Research Article

Assessment of External Apical Root Resorption Following Fixed Orthodontic Treatment in Adolescents: A Retrospective Radiographic Study

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Abstract

Background:
External apical root resorption (EARR) is a recognized adverse effect of orthodontic tooth movement, with its severity potentially influenced by patient- and treatment-related factors. This study evaluated factors associated with the extent of EARR following fixed orthodontic treatment.

Materials and Methods:
A clinical observational study was conducted among patients who underwent fixed orthodontic treatment. EARR was assessed and compared according to sex, extraction status, treatment duration, incisor intrusion, and malocclusion type. Correlation analysis was performed to evaluate associations between EARR and age, treatment duration, and apical displacement. Multivariable logistic regression was used to identify independent predictors of clinically significant EARR.

Results:
Female patients had a mean EARR of 0.84 ± 0.63 mm compared with 0.79 ± 0.61 mm in males probability ($p=0.651$). Mean EARR was significantly greater among patients treated with extractions than among those treated without extractions (1.02 ± 0.68 vs. 0.64 ± 0.52 mm; $p=0.004$). Patients treated for >24 months also demonstrated higher EARR than those treated for ≤24 months (1.12 ± 0.72 vs. 0.68 ± 0.53 mm; $p=0.002$). Incisor intrusion was associated with greater EARR (1.08 ± 0.70 vs. 0.70 ± 0.53 mm; $p=0.001$). EARR differed significantly across malocclusion groups ($p=0.006$), with the highest mean observed in Class II malocclusion (0.98 ± 0.67 mm). Apical displacement ($r=0.48$, $p<0.001$) and treatment duration ($r=0.36$, $p<0.001$) showed significant positive correlations with EARR, whereas age did not ($r=0.12$, $p=0.191$). In multivariable analysis, extraction treatment (adjusted odds ratio OR=2.31, $p=0.047$), treatment duration >24 months (adjusted OR=2.87, $p=0.019$), incisor intrusion (adjusted OR=2.64, $p=0.032$), and apical displacement (adjusted OR=1.76 per 1-mm increase, $p=0.003$) were independently associated with clinically significant EARR.

Conclusion:
EARR was significantly associated with extraction treatment, prolonged orthodontic treatment, incisor intrusion, and greater apical displacement. These findings support careful treatment planning and radiographic monitoring in patients undergoing fixed orthodontic treatment.

Keywords: Apical displacement, External apical root resorption, Fixed orthodontic treatment, Incisor intrusion, Malocclusion, Orthodontic treatment duration.

Introduction

External apical root resorption (EARR) is an undesirable biological consequence that may occur during orthodontic tooth movement and is characterized by the progressive loss of root structure, particularly at the apical region. Although mild root shortening is frequently asymptomatic and may have limited clinical consequences, severe resorption can result in substantial reduction in root length and may adversely affect the long-term prognosis of the involved teeth. EARR is considered a multifactorial phenomenon involving mechanical, biological, and patient-specific factors, with considerable variation in susceptibility among individuals undergoing orthodontic treatment [1].

The prevalence and severity of EARR differ among teeth, with the maxillary anterior region, particularly the maxillary incisors, commonly demonstrating greater susceptibility. The anatomical characteristics of the root, including root length, shape, and apical morphology, may influence the response to orthodontic forces. Teeth with unusual or slender root morphology may be more vulnerable to apical changes during treatment. These findings emphasize the importance of considering pretreatment root characteristics when evaluating the potential risk of EARR [2].

Adolescents constitute a major proportion of patients receiving comprehensive orthodontic treatment with fixed appliances. During this period, active bone remodeling and continuing craniofacial development permit substantial orthodontic tooth movement. However, the biological response to orthodontic forces may vary according to individual characteristics. Age, sex, dental development, and differences in tissue response have therefore been investigated as possible patient-related factors associated with EARR [3]. Genetic and biological differences between individuals may also contribute to variations in susceptibility, explaining why comparable orthodontic mechanics can produce different degrees of root resorption among patients [4].

The characteristics of orthodontic treatment itself may substantially influence the development of EARR. The magnitude and direction of applied forces, duration of treatment, extent of tooth movement, and specific biomechanics used during fixed appliance therapy can affect the stresses transmitted to the periodontal ligament (PDL) and root surface. Movements that produce considerable apical displacement, particularly intrusion and certain forms of torque or bodily movement, have been associated with increased risk of EARR [5].

Treatment duration has also been investigated as a potential predictor of EARR. Longer treatment periods may increase the cumulative exposure of dental tissues to orthodontic forces and repeated periods of periodontal remodeling. However, treatment duration alone does not completely explain the development of EARR, as patients undergoing treatment of similar duration may exhibit markedly different amounts of root shortening. This observation suggests that treatment duration should be interpreted together with other mechanical and patient-related variables [6].

Extraction-based orthodontic treatment may represent another relevant treatment-related factor. Space closure following extraction frequently requires considerable tooth displacement and prolonged orthodontic mechanics, potentially increasing the risk of root resorption in susceptible teeth. Nevertheless, the association between extraction treatment and EARR is not uniform across studies, indicating that the effect may depend on the type and magnitude of tooth movement rather than extraction status alone [7].

Radiographic evaluation remains essential for identifying EARR because early or moderate root changes may not produce clinical symptoms. Conventional periapical radiography has traditionally been used for monitoring root morphology, while digital imaging and three-dimensional (3D) techniques have provided additional opportunities for evaluating root changes and treatment-related risk factors. Repeated radiographic assessment should, however, be appropriately justified because orthodontic patients are frequently adolescents and unnecessary radiation exposure should be minimized [8].

Despite extensive research, the relative contribution of individual clinical and treatment-related predictors of EARR remains inconsistent. Variations in patient age, orthodontic protocols, force systems, treatment duration, tooth movement patterns, imaging techniques, and definitions of root resorption may contribute to differences among reported findings. Consequently, assessment of EARR within a clearly defined adolescent population undergoing fixed orthodontic treatment may provide useful information regarding factors associated with increased susceptibility [9].

Therefore, the present study was designed to evaluate EARR in adolescents following fixed orthodontic treatment and to investigate its association with selected clinical and treatment-related predictors. The study focused on identifying patient and treatment characteristics associated with the occurrence and severity of EARR, with the objective of improving risk assessment and facilitating appropriate monitoring of root integrity during orthodontic treatment.

Materials & Methods

Study Design and Setting

A retrospective observational study was conducted at a tertiary care centre from January 2025 to June 2026 to evaluate the occurrence and severity of EARR following fixed orthodontic treatment. Patient records, along with pretreatment and post-treatment panoramic radiographic images, were reviewed to assess the association of EARR with selected demographic, malocclusion-related, and treatment-related factors. A total of 120 adolescent patients who had undergone comprehensive fixed orthodontic treatment and met the study eligibility criteria were included in the analysis.

Study Population

Patients who had completed comprehensive fixed orthodontic treatment were considered for inclusion. Relevant demographic and clinical information was obtained from orthodontic treatment records. The variables assessed included age, sex, malocclusion type, extraction status, treatment duration, incisor intrusion, and apical displacement.

Inclusion Criteria

- Patients who had undergone comprehensive fixed orthodontic treatment
- Patients with complete pretreatment and post-treatment radiographic records suitable for EARR assessment
- Patients with clearly identifiable maxillary and/or mandibular anterior teeth on the available radiographs
- Patients with documented treatment duration and adequate orthodontic treatment records
- Patients with sufficient clinical information to determine extraction status, malocclusion classification, and major treatment mechanics
- Radiographs of adequate quality for reliable assessment of root length and apical changes

Exclusion Criteria

- Patients with a history of previous orthodontic treatment
- Teeth with pre-existing EARR before commencement of orthodontic treatment
- Patients with a history of significant dental trauma involving the assessed teeth
- Teeth with developmental abnormalities or severe root malformation
- Patients with incomplete orthodontic records or missing essential radiographs
- Radiographs with inadequate image quality that prevented accurate assessment of root morphology or apical changes
- Patients with major craniofacial anomalies or syndromic conditions that could independently influence tooth development or root morphology
- Cases in which treatment was discontinued before completion or the final treatment records were unavailable

Assessment of EARR

EARR was evaluated by comparing standardized pre-treatment and post-treatment panoramic radiographs. Radiographic images were obtained using a digital panoramic unit (e.g., Carestream CS 8100, Carestream Dental, USA) operated at approximately 70–80 kVp, 8–12 mA, with an exposure time of 10–15 seconds, according to the manufacturer's recommended protocol. Patients were positioned using the manufacturer's positioning guides, with the Frankfort horizontal plane and midsagittal plane appropriately aligned to minimize projection-related distortion. Root length was measured from the cemento-enamel junction (CEJ) to the root apex on the pre-treatment and post-treatment panoramic radiographs. EARR was calculated as the difference in root length between the two radiographic assessments and expressed in millimetres. All measurements were performed using a standardized radiographic assessment protocol, and the same criteria were applied to all participants to minimize measurement variability.

Assessment of Treatment-Related Variables

Treatment records were reviewed to determine whether orthodontic treatment involved extractions, incisor intrusion, and the extent of apical displacement. Treatment duration was calculated from the date of appliance placement to the date of treatment completion and categorized as ≤24 months or >24 months. Patients were classified according to Angle's classification into Class I, Class II, and Class III malocclusion groups.

Definition of Clinically Significant EARR

Clinically significant EARR was defined as root shortening of ≥2 mm between the pretreatment and post-treatment radiographic assessments. This threshold was selected to distinguish clinically relevant root resorption from minor changes that may reflect normal measurement variation or radiographic projection differences. For each patient, the measured reduction in root length was compared with the predefined threshold. Patients demonstrating ≥2 mm of apical root shortening in the assessed teeth were classified as having clinically significant EARR, whereas those with <2 mm of root shortening were classified as not having clinically significant EARR. For the subsequent statistical analysis, EARR status was therefore treated as a binary outcome variable, with patients categorized into two groups: (1) clinically significant EARR present (≥2 mm) and (2) clinically significant EARR absent (<2 mm).

Statistical Analysis

All statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were summarized as frequencies and percentages. The level of statistical significance was set at probability (p) <0.05. The study included 120 adolescent patients undergoing fixed orthodontic treatment. The pre-treatment and post-treatment root lengths of the maxillary and mandibular incisors were compared to assess the extent of EARR. Since these measurements represented paired observations, a paired-samples t-test was used to assess the change in root length before and after orthodontic treatment. Mean EARR was calculated as the difference between pre-treatment and post-treatment root length. For comparison of mean EARR between two independent groups, such as male versus female, extraction versus non-extraction treatment, treatment duration ≤24 months versus >24 months, and presence versus absence of incisor intrusion, an independent-samples t-test was used. For comparison of mean EARR across the three malocclusion groups (Class I, Class II and Class III**)**, one-way analysis of variance (ANOVA**)** was performed. When the overall ANOVA was statistically significant, post-hoc comparisons were used to identify the groups contributing to the observed difference. The relationships between EARR and continuous variables were evaluated using Pearson's correlation coefficient (r). Correlation analysis was performed for apical displacement, treatment duration and age. A positive correlation indicated that increasing values of the predictor variable were associated with increasing EARR. To identify independent predictors of clinically significant EARR**,** multivariable binary logistic regression analysis was performed. The dependent variable was clinically significant EARR, while age, sex, extraction treatment, treatment duration >24 months, incisor intrusion and apical displacement were entered as predictor variables. Results were expressed as adjusted odds ratios (ORs) with 95% confidence intervals (CIs) and corresponding p-values. A p-value <0.05 was considered statistically significant, while p≥0.05 was considered statistically non-significant. The statistical analysis therefore evaluated both the extent of EARR and the potential clinical and treatment-related predictors of root resorption.

Results

Table 1 & Figure 1 present data from a total of 120 adolescent patients who underwent comprehensive fixed orthodontic treatment and were included in the analysis. The mean age at treatment initiation was 15.2 ± 1.5 years. Females constituted 55.0% of the study population (66 participants), while males accounted for 45.0% (54 participants). The mean duration of active orthodontic treatment was 22.8 ± 5.1 months.

Table 1: Characteristics of the study population

Variable	n (%) / Mean ± SD
Sample size	120
Age (years)	15.2 ± 1.5
Female	66 (55.0%)
Male	54 (45.0%)
Treatment duration (months)	22.8 ± 5.1
Extraction treatment	58 (48.3%)
Non-extraction treatment	62 (51.7%)

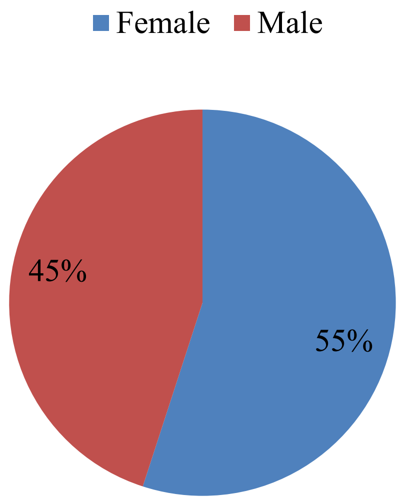

Figure 1: Distribution of participants according to age, sex, and duration of active orthodontic treatment

Table 2 & Figure 2 present the distribution of malocclusion among the 120 adolescent patients included in the study. Class II malocclusion was the most frequently observed type, affecting 55 patients (45.8%). Class I malocclusion was identified in 48 patients (40.0%), whereas Class III malocclusion was observed in 17 patients (14.2%). Overall, Class II malocclusion constituted the largest proportion of the study population, while Class III malocclusion accounted for the smallest proportion.

Table 2: Distribution according to malocclusion

Malocclusion	n	%
Class I	48	40.0
Class II	55	45.8
Class III	17	14.2
Total	120	100.0

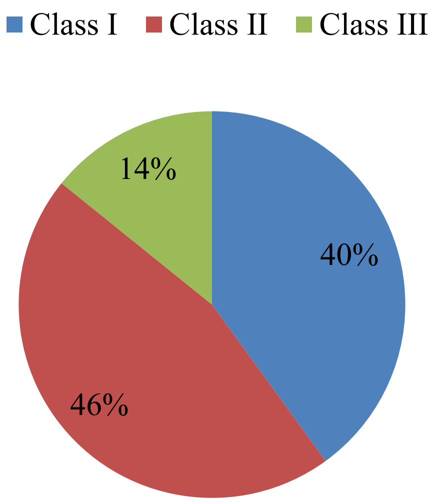

Figure 2: Distribution of adolescent patients according to the type of malocclusion

Table 3 & Figure 3 compare root lengths before and after orthodontic treatment. A statistically significant reduction in root length was observed in all evaluated incisors following treatment ($p<0.001$). The greatest extent of EARR was observed in the maxillary lateral incisors, with a mean reduction in root length of 1.1 ± 0.8 mm, from 11.8 ± 1.2 mm pretreatment to 10.7 ± 1.3 mm post-treatment. The maxillary central incisors demonstrated a mean root-length reduction of 0.9 ± 0.7 mm, with the mean root length decreasing from 12.6 ± 1.1 mm to 11.7 ± 1.2 mm. In the mandibular arch, both the central and lateral incisors showed a mean EARR of 0.6 ± 0.5 mm. The mean root length of the mandibular central incisors decreased from 11.4 ± 1.0 mm to 10.8 ± 1.1 mm, whereas that of the mandibular lateral incisors decreased from 11.9 ± 1.0 mm to 11.3 ± 1.1 mm. Overall, the reduction in root length was more pronounced in the maxillary incisors, with the maxillary lateral incisors showing the greatest amount of EARR among the evaluated teeth.

Table 3: Extent of EARR

Tooth	Pre-treatment root length (mm)	Post-treatment root length (mm)	Mean EARR (mm)	p-value*
Maxillary central incisor	12.6 ± 1.1	11.7 ± 1.2	0.9 ± 0.7	<0.001
Maxillary lateral incisor	11.8 ± 1.2	10.7 ± 1.3	1.1 ± 0.8	<0.001
Mandibular central incisor	11.4 ± 1.0	10.8 ± 1.1	0.6 ± 0.5	<0.001
Mandibular lateral incisor	11.9 ± 1.0	11.3 ± 1.1	0.6 ± 0.5	<0.001
Mean	11.93 ± 1.08	11.13 ± 1.18	0.80 ± 0.63	<0.001

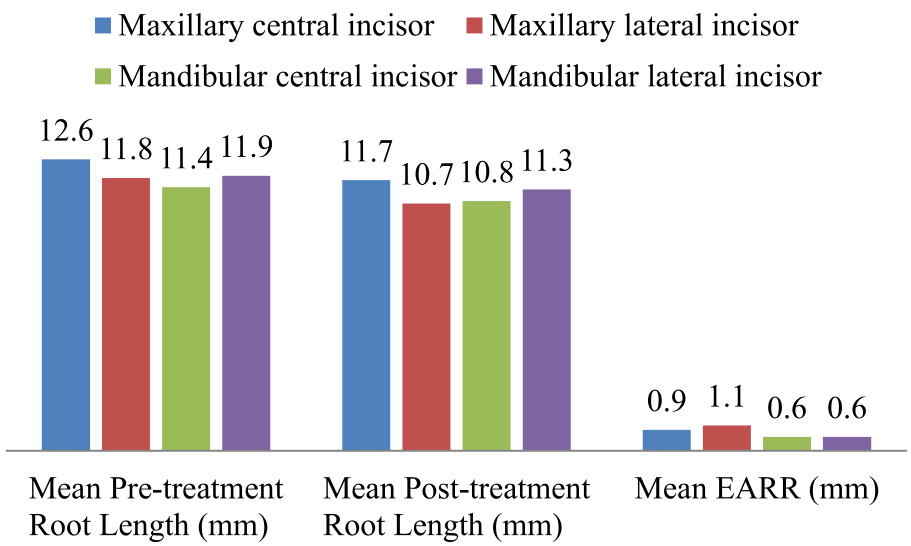

Figure 3: Comparison of pre-treatment and post-treatment root lengths and magnitude of EARR among maxillary and mandibular incisors.

Table 4 & Figure 4 illustrate the distribution of mean EARR according to sex. The mean EARR was 0.84 ± 0.63 mm in female patients and 0.79 ± 0.61 mm in male patients. Although females exhibited a marginally higher mean EARR than males, the difference was not statistically significant ($p=0.651$). Therefore, no significant association was observed between sex and the extent of EARR following fixed orthodontic treatment.

Table 4: Association of sex with EARR

Sex	n	Mean EARR (mm)	SD	p-value
Female	66	0.84	0.63	0.651
Male	54	0.79	0.61	

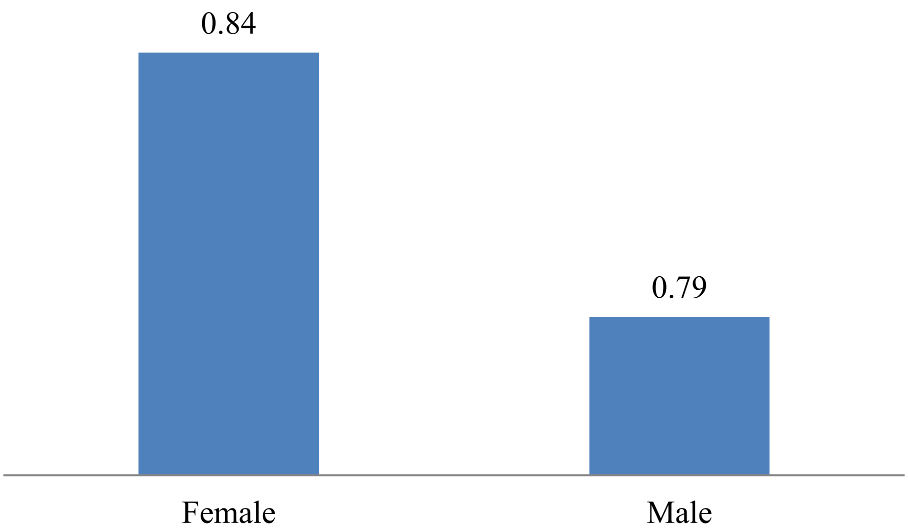

Figure 4: Comparison of mean EARR according to sex following fixed orthodontic treatment

Table 5 & Figure 5 compare the mean EARR between patients treated with and without extractions. Patients who underwent extraction treatment had a mean EARR of 1.02 ± 0.68 mm, whereas those managed without extraction had a lower mean value of 0.64 ± 0.52 mm. The difference between the two treatment groups was statistically significant (p=0.004). These findings demonstrate a significant association between extraction treatment and the extent of EARR following fixed orthodontic treatment.

Table 5: Association of extraction treatment with EARR

Treatment	n	Mean EARR (mm)	SD	p-value
Extraction	58	1.02	0.68	0.004
Non-extraction	62	0.64	0.52	

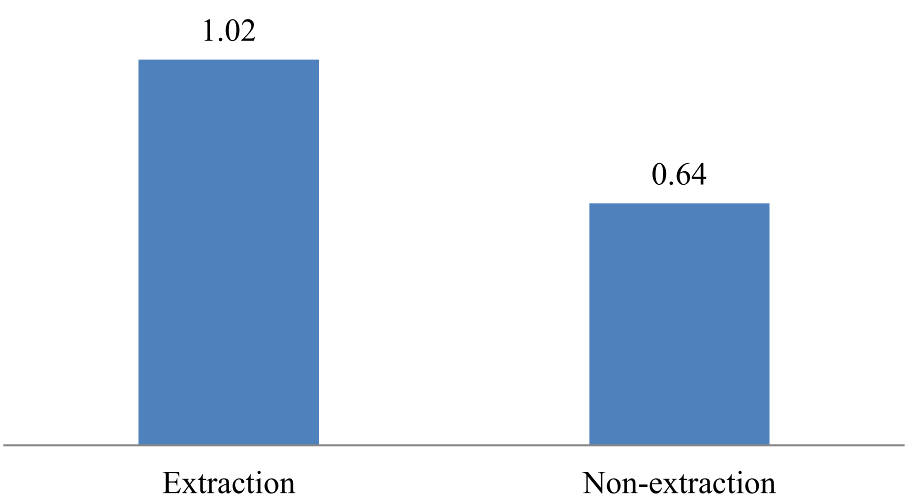

Figure 5: Comparison of mean EARR according to extraction status

Table 6 & Figure 6 compare the mean EARR according to orthodontic treatment duration. Patients whose treatment extended beyond 24 months had a mean EARR of 1.12 ± 0.72 mm, compared with 0.68 ± 0.53 mm among those treated for 24 months or less. The difference between the two groups was statistically significant (p=0.002). These findings demonstrate that a longer duration of orthodontic treatment was significantly associated with greater EARR.

Table 6: Relationship between treatment duration and EARR

Treatment duration	n	Mean EARR (mm)	SD	p-value
≤24 months	82	0.68	0.53	0.002
>24 months	38	1.12	0.72	

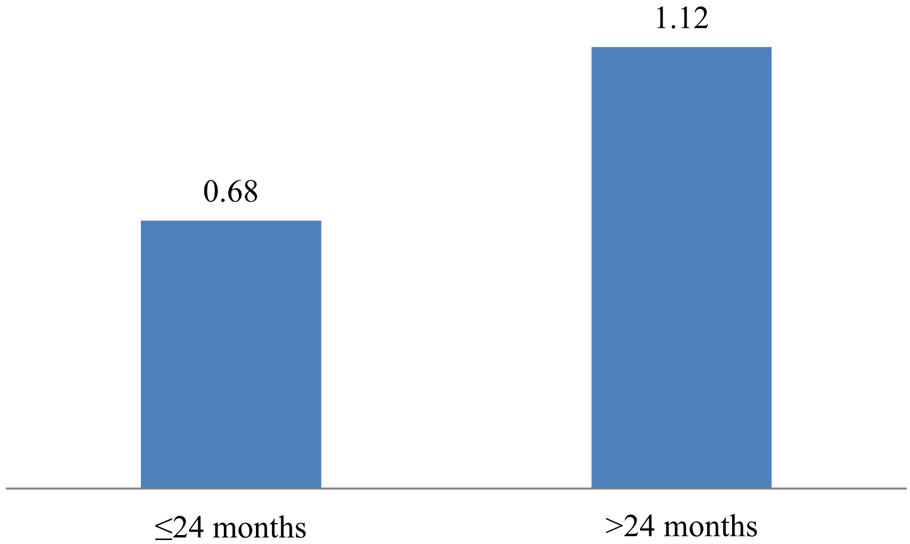

Figure 6: Comparison of mean EARR according to orthodontic treatment duration

Table 7 presents the correlation analysis between EARR and selected clinical variables. A significant positive correlation was observed between apical displacement and EARR (r=0.48, p<0.001), indicating that greater apical displacement was associated with increased root resorption. Treatment duration also showed a significant positive correlation with EARR (r=0.36, p<0.001), suggesting that prolonged orthodontic treatment was associated with greater EARR. In contrast, age was not significantly correlated with EARR (r=0.12, p=0.191). Overall, the correlation analysis suggests that treatment-related parameters, particularly apical displacement and treatment duration, were more strongly associated with EARR than patient age.

Table 7: Relationship between apical displacement and EARR

Variable	Correlation coefficient (r)	p-value
Apical displacement vs EARR	0.48	<0.001
Treatment duration vs EARR	0.36	<0.001
Age vs EARR	0.12	0.191

Table 8 compares the mean EARR according to the presence or absence of incisor intrusion. Patients who underwent incisor intrusion exhibited a mean EARR of 1.08 ± 0.70 mm, whereas those who did not undergo intrusion had a lower mean EARR of 0.70 ± 0.53 mm. The difference between the two groups was statistically significant (p=0.001). These findings indicate a significant association between incisor intrusion and greater EARR following fixed orthodontic treatment.

Table 8: Association of incisor intrusion with EARR

Intrusion	n	Mean EARR (mm)	SD	p-value
Yes	44	1.08	0.70	0.001
No	76	0.70	0.53	

Table 9 summarizes the comparison of mean EARR across the three malocclusion categories. A statistically significant difference in mean EARR was observed among the groups (p=0.006). Patients with Class II malocclusion had the highest mean EARR (0.98 ± 0.67 mm; range: 0.00–3.20 mm), followed by those with Class III malocclusion (0.72 ± 0.55 mm; range: 0.00–2.00 mm) and Class I malocclusion (0.68 ± 0.51 mm; range: 0.00–2.10 mm). One-way ANOVA confirmed a significant difference in EARR across the three malocclusion groups (p=0.006). Post-hoc analysis indicated that the primary significant difference occurred between the Class I and Class II groups.

Table 9: EARR according to malocclusion

Malocclusion	n	Mean EARR (mm)	SD	Minimum–Maximum	p-value
Class I	48	0.68	0.51	0.00–2.10	0.006
Class II	55	0.98	0.67	0.00–3.20	
Class III	17	0.72	0.55	0.00–2.00	

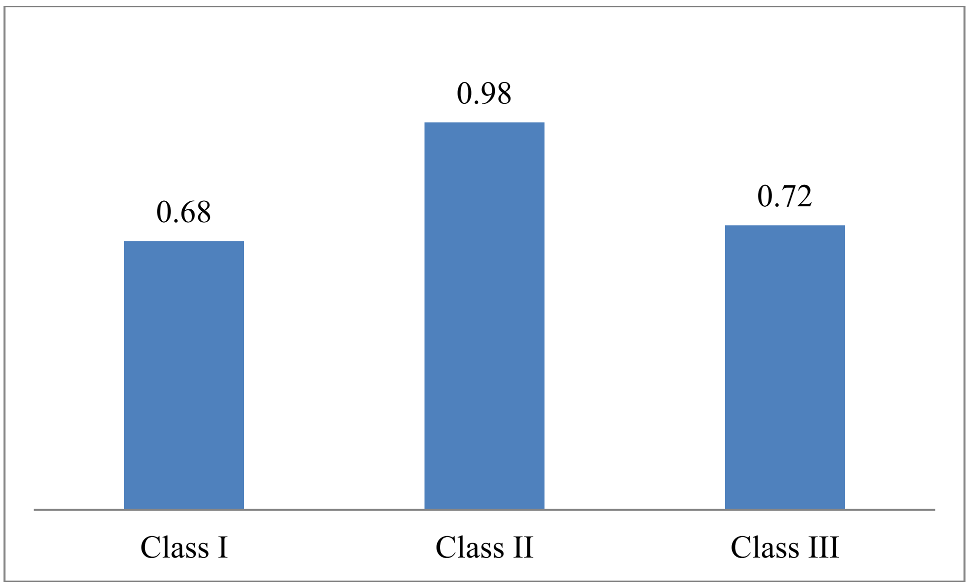

Table 10 presents the results of the multivariable logistic regression analysis conducted to identify factors independently associated with clinically significant EARR. Age was not significantly associated with clinically significant EARR (adjusted OR=1.18, 95% CI: 0.89–1.56; p=0.248). Likewise, male sex did not demonstrate a significant association (adjusted OR=0.91, 95% CI: 0.39–2.10; p=0.826). In contrast, extraction treatment was significantly associated with clinically significant EARR, with patients receiving extraction-based treatment having higher odds of clinically significant EARR (adjusted OR=2.31, 95% CI: 1.01–5.29; p=0.047).

Treatment duration exceeding 24 months was also significantly associated with increased odds of clinically significant EARR (adjusted OR=2.87, 95% CI: 1.18–6.96; p=0.019). Similarly, incisor intrusion was significantly associated with clinically significant EARR (adjusted OR=2.64, 95% CI: 1.09–6.41; p=0.032). Apical displacement showed a significant association as well, with each 1-mm increase corresponding to higher odds of clinically significant EARR (adjusted OR=1.76, 95% CI: 1.22–2.54; p=0.003).

Overall, the adjusted regression model identified extraction treatment, treatment duration >24 months, incisor intrusion, and greater apical displacement as significant predictors of clinically significant EARR, whereas age and sex were not statistically significant predictors.

Table 10: Multivariable logistic regression analysis of clinically significant EARR

Predictor	Adjusted OR	95% CI	p-value
Age (per 1-year increase)	1.18	0.89–1.56	0.248
Male sex	0.91	0.39–2.10	0.826
Extraction treatment	2.31	1.01–5.29	0.047
Treatment duration >24 months	2.87	1.18–6.96	0.019
Incisor intrusion	2.64	1.09–6.41	0.032
Apical displacement (per mm)	1.76	1.22–2.54	0.003

Discussion

EARR is recognized as an important adverse effect of orthodontic tooth movement, although its occurrence and severity vary substantially among individuals. In the present study, the evaluation of clinical and treatment-related characteristics in adolescents undergoing fixed orthodontic therapy provides evidence that EARR should be considered a multifactorial outcome rather than a consequence of a single orthodontic variable.

Nanekrungsan et al. (2012) [10] investigated EARR involving maxillary incisors and reported associations between EARR and several patient- and treatment-related characteristics. Their findings support the observation that maxillary incisors are particularly susceptible to apical root changes during orthodontic treatment. The authors also emphasized the importance of radiographic assessment in identifying root shortening that may not be clinically apparent. These findings are consistent with the present study, in which evaluation of EARR focused on measurable changes in root morphology following fixed appliance therapy.

Agrawal et al. (2015) [11] described a rare case of pronounced EARR occurring during orthodontic treatment in a patient with multiple aplasia. Although a single case cannot establish a general association, the report illustrates the considerable biological variability in individual responses to orthodontic forces. It also suggests that underlying dental or developmental characteristics may influence susceptibility to root resorption. The present findings similarly support the concept that comparable orthodontic treatment does not necessarily produce an identical root response in every adolescent.

The systematic review by Tieu et al. (2014) [12] demonstrated that orthodontically induced EARR is a recognizable outcome following treatment, particularly in incisors. Their review highlighted considerable variation in the reported amount of root resorption among orthodontic patients and emphasized the influence of methodological and treatment-related differences. The findings of the present study reinforce the need to interpret EARR according to the characteristics of the treated population and orthodontic protocol rather than assuming a uniform response across patients.

Sondeijker et al. (2020) [13] developed a clinical practice guideline addressing orthodontically induced EARR and highlighted the importance of identifying patients at increased risk and monitoring root changes during treatment. Their recommendations reflect the clinical significance of detecting EARR before substantial root shortening develops. In the context of adolescent orthodontic treatment, this is particularly relevant because fixed appliance therapy commonly extends over a prolonged period, allowing sufficient time for progressive root changes to occur. The present study therefore contributes to the broader objective of identifying clinical and treatment-related characteristics that may assist in risk assessment.

In a systematic review and meta-analysis, Villaman-Santacruz et al. (2022) [14] evaluated factors associated with root resorption in patients treated with fixed orthodontic appliances. Their findings demonstrated that EARR is influenced by multiple factors and that the magnitude of risk may differ according to the characteristics of orthodontic treatment and individual patients. This multifactorial interpretation is consistent with the present study, where clinical variables and treatment-related parameters were considered together rather than evaluating a single potential predictor in isolation.

Weltman et al. (2010) [15] conducted a systematic review of root resorption associated with orthodontic tooth movement and concluded that orthodontically induced root resorption represents a clinically relevant complication with considerable variation between patients and teeth. Their review also emphasized the importance of orthodontic mechanics and individual susceptibility in determining the extent of root changes. The present study supports this concept by demonstrating that EARR should be interpreted in relation to both patient characteristics and the mechanics or duration of orthodontic treatment.

Collectively, the available evidence indicates that EARR cannot be attributed exclusively to the application of orthodontic force. Differences in root anatomy, individual biological susceptibility, treatment duration, magnitude and direction of tooth movement, and specific orthodontic mechanics may contribute to the observed variation in root resorption. The findings of the present study should therefore be interpreted within this multifactorial framework. In adolescents, systematic assessment of relevant clinical and treatment-related variables may facilitate identification of patients who require closer radiographic monitoring during fixed orthodontic therapy.

The clinical importance of EARR depends not only on its occurrence but also on its extent. Minor apical shortening may have limited functional consequences, whereas substantial root loss may reduce the remaining root-to-crown ratio and potentially compromise long-term tooth stability. Consequently, recognition of potentially modifiable treatment-related factors is important for balancing desired orthodontic tooth movement against the risk of undesirable root changes.

Overall, the present findings, together with previous evidence, indicate that EARR is a variable biological response to orthodontic treatment. The various studies collectively support the importance of considering both individual susceptibility and orthodontic treatment characteristics when evaluating root resorption. These observations underline the value of careful treatment planning and appropriate radiographic monitoring, particularly in adolescent patients undergoing fixed orthodontic treatment.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the study was conducted at a single centre, which may limit the generalizability of the results to patients treated in other clinical settings or populations. Second, the observational nature of the study limits the ability to establish causal relationships between orthodontic treatment factors and EARR. Although multivariable analysis was performed to account for selected potential confounding factors, residual confounding from unmeasured variables cannot be excluded. Third, EARR assessment may be influenced by variations in radiographic image quality, root morphology, angulation, and measurement technique. Fourth, factors such as individual root anatomy, genetic susceptibility, previous dental trauma, periodontal status, magnitude and direction of orthodontic forces, and patient compliance were not comprehensively evaluated and may have contributed to the observed variation in EARR. Fifth, treatment-related variables, including extraction status, treatment duration, incisor intrusion, and apical displacement, may be interrelated, making it difficult to determine the independent contribution of each factor despite adjustment in the regression model. Finally, the study focused primarily on the extent of EARR following fixed orthodontic treatment and did not evaluate the long-term clinical consequences or progression of root resorption after completion of treatment. Future multicentre prospective studies with standardized 3D imaging, longer follow-up periods, and comprehensive assessment of biological and treatment-related risk factors are warranted to validate these findings.

Conclusion

EARR was significantly associated with extraction treatment, treatment duration >24 months, incisor intrusion, and greater apical displacement. Class II malocclusion showed the highest mean EARR, whereas age and sex were not significantly associated with EARR. These findings emphasize the importance of careful treatment planning and radiographic monitoring, particularly in patients requiring prolonged treatment or substantial tooth movement.

Conflicts of Interest: Nil
Financial Support: None

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