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Original Article

A clinical review of external apical root resorption and self-repair of maxillary incisors after orthodontic treatment

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Abstract: The purpose of this study was to investigate the degree of root resorption after orthodontic treatment and self-repair of the root following two years of retention by measuring the root length of the maxillary incisors before, immediately after and two years after orthodontic treatment. Sixty patients with Angle Class II division 1 malocclusion ranging in age from 12 to 22 who were treated with bilateral maxillary first premolar extraction and a straight wire appliance were selected for the study. Parallel periapical radiographs were obtained, and the length of the maxillary incisor roots was measured before treatment (T_1), immediately after treatment (T_2) and two years after treatment (T_3). A Wilcoxon signed-rank test and a chi-square test were used in the statistical analysis. In the present study, 97% of the incisors exhibited different degrees of external apical root resorption (EARR) after orthodontic treatment. The amount of EARR for the central incisors (1.1 mm) was significantly less than that for the lateral incisors (1.3 mm) ($P=0.022<0.05$). Significant differences were observed between the degree of EARR immediately after treatment and two years after treatment for both the central and lateral incisor groups ($P<0.001$). In conclusion, the resorption of the lateral incisors was much greater than that of the central incisors. Self-repair with cementum materialization occurred only in roots with mild or moderate resorption, and only a small portion of teeth with mild EARR could be fully regenerated or remodeled. Additional resorption occurred in roots with severe resorption, and no regeneration or self-repair was observed in these teeth.

Keywords: Root resorption, self-repair, cementum regeneration, parallel periapical radiographs

Introduction

Orthodontics is a specialty that involves the application of orthodontic force to move teeth and complete the periodontal tissue reconstruction process, which is expected to lead to better aesthetics and function for patients. However, this procedure can also cause problems, such as decreased stability of the teeth and reduced marginal attachment. Several studies have documented that different degrees of apical resorption can be observed in the majority of orthodontic patients. However, resorption can occasionally be reversed or remodeled after the removal of active appliances [1-7]. Currently, clinicians and patients pay more attention to the safety of orthodontic treatment. The majority of these studies about root repair after resorption were performed in animal or *in vitro* studies; however, a few clinical studies have been reported [3, 8]. Therefore, whether repair could occur in all types of orthodontic root resorption and the extent of that repair remain largely unclear. The purpose of this study was to analyze the prevalence of apical root resorption and the extent of root self-repair after active orthodontic treatment by measuring the length of the upper incisor roots before, immediately after, and two years after treatment using parallel periapical radiographs.

Materials and methods

Subjects

Sixty patients (29 males and 31 females) who completed orthodontic treatment between 2008 and 2011 were included in this study. The mean age was 17 years, and the range was 12 to 22 years.

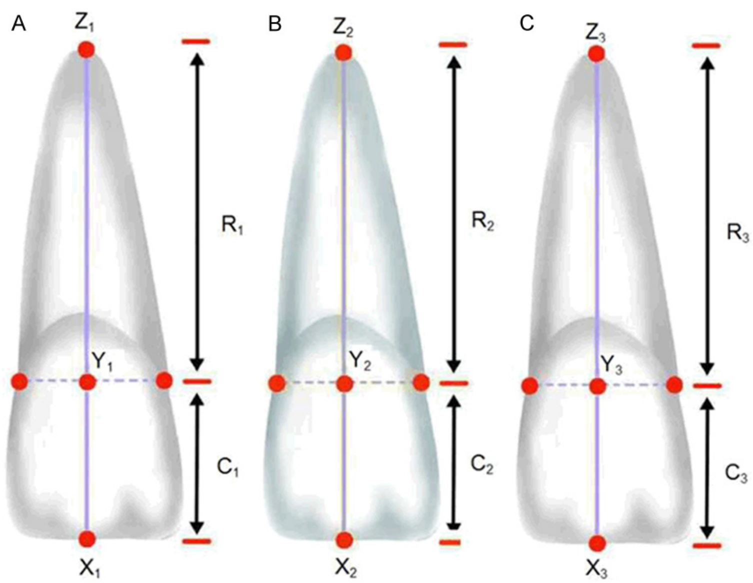

Figure 1. The points used and distances measured on the examination of the parallel periapical radiographs. A. Before treatment; B. Immediately after treatment; C. Two years after treatment. X_1, X_2, X_3, mid-incisal points of the crown; Y_1, Y_2, Y_3, mid-points of the CEJ; Z_1, Z_2, Z_3, most pointed parts of the root; C_1, C_2, C_3, crown lengths; R_1, R_2, R_3, root lengths.

Table 1. The differences in the degree of root resorption of the central incisors at different time points

Time	No EARR	Mild EARR	Moderate EARR	Severe EARR
Before treatment	98	0	0	0
Immediately after treatment	2	74	15	7
Two years after treatment	22	62	6	8

N=98, *P*<0.001.

Table 2. The differences in the degree of root resorption of the lateral incisors at different time points

Time	No EARR	Mild EARR	Moderate EARR	Severe EARR
Before treatment	98	0	0	0
Immediately after treatment	4	50	35	9
Two years after treatment	21	52	14	11

N=98, *P*<0.001.

Inclusion Criteria: 1) Individuals with Angle Class II division 1 malocclusion who were treated for 22 to 30 months (mean, 26 months; SD, 2.1) by a Roth straight wire appliance after extraction of the first premolars. 2) Individuals with parallel periapical radiographs of the maxillary incisors taken before, immediately after, and two years after treatment with the crown, apex and cemento-enamel junction (CEJ) fully visible. 3) Individuals with healthy incisors that had completely developed roots without tooth fracture and with no history of orthodontic treatment or facial trauma before or after treatment. 4) All orthodontic treatments performed by clinicians with 20 years of experience, all orthodontic force applied within the range of 50 to 200 g, and the use of a retainer for two years after treatment.

In total, 196 teeth in 51 patients met the study criteria, including 98 central incisors and 98 lateral incisors.

Parallel periapical radiographs

Standardized periapical radiographs were obtained by a single operator with the Kodak CS2100 Intraoral X-ray Machine (Eastman Kodak, Rochester, New York, USA), set for 70 kv, 10 mA, and an exposure time of 1 second with the long-cone paralleling technique. The angles were obtained by an intraoral XCP positioner (Rinn-Dentisply, Elgin, Illinois, USA). The radiographs were developed with a Dent-X automatic dental film processor, scanned at a resolution of 1000 dpi, and viewed on a large monitor.

The length of root evolution

The measurement and calculation of the external apical root resorption (EARR) [9] were performed as follows. The maxillary incisors were measured on the radiographs obtained before, immediately after, and two years after treatment. The crown length was measured from the median CEJ dot image, which is the midpoint between the mesial CEJ and the distal CEJ points, to the median incisal edge dot image. The root length was measured from the median CEJ dot image to the most apical dot image (**Figure 1**). The

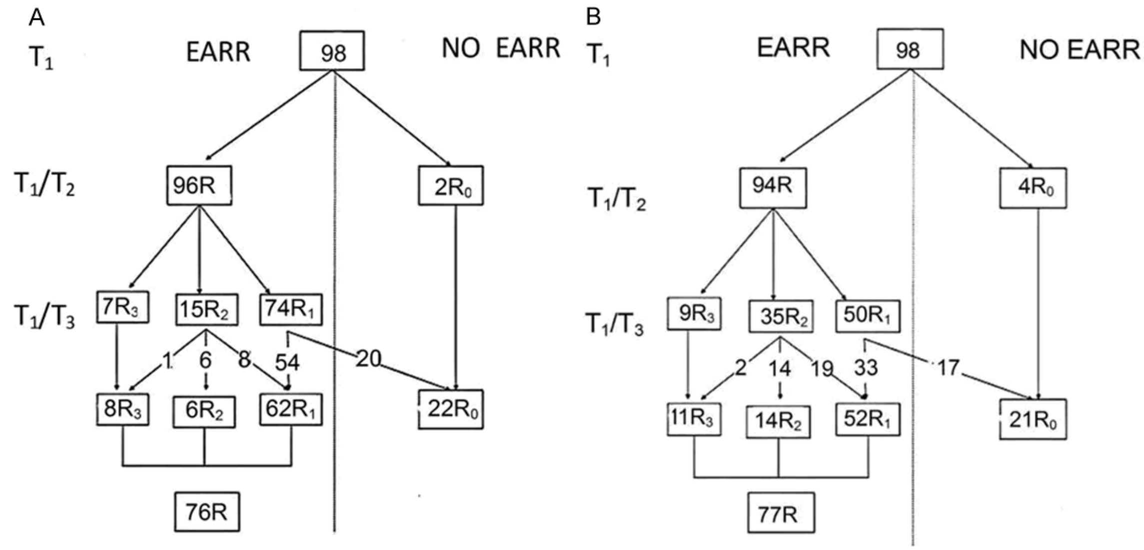

Figure 2. The numbers of central incisors (A) and lateral incisors (B) (n=98) with apical root resorption. T_1, before treatment; T_2, immediately after treatment; T_3, two years after treatment; R, resorption present; R_0, no resorption present; R_1, mild resorption; R_2, moderate resorption; R_3, severe resorption.

root apex, incisal edge, and CEJ dot of each tooth were marked on the scanned images (Microsoft Adobe Photoshop 10.0). The measured value for each tooth in millimeters was calculated with a fine tip measuring 0.01 mm. Any image enlargement and the effects of angular changes between the pre- and post-treatment radiographs could be corrected using the crown length as a reference because it is assumed that the crown length does not change during orthodontic treatment. Therefore, the ratio of the pre-treatment crown length (C_1) to the post-treatment crown length (C_2) was determined as the post-treatment correction factor (CF_1). The two years' post-treatment correction factor (CF_2) was determined using the ratio of C_1 to the crown length two years after treatment (C_3). Correction factors were calculated to assess the root lengths for different times, as shown in the following **Equations**:

Immediately after treatment: $CF_1=C_1/C_2$

$EARR_1=R_1-(R_2\times CF_1)$

Two years after treatment: $CF_2=C_1/C_3$

$EARR_2=R_1-(R_3\times CF_2)$

It was decided to express root resorption as the percentage shortening per tooth because the differences in the root lengths of various teeth make individual comparisons of the root resorption values (in millimeters) less meaningful. Therefore, the percentage value and degree of resorption provide a better method for assessing the EARR [10].

Percentage of EARR per tooth= (EARR×100%)/R1

The degree of EARR was classified based on the percentage shortening per tooth. Four degrees of EARR severity were noted: no EARR, 0%; mild EARR, ≤10%; moderate EARR, >10% to 20%; and severe EARR, >20%.

Statistical analyses

All root lengths were measured twice by one person. The reproducibility of the measurements was assessed by statistically analyzing the differences between these two measurements, which were obtained at least 10 days apart from the T_1, T_2 and T_3 radiographs of 20 randomly selected patients. The test revealed a high correlation (r=0.80) between the first and second measurements. The correlation was considered to be significant at $P<0.05$.

Descriptive statistics were calculated for the analysis of the EARR using a standard statistical software package (SPSS for Windows, version 22.0). Changes in root length between the pre- and post-treatment radiographs for the central and lateral tooth groups were deter-

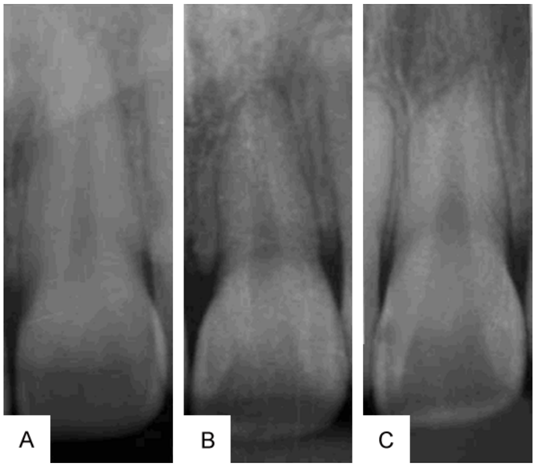

Figure 3. The maxillary central incisor with severe EARR occurred further resorption. A. Before treatment; B. Immediately after treatment; C. Two years after treatment.

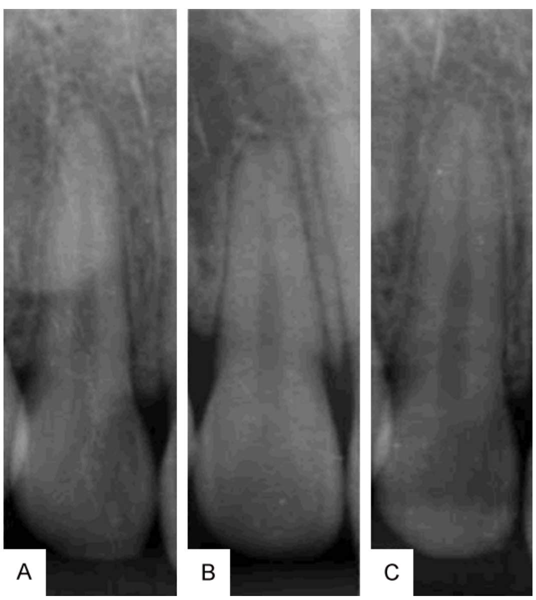

Figure 4. The maxillary lateral incisor with moderate EARR exhibited reversal to mild EARR. A. Before treatment; B. Immediately after treatment; C. Two years after treatment.

mined with a Wilcoxon signed-rank test. A chi-square test was used to test the differences in the degree of EARR between the radiographs obtained immediately after and two years after treatment. The differences were considered to be significant at $P<0.05$.

Results

The changes in the degree of maxillary resorption of the incisors immediately after to two years after treatment were assessed using a chi-square test for data in a 2×4 table (**Tables 1** and **2**). *P*-values less than 0.05 were considered statistically significant.

Of the 196 maxillary incisors examined in this study, 97% exhibited some degree of EARR after treatment. A total of 63.2% of the investigated teeth exhibited mild EARR, 25.5% exhibited moderate EARR, and 8.1% exhibited severe EARR. The mean value for the EARR was significantly different between the central incisors (1.1 mm) and the lateral incisors (1.3 mm) and was determined using a nonparametric rank sum test. This result indicates that the maxillary central incisors had less EARR than did the lateral incisors. The most severe EARR (exceeding 30%) was present in four teeth, all of which had a root length of <9 mm after orthodontic treatment.

The mean percentages of root shortening in the maxillary central incisors immediately after treatment were 2% for the no EARR group, 76% for the mild EARR group, 15% for the moderate EARR group, and 7% for the severe EARR group compared with the pre-treatment values (**Figure 2A**). Two years after treatment, 26% of the teeth with mild EARR exhibited repair activity and regained their original root length. In moderate EARR teeth, although 53% of the resorptive teeth exhibited reversal to mild EARR, the final shape of the root after this process was not identical to the initial shape . In addition, 7% of the moderate EARR teeth developed severe root resorption (>20% of the original root length was lost). No changes in the degree of EARR were observed in 74% of mild and 40% of moderate EARR patients; however, root length repair was observed in the majority of the resorptive teeth in the radiographs taken two years after treatment. In this study, further resorption occurred in the severe EARR roots, and no regeneration or self-repair was observed (**Figure 3**).

For the lateral incisors, 4% were classified as no EARR, 51% as mild EARR, 36% as moderate EARR, and 9% as severe EARR (**Figure 2B**). In the assessment performed two years after treatment, 30% of the teeth with mild EARR immediately after treatment exhibited repair activity and regained their original root length. In the moderate EARR teeth, although 51% of the resorption had reversed to mild EARR, the

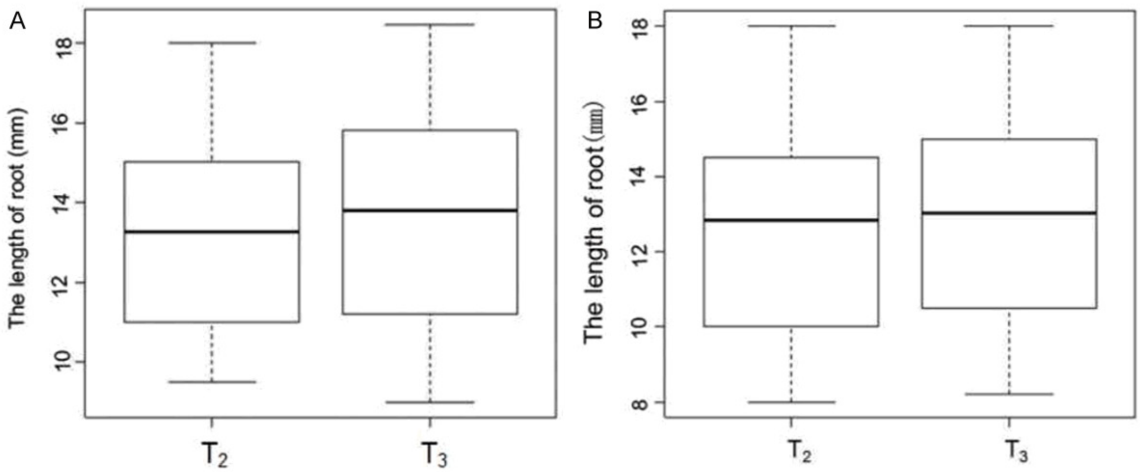

Figure 5. Box and whisker plots of the changes in root length between the radiographs obtained immediately after treatment (T_2) and two years after treatment (T_3) for the maxillary central incisors (A) and lateral incisors (B).

final shape of the root after this process was not identical to the initial shape (**Figure 4**). In addition, 6% of the moderate EARR teeth developed severe root resorption (>20% of the original root length was lost). No changes in the degree of EARR were observed in 70% of the mild EARR teeth and 43% of the moderate EARR teeth. However, root length repair was observed in the majority of the resorptive teeth on the radiographs obtained two years after treatment. In this study, further resorption occurred in the severe EARR roots, and no regeneration or self-repair was observed.

Statistically significant differences were noted in the comparative analysis of the root length between the radiographs obtained immediately after and two years after treatment, as shown in box and whisker plots (**Figure 5**). The present findings suggest that the resorption of orthodontically treated teeth could be repaired to some extent.

Discussion

In this study, only healthy Chinese patients between 12 and 22 years of age with intact proclined maxillary incisors were selected to reduce possible inter-subject variation [11]. Twelve years was selected as the lower age limit of the sample to exclude the undesirable effects of unfinished root formation [12], and 22 was selected as the upper age limit to eliminate the unfavorable effects of aging, which may lead to greater EARR due to the presence of narrower periodontal ligament spaces, denser alveolar bone and fewer bone marrow spaces [13]. Maxillary incisors with Angle Class II division 1 malocclusion were selected because it is well known that root resorption occurs more frequently in these teeth [14]. In our study, some degree of EARR was noted in 97% of the maxillary incisors, which is consistent with earlier observations [10, 15].

Our study supplements previous work and provides a clinical review of root resorption two years after orthodontic treatment, self-repair, and retention based on radiographic comparisons [16-19]. It was previously reported that root resorption was commonly observed in periapical radiographs of orthodontically treated teeth during the first six months of active treatment along with a 3.5-fold increase in resorption during the subsequent six months [16]. After treatment is completed and there is no force being applied, there is still a lasting tendency for root resorption. However, the repair process of the resorbed area begins during active movement when the force provided is below a certain level [17]. There have been controversial findings regarding this observation in animal experiments [15]. Certain rat studies have claimed that root resorption was interrupted when the applied force was removed for one to three days. The repair of resorption gaps includes the deposition of cementum. There is no consensus in the literature regarding the point at which root resorption stops and repair begins.

A retainer provides great resistance against tooth movement and relapse and is beneficial for the regeneration of periodontal tissue [20, 21]. To retain the tooth in its new position and resist the passive stress from the periodontal ligament, a complex regeneration of the periodontal tissues occurs that requires six to 12 months to complete. The repair of the resorbed roots generally continues for a longer period. The attachment of periodontal fibers could occur during this period, and repaired cementum deposited on resorbed surfaces and alveolar bone could increase the reconstruction in the presence of stimulation from normal function. The amount of repaired cementum is related to the time after the cessation of treatment [3, 22]. Therefore, we selected two years after treatment for the final observation to investigate the extent of self-repair of the resorbed roots with longer-term stability of the periodontal tissue.

Most clinicians use panoramic or cephalometric radiographs to detect EARR. Although panoramic films can provide more information, lessen the patient's chair time and reduce the radiation exposure, panoramic radiographs lead to an overestimation due to their approximately 20% magnification of the teeth and because the amount of magnification varies for teeth depending on location. Therefore, metric evaluations using panoramic radiographs are generally considered to be unreliable in addition to having poor reproducibility [23]. Cephalograms also have an inherent inaccuracy when used to evaluate EARR. The root length can become distorted and obscured with this imaging technique due to the number of overlapping structures. The present study used parallel periapical radiographs because these images are superior to the above radiographic images in terms of fine detail and reduced degree of distortion. Some effects may occur due to the angular changes between the tooth and the film with regard to the length of the image of a tooth model, but a method to overcome this inaccuracy using the correction factor [9]. However, parallel periapical radiographs cannot be used to assess the amount of root loss in the buccal and lingual surfaces. Therefore, future studies should be performed using cone beam computed tomography to evaluate three-dimensional EARR.

Root resorption appears to be an inevitable and common sequela to orthodontic tooth movement, and the related risk factors are complex and multifactorial [14, 24]. Although the magnitude of force applied in the present study was less than 200 g, which does not appear to be a significant factor affecting root resorption, 97% of the orthodontically treated teeth exhibited some degree of EARR. This finding is consistent with the findings of several other investigations [14, 25, 26]. In this study, a number of orthodontic treatment-related factors potentially associated with severe root resorption were noted, such as longer apical displacement, low intrusive movement, the use of Class II elastics, and root torque. Orthodontic corrective therapeutic treatment is also accompanied by EARR in the maxillary incisors, and EARR is most evident in the lateral incisors, which may be associated with the more frequent anatomical root variations of the lateral incisors compared to the central incisors [10, 27].

The cementum layer covering the dentin is approximately 50 to 200 μm thick, and the cementum is thicker at the root cervical area than at the root apex. This layer exhibits increased resistance to resorption compared with alveolar bone, which is likely due to the basic biological mechanisms of orthodontic tooth movement. Orthodontically induced inflammatory root resorption has been increasingly recognized as an iatrogenic consequence of orthodontic treatment that leads to the resorption of the dentin underlying the damaged cementum. This is followed by a sequence of repair activity on the resorbed surface [3, 4, 8, 28-30]. Morphologically, the repair process of the resorbed surface occurs on the periphery, the bottom, or in all directions. The placement of acellular cementum is succeeded by cellular cementum, and the resorbed lacunae subsequently become covered with cementum or dentin [8, 28-30]. It has recently been reported that a specific cementum attachment protein, a dentin matrix protein, the Malassez epithelial rest and the regeneration of periodontal fibers may play important roles in the repair process [4, 31]. However, the amount of cementum regeneration in the resorbed root has known limitations [19]. It has been indicated that parathyroid hormone (PTH) has potential benefits (1-34) in promoting the repair process in a rat model [32]. However, other studies have questioned whether PTH (1-34) has undesirable side effects, such as inhibiting the speed of tooth movement. Therefore, more research is needed before PTH (1-34) can be used in humans [33].

Various degrees of apical root shortening exist for different amounts of external surface repair [19, 21, 34-36]. In addition, there is no consensus regarding whether the roots that exhibit resorption in radiographs actually have measurable self-repair or undergo further resorption. In the initial resorption stage, only the outer cemental layers are resorbed and are later fully regenerated or remodeled. However, dentin resorption is usually repaired with cementum material, and the final shape of the root may or may not be identical to the original form. When severe resorption leads to a loss of full hard tissue of the root apex, no regeneration is possible [4, 34]. The results of our study are similar to the above conclusions from previous studies, but we observed some differences. Based on the thickness of the cementum, mild resorption is described as cemental resorption or dentinal resorption. Moderate resorption is considered to be dentinal resorption. During this process, 7% of the central incisors and 6% of the lateral incisors in the present study exhibited severe resorption. This phenomenon is likely related to the removal of the orthodontic force, which resulted in further resorption. A risk of permanent tooth mobility in the maxillary incisors that develop severe resorption during treatment has been noted, particularly in those in which the total root length remains less than 9 mm [21]. In this study, four teeth were in this range. After orthodontic treatment, these teeth underwent further resorption during the two years of retention, indicating that long-term observation is needed to evaluate their final prognosis.

Both root resorption and root self-repair are unique and complex biological processes. Although these processes can be affected by several factors, their mechanisms are not completely known. There is no consensus in the literature regarding the point at which resorption stops and self-repair begins or the maximum capacity of the root repair. Further investigations into the above topics are therefore needed. However, it has been proven that most of the mild resorption that occurs after orthodontic treatment can be repaired, whereas the prognosis of severe resorption is not optimistic. Orthodontically treated teeth present increased resorption that requires careful and regular radiographic monitoring to ensure that root resorption does not exceed mild EARR. Moreover, the mastication function and efficiency should be established after treatment because these can benefit the root self-repair process. The repair process of these resorptive lesions plays an important role in decreasing the side effects of orthodontic treatment. The full advantages and disadvantages of using medication to promote cementum regeneration remain unclear and require further study. However, we believe that it is possible to achieve a good aesthetic appearance, mastication function, and efficiency and simultaneously maintain the health of periodontal tissues. Safe orthodontic treatment should be promoted to ensure that these outcomes are possible.

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Disclosure of conflict of interest

None.

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