatment and 2 - after alignment and dental leveling phase. The initial periapical radiographs were digitized through a transparency scanner. All patients were treated by the same orthodontist, the inclusion criteria were: never having been treated orthodontically; absence of exodontia, agenesis, malformation or defect in teeth, supernumerary teeth, endodontic treatment and impacted incisors. The time interval between the initial and post-leveling radiographs was from 6 to 12 months, with an average time of 9 months. It was observed that 47.8% of the incisors evaluated presented external apical root resorption, being most grade 1 (irregular contour up to 1 mm reabsorption). There was a positive association of external root resorption with the triangular root shape. There was no association between the severity of root resorption and the type of malocclusion. An association was observed between age and resorption severity, that is, patients who have already reached bone maturation were more likely to develop apical external root resorption. Female patients were more likely, but when men developed external root resorption, it tended to be a more severe degree. Female adult patients, with a triangular root shape, anatomical apical pipette shape, regardless of malocclusion type are more likely to develop apical external root resorption in orthodontic treatment.

Keywords: Radiography, Dental, Digital. Orthodontic. Root Resorption.

Resumo

Esse estudo teve como objetivo avaliar a reabsorção radicular apical externa nos incisivos inferiores após alinhamento e nivelamento ortodôntico com radiografias periapicais digitais. A amostra consistiu de 90 radiografias periapicais de incisivos centrais inferiores de 45 pacientes, sendo 19 homens e 26 mulheres com idade entre 12 e 36 anos (média de 22,7 anos). As radiografias periapicais foram realizadas em dois momentos: 1 - inicial antes do tratamento ortodôntico e 2 - após fase de alinhamento e nivelamento dentário. Todas as radiografias foram digitalizadas através de um scanner de transparência. Todos os pacientes foram tratados pelo mesmo ortodontista e preenchiam os seguintes critérios de inclusão: não ter sido tratado ortodonticamente anteriormente; ausência de exodontia, agenesia, malformação ou defeito nos dentes, dentes supranumerários, tratamento endodôntico e incisivos impactados. O intervalo de tempo entre as radiografias inicial e pós-nivelamento foi de 6 a 12 meses, com tempo médio de 9 meses. Observou-se que 47,8% dos incisivos avaliados apresentaram reabsorção radicular apical externa, sendo a maioria de grau 1 (contorno irregular até reabsorção de 1 mm). Houve associação positiva da reabsorção radicular externa com a forma da raiz triangular. Não houve associação entre a gravidade da reabsorção radicular e o tipo de má oclusão. Observou-se associação entre idade e gravidade da reabsorção, ou seja, pacientes que já atingiram a maturação óssea apresentaram maior chance de desenvolver reabsorção radicular externa apical. Pacientes do sexo feminino foram mais frequentes, mas quando os homens desenvolveram reabsorção radicular externa, tenderam a ser mais graves. Um paciente adulto, do sexo feminino, com formato de raiz triangular, região apical na forma anatômica de pipeta, independentemente do tipo de má oclusão, tem maior probabilidade de desenvolver reabsorção radicular externa no tratamento ortodôntico.

Palavras-chave: *Radiografia Dentária Digital. Ortodontia. Reabsorção da Raiz.*

1 Introduction

Orthodontics is the only dental speciality that uses the body's inflammatory system to solve functional and esthetic dental problems[1]. The high frequency of external apical root resorption in orthodontically treated patients has been reported in several studies[2-6]. The loss of up to three millimeters in the apical third should not be a reason for special care[7], and this type of resorption is minimal and without clinical significance[8]. However, even with low frequency, from 10 to 20% of all orthodontic movement can cause extreme and irreversible damage to the dental root, such as severe external apical root resorption. This degree of reabsorption presents an exaggerated shortening of the tooth length, with reduction of the total length of the healthy root greater than two millimeters, being able to reach up to 1/3 of the same[8].

External apical root resorption has a multifactorial etiology, which may occur due to individual biological characteristics

and also due to effects of orthodontic forces. Risk factors for external apical root resorption can be categorized as patient-related and orthodontic treatment. Patient-related factors include: genetic factors, systemic factors, asthma and allergies, chronic alcoholism, malocclusion severity, dental morphology, alveolar bone density, root proximity to cortical bone, endodontic treatment, and patient's age and gender. Risk factors related to orthodontic treatment include duration of treatment, magnitude of applied force, direction of tooth movement, amount of apical displacement, and method of force application[3,6].

Since radiography is the diagnostic method most commonly used to detect the presence of external apical root resorptions[9], digital radiographic imaging has created expectations with its association with more sensitive and specific diagnostic exams in several areas of dentistry. This was performed by allowing the operator to manipulate the images, which can be enlarged, transformed in a negative way, suffer alterations of contrast and brightness, image colorization and pseudo 3D (relief), in order to facilitate the diagnosis[10].

Since orthodontically induced external apical root resorptions in early stages show no clinical signs and / or symptoms, the patient at risk of developing this type of lesion in a severe degree should be identified by radiographic control in the first six months of orthodontic treatment. In addition, determining the characteristics of individuals and root type that present a greater tendency to external root resorption, allows the professional to adopt preventive and control measures to minimize these events.

However, the objectives of this study are to relate the level of external root resorption in relation to several aspects such as root shape, apical shape, age, gender and type of malocclusion, as well as to describe a profile of patients with a higher probability of developing external root resorption during orthodontic treatment.

2 Material and Methods

After the approval by the research ethics committee CAAE – 0035.0.213.000-09, the sample of the present study consisted of 90 lower central incisors, of 45 patients, 19 men and 26 women, aged between 12 and 36 years (average 22.7 years). The initial periapical radiographs were digitized through a transparency scanner after the alignment and dental leveling phase. The sample consisted of patients consecutively selected from the same dental office so that they met the following inclusion criteria: never having been treated orthodontically; absence of exodontia, agenesis, malformation or defect in teeth, supernumerary teeth, endodontic treatment and impacted incisors. The Little Irregularity Index had lower value 3.20 mm, upper value 15.50mm, average 7.1451 (SD 3.86998).

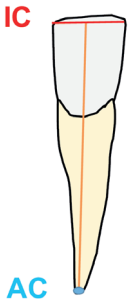
The prevalence of malocclusion in this study was: Class I 26.7 %, Class II 57.7 % and Class III 15.5 %. All patients were treated by the same orthodontist using the StraightWire technique, with slot 0.22"x 0.028" (Abzil-3M - São José do Rio Preto - Brazil), using the wire sequence (Abzil-3M - São José do Rio Preto): 0.014"NiTi, 0.016" SS, 0.018 "SS, 0.017x0.025" SS, with 0.014 "NiTi wire remaining for one month in the arc and the remaining wires remaining on average for two months. Exclusion criteria during treatment were: history of trauma and alteration in the crown incisal portion of the incisors as wear or fractures during orthodontic treatment.

All the periapical radiographs were acquired by the parallelism technique, being performed by the same professional. The time interval between the initial and post-leveling radiographs was from 6 to 12 months, with an average time of 9 months. This period of time 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, USA). The X-ray was digitized using a transparency scanner (HP 4050, California USA).

Digital image evaluation was performed by 2 dental radiology experts after training and calibration. For the evaluators calibration, 50 radiographs of 100 teeth were selected, which were measured twice by each evaluator with an interval of one week among the measurements. 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 calibration, the periapical radiographs of the lower central incisors at the beginning of the treatment and periapical radiographs of the lower central incisors after the alignment and leveling phase were evaluated by each examiner. The total longitudinal length of the tooth over the radiographic image was obtained using the program Adobe Photoshop CS3 from the measurement of the distance of the incisal points coronary (CI) and the apical radicular (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). This measure was performed twice for each tooth and by two evaluators.

Figure 1 - Method for measuring the length of the long axis of the lower incisors on the radiograph: Coronary incisal point (IC) and Apical radicular point (AR).



Source: Authors

Calibration of the magnification among the radiographs was also performed, since they were obtained at different times and could contain some distortion. Since it was a question of moving teeth, it was not possible to use a resin or silicone mold from the first moment for the acquisition of the radiographs. In order to standardize measurements without elongation or root shortening, the distance between the cementoenamel junction and the incisal edge of the tooth 41 was measured and the linear correction between the two moments was performed through a simple rule of three.

Each tooth was classified according to root shape, root apex shape, initial length and final length. The roots were classified according to the root morphology in triangular, rhomboid and square, and the apical morphology was classified as normal, pipette and with dilaceration[11].

The severity of external root resorption was classified as grade 0 to grade 4, where grade 0 - no root resorption, grade 1 - irregular contour up to 1 mm reabsorption, grade 2 - root resorption between 1 and 2 mm, grade 3 - Root resorption between 2 and 3 mm and grade 4 - root resorption greater than 3 mm[8].

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

3 Results and Discussion

Orthodontically induced external root resorption (OIERR) is a common, deleterious, side-effect of this inflammation-driven tooth movement[3]. In the evaluated sample 52.2% of the teeth did not present external apical root resorption detected by digital periapical radiography, although 88.9% presented triangular radicular shape. Of the incisors that presented root resorption, 53.55% were grade 1 (reabsorption up to 1mm), 25.52% grade 2 (reabsorption up to 2mm) and 20.92% grade 3 (reabsorption up to 3mm). Grade 4 reabsorption (reabsorption of more than 3mm) was not found in the sample.

When the degree of apical external root resorption and root shape (triangular, rhomboid or square) were associated, 88.9% of the sample was composed of a triangular root shape. Of these, 45.6% presented apical external root resorption and only 2.2% of the patients with external apical root resorption presented a square root shape. Statistical analysis showed that the root shape shows a positive association with the degree of apical external root resorption, although 43.3% of the patients without root resorption (grade 0) also exhibited a triangular root shape, as Table 1 can demonstrate.

Table 1 - Association between the root shape (triangular, rhomboid and square) and the presence of external root resorption (RR). (P> 0.05 (Chi-Square).

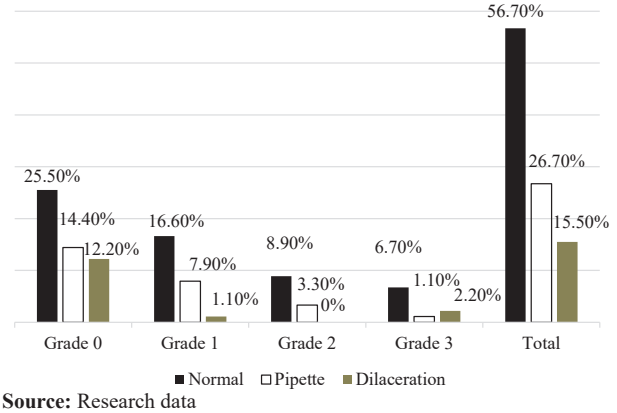
Root Resorption	Triangular	Rhomboid	Square	Total
Without RR	39-43.3%	6-6.7%	2-2.2%	47-52.2%
With RR	41-45.6%	0-0%	2-2.2%	43-47.8%
Total	80-88.9%	6-6.7%	4-4.4%	90-100%

Source: Research data

Of the teeth that presented apical external root resorption and triangular root shape, 23.4% presented grade 1, 12.2% grade 2 and 10% grade 3 reabsorption. When the apical root form (normal, pipette or with dilaceration) were related to ases of apical external root resorption, it was observed that 32.2% presented apical normal root shape, 12.3% presented apical root canal and only 3.3% with dilaceration, this shows a positive association between the root shape and the presence of root resorption.

In Figure 2 it can be observed that the apical form of the normal root was predominant in the sample, both in the group without reabsorption and with external apical root resorption, in its different degree of severity: grade 1 = 16.6%, grade 2 = 8.9% and grade 3 = 6.7%.

Figure 2 - Association between the apical root shape (normal, pipette and dilaceration) and degree of external root resorption (Grade 0, 1, 2, 3).



Source: Research data

In the evaluation of malocclusion and its association with external apical root resorption (Table 2), statistical analysis showed that there is no association between the type of malocclusion and degree of external apical root resorption. However, an association between age and degree of resorption was found, since the adult patient was more likely to develop apical external root resorption ($p < 0.05$ (Chi-Square) than the patient who was still growing, but this resorption tends to present a lighter degree (grade 1 = 20%).

Table 2 - Association between the type of malocclusion (Class I, II and III) and the presence of external root resorption (RR). P> 0.05 (Chi-Square).

Root Resorption	Class I	Class II	Class III	Total
Without RR	9-10%	29-32.3%	9-10%	47-52.2%
With RR	15-16.7%	23-25.5%	5-5.5%	43-47.8%
Total	24-26.7%	52-57.7%	14-15.5%	90-100%

Source: Research data

An association between gender and degree of resorption was found, with female patients being more likely to have root resorption. Analyzing the frequency of the development of external apical root resorption, the female sex is more likely, but when the male develops the external root resorption, it

tends to be in a more severe degree.

As it can be observed, the variable degree of resorption was positively associated with the root shape (triangular, rhomboid or square); The apical root shape (pipette, dilaceration or normal) and the patient's age (growing and adult patients); But there was no association with the type of malocclusion (Class I, II, III) and gender (male or female).

Diagnosis of OIRR is carried out in most cases radiographically, since clinical symptoms are for the majority absent and increased tooth mobility is seen only in severe cases with additional alveolar bone loss through time[12]. There are limitations in establishing comparisons between the results and conclusions of the great majority of studies on root resorption, due to the methodological differences among the studies, especially regarding the classification of external root resorption, which can be done subjectively[13-15] or objectively, quantifying it[8]. Even among radiographic studies, the comparisons are limited due to the different radiographic techniques used in the studies: periapical intraoral radiography[5,7,8,16-22], panoramic radiography[14,15], cephaladiography[13]. Periapical intra-oral radiography and teleradiography[23]. As the periapical technique has shown to be superior to the panoramic view of the diagnosis of external root resorption[25], once that the panoramic radiographic image can overestimate the amount of root loss by 20% or more, it was used in this work as a measurement method the periapical radiography, which presents images closer to the real. A recent research[26] studied the accuracy of digital periapical radiography for diagnosis of natural and simulated external root resorption with micro-computed tomographic imaging as the reference standard and only 74.5 % of natural ERR gaps and 81.8% of artificial gaps were observed on the digital periapical radiographs. The authors concluded that the configuration of the natural ERR gaps is different from those artificially simulated and is much more difficult to observe. However, the root resorption affects every aspect of the root surface in all three-dimensions and therefore, 2D radiographs might mask the true amount of root resorption[1]. Additionally, the true extent of root resorption might be misestimated due to magnification errors and problematic repeatability of 2D radiographs[12].

Only the lower central incisors were selected to constitute the sample of the present study, since these are the group of teeth that present a higher frequency in the development of external apical root resorption[5,7,8,14,25]. In addition, the choice of the lower incisors was also done in order to obtain a sample with as much homogeneity as possible, because regardless of the type of malocclusion, need or not of dental extractions, deep or open bite and amount of overjet, these teeth would receive a similar mechanics in the first phase of the treatment for alignment and leveling.

In the present study, apical external root resorption was found in 47.8% of the sample, distributed in several degrees of severity. This percentage (47.8% with root resorption) is higher than the results found by McNab et al.[15], Nanekrungsan et al.[27] who found an average of 7.78% of root resorption; However, this value is lower than that found by De Shields[17] who found 82.69% of the incisors with external apical root resorption; Goldson and Henrikson[7] with 58%; Levander and Malmgren[4] with 66%, but this author considered without apical external root resorption also those teeth that presented a regular apical contour[4,7,15]. This difference in results can be justified by the methodological difference found in the studies (Table 3).

Table 3 - Comparative table of methodological differences among some authors who have carried out studies on root resorption induced by orthodontic therapy

	Group of Teeth	AGE	Genre	Radiography	Malocclusion
Present study	Lower incisors	12-36 years	19 men and 16 women	Periapical	Class I, II and III
McNab et al.[15]	Posterior teeth	Average 13.9 years	Does not report	Panoramic	Does not report
DeShields[17]	Upper incisors	11-16 years	24 men and 28 women	Cephalometric	Class II
Goldson and Henrikson[7]	Upper and lower incisors	11-20 years	Does not report	Periapical	Class I and II
Levander and Malmgren[8]	Upper incisors	Does not report	Does not report	Periapical	Does not report
Nanekrungsan et al.[27]	Upper incisors	Does not report	Does not report	Periapical	Does not report
Maués et al.[28]	Upper and lower incisors	Does not report	397 men and 562 women	Periapical	Class I, II and III

Source: Research data

Regarding root anatomy, the results of this study demonstrate that the triangular roots are more likely to develop apical external root resorption than the other root (rhomboid and square) anatomies. This result is in agreement with some studies[14,27]. However, it diverges with others[8,24], which observed that the degree of root resorption in teeth with rhomboid apex was higher than that observed in normal roots. When analyzing the root apical anatomy, studies have shown that the apical pipetted form is the most susceptible to develop external apical root resorption[2,4,8,14,19,22,24], which suggests that

the type of root apex shape should be analyzed more carefully before the onset of orthodontic treatment than the root shape as a whole.

In the present study there was no positive association between apical external root resorption and the patient's gender, a result consistent with Nanekrungsan et al.[27] and Maués et al.[28]. Baumrind et al.[23] who found an average of 1.2 mm more apical external root resorption in men than in women. This result is compatible with that found in this study, because although women present a statistically non-significant higher frequency, when men develop apical external root resorption, it tends to present a greater degree of severity. However, other studies have found a higher frequency of apical external root resorption in women[8,14]. Perhaps this difference between sexes may not be linked to hormonal factors, but to the stage of root development at the same age or "orthodontic age", because at the same chronological age the roots of men's teeth are more immature, and therefore less predisposed to reabsorption[29].

Adults seem more likely to develop root resorption[27,29], a fact also observed in this study. The inexorable changes brought about by aging make the periodontal membrane less vascularized, with no elasticity and narrower. These changes create difficulty in tooth movement and predispose to reabsorption. Teeth with open apex would be teeth less susceptible to resorption because their nutrition is probably better, larger cellularity of the apical area , and more effective muscular adaptation to occlusal changes. The precocious approach aimed at correcting maxillomandibular relationships, which is actually longer and / or aggressive, would be based on teeth that are not susceptible to resorption. However, other studies have reported no association between age and predisposition to develop apical external root resorption[8,13,21,23].

There is no association between malocclusion types and root resorption. The association exists between the severity of malocclusion and root resorption, as a consequence of the amount of force employed and the prolonged treatment time in cases with greater severity[10,23,27,28,30]. The type of mechanics used, as well as the duration of the treatment do not influence the amount of root resorption, but the need for dental extractions positively influences the degree of root resorption at the end of the treatment, being in agreement with Maués et al.[28], who also positively associates treatments involving dental extractions with the presence of root resorption, but not the malocclusion itself. These results are compatible with those found in our study, where the type of malocclusion did not present a positive association with the frequency and or degree of external apical root resorption in the sample studied. In 2019, a systematic review[1] made the association between the orthodontic mechanotherapies and their influence on external root resorption and concluded that there are a few evidences to support positive associations among root resorption and increased force levels, force continuity, intrusive forces and treatment duration. Moreover, by including a pause in treatment for patients experiencing root resorption, it may be possible for the clinician to reduce the severity of the condition.

When analyzing the risk of developing root resorption, the literature states that it is impossible to accurately predict whether a patient will develop external apical root resorption before the orthodontic treatment is initiated[2,8,10,16]. This is because the etiological factors of this type of lesion are varied and often peculiar to each individual that cannot be previously identified, besides the varied physiological and genetics factors [3,6]. However, the diagnosis of root resorption can be carried out after 6 months of orthodontic treatment[88]. Thus, patients with a higher risk of root resorption can be identified during treatment[2,8,10,16,19]. What can be observed in some studies is that when the patient did not present root resorption in the initial phase of orthodontic treatment, the risk was minimal to develop this lesion at the end of the therapy[8]. The patient who presented an irregular contour of the root in the initial phase of the orthodontic treatment, the risk was small; Those presenting small apical external root resorption, the risk was moderate; And, finally, those who presented this lesion in severe degrees, the risk was high.

4 Conclusion

Based on the results of this research, it was concluded that it is possible to suggest a patient's profile more likely to develop apical external root resorption at the beginning of the orthodontic treatment: adult patient of both sexes, with a triangular root, apical anatomical form in pipette, regardless of the type of Malocclusion.

References

1. Currell SD, Liaw A, Blackmore Grant PD, Esterman A, Nimmo A. Orthodontic mechanotherapies and their influence on external root resorption: A systematic review. Am J Orthod Dentofacial Orthop 2019;155(3):313-29. doi: 10.1016/j.ajodo.2018.10.015

2. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. Am J Orthod Dentofacial Orthop 1993;103(2):138-46. doi: 10.1016/S0889-5406(05)81763-9

3. Feller L, Khammissa RA, Thomadakis G, Fourie J, Lemmer J. Apical external root resorption and repair in orthodontic tooth movement: biological events. Biomed Res Int 2016;2016:4864195. doi: 10.1155/2016/4864195

4. 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):427-34. doi:10.1093/ejo/20.4.427

5. 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

6. Topkara A. External apical root resorption caused by orthodontic treatment: a review of the literature. Eur J Paediatr Dent 2011;12(3):163-6.

7. Goldson L, Henrikson CO. Root resorption during Begg treatment; a longitudinal roentgenologic study. Am J Orthod 1975;68(1):55-66. doi: 10.1016/0002-9416(75)90159-1

8. 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. doi:10.1093/ejo/10.1.30

9. Harris EF, Kineret SE, Tolley EA. A heritable component for external apical root resorption in patients treated orthodontically. Am J Orthod Dentofacial Orthop 1997;111(3):301-9. doi:10.1016/s0889-5406(97)70189-6

10. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 1. Literature review. Am J Orthod Dentofacial Orthop 1993;103(1):62-6. doi: 10.1016/0889-5406(93)70106-X

11. Consolaro A, Furquim LZ. Extreme root resorption associated with induced tooth movement: a protocol for clinical management. Dental Press J Orthod 2014;19(5):19-26. doi: 10.1590/2176-9451.19.5.019-026.oin

12. Ren H, Chen J, Deng F, Zheng L, Liu X, Dong Y. Comparison of cone-beam computed tomography and periapical radiography for detecting simulated apical root resorption. Angle Orthod 2013;83(2):189-95. doi: 10.2319/050512-372.1

13. Kaley J, Phillips C. Factors related to root resorption in edgewise practice. Angle Orthod 1991;61(2):125-32. doi: 10.1043/0003-3219

14. 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

15. McNab S, Battistutta D, Taverne A, Symons AL. External apical root resorption following orthodontic treatment. Angle Orthod 2000;70(3):227-32. doi: 10.1043/0003-3219

16. Chapnick L. External root resorption: an experimental radiographic evaluation. Oral Surg Oral Med Oral Pathol 1989;67(5):578-82. doi:10.1016/0030-4220(89)90276-4

17. DeShields RW. A study of root resorption in treated Class II, Division I malocclusions. Angle Orthod 1969;39(4):231-45. doi: 10.1043/0003-3219

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):262-73. doi: 10.1067/mod.2000.99136

19. 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. doi:10.1093/ejo/20.1.57

20. Linge BO, Linge L. Apical root resorption in upper anterior teeth. Eur J Orthod 1983;5(3):173-83. doi:10.1093/ejo/5.3.173

21. Lupi JE, Handelman CS, Sadowsky C. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. Am J Orthod Dentofacial Orthop 1996;109(1):28-37. doi:10.1016/s0889-5406(96)70160-9

22. Mirabella AD, Artun J. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. Am J Orthod Dentofacial Orthop 1995;108(1):48-55. doi:10.1016/s0889-5406(95)70065-x

23. Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. Am J Orthod Dentofacial Orthop 1996;110(3):311-20. doi:10.1016/s0889-5406(96)80016-3

24. Taithongchai R, Sookkorn K, Killiany DM. Facial and dentoalveolar structure and the prediction of apical root shortening. Am J Orthod Dentofacial Orthop 1996;110(3):296-302. doi:10.1016/S0889-5406(96)80014-X

25. Westphalen VPD, Moraes IGd, Westphalen FH. Efficacy of conventional and digital radiographic imaging methods for diagnosis of simulated external root resorption. J Appl Oral Scie 2004;12(2):108-12. doi: 10.1590/s1678-77572004000200005

26. Deliga Schroder AG, Westphalen FH, Schroder JC, Fernandes A, Westphalen VPD. Accuracy of digital periapical radiography and cone-beam computed tomography for diagnosis of natural and simulated external root resorption. J Endod 2018;44(7):1151-58. doi: 10.1016/j.joen.2018.03.011

27. Nanekrungsan K, Patanaporn V, Janhom A, Korwanich N. External apical root resorption in maxillary incisors in orthodontic patients: associated factors and radiographic evaluation. Imaging Sci Dent 2012;42(3):147-54. doi: 10.5624/isd.2012.42.3.147

28. Maues 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):52-8. doi: 10.1590/2176-9451.20.1.052-058.oar

29. Sameshima GT, Asgarifar KO. Assessment of root resorption and root shape: periapical vs panoramic films. Angle Orthod 2001;71(3):185-9. doi: 10.1043/0003-3219

30. Mirabella AD, Artun J. Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. Eur J Orthod 1995;17(2):93-9. doi:10.1093/ejo/17.2.93