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Association between root resorption incident to orthodontic treatment and treatment factors

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SUMMARY The purpose of this study was to clarify the prevalence and degree of root resorption induced by orthodontic treatment in association with treatment factors. The files of 243 patients (72 males and 171 females) aged 9–51 years were randomly selected from subjects treated with multi-bracket appliances. The severity of root resorption was classified into five categories on radiographs taken before and after treatment. The subjects were divided into extraction (n = 113 patients, 2805 teeth) and non-extraction (n = 130 patients, 3616 teeth) groups and surgical (n = 56 patients, 1503 teeth) and non-surgical treatment (n = 187 patients, 4918 teeth) groups. These subjects were also divided into two or three groups based on the duration of multiloop edgewise archwire (MEAW) treatment, elastic use, and total treatment time: 0 month (T1; n = 184 patients, 4831 teeth), range 1–6 months (T2; n = 37 patients, 994 teeth), more than 6 months (T3; n = 22 patients, 596 teeth); range 0–6 months (n = 114 patients, 3016 teeth) more than 6 months (n = 129 patients, 3405 teeth); range 1–30 months (n = 148 patients, 3913 teeth) and more than 30 months (n = 95 patients, 2508 teeth). The prevalence of overall and severe root resorption evaluated by the number of subjects and teeth was compared with a chi-square test. A Student's t-test for unpaired data was used to determine any statistically significant differences.

The prevalence of severe root resorption based on the number of teeth was significantly higher in the group with extractions ($P < 0.01$). Longer use of a MEAW appliance and elastics also produced a significantly higher prevalence of root resorption ($P < 0.05$). On the other hand, the prevalence of severe root resorption was not significantly different between the subjects treated with or without surgery, but there was a significant increase when treatment time was prolonged ($P < 0.05$). A significant difference was found in the amount of root movement of the upper central incisors and the distance from their root apices to the cortical bone surface ($P < 0.05$). These are regarded as essential factors in the onset of root resorption. These results indicate that orthodontic treatment with extractions, long-term use of a MEAW appliance and elastics, treatment time, and distance of tooth movement are risk factors for severe root resorption.

Introduction

Apical root resorption during orthodontic treatment is an unfavourable sequelae, which is difficult to predict and repair. There is an individual difference in the prevalence, indicating the influence of host factors. For the prevention of severe root resorption, the progress of root resorption should be periodically assessed on radiographs taken during orthodontic treatment. In addition, in subjects with severe root resorption, treatment should be interrupted and the treatment plan changed.

Root resorption associated with orthodontic treatment has been recognized since the report of Ketcham (1927). Later, Massler and Malone (1954) found root resorption in 86.4 per cent of orthodontic patients. Risks for root resorption such as systemic factors (Linge and Linge, 1983; Goldie and King, 1984), treatment mechanics (Malmgren *et al.*, 1982; Linge and Linge, 1983), treatment period (Linge and Linge, 1983; Levander and Malmgren, 1988; Mirabella and Årtun, 1995), age (Oppenheim, 1942; Newman, 1975; Linge and Linge, 1983), root shape (Goldie and King, 1984; Levander and Malmgren, 1988; Mirabella and Årtun, 1995), density of alveolar bone (Oppenheim, 1942; Goldin, 1989; Kaley and Phillips, 1991), and oral habits (Odenrick and Brattström, 1985) have been investigated.

However, the above studies evaluated risk factors for root resorption in terms of the number of subjects, which may lead to an incorrect interpretation because patients with the same degree of root resorption have a different number of teeth with resorption. Furthermore, no studies have evaluated orthodontic treatment factors relevant to severe root resorption in all types of teeth. Thus, the purpose of the present study was to clarify the prevalence and degree of root resorption induced by orthodontic treatment with special reference to treatment factors.

Subjects and methods

The study was approved by the Ethics Committee of Hiroshima University (Epidemiologic study-142; 1 June 2009).

The files of 243 patients (72 males and 171 females) treated with multi-bracket appliances (0.018 × 0.025 inch bracket slots) were randomly selected from those attending the Orthodontic Clinic at Hiroshima University Hospital. Treatment in all patients resulted in an excellent occlusion with optimal tooth alignment and root parallelism. Those with incomplete records and poor quality radiographs or with incomplete root formation and missing or extracted teeth were excluded. Thus, the subjects included in the present study were aged 9–51 years before treatment [mean 18.9, standard deviation (SD) 6.7] and were treated for 0.4–5 years (mean 2.4, SD 0.8). A total of 243 patients and 6421 teeth from the incisors to second molars in both arches were evaluated.

The subjects were divided into extraction (n = 113 patients, 2805 teeth) and non-extraction groups (n = 130 patients, 3616 teeth) and surgical (n = 56 patients, 1503 teeth) and non-surgical treatment groups (n = 187 patients, 4918 teeth). These subjects were also divided into two or three groups based on the duration of multiloop edgewise archwire (MEAW) treatment, elastic use, and total treatment time: 0 month (T1; n = 184 patients, 4831 teeth), range 1–6 months (T2; n = 37 patients, 994 teeth), and more than 6 months (T3; n = 22 patients, 596 teeth); range 0–6 months (n = 114 patients, 3016 teeth) and more than 6 months (n = 129 patients, 3405 teeth); range 1–30 months (n = 148 patients, 3913 teeth) and more than 30 months (n = 95 patients, 2508 teeth).

The radiographs were obtained using the paralleling long cone technique before and after treatment. The periapical radiographs were scanned with a GT-X970 scanner (Seiko-Epson Corp., Nagano, Japan) with a resolution of 675 dpi at a scale of 1:1. The images were analysed with Photoshop software (version 7.0; Adobe Systems, San Jose, California, USA) at 300 per cent enlargement, without image quality loss. The degree of root resorption was evaluated according to five categories defined by Malmgren *et al.* (1982): 0 = no root resorption, 1 = irregular root contour, 2 = apical root resorption less than 2 mm of the original root length, 3 = apical root resorption from 2 mm to one-third of the original root length, and 4 = root resorption exceeding one-third of the original root length.

Duplicate determination of root resorption categories after treatment showed full agreement for 1870 of 2150 teeth (87 per cent) and a disagreement of one category for 280 teeth (13 per cent). Prior to the examination, duplicate determination of 2150 teeth was performed by two authors (MM and MK). Furthermore, all subjects and teeth with root resorption (n = 190 patients, 1450 teeth) were divided into two groups with mild (categories 1 and 2) and severe (categories 3 and 4) resorption. For both groups, the following orthodontic treatment factors were examined: orthodontic treatment with or without extractions and surgery, the duration of MEAW treatment and elastic use, and treatment time.

To compare the movement of maxillary central incisors with a normal root (category 0, normal group) and incisors with severe root resorption (categories 3 and 4, severe group), 20 subjects were randomly selected from the 243 patients for each group. The subjects satisfied the following criteria: no differences in inclination and rotation of the right and left maxillary incisors and no tooth with an abnormal pre-treatment root shape. The normal group consisted of 5 males and 15 females aged 11–47 years before treatment (mean 21.4, SD 9.3), treated for 1.8–3.5 years (mean 2.4, SD 0.4), and the group with severe root resorption consisted of 8 males and 12 females aged 13–33 years before treatment (mean 19.7, SD 5.7) who were treated for 1.8–3.8 years (mean 2.8, SD 0.5).

On the pre-treatment lateral cephalogram, the trabecular pattern of the maxilla and the outlines of the pterygomaxillary fissure and key ridges were traced. The incisal edge (U1) and the apex (U1′) of the maxillary incisors were also traced. The palatal plane (PP) was drawn as a line connecting anterior and posterior nasal spines (ANS and PNS), and point A′ was as an intersection of a vertical line from point A to PP. The pre-treatment cephalometric tracing was superimposed on the corresponding post-treatment cephalogram according to the ‘best anatomic fit’, defined as the judge’s best estimate of the optimal fit of the hard palate and anterior maxillary images when primary emphasis is given to concordance in the region of the PP and point A′. The post-treatment U1′ was copied from the pre- to the post-treatment tracing using incisors ‘template’. The distances and angles obtained by connecting the related landmarks were measured at the levels of 0.1 mm and 0.5 degrees, respectively, as suggested by Mirabella and Årtun (1995). The amount of movement of the central incisors was evaluated as shown in Figure 1.

The reproducibility of the measurements was assessed by statistically analysing the difference between double measurements taken with an interval of at least 1 week for 40 cephalograms (20 pre- and 20 post-treatment) selected at random. The measurement error was calculated according to the following equation:

$$\mathrm{Sx} = \sqrt{\frac{\sum D^2}{2N}},$$

where D is the difference between duplicate measurements and N is the number of double measurements. The errors were 0.21 mm for Dx, 0.31 mm for Dy, 0.56 mm for Dz, 0.46 mm for Dx′, 0.19 mm for Dy′, 0.18 mm for Dz′, 0.42 degrees for ∠A, and 0.46 degrees for ∠B.

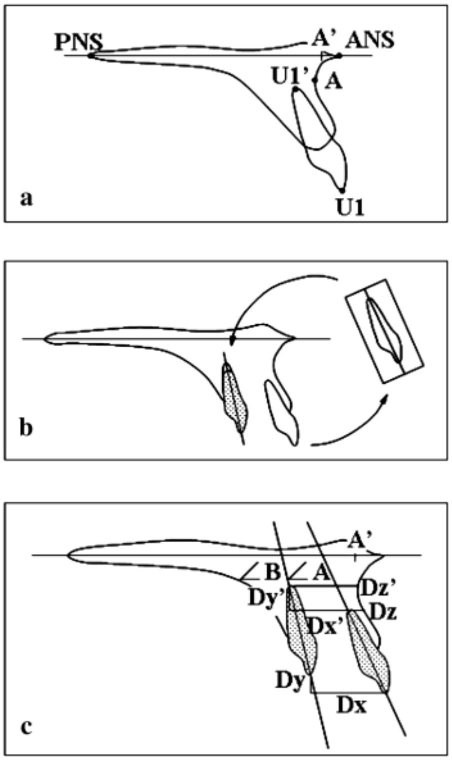

Figure 1 Measurements of maxillary central incisor movement.

Table 1 The prevalence of root resorption between subjects with or without extractions and surgery or no surgery, the duration of multiloop edgewise archwire treatment [0 month (T1), range 1–6 months (T2), and more than 6 months (T3)], elastic use (range 0–6 months or more than 6 months), and treatment time (range 1–30 months or more than 30 months) for the number of patients and teeth.

	Rate of root resorption (%)		P value
The number of patients			
Extraction group (n = 113)	81.4		0.28
Non-extraction group (n = 130)	75.4		
Surgical treatment group (n = 56)	82.1		0.37
Non-surgical treatment group (n = 187)	77.0		
T1 (n = 184)	78.3	a	a; 0.69
T2 (n = 37)	75.7	b c	b; 0.28
T3 (n = 22)	81.8		c; 0.51
Range 0–6 months (n = 114)	74.6		0.27
More than 6 months (n = 129)	81.4		
Range 1–30 months (n = 148)	70.3		0.00**
More than 30 months (n = 95)	90.5		
The number of teeth			
Extraction group (n = 2805)	26.6		0.22
Non-extraction group (n = 3616)	19.5		
Surgical treatment group (n = 1503)	23.8		0.79
Non-surgical treatment group (n = 4918)	22.2		
T1 (n = 4831)	22.0	a	a; 0.94
T2 (n = 994)	21.5	b c	b; 0.23
T3 (n = 596)	28.7		c; 0.27
Range 0–6 months (n = 3016)	21.3		0.67
More than 6 months (n = 3405)	23.7		
Range 1–30 months (n = 3913)	19.3		0.16
More than 30 months (n = 2508)	27.7		

a = T1 versus T2; b = T2 versus T3; c = T1 versus T3.
**P < 0.01.

The prevalence of overall and severe root resorption, evaluated by the number of subjects and teeth, was compared using a chi-square test (Statview; Abacus Concepts, Inc., Berkeley, California, USA). The mean distances and angles obtained by measuring the movement of the central incisors were calculated for the two subgroups of patients and teeth with normal and severe root resorption. A Student's t-test for unpaired data was used to determine any significant differences. The level of significance was defined as $P < 0.05$.

Results

No significant differences in the prevalence of root resorption were observed in terms of the percentages evaluated by the number of patients and teeth in the groups with or without extractions (Table 1). For severe root resorption, no significant differences were found in the number of patients, but the prevalence of severe root resorption evaluated by the number of teeth was significantly greater in the extraction than in the non-extraction group (number of teeth; P = 0.0004; Table 2).

With respect to the prevalence of root resorption evaluated by the number of patients and teeth, no significant differences were found between the two patient groups with or without surgery (Table 1) or in the prevalence of severe root resorption between the two groups in terms of the numbers of patients or teeth (Table 2).

For the relationship between the duration of MEAW treatment and the prevalence of root resorption, no significant differences were observed in the number of patients or teeth with root resorption (Table 1). There were also no significant differences in the number of patients with severe root resorption, but the prevalence evaluated by the number of teeth was significantly higher in the T3 than in the T1 and T2 groups (number of teeth; T1 versus T3, P = 0.00003, T2 versus T3, P = 0.04; Table 2), indicating a significantly greater prevalence of severe root resorption associated with long-term use of MEAW appliances.

For the relationship between the period of elastic use and root resorption, no significant differences in prevalence were observed between the two groups in terms of the numbers of patients and teeth (Table 1). For severe root resorption, no significant difference was found in the number of patients, but the prevalence of severe root resorption evaluated by the number of teeth was significantly higher in the group that used elastics for more than 6 months (number of teeth; P = 0.003; Table 2).

A statistically significant difference was observed for the relationship between treatment time and prevalence of root resorption when evaluated by the number of patients (P = 0.0002) but not by the number of teeth (Table 1). With

Table 2 The prevalence of mild and severe root resorption between subjects with or without extractions, and surgery or no surgery, the duration of multiloop edgewise archwire treatment [0 month (T1), range 1–6 months (T2), or more than 6 months (T3)], elastic use (range 0–6 months or more than 6 months), and treatment time (range 1–30 months or more than 30 months) for the number of patients and teeth.

	Mild resorption		Severe resorption		P value
	N	%	*N*	%	
The number of patients					
Extraction group (n = 113)	66	71.7	26	28.3	0.91
Non-extraction group (n = 130)	71	72.4	27	27.6	
Surgical treatment group (n = 56)	32	69.6	14	30.4	0.66
Non-surgical treatment group (n = 187)	105	72.9	39	27.1	
T1 (n = 184)	108	75.0	36	25.0	a;0.43
T2 (n = 37)	19	67.9	9	32.1	b; 0.40
T3 (n = 22)	10	55.6	8	44.4	c;0.08
Range 0–6 months (n = 114)	63	74.1	22	25.9	0.58
More than 6 months (n = 129)	74	70.5	31	29.5	
Range 1–30 months (n = 148)	81	77.9	23	22.1	0.04*
More than 30 months (n = 95)	56	65.1	30	34.9	
The number of teeth					
Extraction group (n = 2805)	643	86.2	103	13.8	0.00**
Non-extraction group (n = 3616)	648	92.0	56	8.0	
Surgical treatment group (n = 1503)	316	88.5	41	11.5	0.72
Non-surgical treatment group (n = 4918)	975	89.2	118	10.8	
T1 (n = 4831)	966	90.7	99	9.3	a; 0.20
T2 (n = 994)	188	87.9	26	12.1	b; 0.04*
T3 (n = 596)	139	80.3	34	19.7	c; 0.00**
Range 0–6 months (n = 3016)	589	91.7	53	8.3	0.00**
More than 6 months (n = 3405)	704	86.9	106	13.1	
Range 1–30 months (n = 3913)	692	91.5	64	8.5	0.00**
More than 30 months (n = 2508)	599	86.3	95	13.7	

a = T1 versus T2; b = T2 versus T3; c = T1 versus T3.
$^*P < 0.05$; $^{**}P < 0.01$.

respect to severe root resorption, the prevalence obtained by the number of patients and teeth was significantly higher in the group treated for more than 30 months (number of patients; $P = 0.05$, number of teeth; $P = 0.001$; Table 2).

Displacements of maxillary central incisors, Dx, Dx’, Dy’, Dz’, and changes in tooth inclination were significantly larger in the group with severe root resorption than in the group without resorption (Dx, $P = 0.0007$; Dx′, $P = 0.04$; Dy′, $P = 0.04$; Dz′, $P = 0.009$; changes in tooth inclination, $P = 0.003$). Significant differences were found in the vertical and horizontal displacements of U1, the vertical displacement of U1’, the change in tooth inclination during treatment, and the distance between U1′ and the cortical bone surface (Table 3).

Discussion

Apical root resorption that occurs during orthodontic treatment is difficult to predict and repair. Massler and Malone (1954) found root resorption in 86.4 per cent of orthodontic patients. The incidence of root resorption was 78.2 per cent in the present study. However, it is difficult to compare these results because the methods for evaluating the degree of root resorption were different.

In previous studies, treatment-related factors for root resorption were listed as the amount and direction of tooth movement (Stuteville, 1938; Phillips, 1955; Hollender *et al.*, 1980), the type of treatment technique (Kaley and Phillips, 1991; Beck and Harris, 1994; Parker and Harris, 1998), history of extractions (McFadden *et al.*, 1989; Lee *et al.*, 1999; Sameshima and Sinclair, 2001), treatment time (Phillips, 1955; Linge and Linge, 1983; McFadden *et al.*, 1989; Sameshima and Sinclair, 2001), type of wire used (Mirabella and Årtun, 1995; Sameshima and Sinclair, 2001), the period of elastic use (Linge and Linge, 1983; Mirabella and Årtun, 1995; Sameshima and Sinclair, 2001), the amount and direction of orthodontic force (Kurol *et al.*, 1996; Owman-Moll *et al.*, 1995, 1996), and the distance between the apex and cortical bone surface (Mirabella and Årtun, 1995; Kaley and Phillips, 1991). In the present study, the relationship between root resorption and factors such as orthodontic treatment with extractions, surgical treatment, the MEAW technique and elastic use, treatment time, and the amount of movement of upper incisors were investigated.

Lee *et al.* (1999) and McFadden *et al.* (1989) observed a relationship between root resorption and orthodontic treatment with extractions. Sameshima and Sinclair (2001)

Table 3 The amount of movement of the maxillary central incisors with normal (category 0) and severe (categories 3 and 4) root resorption, which was evaluated as Dx: the horizontal movement of U1, Dx′: the horizontal movement of U1′, Dy: the vertical movement of U1, Dy′: the vertical movement of U1′, Dz: the distance between U1′ and the cortical bone surface at pre-treatment, Dz′: the distance between U1′ and the cortical bone surface at post-treatment, ∠A: the angles U1–U1/PP at pre-treatment, ∠B: the angles U1–U1′/PP at post-treatment, ∠A−∠B: change in tooth inclination during treatment.

	Group	Mean	SD	*P* value
Dx (mm)	Normal (*n* = 20)	1.6	1.2	0.00**
	Severe (*n* = 20)	3.4	2.0	
Dx′ (mm)	Normal (*n* = 20)	1.4	0.9	0.04*
	Severe (*n* = 20)	2.2	1.4	
Dy (mm)	Normal (*n* = 20)	1.1	1.1	0.89
	Severe (*n* = 20)	1.1	0.6	
Dy′ (mm)	Normal (*n* = 20)	1.0	0.7	0.04*
	Severe (*n* = 20)	1.6	1.1	
Dz (mm)	Normal (*n* = 20)	4.8	1.4	0.23
	Severe (*n* = 20)	5.5	1.9	
Dz′ (mm)	Normal (*n* = 20)	4.6	1.8	0.00**
	Severe (*n* = 20)	6.5	2.5	
∠A (°)	Normal (*n* = 20)	114.1	8.5	0.54
	Severe (*n* = 20)	115.9	10.0	
∠B (°)	Normal (*n* = 20)	114.3	8.5	0.30
	Severe (*n* = 20)	117.4	10.4	
Change in tooth inclination (°)	Normal (*n* = 20)	4.2	2.8	0.00**
	Severe (*n* = 20)	9.1	6.5	

$^*P < 0.05$; $^{**}P < 0.01$.

reported that patients with four first premolar extractions had greater resorption than those without extractions. In the present study, no significant difference in the prevalence of root resorption was found between patients with or without extractions. However, the prevalence of severe root resorption was higher in the extraction group than in the non-extraction group when evaluated by the number of teeth but not by the number of patients. Parker and Harris (1998) indicated that the amount of tooth movement was a highly predictive parameter, explaining up to 90 per cent of the variation in root resorption. They also identified apical vertical movements and incisor proclination as strong predictors of external apical root resorption. From the present results, it was considered that an increase in tooth movement in the extraction group might cause severe root resorption.

Kaley and Phillips (1991) reported that a Le Fort I osteotomy is a risk factor for apical root resorption. Periods of ischaemia and hyperaemia after Le Fort I osteotomy (Ramsay *et al.*, 1991), which may result in long-term pulpal changes (Ellingsen and Årtun, 1993), may be a reason for root resorption after maxillary osteotomy. On the other hand, this was contradicted by Mirabella and Årtun (1995) who did not find any association between Le Fort I osteotomy and root resorption. In the present study, no significant differences were found in the prevalence of root resorption between patients with or without surgical orthodontic treatment. A similar finding was noted for the prevalence of severe root resorption; however, a tendency towards the higher prevalence of overall and severe root resorption was observed in patients who had undergone surgical orthodontic treatment. Linge and Linge (1991) reported that functional soft tissue factors such as the lips and tongue were significantly associated with apical root resorption. Thus, from these findings, it is considered that an increase in chronic tongue pressure and circumoral muscle tonus after surgical treatment might increase the prevalence of root resorption.

There have been no reports on the relationship between the period of MEAW use and the prevalence of root resorption. In the present study, no significant differences were observed in the number of patients and teeth. However, the prevalence of severe root resorption in terms of the number of teeth was significantly greater in the T3 group than in T1 and T2 groups, whereas no significant difference was found between T1 and T2. From these results, it is demonstrated that orthodontic treatment with the MEAW is not a risk factor for severe root resorption, but the use of the MEAW for more than 6 months causes the most severe root resorption. It is considered that long-term ‘jiggling’ forces to the anterior teeth might increase root resorption, due to less cooperation of patients in using elastics to eliminate the force applied to the teeth.

Various studies have been conducted on the relationship between elastics and root resorption. Mirabella and Årtun (1995) reported that the duration of Class II elastics was associated with canine root resorption. Linge and Linge (1983, 1991) reported that increased apical root resorption was associated with the use of Class II elastics, contrary to the findings of Sameshima and Sinclair (2001). In the present study, no significant difference was found in the prevalence of root resorption between the two groups where elastics were used for less or more than 6 months. For severe root resorption, the prevalence was significantly higher in the group that used elastics for more than 6 months. Thus, it is hypothesized that long-term jiggling force caused by intermittent use of elastics might increase the prevalence of root resorption.

There have been many reports concerning the relationship between root resorption and treatment time. Linge and Linge (1983), Mirabella and Årtun (1995), Lee *et al.* (1999), Phillips (1955), and Morse (1971) reported a negative conclusion; however, Sameshima and Sinclair (2001), DeShields (1969), and McFadden *et al.* (1989) found that long-term orthodontic treatment increased the prevalence of root resorption. From the present results, a significant difference was observed in terms of the number of patients, and a tendency to a higher prevalence of overall root resorption was also recognized for the number of teeth. Furthermore, the prevalence of severe root resorption evaluated by the number of patients and teeth was significantly higher in the group treated for more than 30 months. It was also shown that an increase in overall root resorption leads to an increase in severe root resorption because of continuous stimulation to the root. It is therefore considered that accumulation of surface root resorption might lead to the onset of severe root resorption.

There have been conflicting conclusions concerning the association between root resorption and the distance the teeth are moved. Some studies reported a relationship between root resorption and distance (Stuteville, 1938; Hollender *et al.*, 1980), whereas Phillips (1955) and Dermaut and De Munck (1986) did not find any association. Displacements of Dx, Dx′, Dy′, Dz′, and changes in tooth inclination were significantly greater in the group with severe root resorption than in the controls. A significant difference was observed in the vertical and horizontal displacement of U1, the vertical movement of U1′, the change in tooth inclination, and the distance between U1′ and the cortical bone surface during treatment. Furthermore, displacement of the maxillary central incisors in the severe group was classified as follows: 1. lingual inclination moved the apex close to the labial cortical bone, 2. buccal inclination moved the apex close to the lingual cortical bone, 3. lingual root torque moved the apex close to the lingual cortical bone, 4. lingual bodily movement moved the apex close to the lingual cortical bone. Anatomically, the cortical bone of the alveolus is fourth on the buccal side. In addition, there are the cortical bones of the incisive canal and alveolar bone on the lingual side. It was therefore hypothesized that a maxillary central incisor near the cortical bone of the alveolus and incisive canal might cause severe root resorption. Moreover, the type of tooth movement such as tipping, bodily movement, and torque might be a risk factor.

Other studies evaluated risk factors for root resorption in terms of the number of patients or restricted teeth, which may lead to an incorrect interpretation because patients with the same degree of root resorption had various numbers of root-resorbed teeth and this may not apply to teeth with different root shapes. In this investigation, it was shown that the prevalence of severe root resorption in the number of teeth resulted in a clearer tendency than that number of patients.

Conclusions

Long-term orthodontic treatment increases the prevalence of root resorption, extractions, the period of the MEAW and elastic use, treatment time, and distance of tooth movement are regarded as risk factors for severe root resorption. Among these, long-term use of the MEAW produced the highest prevalence of severe root resorption. Moreover, an increase in overall root resorption leads to an increase in severe root resorption during orthodontic treatment. These should be considered as the predictive factors for overall and severe root resorption.

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