Behavior of partially formed roots of teeth submitted to orthodontic movement

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The occurrence of root resorption in orthodontically treated permanent incisors with partially formed roots was investigated using periapical radiographs taken before and after the orthodontic leveling in the mixed dentition. The mean age at the beginning of treatment was 9 years and the mean treatment time was 7.1 months. The findings showed that the orthodontic movement during root formation causes no root resorption. The longitudinal follow-up showed that incompletely formed roots developed normally.
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INTRODUCTION

Several studies focus on the most common and feared iatrogenic effect of the orthodontic treatment: the root resorption during induced orthodontic movement of teeth with completely formed roots. Such a biological susceptibility is caused by tissue alterations in the periodontal ligament and has never been contested. In fact, the procedures indicated to diminish the damage have derived from the observation of the root resorption process. Guidelines recommend careful standardized approaches throughout the orthodontic treatment that include the use of light, constant or decreasing[1] forces applied in intervals that allow for the periodontal ligament healing.[2] In addition, some clinical procedures have also been suggested, such as obtaining periapical radiographs at the beginning of treatment and six months thereafter in order to evaluate the root behavior before and during treatment.[2-7] A summary of such guidelines has been published in Brazil and entitled "Root resorption in the orthodontic practice: managements toward a preventive care".[3]

On the other hand, only a few studies about root behavior in teeth with open apexes are available. In such teeth, the biological process of root formation is still in course. The lack of information on this issue raises some doubts on the real biological costs involved in the movement of permanent incisors in the mixed dentition during the 4x2 leveling and alignment. The fact that the permanent incisors are greatly involved in this type of mechanics, along with the tradition to present orthodontically induced root resorption, is another point to consider.[8,9] However, histological[10] and radiographic images[11-15] show that teeth with open apexes are less prone to present apical root resorption after induced orthodontic movement than teeth with closed apexes, both in the posterior[11,14,15] and anterior[12,13] regions.

Our experience with interceptive orthodontics has demonstrated that the risk of causing either root resorption or any alteration in the root formation during the induced movement of permanent incisors with open apexes is practically negligible. Forces

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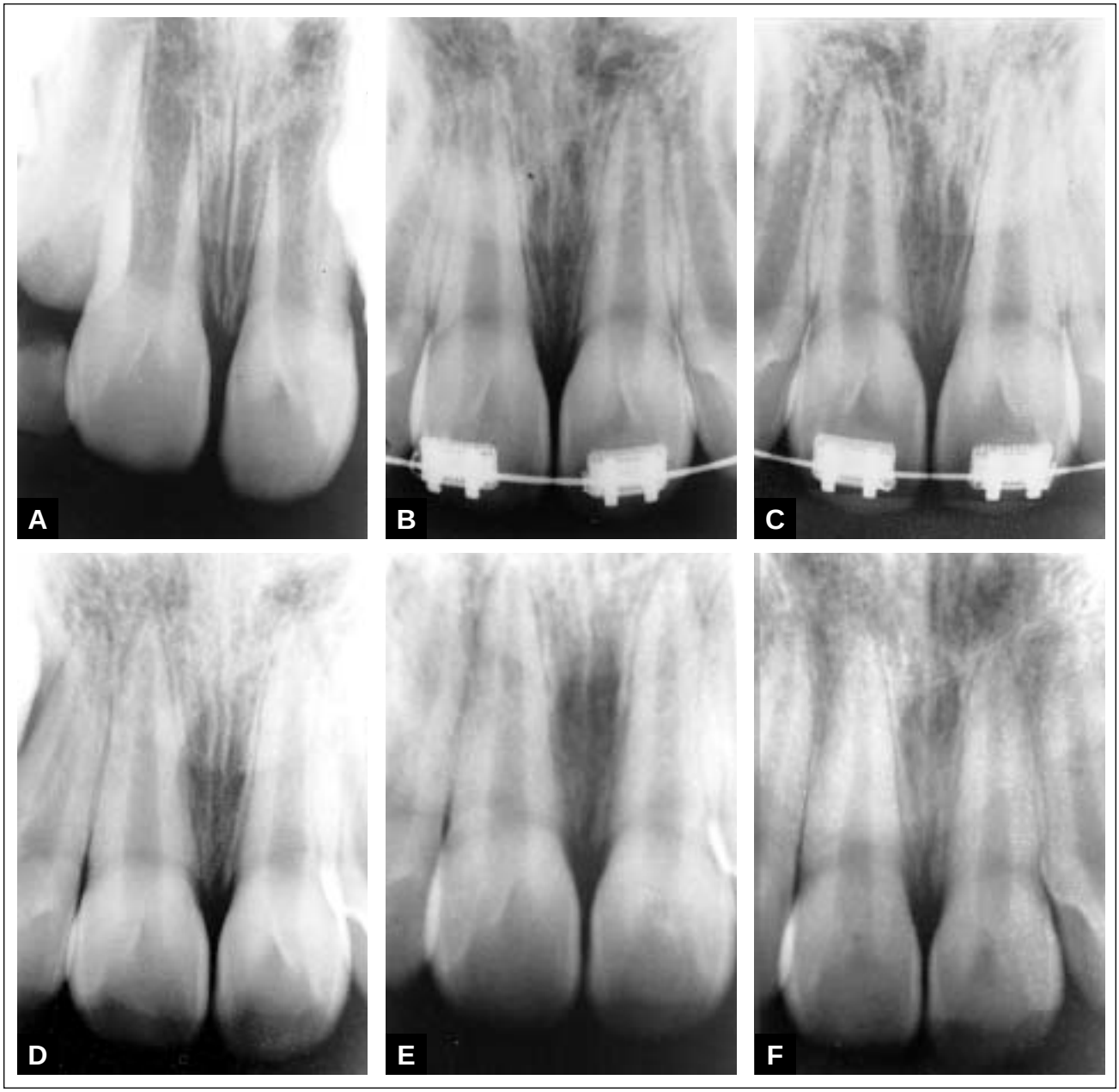


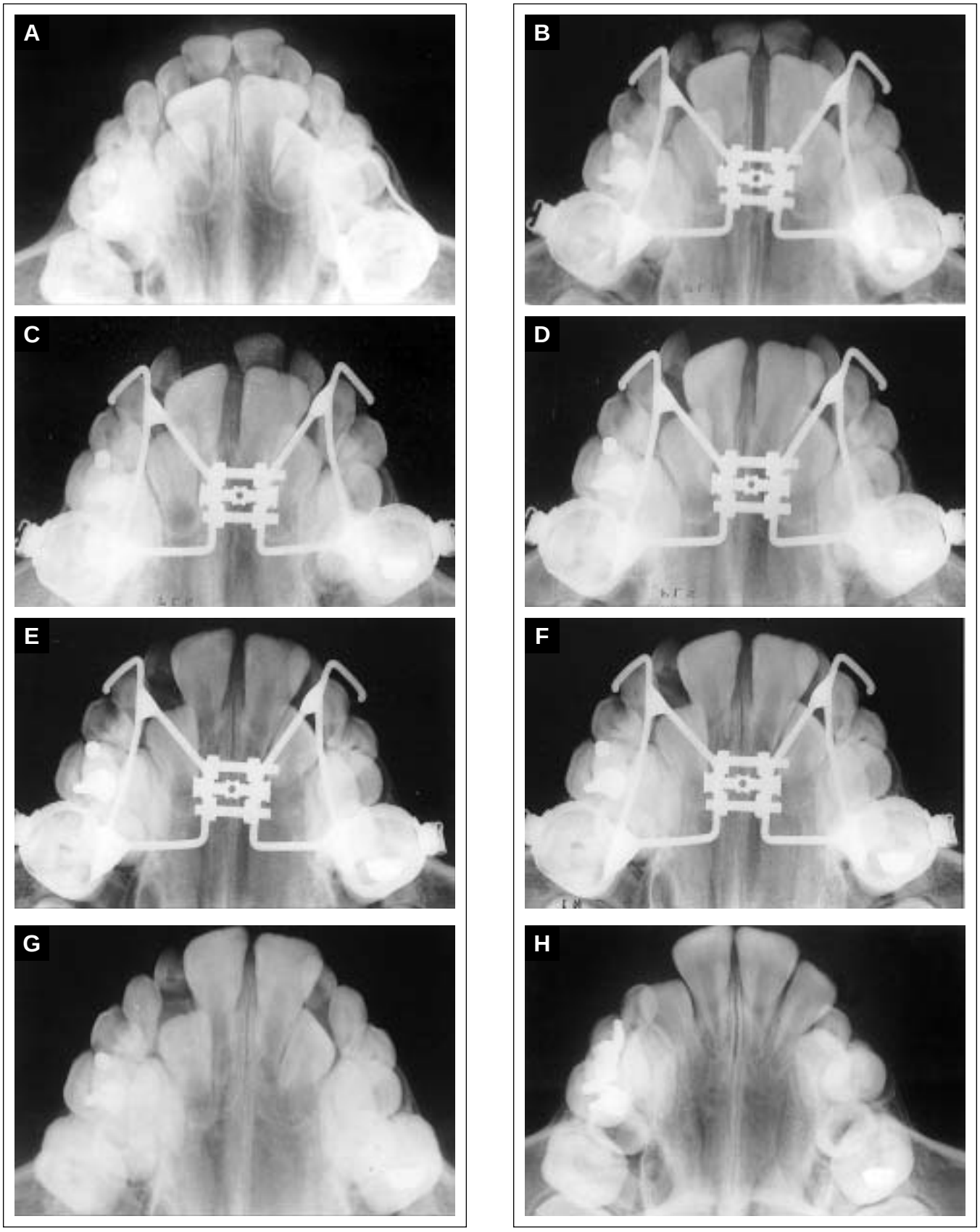
Figures 1A to 1F. Long-term follow-up with periapical radiographs of the pre-treatment stage (A), active phase of orthodontic treatment (B), end of mechanotherapy (C) and post-treatment stage (D, E, F). The radiographic images confirm that the root formation is not altered during treatment and that the typical apical resorption found after orthodontic movement does not exist.

1A 10.08.95 **1B** 11.04.97 **1C** 10.07.97 **1D** 17.04.98 **1E** 21.07.99 **1F** 12.04.01

released by the 4x2 leveling (Figure 1) and forces biologically produced during the opening and closure of the inter-upper central incisors diastema due to rapid maxillary expansion (RME) have demonstrated a low risk of root resorption in such an early stage of the occlusal development (Figure 2). Studies have reassured such findings and justify that this favorable root reaction seems to be related to a biological environment of protection represented by the dental papilla during the root formation process.[16]

LITERATURE REVIEW

The paper that firstly related the amount of root resorption during orthodontic treatment to age was published in 1940 by Rudolph.[15] The author developed a study with panoramic radiographs in which variables like gender, age at the beginning of treatment and treatment time were considered. The findings showed that the percentage of resorption at the beginning of treatment increased according to age and time. Therefore, the author concluded that the orthodontic treatment is less harmful to the root



Figures 2A to 2H. Longitudinal maxillary occlusal radiographs illustrating the behavior of permanent upper incisors before RME. The central incisors buds are separated during the active phase of expansion (2B). Figures 2C to 2H show the re-approximation of the apices during the passive phase of expansion.

2A 22.01.01 **2B** 13.06.01 **2C** 11.07.01 **2D** 13.08.01 **2E** 12.09.01 **2F** 15.10.01 **2G** 29.11.01 **2H** 24.11.02

structure when it starts earlier, though the results should be carefully analyzed due to some failures in the methods, such as: 1) use of panoramic radiographs; 2) undetailed description of the orthodontic appliance and the teeth involved, and 3) use of chronological age instead of the root formation stage as reference, which provided poor information on the degree of root formation.

Three decades later, in 1972, Rosenberg[14] also used panoramic radiographs to determine the incidence and the amount of apical root resorption and dilacerations in teeth with partially formed roots at the beginning of the orthodontic treatment. The average resorption values were insignificant (less than 0.5 mm). Only 6% of all studied teeth showed a resorption greater than 2 mm. The incidence of root resorption found in the research was 37%. The authors concluded that orthodontically moved teeth with partially formed roots can reach expected normal lengths after treatment. Significant side effects that might counter-indicate orthodontic movement of teeth with partially formed roots were not reported. The author detected 8% of root dilacerations in response to the induced dental movement. Again, the results of such study are limited due to the shortcomings of the methodology. Panoramic radiographs are known to present great limitations for the diagnosis of the root structure.

In the 1980's, Linge and Linge[12] studied the incidence and extension of apical root resorption in the upper incisors by means of a more accurate method than in the previous works. The authors examined periapical radiographs that had been standardized by the long cone paralleling technique and checked the influence of the pre- and post-treatment ages. Patients whose treatment initiated at the age of 11, when root development of the upper permanent lateral incisors is supposed to have ceased, showed a mean root shortening twice as great (1.0 mm) in relation to patients whose treatment started earlier (0.5 mm). The authors mentioned that the reason why patients whose treatment had started earlier presented less root damage should not rely only on periodontal tissue-related factors, but also on a better muscular adjustment to the occlusal changes.

Hendrix *et al.*,[11] published a radiographic study to determine the extension of the apical root resorption in posterior teeth (canines and premolars) following fixed orthodontic treatment with edgewise appliance. The work included a possible correlation between the amount of resorption and the following factors: gender, age, stage of root formation and treatment time. Although teeth with partially formed roots did not reach "normal" average length probably due to the apex displacement during treatment, they presented longer post-treatment roots than teeth with fully formed roots. Such finding was justified by the greater resistance to root resorption that teeth with partially formed roots present when compared to teeth with fully formed roots. In face of such data, the authors recommend that the orthodontic treatment be initiated when roots are partially formed. Such as in the studies of Rosenberg[14] and Rudolph[15], the great limitation of this study lies on the use of panoramic radiographs.

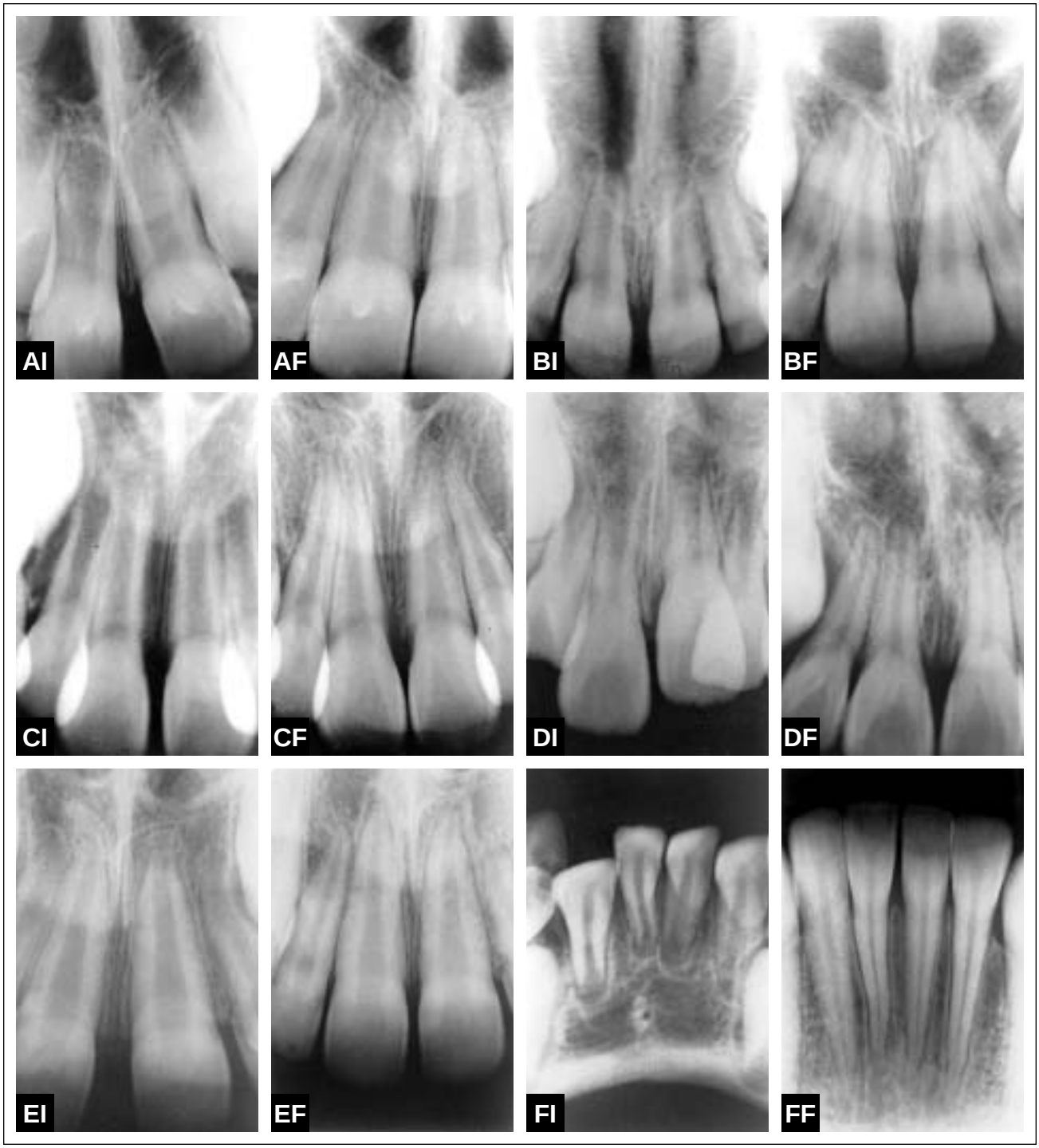
In 1994, Silva Filho *et al.*[17] did a radiographic study about the effects of RME on the anchorage premolars. The comparison between pre- and post-expansion periapical radiographs led the authors to conclude that the force released by RME does not cause resorption either on the proximal surfaces or at the apexes. In patients with open apexes, root formation was not interrupted.

With the aim to investigate the possible biological hazards of RME in the mixed dentition, Silva Filho *et al.*[18], developed a long-term radiographic study to evaluate the behavior of the upper permanent central incisors with partially formed roots in response to RME. Long cone paralleling periapical radiographs were used and neither radiographic characteristics of external root resorption nor signs of anomalies in the root formation were found in the permanent incisors that underwent orthodontic movement in association with RME.

Mavragani *et al.*[13], evaluated the cost/benefit ratio of an early orthodontic treatment with regards to the root resorption of the four upper permanent incisors. The regression analysis revealed that the post-treatment root length was significantly related to the age at the beginning of treatment. When the same age was considered, roots whose length increased during the orthodontic treatment did not present differences when compared to teeth that had not undergone orthodontic forces. Teeth with partially formed roots before treatment reached a greater length than teeth with fully formed roots at the beginning of treatment. The authors concluded that the orthodontic treatment does not cause root resorption in teeth with partially formed roots. Therefore, a definite advantage was attributed to the orthodontic treatment in teeth with open apexes.

MATERIAL AND METHODS

In order to verify the occurrence of root resorption after induced dental movement in permanent central incisors with partially formed roots, periapical radiographs of 46 patients (26 males and 20 females) were evaluated in the Post-Graduate Program of Interceptive Orthodontics at PROFIS, in Bauru, Brazil. The patients were treated with a 4x2 leveling in the mixed dentition (Table 1). Seventy-nine upper permanent central incisors and 12 lower permanent central incisors (n = 91) were examined. The radiographs were obtained by the long cone technique and were taken before and after the 4x2 leveling (Figure 3). The mean age at the beginning of treatment was 9 years 3 months for males and 8 years 11 months for females. The mean treatment time was 7 months for males and 7.25 months for females. The orthodontic mechanics consisted of a fixed edgewise appliance that included two posterior teeth (anchorage) and the four permanent incisors (orthodontic movement). In intervals



Figures 3A to 3I. Periapical radiographs of some of the incisors evaluated in this study, taken before (I) and after (F) the orthodontically induced movement.

3A-I **3A-F** **3B-I** **3B-F** **3C-I** **3C-F** **3D-I** **3D-F** **3E-I** **3E-F** **3F-I** **3F-F**

varying from 3 to 4 weeks, the leveling archwires were substituted by archwires of the same thickness or thicker, following an established clinical sequence: .016" nickel-titanium orthodontic wire and .016", .018" and .020" stainless steel wires. None of the patients received a rectangular archwire.

Five examiners endowed with similar orthodontic credentials did the analysis of the pre- and post-treatment radiographs by projecting them in a dark room. The examiners were instructed to search for any radiographic sign that might suggest the typical root resorption that happens during an orthodontic

treatment. As all teeth presented incomplete roots, no attempt was made to determine the geometric shape of the apical third or to classify the resorptions according to magnitude, i.e. reduction in relation to the original root length. Therefore, the interpretation of the data was based upon the longitudinal qualitative and comparative evaluation of the radiographic image.

Table 1. Components and characteristics of the studied sample

	Male	Female
Number of patients	26	20
Mean age at the beginning of leveling	9 y 3 m	8 y 11 m
Mean treatment time	7 months	7.25 months
Number of examined teeth		
Upper central incisors	47	32
Lower central incisors	4	8

RESULTS

Three of the five examiners did not find images of apical resorption in any of the evaluated radiographs. Only two examiners detected slight signs that suggested root resorption in the post-leveling periapical radiographs. One of the examiners diagnosed root resorption in four incisors, and the other in just one incisor that coincided with one of the four incisors already identified. In a simple descriptive statistic analysis, the prevalence of root resorption found by the five examiners in the 91 permanent central incisors corresponded to 4.4%.

DISCUSSION

The mechano-transduction, which is responsible to move teeth during the orthodontic treatment, triggers the irreversible iatrogenic process of external root resorption in the apical region.[9,10,15,19,20,21] This process is usually mild[28] and is interrupted after removal of the force.[7,10,12,21,22,23] From this point onwards, the areas of tissue loss starts being repaired by acellular and cellular cement,[10,13,21,24,25] without compromising the occlusion in the long-term.[22,23,26] It is correct to state that root resorption always happens in the orthodontic treatment and represents the reaction of the periodontal ligament. After applying an orthodontic force, the pressure over the periodontal ligament induces a sterile inflammatory process that releases chemical messengers to promote the necessary bone remodeling that allows for dental movement.[21] Such alterations in the histochemical environment of the periodontal ligament lead to an external root resorption in both the cement and the dentin and is known as the "orthodontically induced inflammatory root resorption",[20] responsible for the root shortening. A correlation between the hyalinized zones in the periodontal ligament and root resorption seems to exist, as the removal of such hyalinized areas also uncovers the root.[20]

When the cementoblast layer, which consists of an additional protection for the root that covers the pre-cement, is damaged, the highly mineralized surface of the root remains exposed and vulnerable to the action of clasts.[10,21,25,27] Therefore, from a histological standpoint, root resorption starts after a damage or removal of the cementoblasts and pre-cement layer, which is present along the root surface in normal conditions.

Actually, apical resorptions can only be identified in the clinical practice when periapical radiographs are taken, mainly by the long cone technique.[28] Thus, it is mandatory to obtain pre-treatment periapical radiographs in order to follow up the integrity of the roots during the mechanotherapy in all patients where an induced dental movement is indicated, regardless of age. Notwithstanding, the use of periapical radiographs, as a rule, still seems to be usually restricted to initial records of adult patients.[29] It is obvious that periapical radiographs are superior to panoramic radiographs, both in terms of dimensional changes[30,31] and root morphology[31] as well as of distortions and sharpness of the root image.[32] In the current study, the periapical radiograph sufficed to follow up the root formation of permanent central incisors during the mechanotherapy (Figures 1 and 3).

The results for the permanent dentition differed from previous data, in which 100% of the patients exhibited a certain root resorption in any of the teeth during fixed orthodontics.[9] In fact, our findings show normal root behavior in teeth with partially formed roots. The orthodontically moved permanent incisors that comprised the present sample were in the mixed dentition and had open apices, so that the roots were still under formation. However, the stage of such root formation can be regarded as advanced, considering that the protocol of a 4x2 leveling requires that the incisors crowns have reached the occlusal plane, that is, when the active phase of eruption has already ceased. Anyway, such induced movement was done much earlier than in the available studies. The teeth analyzed in the current study had apices under formation. In this circumstance, it is clear that two ongoing processes take place in the apex region at the same time: 1) the biological process of the dental papilla that determines the tooth final length; 2) the biological process induced by the orthodontic mechanics along the periodontal ligament. The radiographic behavior, as identified in the periapical radiographs, suggests that the biological process of the induced dental movement was not able to significantly disturb the biological process of root formation.

Most of the related orthodontic studies, apart from being scarce, present many shortcoming methodologies

but do not counter-indicate the orthodontic treatment in teeth with open apices with regards to a possible root shortening due to induced movements. Conversely, they encourage the orthodontic treatment to be initiated before the closure of the root apex.[10-15] Our concern about the root formation of permanent incisors has been long-lasting and arose from the indication of RME in the primary or early mixed dentitions during very early stages of root formation of permanent central incisors (Figure 2). However, the radiographic follow-up allowed us to conclude that the biological process inherent to the dental papilla did not alter in response to the movement of central incisors or the buds during the splitting and reorganization of the mid-palatine suture.[18]

The orthodontic movement studied in the present research was produced by the 4x2 leveling. Treatment was initiated with .016" nickel-titanium archwires, which were removed at mean intervals of three weeks. The same archwire was re-used if the brackets slots were not still aligned enough to allow for the use of a stainless steel round archwire. Then, a sequence of .016", .018" and .020" round stainless steel archwires were used. No rectangular archwire was used. The root behavior in response to the dental movement was evaluated through longitudinal periapical radiographs.

The analysis of periapical radiographs showed that the moved incisors did not exhibit the typical root resorption commonly seen in orthodontically moved permanent teeth. Moreover, root formation was found to occur simultaneously to dental movement. Therefore, moving teeth with partially formed roots does not seem to cause root resorption and does not even interfere with the normal biological process of apex closure. This result suggests that the biology of the dental papilla surpasses the biology of the dental movement. Hendrix *et al.*,[11] in a study with panoramic radiographs, also concluded that the orthodontic movement does not disturb the root development. Teeth with open apexes at the beginning of the orthodontic treatment keep on developing during the mechanics. Mavragani *et al.*,[13] even concluded that teeth reached the expected length.

An important observation should be emphasized in the present study. In relation to a fixed orthodontic treatment in the permanent dentition, the main dental movement was limited to a tipping of incisors in the alveolar ridge by using round wires only, within a relatively short treatment time (7 months). Recent works have identified some factors such as the extraction of teeth, overjet correction and treatment time as capable of determining the amount of root resorption,[2] mainly in the upper anterior teeth,[2,8] as well as the use of rectangular archwires and treatment time,[12] However, data similar to our results were also obtained in periapical radiographs of permanent incisors treated with orthodontic appliances in which the rectangular archwire was used to correct a Class II, Division 1 malocclusion.[13]

Signs of root dilacerations were not noticed in the periapical radiographs of the permanent incisors studied. This is supported by some studies. Linge and Linge[12] stated that apical anomalies were not observed in periapical radiographs of incisors with partially formed roots after moving them. The matter of root dilacerations in response to an induced dental movement was raised in histological studies and was based upon the bending to which the Hertwig epithelial sheath could be submitted.[33,34] It is possible that such alterations do not go beyond the histological level.

Based upon our positive radiographic results, clinical pitfalls that could counter-indicate the 4x2 leveling were not observed in the mixed dentition. Problems like loss of pulp vitality, crown darkening, pain or significantly increased tooth mobility were not found.

CONCLUSION

From a radiographic perspective, the analysis of longitudinal periapical radiographs did not show iatrogenic characteristics with regards to root integrity and the normal pathway of root formation during the orthodontic movement of permanent central incisors with partially formed roots.

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