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A radiographic comparison of apical root resorption after orthodontic treatment with a standard edgewise and a straight-wire edgewise technique

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SUMMARY The purpose of this study was to compare the severity of apical root resorption occurring in patients treated with a standard edgewise and a straight-wire edgewise technique, and to assess the influence of known risk factors on root resorption incident to orthodontic treatment.

The sample consisted of 80 patients with Angle Class II division 1 malocclusions, treated with extraction of at least two maxillary first premolars. Variables recorded for each patient included gender, age, ANB angle, overjet, overbite, trauma, habits, invagination, agenesis, tooth shedding, treatment duration, use of Class II elastics, body-build, general factors, impacted canines, and root form deviation. Forty patients were treated with a standard edgewise and 40 with a straight-wire edgewise technique, both with 0.018-inch slot brackets. Crown and root lengths of the maxillary incisors were measured on pre- and post-treatment periapical radiographs corrected for image distortion. Percentage of root shortening and root length loss in millimetres were then calculated.

There was significantly more apical root resorption ($P < 0.05$) of both central incisors in the standard than in the straight-wire edgewise group. No significant difference was found for the lateral incisors. Root shortening of the lateral incisors was significantly associated with age, agenesis, duration of contraction period (distalization of incisors), and invagination, while root shortening of the central incisors was related to treatment group and trauma.

Introduction

Apical root resorption as a consequence of orthodontic treatment is considered a multifactorial problem and has been related to factors associated with biological variation (biological factors), as well as treatment modalities (mechanical factors).

Among the mechanical factors investigated, the orthodontic technique used has been related to induced root resorption (Ketcham, 1927a,b; Oppenheim, 1936). Stuteville (1938) and Mollenhauer (1987) found that the Begg technique caused more root resorption than the edgewise technique, whereas Reitan (1960), and Begg and Kesling (1977) observed the opposite trend. Beck and Harris (1994) and Malmgren *et al*. (1982) found no difference between the two techniques. The Speed technique has been tested against the edgewise and no significant difference was found (Blake *et al*., 1995). Similarly, no significant difference has been found between continuous and sectional archwire mechanics (Alexander, 1996).

In a standard edgewise system, all treatment mechanics have to be built into the archwires. A desire for simpler mechanics led to the development of the pre-adjusted orthodontic appliance envisioned as follows: if an ideal gnathologic set-up was completed on study models of a given patient, the ideal pre-adjusted appliance would have bracket bases that accurately fitted each tooth at a predetermined point and bracket slots that passively accepted a straight-wire co-ordinated to the patient's archform. Based on this concept, and after the six keys to normal occlusion which were consistently present in 120 orthodontic normal study models were described (Andrews, 1972), the first commercially available straight-wire appliance was developed. The straight-wire appliance with its diverse variations gained popularity in edgewise treatment mechanics and by 1986 was used routinely by 66.8 per cent of orthodontists in the USA, while the standard edgewise was used by only 24.2 per cent (Gottlieb *et al*., 1986). In the Department of Orthodontics of the University of Bergen, the transition from the standard to the straight-wire edgewise technique took place in 1978.

The straight-wire edgewise technique allowed for less wire bending, less effort for the practitioner, and less chair time for the patient. However, most importantly it provided the possibility for better control of the appliance and subsequent tooth movements, keeping constant the characteristics of first, second, and third order movements which were built into the brackets. Thereby, excessive forces that might be produced when exaggerated torque or tip values are built into the wire by a non-experienced orthodontist are avoided. The result was application of more gentle forces and less jiggling, which has been regarded as a feature common to most of the identified risk factors for root resorption (Linge, 1994). Andrews (1979) also suggested that the reduction of manual manipulation of the archwire, among other benefits, would proportionately reduce the adverse effects of treatment. The prevalence and extent of apical root resorption after orthodontic treatment with a fully programmed edgewise appliance, according to the straight-wire concept with 0.022-inch brackets, and a partly programmed edgewise appliance, according to the conventional full edgewise mechanics with 0.018-inch brackets, have been compared radiographically by Reukers *et al*. (1998). No significant differences could be ascertained between the groups at the end of treatment. In that study which is the only one so far comparing two edgewise techniques, both 0.018- and 0.022-inch brackets were used.

The present investigation was undertaken in order to compare the extent of apical root resorption in patients treated with a standard edgewise and straight-wire edgewise technique, both with 0.018-inch brackets. This study also evaluated the effect of some reported risk factors on the severity of orthodontically induced apical root resorption.

Subjects and methods

Subjects

The sample consisted of patients who had completed orthodontic treatment in the Postgraduate Clinic, Department of Orthodontics and Facial Orthopedics, University of Bergen. Treatment was performed by different postgraduate students under the same regimens of the technique instructed at the department. Complete orthodontic records were available, including standardized intra-oral peri-apical radiographs taken with the long cone paralleling technique (Eggen, 1973), before and after completion of active treatment.

Among the 93 patients initially examined, 13 were excluded. A patient was excluded when the radiographs were unsatisfactory for the purpose of the investigation for more than two of the maxillary incisors examined (e.g. poor projection, crown or apex not fully visible, blurred cemento-enamel junction (CEJ), as well as altered crown dimensions during the treatment period due to fracture or abrasion). Finally, 80 patients were included in the study. All had an Angle Class II division 1 malocclusion, and were treated with extraction of two maxillary first premolars, four first premolars, or two maxillary first and mandibular second premolars. The sample comprised two groups. The 'standard' group consisted of 40 patients (22 males and 18 females) with a mean age of 13.8 years (range: 10.4–35.5; SE: 0.7) at the start of active treatment, treated with a standard 0.018-inch edgewise technique. The 'straight' group consisted of 40 patients (20 males and 20 females) with a mean age of 13.1 years (range: 8.0–33.3; SE: 0.7) treated with a straight-wire 0.018-inch edgewise technique. The appliances used in the treatment of the ‘standard’ group included 0.018-inch twin standard (torque 0 degrees, angulation 0 degrees) brackets (3M Unitek, Monrovia, California). The brackets of the ‘straight’ group were 0.018-inch twin straight-wire edgewise New Bergen Technique brackets (3M Unitek, Dyna-Lock™). In this system the built-in characteristics were: for the central incisors, torque +22 degrees, angulation +5 degrees, base height 0.79 mm; and for the lateral incisors, torque +14 degrees, angulation +9 degrees, base height 1.28 mm. The same characteristics were also built into the archwires for the standard edgewise Bergen technique. The variables recorded for each patient are presented in Table 1.

Root form was scored subjectively as normal, curved, short, blunt, pointed, eroded, pipette-shaped and combinations (Levander and Malmgren, 1988; Mirabella and Årtun, 1995b). The presence of root-treated teeth, root canal obliterations, and roots with external lateral resorption were also recorded. Because of the small sample in each of the abnormal root form categories, root form deviations were grouped together in the statistical analysis. Invaginations were registered when teeth had fillings at the characteristic location for invagination malformation and in the case of teeth with radiographically distinct enamel notching in the same area.

Crown and root lengths of the maxillary incisors were measured on the intraoral periapical films before and after active treatment. Crown length was measured from the tip of the incisal edge to the CEJ, and root length from the CEJ to the apex. All measurements were obtained by perpendicularly projecting these points on the long axis of the tooth, which followed as accurately as possible the root canal. The most distinct CEJ landmark, either mesial or distal, was used, but once decided, the same side was used both for the pre- and post-treatment radiographs (Figure 1). After exclusion of teeth according to the criteria described above, the final evaluation was based on 280 teeth of a theoretical maximum of 320 (80 × 4) included in the study sample. The measurements were performed to the nearest 0.01 mm, using the CUE 3 Image Analysis System version 4.5, 1993 (Olympus, MT007037A Galai Production Ltd., Migdal Haemek, Israel).

Any image distortion between the pre- and post-treatment radiographic exposures was corrected using the crown length registrations, assuming crown lengths to be unchanged over the observation period. For this reason, teeth with obviously fractured or abraded crowns were excluded from the study. This method has earlier been used by Linge and Linge (1983, 1991) and Blake *et al.* (1995), and its accuracy has been

Table 1 Treatment variables and units of measurement.

Treatment variable	Unit
Gender	Male/female
Age at start of treatment with fixed appliances	Months
ANB	Degrees
Overjet	mm
Overbite	mm
Trauma (separately for 12, 11, 21, 22)	Yes/no
Habits (lip-tongue dysfunction, finger-sucking, atypical swallowing pattern, nail-biting)	Yes/no
Invagination (separately for 12, 11, 21, 22)	Yes/no
Agenesis	Yes/no
Late tooth-shedding	Yes/no
Treatment duration	Months
Contraction duration (distalization of incisors)	Months
Class II elastics	Months
Body-build	Normal/light/heavy
General factors (allergies, hormone imbalances)	Yes/no
Impacted canines (separately for 13, 23)	Yes/no
Root form deviations (separately for 12, 11, 21, 22)	(See text)

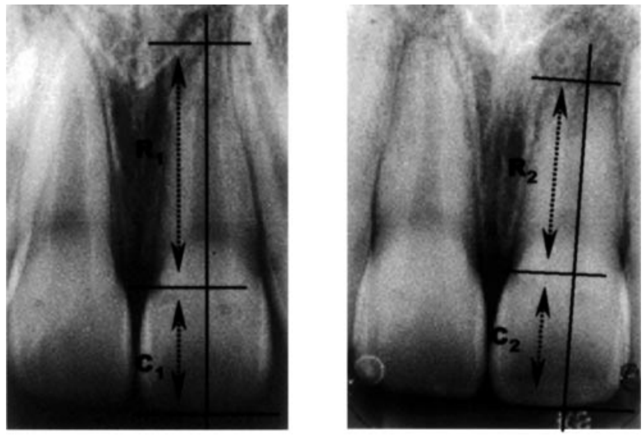

Figure 1 Measurements on pre- and post-treatment radiographs (C_1 = crown length on pre-treatment radiograph, R_1 = root length before treatment, C_2 = crown length on post-treatment radiograph, R_2 = root length after treatment).

tested and found satisfactory (Blake *et al.*, 1995). A correction factor was calculated to relate the pre- and post-treatment radiographs to each other (Figure 1).

$$\text{Correction factor (CF)} = C_1/C_2$$

The apical root resorption per tooth in millimetres was calculated:

$$\text{Apical root resorption (ARR)} = R_1 - (R_2 \times \text{CF})$$

Root resorption was also expressed as the percentage shortening per tooth. This percentage value is a better comparative value, since the differences in the root lengths of various teeth make comparisons of root resorption values in millimetres less meaningful.

$$\text{Percentage resorption per tooth} = \text{ARR} \times 100 / R_1$$

Error of the method

All measurements were performed by one examiner, who was blind with regard to the origin of the radiographs. The reproducibility of the measurements was assessed by analysing the difference between double measurements by the same examiner on radiographs taken at least 3 weeks apart on 29 teeth from eight randomly selected patients. The systematic error between the double measurements was estimated separately for crowns and roots using the paired *t*-test, and the measurement error (τ) separately for crowns and roots was calculated by the formula:

$$\tau = \sqrt{\frac{\sum D^2}{2N}}$$

where D is the difference between duplicated measurements and N is the number of double measurements (Dahlberg, 1940). No significant systematic differences were found (Table 2). The measurement error was comparable with values found in previous investigations. In one of these (Mirabella and Årtun, 1995a), crown and tooth length were measured. The mean error for the crown length measurement was the same as in this study (0.41), while the mean error for tooth length was 0.34. Instead of measuring the whole tooth length, only the length of the root was measured in this investigation. The value of this measurement error was 0.70. The greater error of the root

Table 2 Systematic and measurement error between duplicate measurement on periapical radiographs.

	n	Mean difference	SE	P	τ
Crowns	27	–0.14	0.11	0.20	0.41
Roots	27	0.13	0.19	0.50	0.70

length measurement, in comparison with tooth length, can be attributed to the difficulty in identifying the CEJ compared with the incisal edge.

Statistical methods

In order to investigate if the recorded treatment variables differed significantly between the two treatment groups, a two-sample *t*-test was carried out for the quantitative variables and a chi-square test for the qualitative variables.

A two-sample *t*-test was also used to test for any difference in the root length reduction in millimetres and percentage between the two groups, for each examined tooth (12, 11, 21, 22) separately. In order to test for differences in root resorption between the central and lateral incisors, a paired *t*-test was performed between the central and the lateral maxillary incisor of the same quadrant in each patient.

To assess any association between the percentage root shortening of each tooth and other variables recorded, multiple linear regression analysis was applied. As a first step, the best subsets regression analysis was performed. In this analysis, all one-predictor regression models are evaluated and the model giving the largest adjusted explained variance (R^2 adjusted) is selected. A second step is to examine all two predictor models, and find the one with the largest R^2 adjusted. This process is continued until adding a new predictor variable does not increase R^2 adjusted. The next step is to perform an ordinary multiple regression analysis using the predictor variables selected by the best subsets regression method. The statistical analyses were carried out using the Minitab software package (Minitab Data Analysis Software, State College, PA, USA).

Results

The two patient groups were well matched for all treatment variables, except for overjet which was greater ($P < 0.001$) in the 'standard' (mean: 8.06 mm, S.E: 0.35) than in the 'straight' group (mean 6.11 mm, S.E: 0.39). Variables 'habits' and 'trauma on 22' were significantly more common in the 'standard' ($P < 0.05$), whereas 'late tooth shedding' was more common in the 'straight' group ($P < 0.05$).

The central incisors showed significantly more severe apical resorption in the 'standard' than in the 'straight' group. Negative values indicating root elongation were noticed for all groups of teeth. The analysis of the difference in the root resorption between the two treatment groups, in percentage of root shortening and millimetres, for each tooth, revealed a significant difference at the 5 per cent level for the central, but not for the lateral incisors (Table 3). When

Table 3 Root resorption in percentage of root shortening and in millimetres according to treatment group.

	Standard					Straight					*P*
	n	Mean	SE	Min	Max	*n*	Mean	SE	Min	Max	
Tooth 12											
%	35	12.8	1.8	–28.0	34.43	37	8.8	2.3	–22.27	42.20	0.18
mm		2.33	0.28	–2.11	6.09		1.41	–3.82	6.54	0.068	
Tooth 11											
%	37	13.5	2.2	–22.31	42.65	35	6.9	1.6	–15.26	28.97	0.019*
mm		2.4	0.41	–3.82	8.91		1.20	0.29	–3.01	5.09	0.02*
Tooth 21											
%	35	14.0	2.0	–16.8	34.08	32	7.1	2.1	–38.73	23.23	0.018*
mm		2.48	0.36	–3.25	6.27		1.32	0.31	–5.7	4.36	0.016*
Tooth 22											
%	37	11.0	2.9	–49.3	37.85	32	9.3	2.4	–12.87	40.20	0.67
mm		1.84	0.51	–8.39	7.46		1.69	0.42	–2.22	7.48	0.82

*$P \leq 0.05$.

the lateral incisors were tested against the central incisors in the same quadrant of each patient, no significant difference was detected for the percentage of root shortening or for root length reduction (Table 4).

The results of the regression analysis, with the percentage of root shortening as the dependent variable and all other variables recorded for each tooth as independent variables, revealed explained variance for no more than 30.1 per cent for tooth 12, 21.7 per cent for tooth 11, 30.6 per cent for tooth 21, and 36.8 per cent for tooth 22. Age was a significant predictor variable with a positive correlation coefficient for the lateral incisors during all steps of the regression analysis (Tables 5 and 6). The best predictor for the central incisors was the treatment group ('straight' or 'standard'; Tables 7 and 8). Other values significantly related to root resorption of one of the central incisors were trauma and duration of use of Class II elastics (Table 8). For one of the lateral incisors, agenesis was significantly related to root resorption (Table 6), whereas invagination of the crown showed a negative relationship to the observed root resorption (Table 5). The other variables examined (Table 1), including root form deviations, did not show any significant association with root resorption.

Discussion

Methods

The selection of the maxillary incisors as teeth representative of root resorption, was based on results of previous studies (Phillips, 1955; DeShields, 1969; McFadden *et al.*, 1989). The maxillary lateral incisors have been reported to be more susceptible to root resorption than the central incisors (Kennedy *et al.*, 1983). In the present study, however, the root length reduction did not differ significantly between the maxillary central and lateral incisors in the same individual.

Different indices have been used for the assessment of apical root resorption. In some studies,

Table 4 Difference in percentage root shortening and length reduction in millimetres between the maxillary lateral and central incisors.

Tooth	12 (*n* = 72)		11 (*n* = 72)		*P*	21 (*n* = 67)		22 (*n* = 69)		*P*
	Mean	SE	Mean	SE		Mean	SE	Mean	SE	
Root shortening (%)	12.8	1.8	13.5	2.2	0.80	14.0	2.0	11.0	2.9	0.74
Root length loss (mm)	2.33	0.28	2.40	0.41	0.86	2.48	0.36	1.84	0.51	0.46

Table 5 Regression analysis for tooth 12 (*n* = 72).

	Constant	R^2 (adj) (%)	Treatment duration	Age	Invagination 12
1	4.97	1.6	**0.218** *0.144*		
2	–6.21	8.5	**0.24** *0.097*	**0.064** *0.015**	
3	–2.71	12.7	**0.214** *0.131*	**0.0657** *0.012**	**–5.91** *0.04**

The numbers in column one represent the sequential regression analysis performed by adding one explanatory variable each time, as given by the preliminary best subsets regression analysis amongst all variables. For each regression analysis the partial regression coefficient of the variable is given in bold and the *P*-value of the partial regression coefficient in italics. *$P \leq 0.05$.

Table 6 Regression analysis for tooth 22 (n = 69).

	Constant	R^2 (adj) (%)	Contraction duration	Age	Agenesis	Impacted 23
1	4.63	4.3	**1.62** *0.048**			
2	–9.06	10.6	**1.49** *0.061*	**0.0884** *0.020**		
3	–9.85	14.0	**1.41** *0.070*	**0.0885** *0.018**	**11.9** *0.062*	
4	–10.2	15.0	**1.33** *0.088*	**0.0887** *0.017**	**12.5** *0.050**	**11.5** *0.189*

The numbers in column one represent the sequential regression analysis performed by adding one explanatory variable each time, as given by the preliminary best subsets regression analysis amongst all variables. For each regression analysis the partial regression coefficient of the variable is given in bold and the P-value of the partial regression coefficient in italics. *$P \leq 0.05$.

Table 7 Regression analysis for tooth 11 (n = 72).

	Constant	R^2 (adj) (%)	Treatment group	Root form 11	Trauma 11	Gender	Contraction duration	Overbite
1	13.5	6.2	**–6.61** *0.019**					
2	11.2	6.5	**–5.20** *0.068*	**4.77** *0.093*				
3	9.97	7.3	**–4.41** *0.128*	**4.91** *0.083*	**4.98** *0.218*			
4	8.36	8.1	**–4.56** *0.115*	**4.75** *0.092*	**5.65** *0.164*	**3.49** *0.217*		
5	17.7	8.2	**–5.87** *0.054*	**5.23** *0.065*	**5.02** *0.213*		**–0.751** *0.225*	**–1.27** *0.161*

The numbers in column one represent the sequential regression analysis performed by adding one explanatory variable each time, as given by the preliminary best subsets regression analysis amongst all variables. For each regression analysis the partial regression coefficient of the variable is given in bold and the P-value of the partial regression coefficient in italics. *$P \leq 0.05$.

Table 8 Regression analysis for tooth 21 (n = 67).

	Constant	R^2 (adj) (%)	Treatment group	Trauma 21	Class II elastic duration	Root form 21
1	14.0	6.9	**–6.89** *0.018**			
2	12.7	11.8	**–6.44** *0.024**	**9.18** *0.035**		
3	10.9	14.7	**–6.73** *0.017**	**10.1** *0.02**	**0.485** *0.08*	
4	8.05	17.6	**–6.18** *0.025**	**10.3** *0.015**	**0.548** *0.043**	**4.73** *0.092*

The numbers in column one represent the sequential regression analysis performed by adding one explanatory variable each time, as given by the preliminary best subsets regression analysis amongst all variables. For each regression analysis the partial regression coefficient of the variable is given in bold and the P-value of the partial regression coefficient in italics. *$P \leq 0.05$.

root length has been measured (Linge and Linge, 1983, 1991; Blake *et al*., 1995; Mirabella and Årtun, 1995a; Baumrind *et al*., 1996), and the maximum or average values of root length reduction per patient or per tooth group have been used in statistical analysis of the data. In the present study, each of the four maxillary incisors was evaluated separately, in order to allow regression analysis with variables that were recorded for each tooth separately. This also provided a simple control of the method, since a noticeable variation between the contralateral sides would indicate a method error.

The two groups were well matched considering most of the variables recorded. The regression analysis revealed no significant association between the 'non-matching' variables and apical root resorption. Therefore, these differences did not affect the results.

Results

The decrease in apical root resorption in the 'straight' group may be due to the more efficient force control that this technique can offer. Negative values for root resorption indicating root length increase have also been previously reported and are attributed either to a real increase in root length (Linge and Linge, 1991) or to method error (Mirabella and Årtun, 1995a; Baumrind *et al*., 1996). Considering the age range of the sample and the biological variation, some of the teeth at the start of treatment would still have growth potential. During treatment, even if followed by resorption, growth might, in some cases, result in root elongation. Error in registration of the CEJ should also be considered.

Before comparing the results with previous investigations of apical root resorption, differences in sample selection should be borne in mind. Patients with a variety of malocclusions and treatment approaches have been included earlier, whereas only Angle Class II division 1 malocclusions treated with extractions were considered in the present study. Blake *et al.* (1995) found 12.83 per cent mean resorption of the lateral and 9.41 per cent of the central maxillary incisors treated with the straight-wire edgewise technique. To compare those findings with the results in the present investigation, mean values of the percentage root shortening were calculated for teeth 12, 22, and teeth 11, 21 for the straight-wire edgewise technique. This indicated a shortening of 9.05 per cent for the lateral and 7.0 per cent for the central incisors. In contrast, the values for apical root loss for the 'straight' group were higher than those previously reported for each of the maxillary incisors (Linge and Linge, 1983, 1991).

The two edgewise techniques affected the maxillary incisors to a different extent, resulting in a significant difference in root resorption for the central, but not for the lateral incisors. The variation in the response of these two teeth may be attributed to their different developmental stage; the less mature lateral incisors may tolerate more effectively the factors that cause root resorption and differ between the two techniques. Given that in the present sample the length of the central was greater than that of the lateral incisor, it might be speculated that any difference in the amount of tooth movement between the two techniques would have a greater effect on the central incisors. This can be attributed to the increased displacement of the apex of the longer teeth, for the same changes in torque or angulation, considering the bracket slot as the centre of rotation. It has also been reported that during Begg treatment, the increase in root resorption during uprighting of primary tipped incisors is greater for the maxillary central than the lateral incisors (Goldson and Henrikson, 1975). Mirabella and Årtun (1995b) found that the longer teeth showed significantly more root resorption.

Regression analysis

Regression analysis indicated that more severe resorption of lateral incisors may be expected in older than in younger patients. The age factor also carries information about root length development (Linge and Linge 1983, 1991). Considering age distribution in the present investigation, this was an important explanatory variable for the lateral incisors, but not for the central incisors, which complete their root formation earlier. It may be hypothesized that the younger patients had lateral incisors with incomplete root development.

Agenesis has been related to observed root resorption during treatment and the importance of the innervation factor at the most vulnerable areas of the dentition has been stressed (Kjær, 1995). It is worth noting that in the investigated sample agenesis was related to resorption of the lateral, but not the central incisor. On the other hand, the importance of treatment mechanics for the central incisor was indicated by the fact that treatment group was the most important explanatory variable in the regression analysis for these teeth.

The higher risk of root resorption in teeth with previous trauma has also been previously reported (Linge and Linge 1983, 1991; Brin *et al*., 1991). The investigation of Malmgren *et al*. (1982), however, does not support this idea.

A significant effect of Class II elastics on root resorption has also been previously found (Linge and Linge, 1983). If Class II elastics are used unilaterally, there may be more incisor root resorption on that side (Linge and Linge, 1980). The effect of Class II elastics may result from jiggling forces (Stuteville, 1938) on the incisors due to deformation of light archwires.

Dental morphological characteristics, such as invagination of the crown, have been strongly connected with the tendency for root resorption during orthodontic treatment (Kjær, 1995). In this group of subjects, invagination was very frequent (45 per cent), especially for the lateral incisors, and random variation might explain the negative correlation found for root resorption.

For some of the variables investigated, the sample size was too small to allow valid conclusions. The main aim of the investigation was a comparison of the two orthodontic techniques and the study was planned for this purpose. The results of the regression analysis for each variable should be interpreted with caution bearing in mind the sample size. It is important that the regression analysis did not show more than 36.8 per cent explained variance, even when all the explanatory variables were included in the analysis model. This shows that the most important explanatory variable(s) were absent. It therefore appears that factors related to individual susceptibility, tissue characteristics, cell reactions, and functional adaptation play a major role in explaining the observed variation in tissue response.

Conclusions

This investigation revealed significant differences in the amount of apical root resorption of the central incisors between the standard and the straight-wire edgewise techniques. The introduction of the pre-adjusted appliance has reduced the need for wire bending, and offers the possibility for better control of the appliance and the subsequent tooth movements. The findings may have an impact not so much on the selection of orthodontic technique, since the straight-wire edgewise technique is currently mostly used, but on handling the available mechanics. Since the main difference between the two techniques is the possibility for more gentle and constant forces, these principles should be incorporated into orthodontic practice irrespective of the mechanics used.

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References

Alexander S A 1996 Levels of root resorption associated with continuous arch and sectional arch mechanics. American Journal of Orthodontics and Dentofacial Orthopedics 110: 321–324

Andrews L F 1972 The six keys to normal occlusion. American Journal of Orthodontics 62: 296–309

Andrews L F 1979 The straight-wire appliance. British Journal of Orthodontics 6: 125–143

Baumrind S, Korn E L, Boyd R L 1996 Apical root resorption in orthodontically treated adults. American Journal of Orthodontics and Dentofacial Orthopedics 110: 311–320

Beck B W, Harris E F 1994 Apical root resorption in orthodontically treated subjects: Analysis of edgewise and light wire mechanics. American Journal of Orthodontics and Dentofacial Orthopedics 105: 350–361

Begg P R, Kesling P C 1977 Begg orthodontic theory and technique. W B Saunders, Philadelphia

Blake M, Woodside D G, Pharoah M J 1995 A radiographic comparison of apical root resorption after orthodontic treatment with the edgewise and Speed appliances. American Journal of Orthodontics and Dentofacial Orthopedics 108: 76–84

Brin I, Ben-Bassat Y, Heling I, Engelberg A 1991 The influence of orthodontic treatment on previously traumatized permanent incisors. European Journal of Orthodontics 13: 372–377

Dahlberg G 1940 Statistical methods for medical and biological students. George Allen and Unwin Ltd., London

DeShields R W 1969 A study of root resorption in treated Class II division 1 malocclusion. Angle Orthodontist 39: 231–245

Eggen S 1973 Simplification of radiographic technique. Quintessence International 4: 69–71

Goldson L, Henrikson C O 1975 Root resorption during Begg treatment. A longitudinal roentgenologic study. American Journal of Orthodontics 68: 55–66

Gottlieb E L, Nelson A H, Vogels D S 1986 Study of orthodontic diagnosis and treatment procedures. Journal of Clinical Orthodontics 20: 612–625

Kennedy D B, Joondeph D R, Osterberg S K, Little R M 1983 The effect of extraction and orthodontic treatment on dentoalveolar support. American Journal of Orthodontics 84: 183–190

Ketcham A H 1927a A preliminary report of an investigation of apical root resorption of vital permanent teeth. International Journal of Orthodontia 13: 97–127

Ketcham A H 1927b A radiographic study of orthodontic tooth movement: a preliminary report. Journal of the American Dental Association 14: 1577–1596

Kjær I 1995 Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. European Journal of Orthodontics 16: 25–34

Levander E, Malmgren O 1988 Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. European Journal of Orthodontics 10: 30–38

Linge L 1994 Apical root resorption induced by orthodontic treatment. Clinical manifestations and etiologic considerations. In: Davidovitch Z (ed.) The biological mechanisms of tooth eruption, resorption and replacement by implants. EBSCO Media, Birmingham, Alabama, pp. 527–535

Linge B O, Linge L 1980 Apikale Wurzelresorptionen der oberen Frontzahne. Fortschritte der Kieferorthopädie 41: 276–288

Linge B O, Linge L 1983 Apical root resorption in upper anterior teeth. European Journal of Orthodontics 5: 173–183

Linge B O, Linge L 1991 Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. American Journal of Orthodontics and Dentofacial Orthopedics 99: 35–43

Malmgren O, Goldson L, Hill C, Orwin A, Petrini L, Lundberg M 1982 Root resorption after orthodontic treatment of traumatized teeth. American Journal of Orthodontics 82: 487–491

McFadden W M, Engström C, Engström H, Anholm J M 1989 A study of the relationship between incisor intrusion and root shortening. American Journal of Orthodontics and Dentofacial Orthopedics 96: 390–396

Mirabella A D, Årtun J 1995a Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. European Journal of Orthodontics 17: 93–99

Mirabella A D, Årtun J 1995b Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. American Journal of Orthodontics and Dentofacial Orthopedics 108: 48–55

Mollenhauer B 1987 Towards paradigmless orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics 92: 437–444

Oppenheim A 1936 Biologic orthodontic therapy and reality. Urban and Schwarzenberg, Vienna

Phillips J R 1955 Apical root resorption under orthodontic therapy. Angle Orthodontist 25: 1–22

Reitan K 1960 Tissue behavior during orthodontic tooth movement. American Journal of Orthodontics 46: 881–900

Reukers E A J, Sanderink G C H, Kuijpers-Jagtman A M, van 't Hof M A 1998 Radiographic evaluation of apical root resorption with 2 different types of Edgewise appliances. Journal of Orofacial Orthopedics 59: 100–109

Stuteville O H 1938 Injuries caused by orthodontic forces and the ultimate results of these injuries. American Journal of Orthodontics and Oral Surgery 24: 103–116