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The changes of root length and form in immature teeth after orthodontic treatment

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Previous studies have focused on the causes of root resorption after orthodontic treatment and treatment methods to reduce this phenomenon, and have been mainly associated with developed, mature roots. As parents become increasingly interested in their children's' dentition, orthodontists are performing fixed orthodontic treatment on patients of less than 10 years and before the completion of the immature root.

Thus, the author evaluated the changes of root length and root form of maxillary immature incisors after orthodontic treatment, compared with those of mature teeth, and investigated the correlation according to gender, treatment duration, and displacement of incisors.

The sample consisted of an immature root group of twenty-eight persons (between 8 and 10 years old) and a mature root group of thirty-one persons (between 11 and 15 years old).

The crown and root length of the maxillary four incisors were measured with a periapical radiograph, changes in root length and crown-root ratio were calculated, and root form was classified according to a scoring system.

The results were as follows.

1. The development of immature roots was not affected by orthodontic treatment and mostly showed normal root length and apical form.
2. Root length of immature teeth was sustained or became shorter, partially in long treatment duration or with open bite patients. Even though the teeth reached their normal root length, they demonstrated a blunt form.
3. Most of the mature roots showed mild resorption, and the form of mature roots was more blunt than the developed form of the immature roots ($p<0.05$).
4. The developed form of the immature roots was statistically related to treatment duration, while the form of the mature roots was significantly related to the displacement of incisors ($p<0.05$).
5. In contrast, other variables such as gender, classification of malocclusion, changes in overbite, and changes of U1 to SN showed no correlation with the root resorption of both groups.

Key words : Immature root, Change of root length, Root apical shape, Crown-root ratio

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Table 1. Distribution of patients (Sample characteristics in this study)

		Experimental group (n=28)	Control group (n=31)
Gender	Male	11	7
	Female	17	24
Age (Mean±SD)		9.8 ± 1.0	12.9 ± 1.5
Angle	Class I	12	17
classification	Class II	3	6
	Class III	13	8

SD : standard deviation

Root resorption and change of root form are common undesirable problems associated with orthodontic treatment. Therefore, there has been extensive research on the causes of root resorption and asso-ciated factors. McLaughlin[1] and other investigators[2-4] reported the incidence and amount of apical root resorption on the basis of periapical radiographs of maxillary incisors. Stenvik[5] and Mjor[6] evaluated them utilizing histologic studies, and other studies have been performed to investigate various factors, including treatment method[7,8], materials[9,10], malocclusion classification[11], direction of orthodontic tooth move-ments and duration[12].

Previous studies evaluated the change of root resorption after orthodontic treatment on developed mature teeth roots, and showed that a greater change of root resorption occurred in the maxillary central incisor, the maxillary lateral incisor, and the mandibular incisor[13].

As parents become increasingly interested in their children's' dentition, orthodontists are performing fixed orthodontic treatment on patients of less than 10 years and before the completion of the immature root.

Several studies concerned with immature teeth have been reported. Rosenberg[2] evaluated the degree of root resorption of developing canines on the basis of panorama radiographs of patients with orthodontically-extracted 1st premolars. According to him, the undeveloped roots were less affected and grew to normal length, but in a few cases, they were resorbed at less than 0.5mm and showed dilacerations. Stenvik et al[5] intruded intentionally developing premolars following extraction and found that the osteoclast was inactive at the undeveloped roots, and that root resorption was less affected but influenced the direction of the growth and shape of the roots.

Thus, the author evaluated the changes of root length and root shape of maxillary immature incisors on the basis of periapical films taken before and after orthodontic treatment, compared these with mature teeth, and investigated the correlation with gender, treatment duration, and displacement of incisors.

Subjects and methods

Subjects

Periapical radiographs of 28 orthodontic patients with immature roots and of 31 patients with mature roots were collected from patients' records at the Dept. of Orthodontics of Pusan National University. The mean age of the experimental, immature root group was 9.8 years (ranging from 8 to 10 years) and the control, mature root group was 12.9 years (ranging from 11 to 15 years).

Both samples of patients favored females over males by 69.5%. There were many Cl III malocclusion, edge to edge and crossbite cases in the experimental group, and Cl I malocclusion, mild crowding, canine ectopic eruption, and open bite cases in the control group (Table 1)

All subjects included non-extraction patients, but cleft lip and palate patients were excluded.

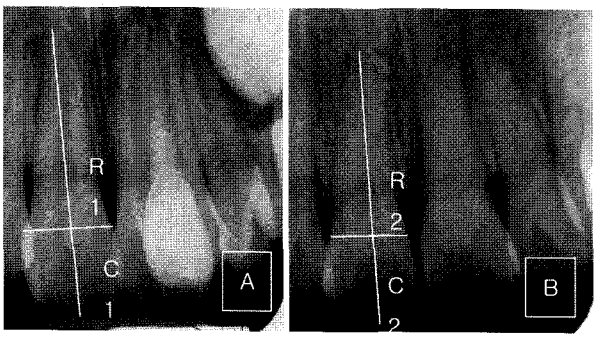

Fig. 1. Crown and root measurement:
A, before treatment; B, after treatment
; horizontal line ,cementoenamel junction plane
; vertical line, long axis of tooth
; C1 and C2 , crown length
; R1 and R2, root length.

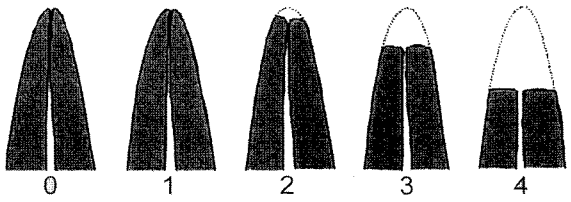

Fig. 2. Score system of Levander and Malmgren:
0, no root resorption(normal);
1, mild resorption;
2, moderate resorption;
3, loss of 1/3 of root length;
4, loss of more than 1/3 of root length.

Methods

1. Measurement of root length

Periapical radiographs of the maxillary four incisors taken with the long cone paralleling technique were used. Root length was measured from the apex to the mid-point of the right and left cementoenamel junctions, and crown length was measured from the same mid-point to the incisal edge. These measurements were made to the nearest 0.1mm directly from the pre- and post-treatment films of both groups (Fig 1). A magnifier and ruler were utilized to measure the length. In the case of rotation of the crown, the mid-point of the oblique incisor edge was taken.

2. Calculation of degree in change of root length

The measured crown and root lengths were used and changes in the root length were calculated by the following formula:

The degree of change of root length

$$= (R_2 \times C_1 / C_2) - R_1 .$$

This method was described by Linge and Linge[3]. C_1 and R_1 represent the crown and root length at pre-treatment, while C_2 and R_2 represent the crown and root length at post treatment. Notice that the C_1/C_2 ratio considers different angulation and magnification between radiographs. We suggested that if the degree of change was less than 0, the root was resorbed in both groups. In the case of no change, the experimental group reflected growth retardation and the control group reflected the maintenance of growth. Additionally, when it was more than 0, the experimental group represented normal root formation.

3. Comparison of apical root shape

Five ordinary grades of root resorption modified from Levander and Malmgren[4] were applied to judge the degree of apical resorption. The immature root group was scored for completion of the root apex, and the mature root group was also assessed for its resorption form (Fig 2).

4. Comparison of Crown/Root ratio

The change of root was re-evaluated by comparing the Crown/Root ratio (C/R ratio) between the two groups using pre- and post-treatment periapical radiographs.

5. Comparison of correlation with variables between two groups

The variables were evaluated as shown in Table 2. The overbite change of maxillary central incisors between pre- and post-treatment on lateral cephalometric radiographs was measured and evaluated according to whether it correlated with root resorption or the formation of the root. In addition, the changes of U1

Table 2. Comparison of variables between two groups

Variable	Immature	Mature	p-value
Treatment time(months)	31.25 ± 13.56	30.48 ± 14.81	0.837
Change in overbite(mm)	1.75 ± 1.92	1.55 ± 1.52	0.659
U1 to FP(mm)	2.88 ± 2.64	2.39 ± 2.17	0.427
U1 to SN(°)	6.13 ± 4.99	6.28 ± 5.87	0.915

Immature: experimental group
Mature : control group
FP : facial plane

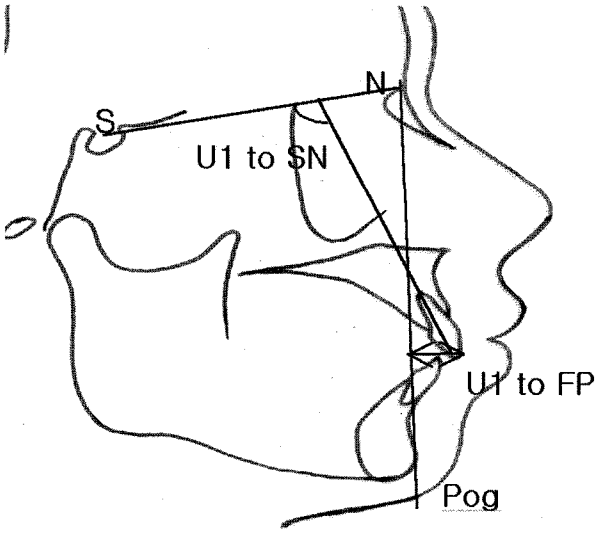

Fig. 3. Reference points and measurement of incisor displacement:
N, nasion; S, sella; Pog, pogonion;
U1, upper central incisor;
U1 to SN (°), inferior posterior angle at junction of line through long axis of maxillary central incisor and sella nasion plane;
U1 to FP(mm), distance from incisal edge of maxillary central incisor perpendicular to facial plane (nasion pogonion plane).

to SN (degree, inferior posterior angle at junction of line through long axis of the maxillary central incisor and the sella nasion plane) and U1 to FP (mm, distance from the incisal edge of the maxillary central incisor perpendicular to the apical plane) were measured and evaluated according to whether the tooth displacement distance and the change of relative position to the skull base correlated with root resorption or formation (Fig 3).

6. Statistical analysis

The root shape, changes in root length and C/R ratio between the two groups was compared by t-test. The change in root length was compared using Fisher's test upon the two groups, and the Spearman rank correlation coefficient was used to evaluate variables such as gender, malocclusion classification, treatment duration, tooth displacement distance, and overbite changes.

RESULTS

The average treatment duration was 31.3 months in the experimental group and 30.5 months in the control group, and the average change of overbite was 1.75 mm in the experimental group and 1.55 mm in the control group. The degree of change of U1 to the facial plane was noted as 2.88 mm in the experimental group and 2.39 mm in the control group, while the degree of change of U1 to SN was 6.13 in the experimental group and 6.28 in the control group. The changes showed no difference between the two groups (Table 2).

In the experimental group, the root length was longer than at pre-treatment in 24 right lateral incisors (85.7%), 19 right central incisors (67.9%), 22 left central incisors (78.6%) and 21 left lateral incisors (75%). Whereas, in the control group, the root length was

Table 3. Comparison of changes of root lengths between two groups

	Right lateral incisor		Right central incisor		Left central incisor		Left lateral incisor	
	I	II	I	II	I	II	I	II
Shorter than RLT	3	19	4	23	3	20	3	20
Same length	1	12	5	8	3	11	4	11
Longer than RLT	24	0	19	0	22	0	21	0
Significance	***		***		***		***	

I: Immature, experimental group
II: Mature, control group
RLT: root length before treatment
*** $p < 0.001$

Table 4. Comparison of degree of root shape using Levander and Malmgren's score system

Score	Right lateral incisor		Right central incisor		Left central incisor		Left lateral incisor	
	I	II	I	II	I	II	I	II
0	18	12	18	10	19	13	16	13
1	7	9	6	13	5	8	10	9
2	3	9	4	8	4	10	2	7
3	0	1	0	0	0	0	0	2
4	0	0	0	0	0	0	0	0
Mean of score	0.46	0.97	0.50	0.94	0.46	0.90	0.50	0.94
SD	0.69	0.91	0.75	0.77	0.74	0.87	0.64	0.96
significance	*		*		*		*	

I : Immature, experimental group
II : Mature, control group
* $p < 0.05$

shorter in 19 right lateral incisors (61.3%), 23 right central incisors (74.2%), 20 left central incisors (64.5%) and 20 left lateral incisors (64.5%). As well, 12 incisors (38.7%), 8 incisors (25.8%), 11 incisors (35.5%) and 11 incisors (35.5%) with the same afflictions showed no change in the control group.

All 4 incisors showed that root length was elongated and that growth was performed completely at about 70% in the experimental group, whereas in the control group the root was resorbed at about 60%, and the root length was shorter than at pre- treatment. The change of root length between both groups was statistically significant ($p < 0.001$) (Table 3).

According to five ordinary grades of root resorption modified from Levander and Malmgren's score system, the root shape of the experimental group had the lowest score (0.46) in the right lateral incisor and left central incisor, and a score of 0.50 in the left lateral and right central incisor. In contrast, the scores of all incisors in the control group were distributed from 0.90 to 0.97. Statistically significant differences in 4 incisors were noted in both groups ($p<0.05$) (Table 4).

Table 5. Comparison of crown / root ratio percentage(%) between two groups (Mean ± Standard deviation)

	Pre-treatment			Post-treatment		
	I	II	Sign.	I	II	Sign.
Rt lateral incisor	62.4 ± 15.9	59.3 ± 8.0	NS	52.6 ± 12.2	60.5 ± 14.0	***
Rt central incisor	60.5 ± 6.2	63.9 ± 11.0	NS	57.0 ± 13.0	64.4 ± 16.8	**
Lt central incisor	61.4 ± 6.9	62.2 ± 12.6	NS	56.8 ± 13.1	63.2 ± 17.9	*
Lt lateral incisor	61.9 ± 15.1	58.2 ± 9.7	NS	53.2 ± 12.6	59.3 ± 14.4	**

I : Immature, experimental group
II : Mature, control group
Rt : right, Lt : left, Sign : significance
NS : not significant

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Table 6. Comparison of Spearman rank correlation between two groups

	Experimental		Control	
	Rt central incisor	Lt central incisor	Rt central incisor	Lt central incisor
Angle's classification	−0.02	−0.19	0.13	0.15
Gender	0.23	0.21	0.11	0.15
Treatment time(months)	0.43*	0.41*	0.29	0.30
Overbite	0.02	−0.04	0.06	0.09
U1 to FP	0.05	0.08	0.36*	0.39*
U1 to SN	−0.20	−0.26	0.33	0.06

Rt : right, Lt : left
U1 to FP : distance from incisal edge of maxillary central incisor perpendicular to facial plane (nasion pogonion plane)
U1 to SN : inferior posterior angle at junction of line through long axis of maxillary central incisor and sella nasion plane

* $p < 0.05$

The C/R ratio between the two groups did not show a statistically significant difference at pre-treatment, but was significant post-treatment, in particular with a highly significant correlation for the left lateral incisor ($p<0.001$) (Table 5).

The Spearman rank correlation coefficient was utilized to evaluate the correlation between the root shape and the variables in the two groups.

In the experimental group, a long treatment duration correlated with root bluntness ($p<0.05$); however, malocclusion classification, gender, change of overbite, change of U1 to SN, change of U1 to the facial plane and the tooth displacement distance did not correlate.

In the control group, a significant correlation between the displacement distance of the incisors and the amount of root resorption was found ($p<0.05$), whereas there was no significant correlation with the other variables (Table 6).

DISCUSSION

Massler and Malone[14] reported that root resorption of permanent human teeth happened by systemic disease, trauma, excessive biting force, pressure of tongue,

crossbite, and so forth. They reported the occurrence of resorption without orthodontic treatment, and claimed that most cases were cured histologically. However, the study also reported that the incidence of root resorption was higher in the orthodontic treatment group than in the non-treatment group. Kennedy et al.[15] found that root resorption by orthodontic fixed appliances, especially rectangular wire, was particularly severe.

Brezniak and Wasserstein[13] classified factors affecting root resorption according to biologic, mechanical, and combined biologic and mechanical factors. Biologic factors were based on genetics, systemic causes, nutrition, age, gender, habits, tooth structure, previously traumatized teeth, endodontically treated teeth, alveolar bone density, classification of malocclusion, and specific tooth vulnerability to root resorption. Mechanical factors were related to the type of appliance type, orthodontic movement type, orthodontic force, and migration distance, while combined factors were treatment duration, relapse and so forth. Individual susceptibility was the major factor in determining root resorption potential with or without orthodontic treatment[14-17].

According to Rygh[16], the root resorption process seems to vary among persons and even within the same person at different times. Metabolic signals that generate changes in the relationship between osteo-clastic activity include hormone, body type, and meta-bolic rate.

Among the associated factors previously mentioned, this study was concerned that age had an influence on the formation of the root apex during orthodontic treatment.

The phenomenon that most orthodontic treatment results in root resorption made us doubt that the developing root apex would be resorbed, and expect that the growth of the root would be retarded or normalized. In previous studies, Kennedy et al.[15] proposed that Class I crowding malocclusion patients with fixed appliance treatment showed 1-2mm more root resorption than a control group treated with serial extraction. Rosenberg[2] reported that 37% of immature tooth samples showed mild root resorption and 8% showed dilaceration, whereas most cases grew to normal length. Slagvold and Bjercke[19] regarded the role of periodontal ligament seriously, and found that the root was completely formed without root resorption when the Hertwig epithelial sheath of partially formed teeth was preserved then transplanted.

Linge and Linge[18] limited the age of subjects to 11.5 years for their studies since patients younger than 11.5 years had the possibility of unknown interaction or tissue reaction. In the present study, patients ranging from 9 to 11 years with immature roots were selected for the experimental group from nonextraction treatment records, because fixed orthodontic appliance is rarely used to treat those younger than 10 years and nonex-traction treatment is predominant in the mixed stage. Some patients needed only maxillary treatment and additional appliances such as a face mask, RPE (rapid palatal expansion), headgear or biteplate.

As there were many Class III malocclusion patients with crossbite, the majority had been treated with incisor expansion treatment using opencoil for the improve-ment of inter incisors and mild crowding. By contrast, patients ranging from 11 to 16 years with mature roots were collected for the control group since they seemed to have a similar tissue reaction. Most patients had inci-sor protrusion, mild crowding, canine ectopic eruption, or mild open bite. The amount of displacement of the incisors was very small, as the average change of over-jet was 1.8 mm, and that of the overbite was 1.6 mm.

Periapical film has been known to be accurate in determining root resorption in previous studies, so we used it to evaluate the change of shape and length of immature and mature roots. Several studies[5] tried to measure root length by calculating the magnification factor in panoramic film. Sameshima and Asgarifar[29] reported that panoramic film may overestimate the amount of root loss by 20% or more compared to periapical film. Though the lateral cephalometric radio-graph is useful in detecting the amount of displacement and in the measurement of the angle of incisors, it is not accurate in measuring root length since it is overlapped. We used Levander and Malmgren's[4] scoring system to assess root resorption and the

maturity of root form. According to others, Massle and Malone[14] used a root resorption index, while Deshields[22] classified six groups and used the root resorption score and the sum of the score of the four maxillary incisors. Newman's method[17], which classified three groups, was similar to Levander and Malmgren's scoring system[4]. Hwang et al.[23] recommended Newman's method[17] for easy delineation by radiograph and to increase reproducibility in classification.

Considerations for root formation and root resorption

This study showed that most immature roots were more elongated than in the pretreatment period and were formed completely, and this result was consistent with Rosenberg[2]. But in some cases, both central incisors and lateral incisors showed no change of root length, and in other cases, they were noted to be shorter than at pretreatment. We can suggest two causes for this result, excepting radiographic or measuring errors. First, the growth of the immature root was retarded or resorbed, and then was formed completely. Second, the root was resorbed and shortened by conti-nuous orthodontic force after it grew to normal length. Why is the latter considered to be reasonable? The treatment duration of maintained or shortened roots in the experimental group ranged from 31.3 to 60 months, which means that it took longer than the average treatment duration in this study. This long duration necessitated that 9 or 10 year-old patients be treated again after their immature roots had matured over 1 or 2 years. Therefore, as stated above, it is assumed that the root was resorbed by orthodontic force after it was formed.

By contrast, both central incisors and lateral incisors in the control group were resorbed by about 0.6 mm, and the root in 30% of the cases was maintained without change.

In comparison with other studies[24,25] which showed that the average amount of root resorption was 1-2 mm, we came to the conclusion that the degree of resorption was mild in this study, because the subjects of this study were nonextraction patients whose displacement distance and treatment duration were shortened. Glenn et al.[21] reported that the roots of four premolars under extraction treatment were more resorbed in comparison with nonextraction treatment, but McFadden[24]and Von der Ahe[8] showed that extraction or nonextraction had no correlation with the amount of root resorption.

Evaluation of root shape after orthodontic treatment

Levander and Malmgren[4]'s scoring system has been widely accepted in evaluating the degree of root resorption, but was used to evaluate the formation shape of immature roots in this study. This is because it was reasonably considered that classifying the differences according to normal root apex formation results in a 0 grade without orthodontic treatment. Most immature roots grew to normal shape over an average treatment duration (31.3 months) as though orthodontic force.

However, 20% of all four incisors were presented with grade 1, and another 10% with grade 2; that is, 30% showed a blunt root apex shape instead of the sharp apex of a normal root after treatment, and the change in root length was maintained, increased and decreased. We considered two causes, as mentioned above. In contrast to the experimental group, the percentage of mature roots of grades 0, 1, or 2 ranged from 20 to 30%, respectively, while that of grade 3 was about 5%.

The degree of root shape using Levander and Malmgren's score system showed a statistically significant difference between the two groups ($p<0.05$). This result could be explained in that the final shape of the immature root was similar to the normal root shape, even though it was more blunt than the normal root.

Comparison of crown/root (C/R) ratios

We compared the C/R ratio to evaluate the growth and resorption state of the root upon pre- and post-treatment. It was expected that the difference of C/R ratio in pre-treatment between the two groups was

significant due to the fact that the roots of the experimental group were developing, but no statistically significant results were discovered. Even though the roots of the experimental group were developing, the difference of C/R ratio between the two groups was not statistically significant because the average change of root length was so small (that of the right lateral incisor, the central incisor, the left central incisor and the lateral incisor were 1.6, 0.4, 0.7 and 1.4 mm, respectively). However, the C/R ratio showed significant differences between the two groups in the post-treatment period, owing to the fact that more immature roots tend to be developed and elongated but mature roots are resorbed and shortened. From the above results, a significant difference in the change of root length and root shape between the two groups can be reconfirmed.

Correlation of the shape of root apex with other relevant variables

We evaluated the correlation of the scores of the roots with variables such as gender, malocclusion classification, treatment duration, overbite change, displacement distance, and changes of tooth position relative to the skull base. Previous studies[14,15,24,25] concluded that gender did not correlate with root resorption; on the other hand, females are more susceptible to root resorption according to other studies[17,26].

Newman[17] reported that the idiopathic root resorption ratio was 3.7:1 for females to males. Linge and Linge[3]'s apical root material loss was greater in treated females (0.73 mm) compared to treated males (0.67 mm). Dougherty[26] speculated that this may reflect the difference in root maturity as the male is chronologically less mature than the female, and male roots are less susceptible to the traumatic effects of orthodontic stress. However, this study showed no associations between gender and apical resorption.

Von der Ahe[8] found no correlation between root resorption and malocclusion classification, while Edward[27] noted no difference between root resorption and predictable factors by malocclusion classification. In this study, the data was not correlated with malocclusion classification either.

While the change of root shape was significantly associated with treatment duration, it was supposed that longer treatment duration allowed the root to become completely formed and then resorbed and shortened.

In conclusion, even though the possibility of resorption of the immature root is reduced, and if treatment duration is longer no difference will be expected in the mature root.

There was no correlation with overbite change amongst the two groups. Linge and Linge[3,18] reported that root resorption was not associated with overjet and overbite in orthodontic treatment, and Philips[28] concluded that the larger overjet resulted in more root resorption than normal. While there was a significant difference in the control group between root resorption and the change of U1 to the facial plane that indicated the migration distance of the tooth, it was consistent with Glenn and Peter's conclusion that increased horizontal migration distance resulted in more root resorption.

Before treatment there was a poor shape of roots in openbite cases, and after treatment they showed more resorption and bluntness. That is, other studies[3,18] suggested that abnormal pressure of the tongue, besides orthodontic force, is connected to root resorption.

This study was meaningful in proving statistical consultation in orthodontic treatment planning and the prognosis of younger patients with immature roots, and was consistent with the results of previous studies. Therefore, in view of the change of root length and shape, we concluded that if orthodontic treatment is begun before the formation of the root apex in immature teeth, it will be helpful in the reduction of root resorption. However, we focused on the change of root length and shape by radiographs of immature teeth excepting other factors such as histologic aspects, history of trauma or habit.

It is thought to be necessary to consider factors such as trauma, habit, and the histologic condition of immature teeth upon further investigation, and trial and long-term follow-up with many more cases and will be required in the years ahead.

CONCLUSION

We evaluated the changes of root length and root form of maxillary immature incisors after orthodontic treatment, and compared the results with those of mature teeth on periapical films of pre- and post-treatment. Our investigation indicated that they correlated with gender, treatment duration, and displacement of incisors.

The results were as follows:

1. Most immature roots demonstrated elongation after orthodontic treatment, and mainly showed normal root length and apical form;
2. Partially in cases of long treatment duration or open bite, immature root length was maintained or became shorter, and the roots had a blunt form even though they had reached their normal length;
3. Most of the mature roots showed mild resorption and the form of the mature roots was more blunt than the developed form of the immature roots ($p<0.05$);
4. The developed form of the immature roots was statistically related to treatment duration, and the form of the mature roots was significantly related to displacement of the incisors ($p<0.05$);
5. In contrast, other variables such as gender, classification of malocclusion, changes in overbite, and changes of U1 to SN showed no correlation with root resorption in the two groups.

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국문초록

교정치료시 발생하는 미완성 치근의 길이와 형태변화

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교정치료에 대한 인지도 변화 및 보호자의 관심증가로 조기에 내원하는 환자가 많으며 그 중 일부가 전치부 치근첨이 완성되기 전인 10세 이전에 고정식 교정장치가 필요하게 된다. 따라서 본 연구에서는 미완성 치근의 치료 전후 치근의 길이 변화를 측정하고 형태변화를 관찰하여 완성된 치근의 교정력에 의한 변화양상과 비교하고, 환자의 성별, 기간, 이동양상 등과의 연관성을 조사하였다. 상악의 전치부 치근첨이 완성되지 않은 상태에서 고정식 교정치료를 시작한 8~10세 환자 28명을 실험군으로 하고, 치근첨이 완성된 상태에서 고정식 교정치료를 시작한 11~15세 환자 31명을 대조군으로 삼았다. 상악 4전치의 치료 전후 치근단 방사선사진상에서 치관,치근길이를 측정해서, 치근길이의 변화량, 치관/치근 비의 변화량을 계산했고 분류체계에 따라 치근형태에 점수를 부여했다.

결과는 다음과 같다.

1. 대부분의 미완성 치근은 교정치료 후에도 치근 길이가 증가하였으며 정상적인 치근첨 형태를 보였다.
2. 치료기간이 길어지거나 개방교합의 경우, 미완성 치근이라도 치근길이가 증가하지 않거나 더 짧아진 경우도 있었으며 정상적인 길이가 되더라도 치근첨의 완성 형태가 뭉툭한 흡수 형태를 보였다.
3. 완성치근에서는 교정치료에 의하여 대부분의 치근이 경미한 치근흡수를 보였으며, 흡수된 치근첨의 형태는 미완성 치근의 완성형태보다 더 뭉툭하였다($p<0.05$).
4. 미완성 치근에서는 치료기간과, 완성치근에서는 치아의 이동거리(U1 to facial plane의 변화량)와 유의한 상관관계를 보였다($p<0.05$).
5. 미완성 치근, 완성치근 모두 성별, 부정교합 분류, 수직피개의 변화량, 두개저에 대한 치아의 위치 변화(U1 to SN의 변화량)등과는 유의한 상관관계를 보이지 않았다.

주요 단어 : 미완성 치근, 치근길이의 변화, 치근첨 형태, 치관치근비