Original Article

Apical root resorption due to orthodontic treatment detected by cone beam computed tomography

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ABSTRACT

Objective: To determine the frequency of apical root resorption (ARR) due to orthodontic treatment using cone beam computed tomography (CBCT) in a sample of 1256 roots from 30 patients.

Materials and Methods: All patients had Class I malocclusion with crowding. Of the 30 patients evaluated, 11 were boys and 19 were girls; their mean age was 13 years (11 to 16 years). Orthodontic treatment followed the nonextraction treatment. CBCT images were obtained before and after orthodontic treatment, and ARR was determined using Axial Guided Navigation of CBCT images.

Results: All patients had ARR. No statistically significant association was found between resorption frequency, gender, and age. ARR was detected using CBCT in 46% of all roots that underwent orthodontic treatment.

Conclusions: CBCT was effective for detecting in vivo even minimal degrees of ARR due to orthodontic treatment and allowed three-dimensional evaluation of dental roots and visualization of palatine roots of maxillary molars. The highest frequencies and the most significant ARR occurred in incisors and distal roots of first maxillary and mandibular molars. (*Angle Orthod.* 2013;83:196–203.)

KEY WORDS: Cone beam computed tomography; Diagnostic imaging; Root resorption; Orthodontic treatment

INTRODUCTION

Orthodontics may be the most common cause of apical root resorption (ARR) in the modern world. ARR is characterized by loss of the superficial layer of cells that protect the tooth roots, the action of clastic cells, and hyalinization.[1–3] Its prevalence is high and it depends on different factors, such as root shape, tooth groups, and measurement techniques.[4–7] Some of the risk factors of orthodontic treatment are time, movement direction, orthodontic technique, type, and magnitude of the force applied.[6–12]

Different aspects of tooth resorption have been studied[1–3,5,7,12–14] using conventional radiographs; these include prevalence, etiology, classification, and pathologic mechanisms. Several orthodontic studies[4,5,9,10,13,15–17] used conventional radiographs to determine ARR frequency. However, conventional radiographs may either underestimate or overestimate the amount of root structure loss.[4,5,7,9–11,13,17–21]

Orthodontic treatment plans include radiographs as a diagnostic tool. Panoramic radiographs overestimate ARR by 20% when compared with periapical radiographs,[5] but they may also underestimate root resorption when compared with microtomography.[18] ARR is a three-dimensional change that may affect the whole root surface. Therefore, careful investigations should provide accurate data about ARR frequency and location.[20,22]

A scientific revolution occurred with the invention of computed tomography (CT),[23] but this imaging modality was rarely used in dentistry because of factors such

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as cost, amount of radiation, and scanner size.[24] After scientific and technological improvements in this area, cone beam computed tomography (CBCT) was introduced to specific areas of dentistry.[25,26] CBCT scans provide more accurate three-dimensional images of teeth than do radiographs.[20,21,27] Dudic et al.[19] found that, compared with CBCT, panoramic radiographs underestimate ARR as a result of orthodontic tooth movement.

As a modality of examination, though, CBCT should be carefully used. The effective dose of CBCT may be 1.5 to 33 times higher than that associated with panoramic radiographs.[28,29] The amount of radiation absorbed when different radiographic methods are used has not been clearly defined yet and depends on the purpose of the radiographic examination, exposure time, scan size, and voltage.[28,29] Silva et al.[28] compared the radiation associated with conventional panoramic radiographs, CBCT, and multislice CT cephalometric radiographs. The effective dose of CBCT is five to six times higher than that of panoramic radiographs and about seven to eight times smaller than that of multislice CT.

Conventional radiographs have several limitations, and few studies have evaluated the diagnostic value of three-dimensional imaging methods. This study used CBCT to determine the frequency of ARR resulting from orthodontic treatment.

MATERIALS AND METHODS

CBCT was used to evaluate 1256 roots of 30 patients (11 boys and 19 girls) who underwent nonextraction orthodontic treatment in private clinics (Goiânia, Goiás, Brazil). Mean patient age was 13 years (11 to 16 years) at the beginning of the orthodontic treatment. Inclusion criteria were the following: healthy patient with Angle Class I malocclusion, permanent dentition, crowding, absence of caries, and periodontitis. Exclusion criteria were use of continuous medication, previous orthodontic treatment, bruxism, previous traumatic dental injuries, and metal restorations. Informed consent was obtained from the parents of the patients; we also obtained the ethical approval of the Research Ethics Committee of Federal University of Goiás (Brazil, No. 235/2010).

CBCT images were obtained using an i-CAT Cone-Beam tomography unit (Imaging Sciences International, Hatfield, Pa) before and after orthodontic treatment. Images were examined using Xoran 3.1.62 software (Xoran Technologies, Ann Arbor, Mich) in a workstation with Microsoft Windows XP professional SP-2 (Microsoft Corp, Redmond, Wash). Volumes were reconstructed using 0.25-mm isometric voxel; tube voltage was 120 kVp; current measured 3.8 mA; and exposure time was 40 seconds (field of view: 13 cm). Other parameters included the following: gray scale (14 bit); 0.5-mm focal distance; and image acquisition with single 360° rotation.

Orthodontic treatments were conducted by the same orthodontist with fixed appliances bonded on all teeth except for the third molars. The straight-wire technique (Roth prescription) was used, the subjects were reviewed at 4-week intervals, and the average sequence of wires used was as follows: 0.012-inch, 0.014-inch, 0.018-inch, and 0.016 inch × 0.022-inch nickel-titanium and .019-inch × .025-inch stainless-steel wire on a 0.022-inch slot. Treatments lasted from April 2009 to February 2011, and the patients did not undergo extractions or palatal expansion.

To analyze ARR using CBCT in all permanent teeth, excluding third molars, the linear length between the root apex and incisal edges and cusps was measured by one examiner (orthodontist). The reference points for the measurements were as follows (Figure 1): AB, from incisal edge to apex of the central and lateral incisors (sagittal section); CD, from cusp tip to apex of canines (sagittal section); EF, from buccal cusp tip to apex of single-rooted premolar (sagittal section); GH, from buccal cusp tip to apex of buccal root of two-rooted premolar (sagittal section); IJ, from lingual cusp tip to apex of the lingual root of two-rooted premolar (sagittal section); KL, from mesiolingual cusp tip to apex of lingual root of molar (sagittal section); MN, from mesiobuccal cusp tip to apex of mesiobuccal root of molar (coronal section); OP, from distovestibular cusp tip to the apex of distovestibular root of molar (coronal section); QR, from mesiobuccal cusp tip to apex of mesial root of molar (coronal section); and ST, from distovestibular cusp tip to apex of distal root of molar (coronal section).

The maximum linear length between cusps and root apex was measured using axial multiplanar reconstruction at 0.25-mm isometric voxel (Figure 2A,D). The axial movement of the cursor on sagittal (Figure 2C,F) or coronal (Figure 2B,E) multiplanar reconstruction defined the reference points (Figure 2A, root apex; Figure 2D, incisal edge/cusp).

The reference points were at the intersection of the sagittal or coronal cursor with the axial cursor (Figure 2B,C,E,F). The distances between the reference points were marked in the sagittal or coronal multiplanar reconstruction, providing measurements in millimeters (Figure 2G–J). This method was termed Axial Guided Navigation (AGN) because measurements are made by moving the axial cursor on the sagittal or coronal multiplanar reconstructions guided by the axial multiplanar reconstruction. ARR was measured before and after orthodontic treatment, and data were recorded using Microsoft Office Excel™ 2007.

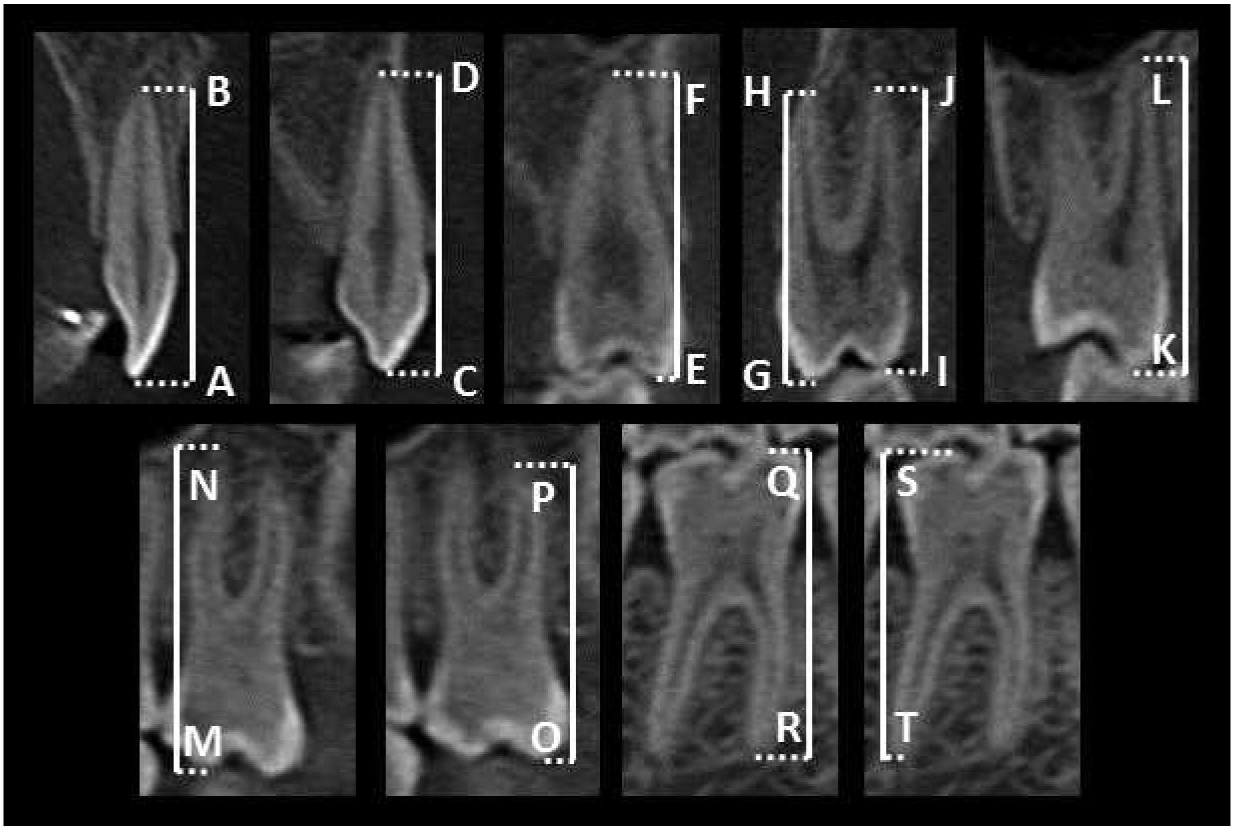

Figure 1. Reference points to measure maximum linear length.

The measurements before and after orthodontic treatment are presented as means and standard deviations for each tooth root. The significance between means was evaluated using the Student's *t*-test (parametric data) and the Wilcoxon (nonparametric data) test. The association between gender and ARR was assessed using the chi-square test, and the correlation of age was evaluated using the Pearson correlation coefficient. The statistical analysis was performed using SPSS® 19.0 (SPSS Inc, Chicago, Ill).

The Dahlberg[30] formula was used to check AGN method error, and the result was 0.36 mm. The Student's *t*-test for independent samples was used to evaluate the significance of measurements taken at different times when data presented normal distribution, and the Mann-Whitney test was applied to nonparametric data. Both tests evaluated the means of two measurements, taken by the same examiner, at 2-week intervals (intraexaminer variations). No statistically significant difference ($P < .05$) was found, and the method presented high reproducibility.

RESULTS

All patients and 46% of the 1256 roots presented with ARR. The frequency of ARR was high in maxillary central incisors (73%), maxillary lateral incisors (73%), mandibular central incisors (72%), mandibular lateral incisors (70%), and distal roots of mandibular first molars (63%). In contrast, ARR frequency was low in buccal roots of maxillary second premolars (17%), distobuccal and lingual roots of maxillary second molars (18%), and distal roots of mandibular second molars (20%) (Table 1).

ARR was statistically significant ($P < .05$) in the roots of central and lateral incisors and of maxillary (distobuccal) and mandibular (mesial and distal) first molars (Table 2). The box plot graphs represent the values of ARR in the roots in which resorption was statistically significant (Figure 3). The correlations between gender (Table 3), age (Table 4), and ARR frequency were not statistically significant.

DISCUSSION

This study aimed to determine the frequency of ARR using CBCT. Although a number of studies have already evaluated ARR using CBCT images, the present study allowed a total view of resorption (possible resorption in all teeth that underwent orthodontic forces).

The conventional two-dimensional imaging methods show a high frequency of ARR after orthodontic

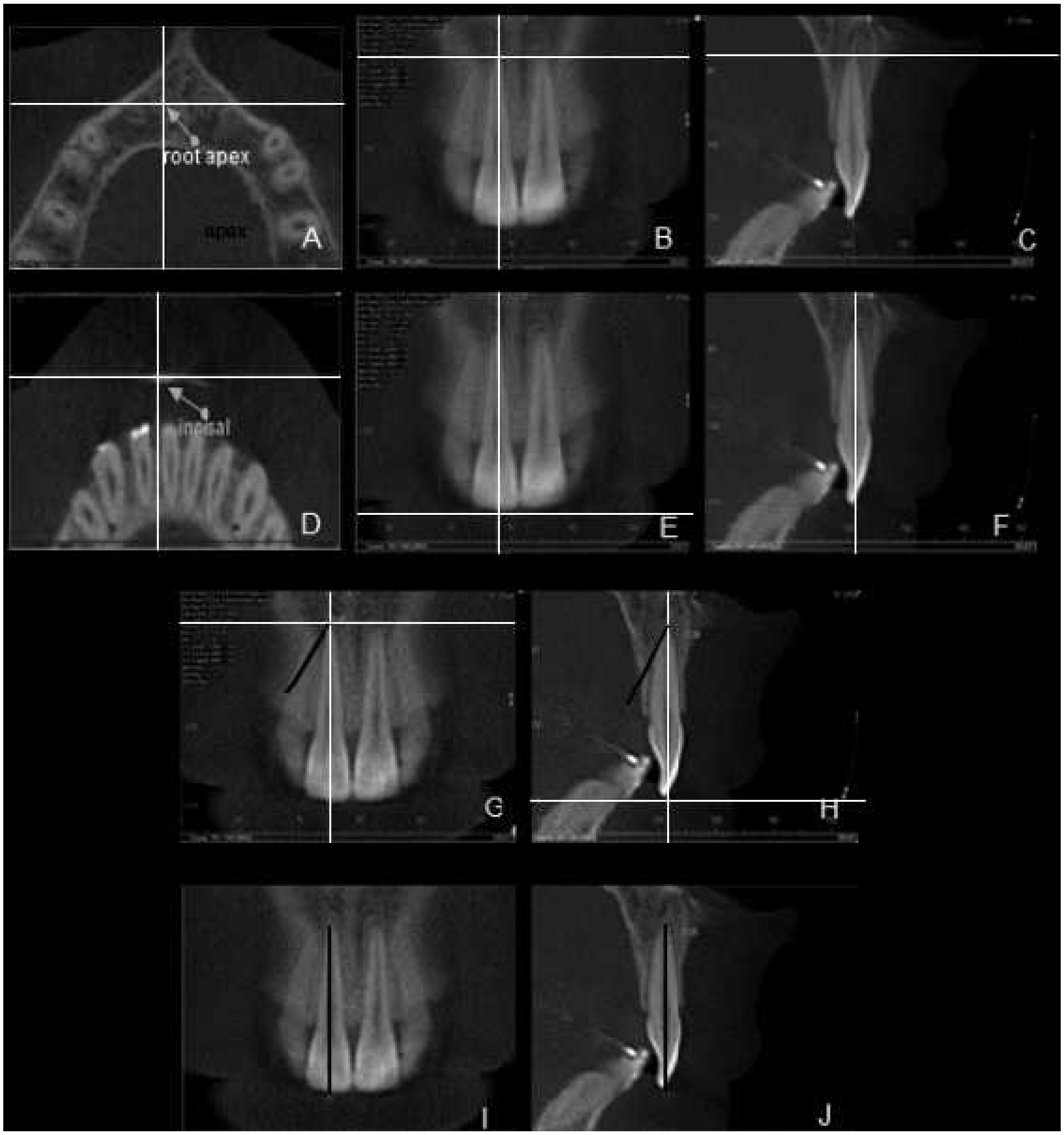

Figure 2. Axial multiplanar reconstruction with identification of root apex (A) as a reference point. Coronal (B) and sagittal (C) multiplanar reconstruction identifies root apex on intersection of axial cursor with coronal and sagittal cursors. Identification of incisal edge and cusp (D) as reference points after axial cursor movement on coronal (E) and sagittal (F) multiplanar reconstruction. Tracing with CT software measuring tool on sagittal (G and I) or coronal (H and J) cursor line based on landmarks identified in axial multiplanar reconstruction (A and D).

treatment.[4,5,7–11,13,17,31] However, CBCT images provide a more accurate analysis of treatment results.[19–22,26,27,29,32] In this study, the difference in tooth length before and after orthodontic treatment, measured using three-dimensional images, defined ARR frequency. CBCT was used to analyze the images of 1256 roots, and our results showed that 46% of them had ARR in nonextraction Class I malocclusion treatments. In some previous studies[13] ARR prevalence rates ranged from 43% to 51%. Higher frequencies were found in other studies.[9,33] Janson et al.[9] used periapical radiographs and found an ARR prevalence of 97.75% in roots of maxillary and mandibular incisors after orthodontic movement.

Preoteasa et al.[33] analyzed ARR in panoramic radiographs of 50 patients and found a prevalence of 96%. These differences may be attributed to the use of two-dimensional radiographs, which may either overestimate or underestimate loss of root structure.[5,7,10,18–21] Comparing the accuracy of CBCT to that of periapical radiographs with regard to detection of root resorption, several studies[20–22,34] showed that the three-dimensional method was more effective and reliable.

Table 1. Absolute Frequency and Percentage Frequency (%) of Apical Root Resorption[a]

Arcade	Tooth	Roots	n	Absolute Frequency	Frequency, %
Maxillary	Central incisor	SR	60	44	73
	Lateral incisor	SR	60	44	73
	Canine	SR	60	31	52
	First premolar	SR	22	9	41
		BR	38	13	34
		PR	38	18	47
	Second premolar	SR	42	13	31
		BR	18	3	17
		PR	18	5	28
	First molar	MBR	60	26	43
		DBR	60	33	55
		PR	60	32	53
	Second molar	MBR	60	14	23
		DBR	60	11	18
		RP	60	11	18
Mandibular	Central incisor	SR	60	43	72
	Lateral incisor	SR	60	42	70
	Canine	SR	60	26	43
	First premolar	SR	60	28	47
	Second premolar	SR	60	28	47
	First molar	MR	60	30	50
		DR	60	38	63
	Second molar	MR	60	18	30
		DR	60	12	20
		Total	1256	572	46

[a] MBR indicates mesiobuccal root; DBR, distobuccal root; SR, single root; BR, buccal root; PR, palatal root; MR, mesial root; and DR, distal root.

Table 2. Mean ($\bar{X}$), Standard Deviation (SD), and Level of Significance (*P*) of the Initial and Final Measurements Obtained by Teeth (in Millimeters)[a]

Arcade	Tooth	Root	T_1, $\bar{X} \pm$ SD	T_2, $\bar{X} \pm$ SD	T_2–T_1	*P*
Maxillary	Central incisor	SR	24.85 ± 1.73	24.39 ± 1.75	−0.46	<.001*
	Lateral incisor	SR	23.59 ± 1.85	23.10 ± 1.87	−0.49	<.001*
	Canine	SR	27.23 ± 1.84	27.20 ± 1.86	−0.03	.505
	First premolar	SR	21.75 ± 1.99	21.99 ± 1.97	0.24	.829
		BR	21.76 ± 1.15	21.79 ± 1.00	0.04	.919
		PR	20.61 ± 1.35	20.51 ± 1.25	−0.10	.343
	Second premolar	SR	21.03 ± 1.79	21.21 ± 1.56	0.18	.248
		BR	21.25 ± 1.06	21.50 ± 0.99	0.25	.04
		PR	20.65 ± 1.37	20.93 ± 1.27	0.28	.163
	First molar	MBR	19.98 ± 1.33	19.84 ± 1.35	−0.14	.077
		DBR	19.87 ± 1.48	19.55 ± 1.47	−0.32	<.001*
		PR	21.35 ± 1.43	21.18 ± 1.53	−0.17	.076
	Second molar	MBR	18.86 ± 1.82	19.61 ± 1.56	0.75	<.001
		DBR	18.64 ± 1.85	19.54 ± 1.66	0.90	<.001
		PR	19.88 ± 1.59	20.80 ± 1.71	0.91	<.001
Mandibular	Central incisor	SR	21.61 ± 1.49	21.20 ± 1.51	−0.40	<.001*
	Lateral incisor	SR	22.84 ± 1.45	22.36 ± 1.44	−0.47	<.001*
	Canine	SR	25.75 ± 1.97	25.63 ± 2.00	−0.12	.162
	First premolar	SR	22.55 ± 1.25	22.58 ± 1.51	0.02	.414
	Second premolar	SR	22.12 ± 1.47	22.28 ± 1.61	0.16	.522
	First molar	MR	21.22 ± 1.20	21.05 ± 1.31	−0.17	.045*
		DR	20.76 ± 1.25	20.43 ± 1.26	−0.32	<.001*
	Second molar	MR	20.01 ± 1.49	20.44 ± 1.49	0.43	<.001
		DR	19.89 ± 1.63	20.49 ± 1.54	0.60	<.001

[a] $\bar{X} \pm$ SD indicates mean ± standard deviation; MBR, mesiobuccal root; DBR, distobuccal root; SR, single root; BR, buccal root; PR, palatal root; MR, mesial root; DR, distal root; T_1, initial measurements; and T_2, final measurements.

* Statistically significant.

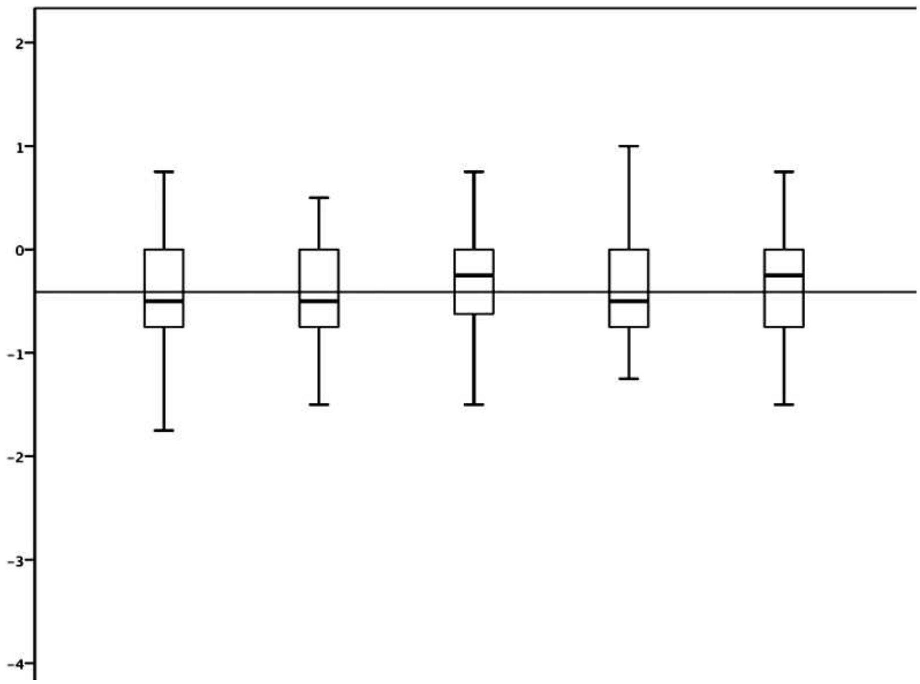

Figure 3. Box plots of the apical root resorption values in the roots in which resorption was statistically significant, including minimum/maximum values and outliers.

In this study, a specific tool of the CT software, which provides values in millimeters, was used to obtain accurate linear measurements. Only crowns without metal restorations or fractures were included in the study to ensure good visualization of the images and to avoid artifacts. AGN strategy allows navigation in all planes of the image and minimizes limitations inherent in conventional two-dimensional radiographs, such as lack of standardized radiographic technique and overlapping of anatomical structures.[22,35]

Linge and Linge[31] described a method to quantify root resorption in which measurements were made on periapical radiographs before and after treatment. Their reference points included the distance from the cementoenamel junction to the root apex, and the correction of magnification was based on the ratio of crown length obtained on the radiographs before and after treatment. The measurement of root resorption was technically complex in this method. Changes in tooth length, due to magnification radiographic technique, difficulty locating the junction cementoenamel, and variations in the incidence of X-rays, were considered a limiting factor of this method.

Levander and Malmgren[4] suggested a method to analyze root resorption based on qualitative scores obtained from two-dimensional images. Estrela et al.[27] used the i-CAT software and three-dimensional images and suggested a quantitative method to evaluate inflammatory root resorption according to the root third and surface and the extent of root resorption. In our study, the acquisition of images using CBCT, the AGN method, and the software measuring tool ensured precise measurements from incisal edge or cusp to the root apex without the limiting factors associated with two-dimensional radiographs.

ARR occurs more frequently in incisors after orthodontic treatment, at rates ranging from 47% to 95%.[7,13,33] Because of the limitations of two-dimensional radiographs,[18,19,28,34] few studies have determined ARR frequency in the roots of different tooth groups,[7,8] particularly molars. In our study, the frequency of ARR in molars was higher than that reported by Apajalahti

Table 3. Absolute Frequency and Percentage Frequency (%) of Root Resorption by Gender

	No. of Roots With Resorption		No. of Roots Without Resorption		
Gender	Absolute Frequency	Frequency, %	Absolute Frequency	Frequency, %	*P*
Female	365	46	427	54	>.05*
Male	207	45	257	55	–
Total	572	46	684	54	–

* Not significant.

Table 4. Absolute Frequency and Percentage Frequency (%) of Root Resorption by Age

	No. of Roots With Resorption		No. of Roots Without Resorption		
Age, y	Absolute Frequency	Frequency, %	Absolute Frequency	Frequency, %	*P*
11	55	25	161	75	>.05*
12	42	33	84	67	–
13	202	53	179	47	–
14	169	46	198	54	–
15–16	104	63	62	37	–
Total	572	46	684	54	–

* Not significant.

and Peltola,[7] who used panoramic radiograph and found ARR in 7% and 10% of the maxillary and mandibular molars, respectively.

Factors such as the time of treatment, the direction of movement, and the magnitude and type of force applied affect ARR prevalence.[6–12] Epidemiological studies[7,9,13] of ARR prevalence have evaluated heterogeneous samples in terms of type of malocclusion and have used different orthodontic techniques and types of orthodontic appliances. All patients selected for our study had Class I malocclusion and low-severity crowding, and all of them received nonextraction treatment with fixed appliances for a mean time of 22 months, factors that may have contributed to the low severity of root resorption observed.

In our study, ARR did not change with age in patients aged 11 to 16 years. These results are in agreement with those reported by Harris et al.,[10] who also found no correlation between age and ARR, but they disagree with those registered by Preoteasa et al.,[33] who observed that ARR prevalence was affected by age and was higher among older patients.

No significant differences were found in ARR frequency between genders, in agreement with the findings of previous studies.[6–8,11] In contrast, Preoteasa et al.[33] analyzed morphological risk factors of ARR in 50 patients using panoramic radiographs and found a higher frequency among boys, whereas Levander and Malmgren[4] used periapical radiographs and detected a higher frequency among girls during orthodontic treatment of 390 maxillary incisors.

The association between orthodontic treatment and root resorption has been widely studied, but the comparison of the results is difficult as a result of differences in treatment techniques, radiographic evaluation criteria, and diagnostic imaging methods.[4,5,9–13,17–19]

Although CBCT provides an accurate assessment of ARR and no overlapping images,[20,21,27] further studies should be conducted to justify its routine use in orthodontic treatment planning. The indication of CBCT imaging studies should be evaluated carefully, with consideration of the risks and benefits.

CONCLUSIONS

- CBCT was effective for detecting even minimal degrees of ARR in vivo due to orthodontic treatment and allowed three-dimensional evaluation of dental roots and visualization of palatine roots of maxillary molars without overlapping images.
- The highest frequencies and the most significant ARR occurred in incisors and distal roots of first maxillary and mandibular molars.

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