ORIGINAL ARTICLE

Identification of orthodontic patients at risk of severe apical root resorption

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Introduction: Current information suggests that the major variation in orthodontic root resorption can be explained by differences in individual predisposition. Our aim was therefore to test the predictive value of the amount of maxillary incisor resorption about 6 and 12 months after bracket placement for the resorption at appliance removal. **Methods:** We measured tooth length of the maxillary incisors on digitally converted periapical radiographs, adjusted for projection errors, made before treatment (T1), about 6 months (T2) and 12 months (T3) after bracket placement, and at the end of active treatment (T4) of 267 prospectively enrolled orthodontic patients, and interpreted reduced tooth length as apical root resorption. Anatomic and occlusal parameters were scored on the T1 radiographs and study models. Anamnestic and treatment parameters were collected from standardized recordings in the charts. **Results:** The Spearman R for resorption of each incisor ranged from 0.61 to 0.76 at T2 vs T4, and from 0.77 to 0.88 at T3 vs T4 ($P < 0.001$). Only 0.6% of the patients with no incisors with >1.0 mm of resorption at T2 and 0.5% of those with no incisors with >2.0 mm of resorption at T3 had at least 1 incisor with >5.0 mm of resorption at T4. Amount of resorption at T3 and maxillary tooth extraction were included in the final prediction model for resorption of the most severely affected central and lateral incisors at T4, with explained variances of 0.71 and 0.67, respectively. Treatment duration and time with square wires was not related to resorption ($P > 0.05$). **Conclusions:** Patients at risk of severe apical root resorption can be identified according to the amount of resorption during the initial treatment stages. (Am J Orthod Dentofacial Orthop 2009;135:448-55)

The average amount of resorption per root of examined maxillary incisors or anterior teeth is less than 1.5 mm during comprehensive orthodontic treatment,[1-4] and the lateral incisors have been found to resorb more than the central incisors.[2-4] About 5% of adults[3] and 2% of adolescents[1] are likely to have at least 1 tooth with resorption of more than 5 mm during active treatment. Similarly, simultaneous subjective scoring of pretreatment and posttreatment panoramic radiographs of a large, representative patient sample suggests that about 3% experience resorption of more than a quarter of the root length of both maxillary central incisors during fixed appliance therapy.[5] Although resorption stops once the active appliances are removed, the longevity of severely resorbed teeth might be compromised in patients susceptible to marginal periodontal breakdown.[6] In addition, teeth with abnormally short roots might not be suitable as abutments if bridge restorations are required in the future. The ability to identify the small proportion of patients at risk of severe apical root resorption might have clinical significance.

Studies using univariate or multivariate regression that have included amount of tooth movement[7,8] and abnormal root form as variables in the analyses[4,7] agree that those parameters are risk factors. Similarly, the amount of resorption increases with increased tooth length (TL)[4,7] and reduced root width (RW).[7,9] Teeth with short, blunt roots are not at increased risk of resorption.[4,7] Also, split-mouth[10] and intergroup[7] comparisons of representative patient samples conclude that endodontic treatment is a preventive factor. However, findings regarding the effect of treatment parameters are inconsistent.[2,7,8]

Studies using multivariate analyses conclude that the explained variance of the parameters in the final prediction model is less than 20%.[2,7,9] Similarly, only minor differences in tooth morphology and treatment parameters have been found between patients with more than 20% of apical resorption of all 4 maxillary incisors and controls without severe resorption, matched for age, sex, practitioner, race, and treatment time.[11] Such findings indicate the effects of unidentified risk factors. A recent case series suggested that dental anomalies on at

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Supported by grant DD02/00 from Kuwait University.
The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
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Submitted, March 2007; revised and accepted, June 2007.
0889-5406/$36.00

doi:10.1016/j.ajodo.2007.06.012

least 1 tooth—a reason that has not been used as a variable in previous studies[2,4,7-9,11]—are major risk factors for orthodontic root resorption.[12] However, a later study found no differences in apical maxillary incisor resorption between patient groups with and without dental anomalies, matched for known risk factors.[13] Similarly, there is no evidence that peg-shaped and small maxillary lateral incisors have an increased risk of resorption,[14] or that dental invagination is a risk factor.[15]

The limited effect of identified risk factors suggests that the major variation in orthodontic root resorption might be explained by differences in individual predisposition.[2,7,9] If so, predisposed patients might experience root resorption already in the initial leveling stages. Few studies have explored that hypothesis.[16,17] One study evaluated 390 teeth in 98 patients.[16] However, the availability of only nonstandardized periapical radiographs necessitated simultaneous, subjective scoring of the pretreatment and posttreatment radiographs, introducing a risk of bias. Also, the scoring scale might not have been sufficiently accurate to depict the small changes that are likely during the initial treatment stages. The other study evaluated 92 maxillary incisors in 45 patients selected according to root morphology, therefore precluding inferences to the population.[17]

Previous studies on apical orthodontic root resorption were designed in retrospect relative to the timing of the active treatment, selecting the pretreatment and posttreatment records to be measured from various patient files.[1-17] The results are not likely to be different in studies designed before the start of active treatment, if the patient materials were representative, the radiographs of sufficient quality, and anamnestic parameters appropriately recorded. In both situations, the actual experimental design would be identical, analyzing the data after all active treatment, either prospectively by testing the outcome differences[1-4,6-10,13-17] or retrospectively by testing the pretreatment differences between subjects and controls.[5,11] However, valid results on effect of treatment parameters such as time period with square wires and use of elastics might require a concurrent, prospective study design to ensure accurate chart notes. Similarly, the effect of resorption during the initial treatment stages as a clinically meaningful predictor would require a study to be designed before treatment because of lack of record bases of sufficient size and representativity.

We recently enrolled a large, representative group of orthodontic patients prospectively. We documented the prevalence and the severity of maxillary incisor resorption about 6 and 12 months after bracket placement,[18,19] as well as a clinically significant association between amounts of resorption during the first and second 6-month periods.[19] The aim of this study was to test the predictive value of the amount of resorption about 6 and 12 months after bracket placement for the amount of resorption after active treatment. Our specific aims were to test the hypotheses (1) that there is a clinically significant association between initial and posttreatment amounts of resorption, (2) that the risk of severe resorption is minimal in patients with little initial resorption, and (3) that the explained variance of the prediction model is larger than previously documented when the initial amount of resorption is a variable.

MATERIAL AND METHODS

After ethical clearance from Kuwait University, 302 orthodontic patients were consecutively enrolled between March 2001 and July 2002 at 3 centers in Kuwait, Nijmegen, The Netherlands, and Seattle, Wash. All patients were treated with multi-bonded preadjusted appliances, with either 0.018-in (113 patients) or 0.022-in (189 patients) bracket slots. The protocol called for 3 radiographic projections, 1 with the central ray between the 2 central incisors, and 1 with the ray centered at the lateral incisor on either side, made according to a paralleling technique before treatment (T1), at approximately 6 (T2) and 12 (T3) months after placement of maxillary incisor brackets, and after active treatment (T4). Sixteen patients refused to participate in the final radiographic examination, another 6 had insufficient quality of the T1 radiographs, and another 13 had a total treatment time shorter than 18 months. Hence, the final sample consisted of 267 patients (178 female, 89 male) with ages of 10.1 to 55.5 years at T1 (mean, 18.8; SD, 10.1 years). No differences were found in age, sex, or extraction decision between the included and rejected subjects ($P > 0.05$). The mean time periods from T1 to T2, T1 to T3, and T1 to T4 were 6.4 months (SD, 0.9), 12.5 months (SD, 1.0), and 24.9 months (SD, 7.3), respectively. All radiographs were missing in 3 patients at T2 and in 36 patients at T3. Eight teeth were not scored in 4 patients at T2, 2 teeth were not scored in 1 patient at T3, and 5 teeth were not scored in 2 patients at T4. In addition, 66 teeth were omitted at all time periods in 46 patients because of congenital absence, incomplete radiographic projection, or unsuccessful radiographic reconstruction.

Previous orthodontic treatment was recorded as present or absent through patient interview. A history of traumatic injury to at least 1 maxillary incisor was recorded through clinical and radiographic examinations and patient interviews at T1, and recorded as present or absent.

The number of congenitally absent teeth other than third molars was scored on the panoramic radiographs at T1. Root form was scored subjectively as normal, blunt,

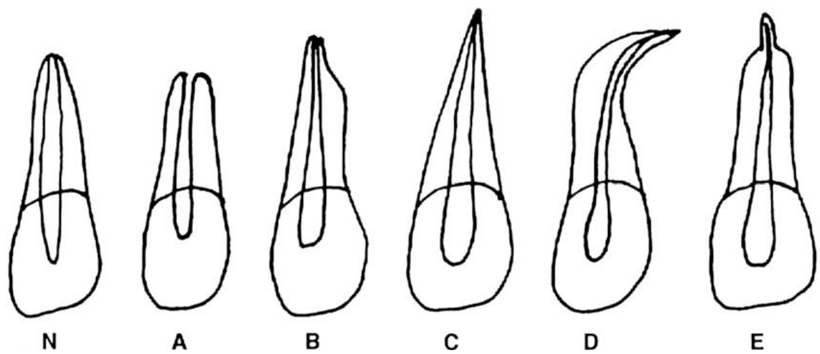

Fig 1. Criteria for subjective scoring of root form: *N,* normal; *A,* blunt; *B,* eroded; *C,* pointed; *D,* deviated; *E,* bottle shaped (adapted and reprinted with permission from Mirabella and Årtun[3]).

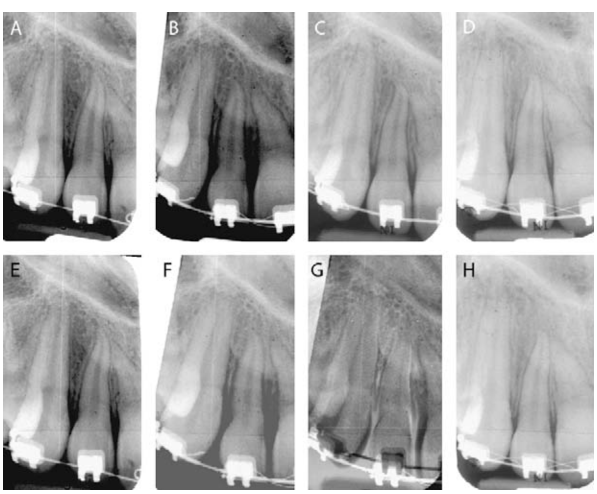

Fig 2. Reconstruction T1, T2 (5.2 months), and T4 (18.2 months) periapical radiographs of the maxillary right lateral incisor according to the radiographic projection at T3 (12.9 months): **A,** original T1 image; **B,** original T2 image; **C,** original T3 image; **D,** original T4 image; **E,** reconstructed T1 image; **F,** reconstructed T2 image after gamma correction and contrast optimization; **G,** subtraction of reconstructed T2 image from original T3 image; **H,** reconstructed T4 image. Note 1.0 mm of resorption at T2, 0.3 mm elongation at T3, and 1.4 mm elongation at T4 according to original images; and 0.1 mm of resorption at T2, 0.3 mm of resorption at T3, and 0.5 mm of resorption at T4 according to the reconstructed images.

eroded, pointed, bent, or bottle shaped on the T1 radiographs (Fig 1).

Extraction alternative was recorded as nonextraction and extraction of maxillary teeth with or without extraction in the mandible (various premolar and molar combinations). In addition, the number of months with the use of square wire and anterior or posterior elastics, and total treatment time were recorded.

A trained assistant in Nijmegen converted all periapical radiographs to digital images using a scanner (Scanjet 5470c Hewlett-Packard, Palo Alto, Calif) at a resolution of 300 dpi. An author (J.Å.) evaluated all available images of each incisor at the 4 times simultaneously on the screen (Fig 2, *A-D*). Gamma correction and contrast optimization were performed if necessary (Fig 2, *B* and *F*). By choosing the T2 or T3 projection judged most favorable as a reference, each remaining image was reconstructed according to the reference image to correct for differences in enlargement and projection (Fig 2, *E, F,* and *H*). This was done through pairwise superimposition on 4 identical anatomic landmarks, 2 as far incisally and 2 as far apically as possible, by using the Windows-based Emago/Advanced software package (version 2.20, SODS, Amsterdam, The Netherlands).[18-20] The quality of the reconstruction was checked by subtracting the reconstructed image from the reference image.[18-20] If only minimal root and crown structures could be discerned on the subtracted image, the reconstruction was considered successful (Fig 2, *G*).

All reconstructed and reference radiographic images were coded and measured in random order with the Emago software, recording the number of pixels between landmark pairs.[18-20] TL was measured as the distance from the apex tip to the midpoint of either the incisal edge or the line connecting the mesial and distal outlines of cementoenamel junction, depending on the location of the incisal reference points used for reconstruction. RW was measured 4 mm from apex. Assuming that the enlargement factor was negligible, absolute distances were calculated according to the formula that 1 pixel = 0.085 mm, since all images were scanned at a resolution of 300 dpi.

Intraobserver reliability was assessed by statistically analyzing the difference between double measurements taken at least a week apart on study models at T1 and radiographs at T1 and T4 of 20 randomly selected subjects. For the computerized measurements, all

Table I. Descriptive statistics for resorption of each maxllary incisor and the most severely resorbed incisor, and average resorption of both lateral incisors, both central incisors, and all 4 incisors per patient in millimeters at appliance removal

Tooth	*Mean*	*SD*	*Minimum*	*Maximum*
12	1.24	1.26	–0.34	6.97
11	1.01	1.05	–0.34	6.63
21	0.88	1.17	–0.68	8.50
22	0.95	1.17	–0.17	7.40
Inc max	1.69	1.34	0.00	8.50
12, 22	1.17	1.15	–0.17	7.18
11, 21	1.01	1.05	–0.30	7.57
12, 11, 21, 22	1.10	1.02	–0.09	7.37

12, Maxillary right lateral incisor; *11,* right central incisor; *21,* maxillary left central incisor; *22,* maxillary left lateral incisor; *Inc max,* the most severely resorbed incisor.

reconstruction and landmark identification procedures were repeated. The errors of the continuous variables were calculated from the equation:

$$S_x = \sqrt{\frac{\Sigma D^2}{2N}}$$

where *D* is the difference between duplicate measurements and *N* is the number of double measurements,[21] and according to the Pearson correlation coefficient (r). The errors for the measurements of the radiographs at T1 were 0.46 mm for TL (r = 0.96) and 0.25 mm for RW (r = 0.70). The error for calculation of root resorption was 0.37 mm (r = 0.72). The kappa for subjective scoring of root shape was 0.74.

Statistical analysis

The data were analyzed with SPSS for Windows software (version 13.0, SPSS, Chicago, Ill). Apical root resorption amounts at T2, T3, and T4 were calculated by subtracting each respective TL from the corresponding TL at T1. Analysis of variance (ANOVA) was used to test the effect of operator and slot size on apical root resorption. Spearman rank correlation coefficients were used to test the association between amount of resorption at T2 and T4 and at T3 and T4. The Pearson chi-square or the Fisher exact test was used to test the differences in proportions of patients with at least 1 incisor with >5.0 mm of resorption at T4 in patients with and without at least 1 incisor with >1.0 mm and with >2.0 mm of resorption at T2, and with and without at least 1 incisor with >2.0 mm and with >3.0 mm of resorption at T3, respectively. Linear regression analyses were used to identify predictors for resorption at T4. After univariate regression, stepwise multiple regression with forward selection was used to develop a prediction model. Variables with lowest *P* value were successively entered into the model if their effects were significant at $P < 0.05$. Separate analyses were made for the central and lateral incisors, using the most severely resorbed tooth of each pair as the dependent variable.

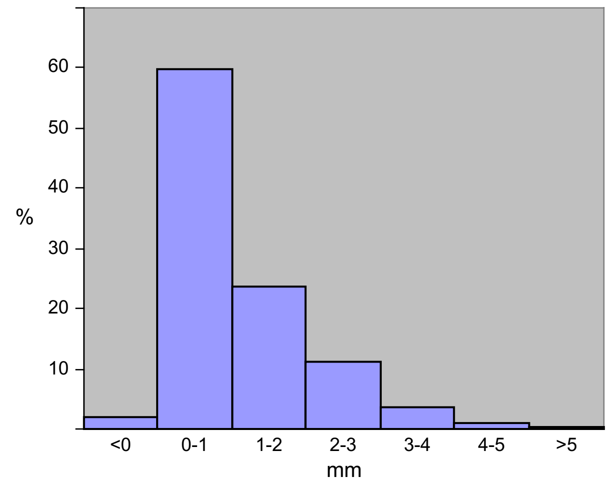

Fig 3. Percentages of patients with average apical root resorption of all measured maxillary incisors in each 0.5-mm interval.

RESULTS

The average patient had 1.10 mm (SD, 1.02) of resorption per tooth when averaging all measured incisors, and 1.69 mm (SD, 1.34) of resorption of the most severely affected incisor at T4 (Table I). No difference was found when comparing average resorption of the measured central and lateral incisors ($P > 0.05$, Table I). The amount of resorption was similar among patients treated by the practitioners at the 3 centers ($P > 0.05$), and no difference was found between patients treated with .018-in and .022-in bracket slots ($P > 0.05$). When averaging all measured incisors, 16.5% of the patients (95% CI, 12.0%-21.0%) had >2.0 mm of resorption per tooth, 5.2% (95% CI, 2.5%-7.9%) had >3.0 mm of resorption per tooth, and 1.5% (95% CI, 0%-3.0%) had >4.0 mm per tooth, with a maximum of 7.37 mm (Figs 3 and 4). When evaluating the most severely affected incisor, 5.6% of the patients (95% CI, 2.8%-8.4%) had >4.0 mm of resorption, 3.4% (95% CI, 1.2%-5.6%) had >5.0 mm of resorption, and 0.7% (95% CI, 0%-1.9%) had >6.0 mm of resorption, with a maximum of 8.5 mm (Figs 4 and 5). Of the 4.9% of the teeth calculated to have tooth elongation, the maximum value was 0.68 mm (Table I). As a result, 1.9% of the patients were calculated to have tooth

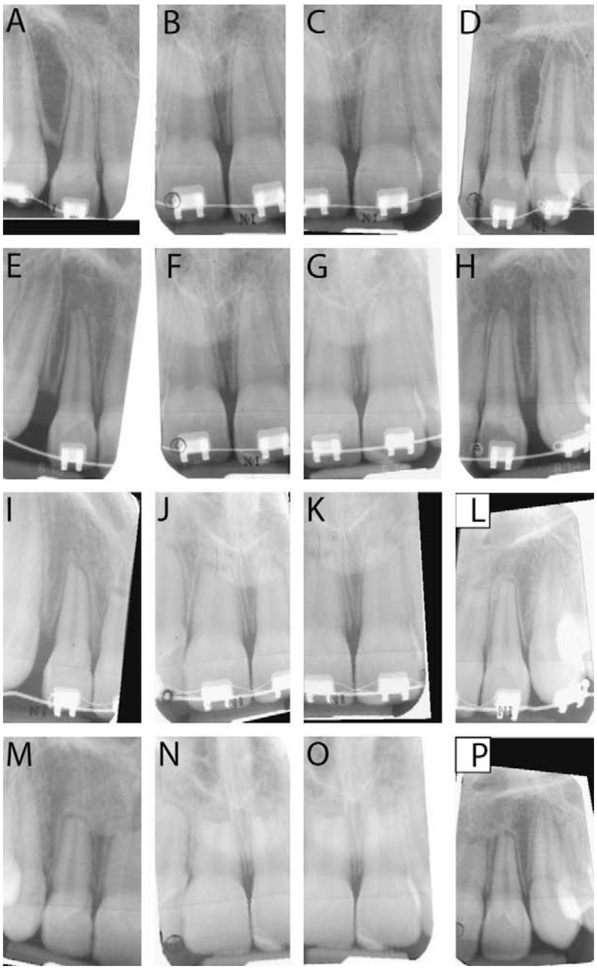

Fig 4. Reconstruction of T1, T3 (11.9 months), and T4 (22.1 months) periapical radiographs of all 4 maxillary incisors according to radiographic projection at T2 of a patient with average resorption of 2.2 mm at T2, 5.5 mm at T3, and 7.4 mm at T4 of all 4 incisors; and with resorption of the left central incisor of 2.7 mm at T2, 5.1 mm at T3, and 8.5 mm at T4. **A-D**, Reconstructed T1 images; **E-H**, original T2 images; **I-L**, reconstructed T3 images; **M-P**, reconstructed T4 images.

elongation when averaging the change in TL from T1 to T4 of all measured incisors, whereas none had a negative value (representing tooth elongation) when calculating the most severely resorbed tooth.

Spearman R values for amount of resorption at T2 vs T4 ranged from 0.61 to 0.76 for each incisor; were 0.65, 0.77, and 0.74 for average resorption of the measured central incisor, the measured lateral incisor, and all measured incisors, respectively; and was 0.73 for the most severely resorbed incisor per patient ($P < 0.001$). Similar coefficients at T3 vs T4 ranged from 0.77 to 0.88 for each incisor; were 0.80, 0.86, and 0.86 for average resorption of the measured central incisor, the measured lateral incisor, and all measured incisors, respectively; and was 0.85 for the most severely resorbed incisor per patient ($P < 0.001$).

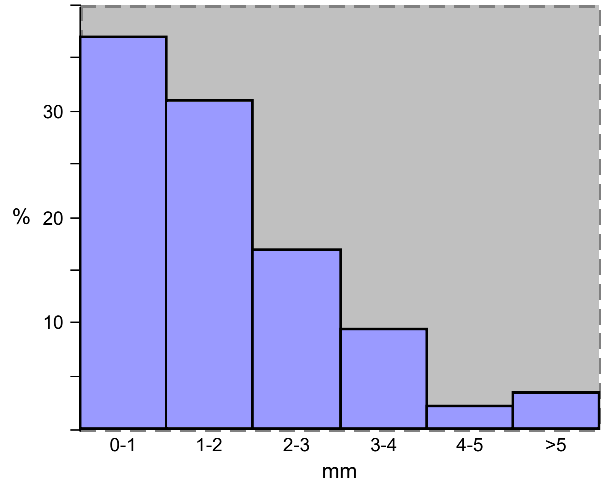

Fig 5. Percentages of patients with maximum resorption of 1 maxillary incisor in each 0.5-mm interval.

As shown in Table II, only 0.6% of the patients with ≤1.0 mm of resorption at T2 and 0.5% of the patients with ≤2.0 mm of resorption at T3 of any incisor had at least 1 incisor with >5.0 mm of resorption at T4, whereas 35.0% of those with >2.0 mm of resorption at T2 and 47.1% of those with >3.0 mm of resorption at T3 had at least 1 incisor with >5.0 mm of resorption at T4. The risk of at least 1 tooth with >5.0 mm of resorption at T4 was 2.7 times higher (95% CI, 2.0%-3.6%; $P < 0.01$) in patients with at least 1 tooth with >1.0 mm of resorption at T2 than in those without, and 15.3 times higher (95% CI, 8.1%-28.8%; $P < 0.001$) in patients with at least 1 tooth with >2.0 mm of resorption at T2 than in those without. Similarly, the risks were 5.8 times higher (95% CI, 3.9%-8.5%; $P < 0.001$) and 21.9 times higher (95% CI, 11.1%-43.3%; $P < 0.001$) in patients with at least 1 tooth with >2.0 mm and >3.0 mm of resorption at T3, respectively, than in those without.

Univariate linear regression showed that a history of traumatic injury ($P < 0.05$) and amount of resorption at T2 ($P < 0.001$, $r^2 = 0.46$) and T3 ($P < 0.001$, $r^2 = 0.70$) were associated with the amount of resorption of the most severely affected central incisors at T4 (Table III). Only the amount of resorption at T3 and extraction therapy were included in the final model as risk factors (Table III), with r^2 (explained variance) of 0.72 and with an intercept of 0.54. The amount of resorption of the most severely affected central incisor at T4 could therefore be predicted with this formula:

Table II. Numbers and percentages of patients with and without at least 1 incisor with >5.0 mm of resorption at T4 among patients with and without at least 1 incisor with >1.0 mm and >2.0 mm of resorption at T2 and with and without at least 1 incisor with >2.0 mm and >3.0 mm of resorption at T3

	>5.0 mm at T4		*≤5.0 mm at T4*	
	n	*%*	*n*	*%*
≤1.0 mm at T2 (n = 172)	1	0.6	171	99.4
>1.0 mm at T2 (n = 92)	8	8.7	84	91.1
≤2.0 mm at T2 (n = 244)	2	0.8	242	99.2
>2.0 mm at T2 (n = 20)	7	35.0	13	65.0
≤2.0 mm at T3 (n = 189)	1	0.5	188	99.5
>2.0 mm at T3 (n = 42)	8	19.0	34	81.0
≤3.0 mm at T3 (n = 214)	1	0.5	213	99.5
>3.0 mm at T3 (n = 17)	8	47.1	9	52.9

$$\text{resorption at T4} = 0.54 + 1.18(\text{resorption at T3}) + 1.70(\text{extraction})$$

For the most severely resorbed lateral incisor (Table III), an association at $P < 0.05$ was found between the amount of resorption at T4 and reduced age at T1, abnormal root form, use of posterior elastics, and increased overjet; an association at $P < 0.01$ between amount of resorption at T4 and no previous treatment, increased TL, reduced RW, and maxillary tooth extraction; and an association at $P < 0.001$ between amount of resorption at T4 and amount of resorption at T2 ($r^2 = 0.56$) and T3 ($r^2 = 0.71$). ANOVA showed that the association between root form and root resorption was due to pointed and deviated roots. Only extraction therapy and amount of resorption at T3 were included in the final model as risk factors (Table III), with r^2 (explained variance) of 0.72 and with an intercept of 1.90. Hence, the amount of resorption of the most severely affected lateral incisor at T4 could be predicted with this formula:

$$\text{resorption at T4} = 1.90 + 1.09(\text{resorption at T3}) + 1.97(\text{extraction})$$

DISCUSSION

Objective evaluation of root resorption requires radiographs made according to a standardized paralleling technique to minimize projection and magnification errors. However, interpretation of the whole range of root resorption estimates on such radiographs shows that some teeth have tooth elongation even though continued root growth can be ruled out, suggesting that projection and magnification errors can still occur.[1-3] Such errors are likely to be random and evenly distributed with standardized radiographs, and might not affect the mean values. However, some subjects might have been inaccurately recorded, biasing the results of the correlation analyses. The minor amount of resorption that is likely to occur early in treatment can be particularly difficult to record. Attempting to minimize this problem, we used a recently introduced digital reconstruction technique[20] that might be a reliable method for adjustment of projection errors.[17-19] The fact that maximum enlargement was less than 0.7 mm in our study rather than 2 mm or more without reconstruction confirms the usefulness of the technique.[1-3] As an alternative, a metal wire placed 9 mm from the crown and parallel to the long axis of the tooth can be a suitable jig for accurate measurement of TL changes on periapical radiographs.[22]

In keeping with previous studies, we found that apical root resorption is a minor problem for the average orthodontic patient, and few patients are severely affected (Figs 3 and 5).[1-5] However, we failed to find the previously documented difference in amount of resorption between the central and lateral incisors.[2-4] One reason might be that our reconstruction technique reduced the risk of bias caused by enlarging the lateral incisors on the pretreatment radiographs.

We confirmed our hypothesis of an association between T1 and T4 resorption. Correlation coefficients of 0.61 to 0.76 for amount of resorption about 6 months after bracket placement, and of 0.77 to 0.88 for amount of resorption about 12 months after bracket placement vs at end of treatment, might be considered clinically significant. Our finding that the odds of severe posttreatment resorption, defined as at least 1 incisor with more than 5 mm of resorption, is about 3 times higher in patients with more than 1 mm of resorption and about 15 times higher in patients with more than 2 mm of resorption on individual incisors after about 6 months of treatment might be particularly important. Even more so might be that the odds of severe resorption were about 6 times higher in patients with at least 1 incisor with more than 2 mm of resorption and 20 times higher in patients with at least 1 incisor with more than 3 mm of resorption after 12 months of treatment. The direct clinical relevance might be that routine radiographic examinations after about 6 months of treatment and additional examinations after 12 months of those with visible signs of resorption could be predictable means to identify high-risk patients.

We also confirmed our hypothesis that predictability of apical root resorption at T4 increases when the amount of resorption during the early treatment stages

Table III. Results of univariate and multivariate regression analyses with forward selection with the most severely resorbed maxillary central and lateral incisors at T4 while testing the effect of parameters at T1 and amounts of resorption at T2 and T3

		Central incisor				*Lateral incisor*			
		Univariate		*Multivariate*		*Univariate*		*Multivariate*	
Variable (unit)		*Effect*	P	*Effect (SE)*	P	*Effect*	P	*Effect (SE)*	P
Age at T1	(y)	–0.15	0.09			–0.20	<0.05		
Time T1-T4	(mo)	0.15	0.19			0.19	0.14		
Sex	(m or f)	–2.46	0.18			–1.46	0.46		
Previous treatment	(yes/no)	–4.82	0.19			–11.62	<0.01		
Time of square wire	(mo)	0.04	0.72			0.12	0.33		
Tooth length	(mm)	0.04	0.24			0.10	<0.01		
Trauma	(yes/no)	6.15	<0.05			2.31	0.36		
Root width	(mm)	–0.06	0.68			–0.42	<0.01		
Normal root form	(yes/no)	0.33	0.64			1.20	<0.05		
Anteior elastics	(mo)	0.21	0.25			0.25	0.23		
Posterior elastics	(mo)	–0.01	0.99			0.27	<0.05		
Extraction	(yes/no)	1.95	0.09	1.70 (0.69)	<0.05	3.46	<0.01	1.97 (0.73)	<0.01
Agenesis	(yes/no)	3.85	0.15			4.87	0.11		
Surgery	(yes/no)	–1.94	0.26			–2.15	0.26		
Resorption at T2	(mm)	1.56	<0.001			1.59	<0.001		
Resorption at T3	(mm)	1.18	<0.001	1.18 (0.05)	<0.001	1.15	<0.001	1.09 (0.06)	<0.001

is considered. The explained variance amounts of initial resorption were about 50% after 6 months of fixed appliance therapy and about 70% after 12 months of active treatment. Moreover, the explained variance of our final prediction model was about 70% as opposed to less than 20% in previous studies without access to information on initial amount of resorption.[2,7,9]

The enhanced prediction after active appliance therapy underscores the significance of individual predisposition as an etiologic factor for apical orthodontic root resorption. The fact that no differences were found among the patient groups treated by the doctors at the 3 centers or between patients treated with brackets of different slot sizes might support this notion. Recent findings of great individual variations in resorption after orthodontic intrusion and extrusion of premolars, but an association between amount of resorption of contralateral teeth subject to extrusion on 1 side and intrusion on the other, might also be interpreted as support.[23]

We did not measure amount of incisor root movement in this study. However, we confirmed that extraction therapy, which could be considered a surrogate variable for amount of tooth movement, is a risk factor for apical resorption of the maxillary incisors.[8] The fact that extraction was included in the final prediction model in this study can be interpreted as support of previous findings that amount of root movement is a risk factor.[7,8] No parameters other than extraction and amount of initial resorption were included in the final prediction models, suggesting colinearity between the identified risk factors and the amount of initial resorption. Despite the large explained variance of the effect of the amount of resorption at T2, only resorption at T3 was included in the final models. In keeping with our previous results, this finding suggests an association between amounts of resorption at 6 and 12 months of treatment, and that resorption at 12 months is the most important predictor.[19]

Valid results on the effects of treatment variables such as time period with square wires, use of different types of elastics, or effects of anamnestic variables such as history of trauma and dysfunction, might require a concurrent prospective study design, thereby ensuring accurate recordings in the various patient files before and during active treatment. This could explain different findings in studies designed in retrospect.[2,7-9] However, our findings and those of a previous study[7] suggest that total treatment time is not a risk factor when initial amount of resorption and amount of tooth movement are considered. Although we confirmed that use of elastics might be a risk factor, the association was weak and not included in the final prediction model.[2,7] Accordingly, the minimal risk of resorption in patients with less than 1 mm of resorption at T2 and less than 2 mm of resorption at T3 might suggest that patients with minimal incisor resorption during the initial treatment stages can be treated for a long period without risking severe apical root resorption, regardless of the type of mechanics.

CONCLUSIONS

1. The association between initial and posttreatment amounts of orthodontic root resorption of each maxillary incisor is clinically significant, with r^2 values ranging from 0.61 to 0.76 for resorption about 6 months after bracket placement and from 0.77 to 0.88 for resorption at about 12 months after bracket placement vs resorption at the end of treatment.
2. The risk of severe resorption at the end of treatment, defined as at least 1 incisor with more than 5 mm of resorption, is minimal in patients with no incisors with more than 1 mm of resorption after about 6 months and more than 2 mm of resorption after about 12 months of active treatment.
3. The explained variance of the prediction model for the amount of resorption of the most severely affected incisor is greater than 0.70 when the amount of initial resorption is a variable.

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