Original Article

External Apical Root Resorption Following Orthodontic Treatment

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Abstract: This study investigated the association of appliance type and tooth extraction with the incidence of external apical root resorption (EARR) of posterior teeth following orthodontic treatment. Pre- and posttreatment orthopantomograms were compared for 97 patients and a 4-grade ordinal scale used to measure EARR. The incidence of EARR was positively associated with tooth position ($P < .001$), appliance type ($P = .038$), and extractions ($P = .001$). This was observed in an overall analysis mutually adjusted for the effects of age at start of treatment, pretreatment overbite and overjet, use of headgear, tooth extraction, and type of appliance. The incidence of EARR was 2.30 times higher for Begg appliances compared with edgewise, and it was 3.72 times higher where extractions were performed. (*Angle Orthod* 2000;70:227–232.)

Key Words: External apical root resorption; Fixed orthodontic appliance; Posterior teeth

INTRODUCTION

External apical root resorption (EARR) is an undesirable sequela of orthodontic treatment that results in permanent loss of tooth structure from the root apex. Its pathogenesis is associated with removal of necrotic tissue from areas of the periodontal ligament that have been compressed by an orthodontic load.[1] The identification of factors that predispose a patient to EARR has been the focus of numerous studies. Brezniak and Wasserstein,[2,3] in an extensive review of root resorption following orthodontic treatment, categorized the factors associated with increased levels of EARR under the following headings: (1) biological factors, (2) mechanical factors, (3) combined biological and mechanical factors, and (4) other factors. This review notes conflicting findings of the previous studies on EARR.

Several studies have examined EARR of posterior teeth. Beck and Harris[4] reported no difference in the amount of EARR of posterior teeth following orthodontic treatment with either the Begg or Tweed technique. Furthermore, they found no significant association between the duration of treatment and amount of EARR. Hendrix et al[5] found no correlation between the amount of root resorption of posterior teeth and treatment duration, extraction vs nonextraction, and age of the patient at the start of treatment.

The aim of this study was to examine posterior teeth in patients following orthodontic treatment and to determine whether an association existed between the incidence of EARR and the type of fixed appliance used, the length of treatment, and whether extractions were performed as a part of treatment.

MATERIALS AND METHODS

Sample selection

Records were obtained from patients treated with fixed appliances in both arches at the School of Dentistry, the University of Queensland, Australia. Criteria for the selection were patients with no known medical condition who had a medical history updated at the beginning of treatment; complete records of the malocclusion, treatment plan, and treatment history; and a pretreatment orthopantomogram (OPG). Another OPG was taken within 1 month of debanding; we used the same machine and a standardized technique. Patients with dental agenesis, invaginations, and taurodontism were excluded, as these dentitions have been found to have an increased risk of root resorption.[6] The Dental Sciences Human Ethics Committee granted ethical approval.

Four hundred and four patient files were examined. Of

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these, 97 patients satisfied the selection criteria. The mean age of the patients in this study at the start of treatment was 13.9 years, with treatment time averaging 1.9 years. Almost 60% of these patients were treated with extractions, and more patients were treated with an edgewise appliance (n = 71, 74%) compared with the Begg appliance (n = 25, 26%).

EARR measurement

Posterior EARR was measured on all first and second premolars, mesiobuccal and distobuccal roots of the upper first molars (which will be referred to as mesial and distal, respectively), and mesial and distal roots of lower first molars, providing 4 measurements per quadrant. A 4-grade ordinal scale, modified from Sharpe et al,[7] was used to determine the degree of EARR as follows: 0 = no apical root resorption; 1 = slight blunting of the root apex; 2 = moderate resorption of the root apex beyond blunting and up to one third of the root length; and 3 = excessive (severe) resorption of the root apex beyond one third of the root length.

Only teeth that had completed root formation were measured. Apices, which could not be visualized accurately, were excluded. Apices were examined by use of an X-ray viewing box at 2× magnification.[8,9] All measurements were repeated to determine intraexaminer error and were performed by another operator to calculate the interexaminer error.

Statistical methods

Potentially confounding variables. The patient's age at start of treatment was recorded, as was appliance type (Begg or edgewise) and use of headgear. Other dental information collected included overjet, overbite, and extraction pattern. Too few subjects for meaningful analysis represented several extraction patterns, and this variable was recorded as either positive (yes) or negative (no).

Analytical approach. Too few teeth with pretreatment root resorption were available for meaningful analysis. Hence, for any given tooth, the analyses were restricted to those teeth that recorded no pretreatment root resorption. Proportional odds logit models[10] based on generalized estimating equations[11] were used for the overall analysis of the association between severity of root resorption and effects of appliance (Begg/edgewise) or extraction (yes/no). Similar models were fitted on a tooth-by-tooth basis to determine which teeth were most affected by these variables. All analyses were adjusted for the potential confounding variables listed above. Analyses were performed by the SPSS-PC+ version 7.5 for Windows statistical package and by the SUDAAN version 7.0 statistical package (PSS Inc Headquarters, Chicago, IL). Associations were declared statistically significant at the conventional 95% significance level (2-tailed). However, because a priori power calculations were not performed, the strength of associations was also considered in reporting clinically meaningful results. Odds ratios of 2.0 and more were also therefore reported as being important, regardless of statistical significance. These statistics may be interpreted as the relative excess of root resorption associated with, for example, one appliance over the other.

RESULTS

Measurement error

There was good to high agreement in readings over time for the examiner and between independent examiners. Kappa coefficients of intraexaminer agreement were 0.87 for the maxilla posttreatment and 0.96 for the mandible posttreatment. Interexaminer agreement coefficients were 0.78 and 0.67, respectively. Agreement for pretreatment was almost 100% in both arches for both the intra- and interexaminer readings. Limiting readings to teeth with complete apices that could be visualized accurately provided 1175 observations (some teeth could not be included, as they were extracted as part of the orthodontic treatment).

Pretreatment root resorption

There were few instances where pretreatment root resorption was observed in the 97 subjects. In a total of 1175 observations over the 16 different sites studied, only 19 sites were observed to have pretreatment resorption grades of 1 to 3. Of these 19, 6 had a different posttreatment score compared with the pretreatment value. Given that it would be necessary to adjust for the presence of pretreatment resorption when comparing posttreatment resorption between the patient groups and that these low numbers would make the adjustment impossible, it was decided to exclude data from teeth where pretreatment resorption was present. Therefore, the analysis made direct use of posttreatment degree of root resorption as its outcome from 1156 observations.

Factors influencing root resorption

The distribution of the grades of posttreatment EARR for each tooth site is shown in Table 1. The distribution of the grades for posttreatment EARR with respect to appliance type, use of headgear, and extraction history is summarized in Table 2 (Appendix Tables A1, A2, and A3 present tooth-specific associations between severity of root resorption and appliance type, use of head gear, and extraction history). Adjustment for the potentially confounding factors of age at the start of treatment, overjet, overbite, extraction, and appliance (in a model accounting for the fact that multiple teeth were considered for each subject) did not significantly alter the conclusion from the initial crude analyses that the degree of posttreatment root resorption was related to tooth position (crude $P < .001$; adjusted $P < .001$).

TABLE 1. Distribution of Posttreatment Root Resorption Scores for Teeth With No Pretreatment External Apical Root Resorption

	Score							
	0		1		2		3	
Tooth	n	%	n	%	n	%	n	%
Maxillary right molar (distal)	53	57.0	24	25.8	10	10.8	6	6.5
Maxillary right molar (mesial)	53	57.6	24	26.1	12	13.0	3	3.3
Maxillary right second premolar	44	83.0	6	11.3	3	5.7	0	0
Maxillary right first premolar	37	82.2	6	13.3	1	2.2	1	2.2
Maxillary left molar (distal)	48	52.7	23	25.3	17	18.7	3	3.3
Maxillary left molar (mesial)	53	58.2	19	20.9	18	19.8	1	1.1
Maxillary left second premolar	44	83.0	8	15.1	1	1.9	0	0
Maxillary left first premolar	40	87.0	4	8.7	1	2.2	1	2.2
Mandibular left molar (distal)	34	36.6	33	35.5	20	21.5	6	6.5
Mandibular left molar (mesial)	46	48.9	37	39.4	9	9.6	2	2.1
Mandibular left second premolar	30	73.2	10	24.4	1	2.4	0	0
Mandibular left first premolar	55	78.6	10	14.3	4	5.7	1	1.4
Mandibular right molar (distal)	30	32.6	33	35.9	25	27.2	4	4.3
Mandibular right molar (mesial)	33	35.1	44	46.8	15	16.0	2	2.1
Mandibular right second premolar	32	78.0	6	14.6	3	7.3	0	0
Mandibular right first premolar	50	74.6	10	14.9	6	9.0	1	1.5

Averaged over all teeth, there were also significant positive associations between root resorption and appliance ($P = .015$) and extraction ($P = .001$). Although overjet, overbite, and age at start of treatment were not individually statistically associated with root resorption ($P = .155$, .671, and .120, respectively), they were included in all analysis models because they were identified a priori as confounders of the association between root resorption and appliance. It was also possible that their exclusion from the model could distort the association of interest. By use of estimates from the adjusted model, it was determined that the degree of root resorption was on average 2.30-fold higher for the Begg appliance compared with edgewise appliances (95% confidence interval [CI], 1.17–4.53, $P = .017$). In addition, a positive extraction history was associated with a 3.72-fold relative excess in the incidence of root resorption compared with a negative extraction history (95% CI 1.96–7.04, $P < .001$).

The analysis also identified subgroups of teeth within which the distribution of severity of EARR was of a similar magnitude (Table 3).

Tooth-specific results

On a tooth-by-tooth basis and adjusted for age at start of treatment, overjet, overbite, and appliance, a positive history of tooth extraction was associated with significantly greater posttreatment root resorption of most teeth (mandibular right molar distal [$P = .034$] and mandibular right molar mesial [$P = .001$]; mandibular right second premolar [$P = .049$]; mandibular right first premolar [$P = .002$]; mandibular left first premolar [$P = .050$]; mandibular left second premolar [$P = .016$] and mandibular left molar mesial [$P = .005$]; and mandibular left molar distal [$P = .008$]). Although not quite attaining statistical significance, there was some evidence to suggest that there was an association for root resorption of the maxillary left first premolar ($P = .068$) and maxillary left molar mesial root ($P = .056$), which could not be entirely discounted.

On a tooth-by-tooth basis and adjusted for age at start of treatment, overjet, overbite, appliance, and extraction, root resorption was also significantly greater when the Begg appliance was used compared to the edgewise appliance. This was true for the mandibular right molar distal ($P = .001$) and mandibular right molar mesial ($P = .007$) roots, mandibular right first premolar ($P = .030$), and mandibular left molar distal root ($P = .043$). Although not statistically significant, root resorption tended to be consistently higher for the Begg appliance than for the edgewise appliance for all other teeth.

No other statistically significant differences were noted.

DISCUSSION

In this study, the incidence of EARR in the posterior teeth of healthy patients was positively associated with tooth position ($P < .001$), type of appliance used ($P = .038$), and tooth extraction ($P = .001$). This was observed in an overall (all teeth combined) analysis that was adjusted for the potentially confounding factors of age at the start of treatment, pretreatment overbite and overjet, use of headgear, extraction, and appliance. The incidence of EARR was 2.30 times higher for patients treated with Begg appliances compared with edgewise appliances, and it was 3.72 times higher for patients for whom extractions were performed, compared with those for whom no extractions were performed.

Several previous studies have examined the association of posterior EARR with appliance type and the presence of extractions.[4,5,12] This study used an ordinal scale rather than

TABLE 2. Treatment Variable and Distribution of Posttreatment Root Resorption Sites

Variable	Number of Cases	Site 0 n	Site 0 %	Site 1 n	Site 1 %	Site 2 n	Site 2 %	Site 3 n	Site 3 %
Edgewise	72	566	64.0	196	22.5	90	10.3	19	2.2
Begg	25	116	40.7	101	35.4	56	19.7	12	4.2
No headgear	69	478	56.7	212	25.2	125	14.8	28	3.3
Headgear	28	204	65.2	85	27.2	21	6.7	3	0.9
Nonextraction	39	377	75.9	87	17.5	31	6.2	2	0.4
Extraction	58	305	46.1	210	31.7	119	18.0	28	4.2

TABLE 3. Subgroups of Teeth Showing Similar Amounts of External Apical Root Resorption

Resorption Level	Tooth
Most	Distal root of mandibular molars; mesial root of mandibular right molar
	Mesial root of mandibular left molar; mesial and distal roots of maxillary molars
	Mandibular premolars; maxillary right first premolar
Least	Maxillary second premolars; maxillary left first premolar

direct measurements of tooth length to avoid the errors associated with magnification of teeth in OPGs and measurement error associated with landmark identification. Friedland[13] stated that measurements could not be made from a panoral film with sufficient accuracy to be used for orthodontic diagnosis, as the degree of magnification for any particular area is not known. Previous studies[4,12] that have used ordinal scales to measure posterior EARR did not adjust for the potential confounding effects of age at the start of treatment, overjet, overbite, appliance type, and the presence of extraction. Unless the comparison groups are perfectly balanced, testing for a statistically significant difference between pretreatment groups, as these authors did, is not the same as adjusting for these potentially confounding factors in the model and may influence the finding of significance or nonsignificance. More importantly, this current study differs from previous ordinal studies on posterior EARR in that it has accounted for the correlated nature of the collected data across teeth and between pretreatment and posttreatment measurements.

More EARR was recorded for molar teeth compared with premolar teeth. Sharpe et al[7] observed that molars had the second highest incidence of EARR after maxillary central incisors. Beck and Harris[4] discussed the likely relationship between the biomechanics of bite opening and resorption of the molar roots. In the Begg technique, the first molars in both arches had tip-back bends placed mesial to the molar tube.[14] In Rickett's Bioprogressive, tip-back bends were similarly placed for utility arches.[15] the straight wire technique often used a reverse curve of Spee in the lower arch wire to assist with leveling,[16] and both edgewise techniques employed headgear to the upper molar tubes. In addition, for both the Begg technique and in some edgewise cases, 2 × 4 or 2 × 6 bandups were performed for the initial stages of treatment, reducing the total time premolar teeth were subjected to direct orthodontic loading. The high incidence of posttreatment EARR of molar teeth may reflect the increased mechanical stresses placed on molar teeth for longer periods of time compared with premolar teeth.

The association between type of appliance used and the incidence of EARR was significant. Patients treated with the Begg appliance were more than twice as likely to exhibit posterior EARR. The tooth-specific analysis found a significantly higher incidence of root resorption when the Begg appliance was used for the mesial and distal roots of the lower right molar, the lower right first premolar, and the distal root of the lower left molar. As the distal roots of both lower molars exhibited increased amounts of EARR, this finding was unlikely to be a statistical artefact and may indicate an increased severity of tip-back bend in the lower arch compared with the upper arch. The clinical records did not contain sufficiently accurate information to permit a more detailed analysis of this speculated association.

Both the overall and tooth-specific analyses in this study found a higher incidence of EARR in cases where extractions were performed. The tooth-specific analysis found that extraction treatment was associated with a higher incidence of EARR than nonextraction treatment for nearly all teeth. As these analyses were adjusted for appliance type, age at the start of treatment, and pretreatment overbite and overjet, the mechanism by which extraction of teeth increases the incidence of EARR is likely to be independent of these factors. One possible explanation could be the increased tooth movement (mesial-distal) of the posterior teeth compared with nonextraction cases in order to close extraction spaces. Studies on anterior teeth have found weak correlations between the degree of EARR and movement of the apex[17] and retraction of the apex.[18] The amount of tooth movement was not measured in this study, and further investigation into the association between the degree of movement of the posterior teeth and the incidence of EARR is warranted.

CONCLUSION

In this study, nonextraction patients with an edgewise appliance demonstrated relatively less posterior EARR compared with patients in which extractions or a Begg appliance were involved.

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TABLE A1. Appliance Type and Distribution of Posttreatment Root Resorption

	Edgewise								Begg							
	0		1		2		3		0		1		2		3	
Tooth	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Maxillary right molar (distal)	43	62.3	17	24.6	5	7.3	4	5.8	10	41.7	7	29.2	5	20.8	2	8.3
Maxillary right molar (mesial)	44	63.8	14	20.3	9	13.0	2	2.9	9	39.1	10	43.5	3	13.0	1	4.3
Maxillary right second premolar	34	87.2	3	7.7	2	5.1	0	0.0	10	71.4	3	21.4	1	7.1	0	0.0
Maxillary right first premolar	33	82.5	5	12.5	1	2.5	1	2.5	4	80.0	1	20.0	0	0.0	0	0.0
Maxillary left molar (distal)	39	58.2	16	23.9	10	14.9	2	3.0	9	37.5	7	29.2	7	29.2	1	4.2
Maxillary left molar (mesial)	42	62.7	13	19.4	12	17.9	0	0.0	11	45.8	6	25.0	6	25.0	1	4.2
Maxillary left second premolar	35	87.5	4	10.0	1	2.5	0	0.0	9	69.3	4	30.7	0	0.0	0	0.0
Maxillary left first premolar	35	87.5	3	7.5	1	2.5	1	2.5	5	83.3	1	16.7	0	0.0	0	0.0
Mandibular left molar (distal)	29	42.6	26	38.2	10	14.7	3	4.4	5	20.0	7	28.0	10	40.0	3	12.0
Mandibular left molar (mesial)	37	53.6	24	34.8	7	10.1	1	1.5	9	36.0	13	52.0	2	8.0	1	4.0
Mandibular left second premolar	24	80.0	5	16.7	1	3.3	0	0.0	6	54.5	5	45.5	0	0.0	0	0.0
Mandibular left first premolar	45	83.3	6	11.1	2	3.7	1	1.9	10	62.5	4	25.0	2	12.5	0	0.0
Mandibular right molar (distal)	28	41.8	24	35.8	13	19.4	2	3.0	2	8.0	9	36.0	12	48.0	2	8.0
Mandibular right molar (mesial)	31	44.3	28	40.0	10	14.3	1	1.4	2	8.3	16	66.7	5	20.8	1	4.2
Mandibular right second premolar	24	82.8	3	10.3	2	6.9	0	0.0	8	72.7	3	27.3	0	0.0	0	0.0
Mandibular right first premolar	43	82.7	5	9.6	3	5.8	1	1.9	7	46.7	5	33.3	3	20.0	0	0.0
Total	566	64.0	196	22.5	90	10.3	19	2.2	116	40.7	101	35.4	56	19.7	12	4.2

TABLE A2. Use of Headgear and Distribution of Posttreatment Root Resorption

	Headgear								No Headgear							
	0		1		2		3		0		1		2		3	
Tooth	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Maxillary right molar (distal)	16	59.3	9	33.3	1	3.7	1	3.7	37	56.1	15	22.7	9	13.6	5	7.6
Maxillary right molar (mesial)	17	63.0	7	26.0	2	7.3	1	3.7	36	55.4	17	26.2	10	15.4	2	3.1
Maxillary right second premolar	14	100.0	0	0.0	0	0.0	0	0.0	30	76.9	6	15.4	3	7.7	0	0.0
Maxillary right first premolar	8	88.9	1	11.1	0	0.0	0	0.0	29	80.5	5	13.9	1	2.8	1	2.8
Maxillary left molar (distal)	15	57.7	7	26.9	4	15.4	0	0.0	33	50.8	16	24.6	13	20.0	3	4.6
Maxillary left molar (mesial)	18	69.2	6	23.1	2	7.7	0	0.0	35	53.8	13	20.0	16	24.6	1	1.5
Maxillary left second premolar	13	92.9	1	7.1	0	0.0	0	0.0	31	79.5	7	17.9	1	2.6	0	0.0
Maxillary left first premolar	10	100.0	0	0.0	0	0.0	0	0.0	30	83.3	4	11.1	1	2.8	1	2.8
Mandibular left molar (distal)	12	44.4	12	44.4	3	11.1	0	0.0	22	33.3	21	31.8	17	25.8	6	9.1
Mandibular left molar (mesial)	16	57.1	10	35.7	2	7.2	0	0.0	30	45.5	27	40.9	7	10.6	2	3.0
Mandibular left second premolar	8	80.0	2	20.0	0	0.0	0	0.0	22	71.0	8	25.8	1	3.2	0	0.0
Mandibular left first premolar	14	82.4	2	11.8	1	5.9	0	0.0	41	77.4	8	15.1	3	5.7	1	1.9
Mandibular right molar (distal)	11	42.3	12	46.2	3	11.5	0	0.0	19	28.8	21	31.8	22	33.3	4	6.1
Mandibular right molar (mesial)	12	44.4	13	48.1	1	3.7	1	3.7	21	31.3	31	46.3	14	20.9	1	1.5
Mandibular right second premolar	7	77.8	1	11.1	1	11.1	0	0.0	25	78.1	5	15.6	2	6.3	0	0.0
Mandibular right first premolar	13	81.3	2	12.5	1	6.3	0	0.0	37	72.5	8	15.7	5	9.8	1	2.0
Total	204	65.2	85	27.2	21	6.7	3	0.9	478	56.7	212	25.2	125	14.8	28	.3

TABLE A3. Extraction History and Distribution of Posttreatment Root Resorption

	Extractions								No Extractions							
	0		1		2		3		0		1		2		3	
Tooth	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Maxillary right molar (distal)	27	46.6	18	31.0	8	13.8	5	8.6	26	74.3	6	17.1	2	5.7	1	2.9
Maxillary right molar (mesial)	26	45.6	20	35.1	8	14.0	3	5.3	27	77.1	4	11.4	4	11.4	0	0.0
Maxillary right second premolar	22	75.9	4	13.8	3	10.3	0	0.0	22	91.7	2	8.3	0	0.0	0	0.0
Maxillary right first premolar	13	72.1	3	16.7	1	5.6	1	5.6	24	88.9	3	11.1	0	0.0	0	0.0
Maxillary left molar (distal)	22	39.3	19	33.9	12	21.4	3	5.4	26	74.3	4	11.4	5	14.3	0	0.0
Maxillary left molar (mesial)	26	46.4	15	26.8	14	25.0	1	1.8	27	77.1	4	11.4	4	11.4	0	0.0
Maxillary left second premolar	22	75.9	6	20.7	1	3.4	0	0.0	22	91.7	2	8.3	0	0.0	0	0.0
Maxillary left first premolar	14	82.4	3	17.6	0	0.0	0	0.0	26	96.3	1	3.7	1	5.0	1	5.0
Mandibular left molar (distal)	13	24.1	20	37.0	15	27.8	6	11.1	21	53.8	13	33.3	5	12.8	0	0.0
Mandibular left molar (mesial)	18	32.7	27	49.2	8	14.5	2	3.6	28	71.8	10	25.6	1	2.6	0	0.0
Mandibular left second premolar	12	57.1	8	38.1	1	4.8	0	0.0	18	90.0	2	10.0	0	0.0	0	0.0
Mandibular left first premolar	28	70.0	8	20.0	3	7.5	1	2.5	27	90.0	2	6.7	1	3.3	0	0.0
Mandibular right molar (distal)	12	22.2	21	38.9	17	31.5	4	7.4	18	47.4	12	31.6	8	21.1	0	0.0
Mandibular right molar (mesial)	13	23.2	26	46.4	15	26.8	2	3.6	20	52.6	18	47.4	0	0.0	0	0.0
Mandibular right second premolar	14	66.7	4	19.0	3	14.3	0	0.0	18	90.0	2	10.0	0	0.0	0	0.0
Mandibular right first premolar	23	60.5	8	21.1	6	15.8	1	2.6	27	93.1	2	6.9	0	0.0	0	0.0
Total	305	46.1	210	31.7	119	18.0	28	4.2	377	75.9	87	17.5	31	6.2	2	0.4