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Original Article

A radiographic study of external apical root resorption in patients treated with single-phase fixed orthodontic therapy

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ABSTRACT

Background: External apical root resorption (EARR) is one of the most common iatrogenic consequences of orthodontic tooth movement. Many factors like gender, duration, orthodontic force and duration of orthodontic treatment have been implicated to cause EARR. **Methods:** Pre- and post-treatment OPGs of 60 orthodontic patients (30 males and 30 females) who had undergone treatment with a single phase of fixed orthodontic therapy were randomly selected from institutional archives. The root apices were evaluated for EARR by a single operator on an radiograph viewing box at a standardized source of light using a four-grade ordinal scale. Anterior EARR was measured on the maxillary and mandibular canines. Posterior EARR was measured on premolars, mesiobuccal and distobuccal roots of maxillary first molars and mesial and distal roots of mandibular first molars. The results were compiled and subjected to statistical analysis.

Results: The cases in which the patients underwent therapeutic extraction had a relatively higher amount of EARR compared to the cases in which the patients were treated by non-extraction therapy ($P < 0.001$). Odds ratio indicated that extraction cases had two-fold increased risk of EARR than non-extraction cases ($P < 0.001$). No statistically significant difference was observed in the distribution of EARR based on gender or duration of orthodontic treatment ($P > 0.05$).

Conclusion: Therapeutic extraction is an important determinant of post-treatment EARR. Gender and duration of orthodontic treatment may not be important variables in the causation of EARR according to the findings of this study. However, longitudinal studies with larger sample size are required to validate the results of this study.

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Introduction

External apical root resorption (EARR) is one of the most common iatrogenic consequences of orthodontic tooth movement. Histological evaluation shows microscopic areas of resorption lacunae on affected root surfaces often leading to permanent loss of tooth structure and shortening of root apex.^{1,2} Its prevalence is up to 100% in histologically examined teeth and much lower in teeth examined by routine two-dimensional radiographs.^{3,4}

EARR following orthodontic treatment can be caused by patient-related factors like age, sex, systemic conditions, type of malocclusion and treatment-related factors like appliance type, treatment duration, magnitude of orthodontic force and type of orthodontic tooth movement.^{4,5} The magnitude of orthodontic force is believed to be an important factor in the aetiology of EARR and it is believed that too strong forces will cause an increased damage to the affected tissues leading to root resorption (RR). A few studies consider duration of force to be a more critical factor than the magnitude of the force, especially in connection with long treatment periods.⁶ The orthodontic force produces a local inflammatory response with characteristic signs of inflammation. This inflammation, which is essential for tooth movement, is actually the fundamental component behind the RR process.^{7,8}

Lateral cephalogram and orthopantomogram (OPG) are routinely ordered radiographs during various stages of orthodontic treatment and are often used to diagnose early conditions like EARR, so as to plan a suitable modification in the mechanotherapy. The advantages of OPG are less radiation exposure, both maxillary and mandibular skeletal and dental structures can be visualized in a single radiograph, low cost and usually there is no need for additional full mouth intraoral periapical (IOPA) radiographs for evaluating EARR. OPG being a two-dimensional representation of three-dimensional structures has certain limitations also like magnification errors, need of proper head positioning during radiography and inability to be readily repeated and reproduced. OPG often overestimates EARR by 20% when compared with periapical radiographs.^{9,10} Though three-dimensional imaging modalities like magnetic resonance imaging (MRI) and computed tomography (CT) have provided better visualization, accuracy and greater degree of reproducibility than conventional radiography, their use in routine orthodontic practice is limited due to cost factor and high radiation exposure, as seen in CTs. In addition, trained radiologists are often required for the interpretation of CT images, which further reduces its use in routine orthodontic practice.^{11,12}

Any flaws in predictability, prevention and early diagnosis of this condition, especially in cases of extensive RR, can cause drastic consequences to both orthodontic treatment and patient's health. It is therefore important to determine the magnitude and prevalence of RR in various populations, as well as related risk factors. Hence, a study was undertaken to evaluate EARR of teeth in patients treated with a single phase of fixed orthodontic therapy from the patient records available in the Division of Orthodontics and Dentofacial Orthopaedics at a government post-graduate teaching institution.

The aim of this study was to evaluate EARR of teeth in patients who have undergone single phase of fixed orthodontic therapy. The objectives were as follows:

- To determine EARR, if any, in healthy patients who underwent treatment with a single phase of fixed orthodontic therapy.
- To determine if any association existed between EARR and gender of the patient.
- To determine if any association existed between EARR and duration of orthodontic therapy.
- To determine if any association existed between EARR and therapeutic extractions associated with orthodontic therapy.

Material and methods

Study sample

The study sample was selected on the basis of convenience sampling, i.e. all the cases who had undergone treatment with a single phase of fixed orthodontic therapy at the division of orthodontics, AFMC Pune during 2006–2012 and met the inclusion and exclusion criteria of the study were selected for the study. The orthodontic records (hard copy of pre- and post-treatment OPG) of 60 orthodontic patients were finally selected based on the criteria mentioned below. All OPGs used in the study were recorded using the same machine (Model: ADVAPX cephalostat machine, Company: Panoraitic System, Printer: Fujifilms DRY PIX 7000) with a standardized technique.

Inclusion criteria

- OPGs of only those patients were selected for the study for which a complete medical history was taken prior to the treatment and any necessary investigations were carried out (if required) to rule out any known medical condition affecting bone metabolism (minimum of 800 teeth were included in the study sample).
- Complete pre- and post-treatment records of malocclusion, including orthodontic case sheet, study models and OPGs.
- Age between 15 and 40 years.
- Pre- and post-treatment OPG from same source of X-ray machine with a standardized technique.
- Patients treated with fixed orthodontic appliance therapy in both the arches.
- Extraction cases included class I bimaxillary protrusion cases treated with 1st premolar extraction and non-extraction cases included those treated for crowding less than 5 mm.
- The sample teeth, which have completed root formation, will only be evaluated.
- No radiographic evidence of pre-treatment EARR.

Exclusion criteria

- History of prior trauma.
- Incomplete apexogenesis.

- Radiographic evidence of pre-treatment RR.
- Patients who have undergone previous fixed orthodontic treatment.
- History of endodontic treatment.
- Invaginations or severe dilacerations of the roots.
- Taurodontism.
- OPGs of patients with systemic diseases affecting bone and bone metabolism, such as osteoporosis, hyperthyroidism, hyper-parathyroidism, etc., were not included in the study. Such conditions affect bone turnover and hence RR during orthodontic treatment.
- Stained radiographs.
- Tooth apices that could not be clearly seen while viewing the OPG on an X-ray viewing box at a standardized source of light.
- Patients not treated with fixed appliance in both the arches.

Ethical considerations

The research protocol of the present study was reviewed and approved by the Institutional Ethical Committee.

Categorization of study sample

Equal numbers of male and female patients were selected for this study (30 males and 30 females). All the patients selected for this study were treated using 0.018 Roth (29 cases) or MBT (31 cases) pre-adjusted edgewise appliance (PEA).

Based on the duration of orthodontic treatment, the patients were divided into the following two groups:

Group 1 – treatment duration ≤ 24 months,

Group 2 – treatment duration > 24 months

Based on the therapeutic extraction associated with orthodontic treatment, the patients were further classified into the following two groups:

Group A – treated with extraction of upper and lower first premolars and

Group B – treated with non-extraction therapy.

All extraction cases had class I bimaxillary protrusion and were treated with therapeutic extraction of upper and lower

first premolars using same mechanics (i.e. individual canine retraction with friction mechanics followed by retraction of incisors using loop mechanics). The anchorage employed was group I anchorage, which was achieved by transpalatal arch across first molars and banding of second molars. Non-extraction cases were managed by conventional non-extraction approaches like arch expansion, proclination of anteriors and proximal stripping.

Measurement of EARR

The root apices were evaluated for the presence of EARR by a single operator on an radiograph viewing box at a standardized source of light. Anterior EARR was measured on the maxillary and mandibular canines. Posterior EARR was measured on premolars, mesiobuccal and distobuccal (MB and DB, respectively) roots of maxillary first molars and mesial and distal roots (M and D, respectively) of mandibular first molars. A four-grade ordinal scale proposed by Scott McNab,¹³ which is a modification of the scale recommended by Sharpe et al.,¹⁴ was used for measuring EARR, which is as below:

0 = no apical RR (Fig. 1).

1 = slight blunting of root apex (Fig. 2).

2 = moderate resorption of root apex beyond blunting and up to one-third of the root length (Fig. 3).

3 = severe resorption of root apex beyond one-third of root length.

The measurements of EARR were repeated for 10 randomly selected OPGs after 1 week by the same operator to calculate intra-examiner reliability and also by another operator to calculate inter-examiner reliability. The data were compiled in MS Excel work sheet and were subjected to statistical analysis.

Statistical analysis

The statistical analysis was performed using statistical package for social studies SPSS, version 11.3 for MS Windows. The Cohen Kappa test was done for the assessment of intra- and inter-operator reliability. The Pearson Chi-square test was used to test the distribution of extent of EARR across various groups, such as gender, duration of treatment and history of therapeutic extractions associated with the orthodontic treatment. The level of statistical significance was set at

Fig. 1 – Grade 0 – no apical root resorption.

Fig. 2 – Grade 1 – slight blunting of the root apex.

$P < 0.05$. In order to measure the strength of association between extent of EARR and history of extraction, an odds ratio (OR) (with 95% CI) was calculated.

Results

There was a statistically significant intra-operator (Kappa score – 0.858, $P < 0.001$) and inter-operator agreement (Kappa score – 0.828, $P < 0.001$) in the evaluation and grading of EARR.

A total of 1068 root apices (5 in each quadrant in non-extraction cases and 4 in each quadrant in extraction cases) were evaluated for EARR. 46.8% of teeth showed evidence of EARR (Grade 1 – 44.4%, Grade 2 – 2.4%). No Grade 3 EARR was observed. No radiographic evidence of EARR (i.e. Grade 0) was observed in 53.2% of cases. Maximum EARR was observed in maxillary right first molars (63.3%). Minimum EARR was observed in maxillary and mandibular first premolars (6–8%) [Table 1, Fig. 4].

45.4% males (Grade 1 – 43.2% and Grade 2 – 2.2%) and 48.3% females (Grade 1 – 45.6% and Grade 2 – 2.7%) showed evidence of EARR. No statistically significant gender variation was observed ($P > 0.05$) [Table 2].

55.9% cases (Grade 1 – 54.4% and Grade 2 – 1.5%) in which patients underwent therapeutic extraction and 37.9% cases (Grade 1 – 34.6% and Grade 2 – 3.3%) in which patients were treated by non-extraction therapy showed evidence of EARR ($P < 0.05$). The cases in which patients underwent therapeutic extraction had a relatively higher amount of

EARR compared to the cases in which patients were treated by non-extraction therapy, which was statistically significant ($P < 0.001$) [Table 3a].

An odds ratio (OR) was calculated to evaluate the strength of association between the extent of EARR and the history of therapeutic extraction among the cases selected for this study. Table 3b shows the OR calculations with OR (95% CI) being 2.07 (1.62–2.64). This indicates that the cases that had history of therapeutic extraction had two-fold increased risk of EARR than the cases that did not have history of extraction and this association was statistically significant ($P < 0.001$).

The mean duration of treatment for non-extraction cases was 19.2 months and that for extraction cases was 27.6 months. 42% (Grade 1 – 40.4%, Grade 2 – 1.6%) of the cases, whose duration of treatment was ≤ 24 months, and 47.8% (Grade 1 – 45.2%, Grade 2 – 2.6%) of the cases, whose duration of treatment was > 24 months, showed evidence of EARR and the extent of EARR was statistically significantly different across all the teeth treated ($P < 0.01$). However, no statistically significant difference was observed in the distribution of EARR between the cases whose duration was ≤ 24 months and those cases whose duration was > 24 months ($P > 0.05$) [Table 4].

Discussion

Radiographically, there are two methods to assess RR, i.e. direct measurement of root length from the radiograph¹⁴ or the use of ordinal scales to grade the degree and severity of

Fig. 3 – Grade 2 – moderate resorption of the root apex beyond blunting and up to one-third of the root length.

Table 1 – The distribution of post-treatment EARR (Overall).

Tooth no.	Tooth	0: No	1: Mild	2: Moderate	3: Severe
16DB	Maxillary right first molar (distobuccal)	24 (40.0)	36 (60.0)	0	0
16MB	Maxillary right first molar (mesiobuccal)	22 (36.7)	38 (63.3)	0	0
15	Maxillary right second premolar	26 (43.3)	32 (53.3)	2 (3.3)	0
14	Maxillary right first premolar	19 (70.4)	6 (22.2)	2 (7.4)	0
13	Maxillary right canine	30 (50.0)	26 (43.3)	4 (6.7)	0
23	Maxillary left canine	28 (46.7)	31 (51.7)	1 (1.7)	0
24	Maxillary left first premolar	20 (74.1)	6 (22.2)	1 (3.7)	0
25	Maxillary left second premolar	20 (33.3)	37 (61.7)	3 (5.0)	0
26MB	Maxillary left first molar (mesiobuccal)	27 (45.0)	32 (53.3)	1 (1.7)	0
26DB	Maxillary left first molar (distobuccal)	27 (45.0)	32 (53.3)	1 (1.7)	0
46D	Mandibular right first molar (distal)	37 (61.7)	22 (36.7)	1 (1.7)	0
46M	Mandibular right first molar (mesial)	37 (61.7)	23 (38.3)	0	0
45	Mandibular right second premolar	48 (80.0)	12 (20.0)	0	0
44	Mandibular right first premolar	18 (66.7)	9 (33.3)	0	0
43	Mandibular right canine	29 (48.3)	28 (46.7)	3 (5.0)	0
33	Mandibular left canine	25 (41.7)	32 (53.3)	3 (5.0)	0
34	Mandibular left first premolar	20 (74.1)	6 (22.2)	1 (3.7)	0
35	Mandibular left second premolar	43 (71.7)	17 (28.3)	0	0
36M	Mandibular left first molar (mesial)	38 (63.3)	22 (36.7)	0	0
36D	Mandibular left first molar (distal)	30 (50.0)	27 (45.0)	3 (5.0)	0
–	Overall	568 (53.2)	474 (44.4)	26 (2.4)	0

Values are n (% of cases).

RR.¹³ The present study used an ordinal scale rather than direct measurements of tooth length¹⁴ to avoid the errors associated with magnification of teeth in OPGs and measurement error associated with landmark identification similar to various other studies.^{15,16} Friedland¹⁷ stated that it is impossible to make accurate measurements from OPG for orthodontic diagnosis since the degree of magnification at a particular area is unknown.

The prevalence of EARR as per existing literature ranges from 65.6% to 98.1%, depending on whether it is calculated per patient (65.6–98.1%) or per tooth (72.9–94.2%).^{18–20} Overall RR reported in the present study (46.8%) was less than this range. However, it was greater than 1.7–27.1% reported by De Shields,¹⁸ Hollender et al.¹⁹ and Martins et al.²¹ in their studies. On per tooth basis, the range was 6–63.3% (maximum EARR was observed in maxillary right first molars – 63.3% and

Fig. 4 – The distribution of post-treatment EARR (overall).

Table 2 – The distribution of post-treatment EARR according to gender.

Tooth	Male			Female		
	0	1	2	0	1	2
Maxillary right first molar (distobuccal)	13 (43.3)	17 (56.7)	0	11 (36.7)	19 (63.3)	0
Maxillary right first molar (mesiobuccal)	14 (46.7)	16 (53.3)	0	8 (26.7)	22 (73.3)	0
Maxillary right second premolar	11 (36.7)	18 (60.0)	1 (3.3)	15 (50.0)	14 (46.7)	1 (3.3)
Maxillary right first premolar	11 (73.3)	3 (20.0)	1 (6.7)	8 (66.7)	3 (25.0)	1 (8.3)
Maxillary right canine	19 (63.3)	9 (30.0)	2 (6.7)	11 (36.7)	17 (56.7)	2 (6.7)
Maxillary left canine	18 (60.0)	12 (40.0)	0	10 (33.3)	19 (63.3)	1 (3.3)
Maxillary left first premolar	12 (80.0)	2 (13.3)	1 (6.7)	8 (66.7)	4 (33.3)	0
Maxillary left second premolar	10 (33.3)	19 (63.3)	1 (3.3)	10 (33.3)	18 (60.0)	2 (6.7)
Maxillary left first molar (Mesiobuccal)	14 (46.7)	15 (50.0)	1 (3.3)	13 (43.3)	17 (56.7)	0
Maxillary left first molar (Distobuccal)	10 (33.3)	19 (63.3)	1 (3.3)	17 (56.7)	13 (43.3)	0
Mandibular right first molar (Distal)	20 (66.7)	9 (30.0)	1 (3.3)	17 (56.7)	13 (43.3)	0
Mandibular right first molar (Mesial)	17 (56.7)	13 (43.3)	0	20 (66.7)	10 (33.3)	0
Mandibular right second premolar	22 (73.3)	8 (26.7)	0	26 (86.7)	4 (13.3)	0
Mandibular right first premolar	10 (66.7)	5 (33.3)	0	8 (66.7)	4 (33.3)	0
Mandibular right canine	14 (46.7)	15 (50.0)	1 (3.3)	15 (50.0)	13 (43.3)	2 (6.7)
Mandibular left canine	12 (40.0)	18 (60.0)	0	13 (43.3)	14 (46.7)	3 (10.0)
Mandibular left first premolar	12 (80.0)	3 (20.0)	0	8 (66.7)	3 (25.0)	1 (8.3)
Mandibular left second premolar	21 (70.0)	9 (30.0)	0	22 (73.3)	8 (26.7)	0
Mandibular left first molar (Mesial)	21 (70.0)	9 (30.0)	0	17 (56.7)	13 (43.3)	0
Mandibular left first molar (Distal)	14 (46.7)	14 (46.7)	2 (6.7)	16 (53.3)	13 (43.3)	1 (3.3)
Overall	295 (54.6)	233 (43.2)	12 (2.2)	273 (51.7)	241 (45.6)	14 (2.7)

Values are n (% of cases).

For males: Chi-square value = 50.061, P = 0.001.

For females: Chi-square value = 51.223, P = 0.001.

For males v/s females: Chi-square value = 1.006, P = 0.605.

Table 3a – The distribution of post-treatment EARR according to the history of extraction.

Tooth	Extraction			Non-extraction		
	0	1	2	0	1	2
Maxillary right first molar (distobuccal)	12 (36.4)	21 (63.6)	0	12 (44.4)	15 (55.6)	0
Maxillary right first molar (mesiobuccal)	8 (24.2)	25 (75.8)	0	14 (51.9)	13 (48.1)	0
Maxillary right second premolar	13 (39.4)	19 (57.6)	1 (3.0)	13 (48.1)	13 (48.1)	1 (3.7)
Maxillary right first premolar	0	0	0	19 (70.4)	6 (22.2)	2 (7.4)
Maxillary right canine	14 (42.4)	19 (57.6)	0	16 (59.3)	7 (25.9)	4 (14.8)
Maxillary left canine	12 (36.4)	21 (63.6)	0	16 (59.3)	10 (37.0)	1 (3.7)
Maxillary left first premolar	0	0	0	20 (74.1)	6 (22.2)	1 (3.7)
Maxillary left second premolar	9 (27.3)	22 (66.7)	2 (6.1)	11 (40.7)	15 (55.6)	1 (3.7)
Maxillary left first molar (mesiobuccal)	14 (42.4)	19 (57.6)	0	13 (48.1)	13 (48.1)	1 (3.7)
Maxillary left first molar (distobuccal)	16 (48.5)	17 (51.5)	0	11 (40.7)	15 (55.6)	1 (3.7)
Mandibular right first molar (distal)	17 (51.5)	15 (45.5)	1 (3.0)	20 (74.1)	7 (25.9)	0
Mandibular right first molar (mesial)	15 (45.5)	18 (54.5)	0	22 (81.5)	5 (18.5)	0
Mandibular right second premolar	25 (75.8)	8 (24.2)	0	23 (85.2)	4 (14.8)	0
Mandibular right first premolar	0	0	0	18 (66.7)	9 (33.3)	0
Mandibular right canine	13 (39.4)	20 (60.6)	0	16 (59.3)	8 (29.6)	3 (11.1)
Mandibular left canine	12 (36.4)	19 (57.6)	2 (6.1)	13 (48.1)	13 (48.1)	1 (3.7)
Mandibular left first premolar	0	0	0	20 (74.1)	6 (22.2)	1 (3.7)
Mandibular left second premolar	24 (72.7)	9 (27.3)	0	19 (70.4)	8 (29.6)	0
Mandibular left first molar (mesial)	15 (45.5)	18 (54.5)	0	23 (85.2)	4 (14.8)	0
Mandibular left first molar (distal)	14 (42.4)	17 (51.5)	2 (6.1)	16 (59.3)	10 (37.0)	1 (3.7)
Overall	233 (44.1)	287 (54.4)	8 (1.5)	335 (62.0)	187 (34.6)	18 (3.3)

Values are n (% of cases).

For extraction: Chi-square value = 88.756, P = 0.001.

For non-extraction: Chi-square value = 33.212, P = 0.016.

For extraction v/s non-extraction: Chi-square value = 43.131, P = 0.001.

Table 3b – The overall distribution of EARR according to the history of extraction.

	Extraction	Non-extraction	P-value	Odds ratio (95% CI)
No resorption	233 (44.1)	335 (62.0)	0.001	2.07 (1.62–2.64)
Resorption	295 (55.9)	205 (38.0)		
Total	528 (100.0)	540 (100.0)		

Values are n (%). P-value by Chi-square test.

minimum in maxillary and mandibular first premolars – 6–8% [Table 1]). This less prevalence in maxillary and mandibular first premolars may be attributed to the fact that these teeth were taken up for measurement only in non-extraction cases (where less tooth movement/strain is usually involved as will be discussed later) since first premolars were extracted in therapeutic extraction cases for the present study. In the present study, no radiographic evidence of Grade 3 EARR (severe) was observed. This finding is in concurrence with previous studies reported in literature, such as that of Martins et al.²¹ who found severe EARR as low as 6.25% in maxillary incisors. Eisel et al.²² in their study reported a much higher prevalence of severe EARR (17.2%) in treated patients who experienced EARR greater than 4 mm in at least one maxillary incisor. However, maxillary and mandibular incisors were not evaluated in the present study. It should be understood that each study classified and measured RR differently. However, all reported that the majority of

teeth experienced mild to moderate resorption following treatment.^{18–20}

In the present study, more EARR was observed in molar teeth compared to other teeth. Maximum EARR was observed in maxillary molars (53.3–63.3%). In mandibular molars, EARR was 36.7–45%. Sharpe et al.¹⁴ observed that molars had the second highest incidence of EARR after maxillary central incisors. In the present study, incisors were not evaluated for EARR and therefore findings of the present study are in concurrence with their study. Beck et al.¹⁵ in their study had results similar to the present study. Their study also discussed the likely relationship between the biomechanics of bite opening and resorption of the molar roots. The high incidence of post-treatment EARR of molar teeth may reflect the increased mechanical stresses placed on these teeth for longer periods compared with premolar teeth.

Gender has been reported to be a potential individual risk factor for RR. In the present study, 45.4% males and 48.3% females showed radiographic evidence of EARR. No statistically significant gender variation was observed ($P > 0.05$). These findings are in concurrence with those of Jiang et al.,²³ Sameshima et al.²⁴ and Ravanmehr et al.²⁵ who reported no statistically significant gender variation in the extent of RR in their studies. Zahedani et al.²⁶ observed that male patients in their study had a higher rate of RR than female patients and this was statistically significant ($P < 0.05$). Ravanmehr et al.²⁵ reported that although different levels of sexual hormones may be attributed to susceptibility to RR, no difference is seen in males and females after treatment.²¹ Mohandesan et al.²⁷ in their study reported that the maxillary incisors of

Table 4 – The distribution of post-treatment EARR according to the duration of orthodontic treatment.

Tooth	≤24 months			>24 months		
	0	1	2	0	1	2
Maxillary right first molar (distobuccal)	6 (54.5)	5 (45.5)	0	18 (36.7)	31 (63.3)	0
Maxillary right first molar (mesiobuccal)	5 (45.5)	6 (54.5)	0	17 (34.7)	32 (65.3)	0
Maxillary right second premolar	6 (54.5)	5 (45.5)	0	20 (40.8)	27 (55.1)	2 (4.1)
Maxillary right first premolar	2 (66.7)	1 (33.3)	0	17 (70.8)	5 (20.8)	2 (8.3)
Maxillary right canine	5 (45.5)	6 (54.5)	0	25 (51.0)	20 (40.8)	4 (8.2)
Maxillary left canine	4 (36.4)	6 (54.5)	1 (9.1)	24 (49.0)	25 (51.0)	0
Maxillary left first premolar	2 (66.7)	1 (33.3)	0	18 (75.0)	5 (20.8)	1 (4.2)
Maxillary left second premolar	7 (63.6)	4 (36.4)	0	13 (26.5)	33 (67.3)	3 (6.1)
Maxillary left first molar (mesiobuccal)	6 (54.5)	5 (45.5)	0	21 (42.9)	27 (55.1)	1 (2.0)
Maxillary left first molar (distobuccal)	9 (81.8)	2 (18.2)	0	18 (36.7)	30 (61.2)	1 (2.0)
Mandibular right first molar (distal)	8 (72.7)	3 (27.3)	0	29 (59.2)	19 (38.8)	1 (2.0)
Mandibular right first molar (mesial)	3 (27.3)	8 (72.7)	0	34 (69.4)	15 (30.6)	0
Mandibular right second premolar	10 (90.9)	1 (9.1)	0	38 (77.6)	11 (22.4)	0
Mandibular right first premolar	3 (100.0)	0	0	15 (62.5)	9 (37.5)	0
Mandibular right canine	5 (45.5)	6 (54.5)	0	24 (49.0)	22 (44.9)	3 (6.1)
Mandibular left canine	5 (45.5)	6 (54.5)	0	20 (40.8)	26 (53.1)	3 (6.1)
Mandibular left first premolar	2 (66.7)	0	1 (33.3)	18 (75.0)	6 (25.0)	0
Mandibular left second premolar	10 (90.9)	1 (9.1)	0	33 (67.3)	16 (32.7)	0
Mandibular left first molar (mesial)	4 (36.4)	7 (63.6)	0	34 (69.4)	15 (30.6)	0
Mandibular left first molar (distal)	7 (63.6)	3 (27.3)	1 (9.1)	23 (46.9)	24 (49.0)	2 (4.1)
Overall	109 (58.0)	76 (40.4)	3 (1.6)	459 (52.2)	398 (45.2)	23 (2.6)

Values are n (% of cases).

For ≤24 months: Chi-square value = 33.441, $P = 0.015$.

For >24 months: Chi-square value = 38.551, $P = 0.003$.

For ≤24 months v/s >24 months: Chi-square value = 2.450, $P = 0.294$.

female patients showed more resorption than those of male patients but the effect of gender was found only for the maxillary lateral incisors. In the present study, females had more RR than males but this association was not statistically significant ($P > 0.05$). Sameshima et al.²⁴ in their study observed that male patients experienced more resorption of the anterior dentition than female patients, but the findings were not statistically significant. However, most large-scale studies reported in literature have found no statistically significant gender difference in the rate and extent of RR.^{20,24,25}

In the present study, the cases in which patients underwent therapeutic extraction had a relatively higher amount of EARR (55.9%) compared to the cases in which patients were treated by non-extraction therapy (37.9%) and this was statistically significant ($P < 0.001$). It is in agreement with other studies that described more resorption after extraction therapy.^{23,24,27} One possible explanation could be an increased mesiodistal tooth movement of the posterior teeth compared with non-extraction cases in order to close extraction spaces. The findings of the present study are not in agreement with those of Nigul et al.,²⁸ who observed that extraction treatment was not associated with excessive RR. In the present study, OR assessment indicated that the cases that had history of therapeutic extraction had two-fold increased risk of EARR than non-extraction cases and this association was statistically significant ($P < 0.001$). This OR was lower than that reported by McNab et al. in their study,¹³ where they reported incidence of EARR to be 3.72 times higher when extractions were performed compared to non-extraction cases.

It is controversial in the literature whether treatment time is related to RR. In the present study, increased EARR was found in cases whose duration of treatment was >24 months (47.8%) when compared to those whose duration of treatment was ≤ 24 months (42%), but this association was not statistically significant ($P > 0.05$). De Shields in his review¹⁸ associated RR to treatment time and reported a weak to moderate positive correlation between duration of treatment and apical EARR. His findings support the notion that treatment time is related to RR, as suggested by McFadden et al.²⁹ However, it contradicts other studies, which suggest that the two factors are unrelated.³⁰

Limitations

The present study is a cross-sectional record-based study, which evaluated OPGs for determination of EARR. Prospective studies are ideally suited but have disadvantages like increased cost and long-term follow-up of the study sample. 3D modalities like CBCT are more accurate in assessing EARR but entail extra cost and increased radiation dosage without commensurate benefits for the patient. Magnification and blurring seen in OPGs make accurate estimation of EARR difficult. However, in the present study, only those OPGs in which root apices were clearly visible were evaluated for EARR.

Conclusion

In the present study, 46.8% of teeth showed evidence of EARR. No statistically significant association was observed between

the prevalence and extent of EARR with the gender and duration of orthodontic treatment. Those treated with extraction therapy had approximately two-fold increased risk of EARR as compared to those treated with non-extraction therapy. Prospective studies with three-dimensional imaging modalities are recommended to substantiate the findings of our study.

Conflicts of interest

The authors have none to declare.

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