# CHAPTER V
# DISCUSSION

One hundred and eighty one patients were selected from 350 who had completed orthodontic treatment. The selection was based on those who satisfied the study criteria; treatment with complete maxillary and mandibular fixed appliances and pre- and post-treatment records, including examination records, treatment records and intra-oral periapical radiographs. Periapical radiographs were excluded if the projection was poor, crown or apex was not fully visible, the CEJ was blurred or crown dimensions were altered during the treatment period due to fracture or abrasion. Those selection criteria were chosen to increase the accuracy of root resorption measurement and calculation, and resulted in 564 teeth being investigated. However, a greater sample size might have produced greater reliability in this retrospective study.

There are many diagnostic aids for detecting EARR. The periapical radiographs were used to detect EARR in this study. They produced fewer distortion and superimposition errors than panoramic or lateral cephalomatric radiographs would have produced. Although, they could not assess the amount of root loss in buccal and lingual root resorption, they provided the most appropriate information with the least irradiation to patients. However, periapical radiographs have consequential projection errors from the imaging technique. Linge and Linge[5], Blake et al[74] and Mavragani et al[75] used periapical radiographs with correction factors to correct enlargement differences and measure the amount of EARR. Breniak et al[72,73] recently confirmed this technique as the best for this purpose. For this reason, we used the same technique. Because of the limitations identified above, computed tomography (CT) is suggested for use in further studies.

The validity and reliability of the measurements in the EARR measurement method were considered. The accuracy of the digital vernier caliper was calibrated with a standard ruler before radiographic measurement. The radiographs of 20 patients were measured twice by one examiner, using Pearson's product-moment correlation. Statistical analysis showed highly statistically significant correlation between the first and second measurements ($r = 0.81$).

**Occurrence**

It was difficult to compare the frequency and severity of EARR in this study with those in other studies because of the differences in techniques and methods employed. The EARR has been reported both in millimeters and in percentage root resorption per tooth. However, most studies reported EARR in millimeters. The average amount of EARR ranged from 0.72 to 1.47 mm, as reported by Linge and Linge[6], Sameshima and Sinclair[3], Mirabella and Artun[4]. The percentage of teeth with EARR has been reported in the literature review of Lupi et al. [80] to range from 3.5% to 92% of root length. In this study, the average amount of EARR was 1.53±1.30 mm. and the mean percentage of EARR per tooth was 9.23±7.80%. The maximum EARR was 11.72 mm or 66.43%. The minimum EARR was -0.09 mm or -0.45%.

Interpretation of the whole range of EARR revealed that some teeth were judged to have root elongation although incomplete root formation was ruled out before root measurement. In this study, eight teeth (0.014% of all investigated teeth) had increased root length. The most elongated tooth was a central incisor. The increased root length was 1.68 mm or 11.82% of root length. However, root elongation was also found in other studies. Linge and Linge,[6] who examined the maxillary incisors of 485 orthodontically treated patients (aged 11.5-25 years) found that one person had root elongation >0.5 mm, even though all investigated teeth had completed root formation before treatment. Baumrind et al[39] examined the maxillary central incisors of 81 adult patients (aged >20 years). They, also, found root elongation The most elongated tooth in their study had an increased root length of 1.03 mm.

One possible reason why some roots were elongated was identified by Thilander et al.[81] They stated that the cementum on the root surface can increase in thickness by gradual apposition throughout life, especially at the apex. They also suggested that activation of odontogenic cells during tooth movement can result in root elongation. Other reasons why elongation might be seen on radiographs are projection, magnification or measurement errors. However, root elongation after orthodontic tooth movement is not clearly understood.

Most studies[3,4,82] have indicated that EARR occurs in maxillary lateral incisors more frequently than in maxillary central incisors (Figure 5.1).

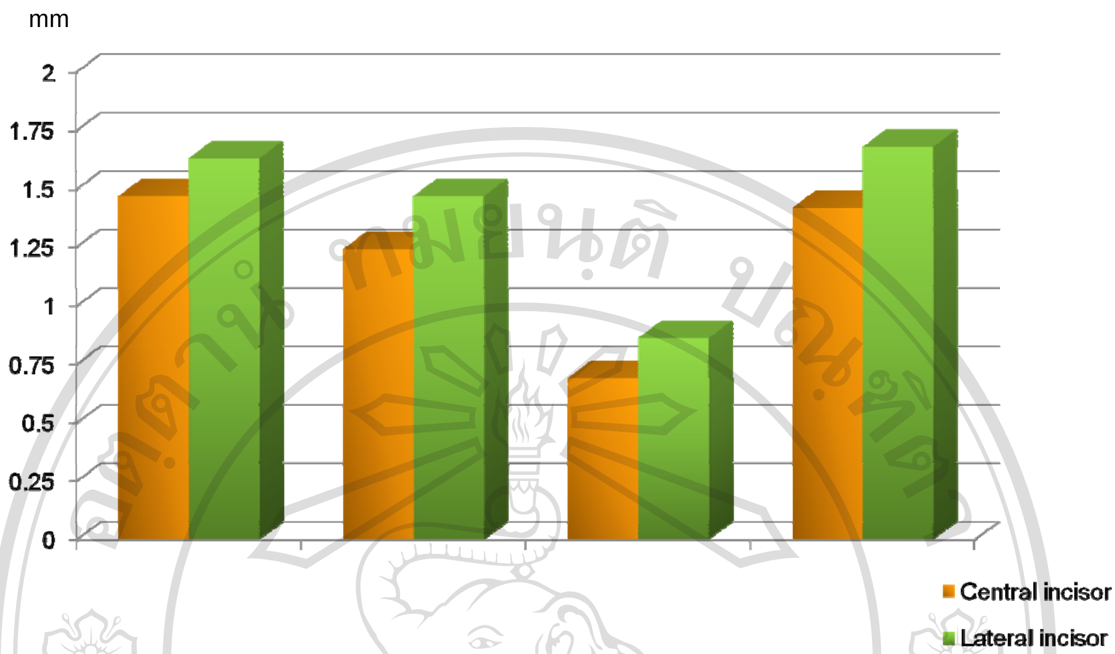


**Figure 5.1** EARR in maxillary central and lateral incisors after orthodontic treatment in previous and present studies

Mirabella and Artun[4] found that means EARR in maxillary central and lateral incisors were 1.47±1.40 and 1.63±1.24 mm, respectively. They studied 343 adult patient records, and pre- and post-treatment cephalograms and periapical radiographs of maxillary anterior teeth. The root measurements were made on periapical radiographs; tooth length was measured from the incisal edge to the root apex with a transparent ruler.

In a study by Sameshima and Sinclair[3] the most resorbed tooth was the maxillary lateral incisor followed by the maxillary central incisor. The means EARR in central and lateral incisors were 1.24±1.41 mm and 1.47±1.52 mm, respectively. They studied the records of 868 patients who were treated with maxillary and mandibular fixed edgewise appliances. Full-mouth periapical radiographs were used to accurately assess EARR from first molar to first molar in both arches. The full-mouth periapical films were scanned then viewed at double magnification on a large color monitor with 0.25 dot pitch resolution. Root length was measured on the scanned images from the apex to the midpoint of the right and left cemento-enamel junctions. Crown length was measured from the same midpoint to the incisal edge or cusp tip.

These measurements were made on both pre- and post-treatment images. The investigators used the pre- and post-treatment crown height ratio as a coefficient to account for different angulations and magnifications between films after the post-treatment total tooth length was subtracted from the pre-treatment length.

Artun et al [82] found that the mean EARR of maxillary lateral incisors was greater than that of maxillary central incisors, 0.84±0.82 and 0.67±0.70 mm, respectively. They evaluated periapical radiographs of the maxillary incisors before orthodontic treatment and at 12 months after bracket placement in 247 patients. They converted the radiographs to digital images and used commercially available software to correct for differences in projection. Tooth length was measured as the distance from the tip of the apex to the midpoint of the incisal edge in both in pre-treatment and 12-months-after-bracket-placement periapical radiographs. Assuming that the enlargement factor was negligible, absolute distances of root resorption were calculated.

In agreement with several studies, this study found that maxillary lateral incisors had more EARR than did maxillary central incisors. The average amount of EARR in maxillary lateral incisors was 1.69±1.14 mm, whereas in maxillary central incisors it was 1.39±1.27 mm. The percentages of EARR per tooth in maxillary lateral and central incisors were 10.16±6.78% and 8.24±7.22%, respectively.

A possible explanation why maxillary lateral incisors are more severely affected is that of all teeth, maxillary lateral incisors demonstrate the highest percentages of abnormal root shapes or narrow roots.[3,4,7,43] In this study, maxillary lateral incisors had more EARR than maxillary central incisors. The data confirmed that 7.10% of maxillary lateral incisors had pointed or dilacerated root shapes compared to 2.84% in maxillary central incisors. The roots may have been more susceptible to resorption in maxillary lateral incisors than in maxillary central incisors because of the abnormal shape.

There is no generally-accepted classification of degree of EARR. Several authors classified used their own classifications for the degree of EARR in their studies. Sameshima and Sinclair[79] identified severe root resorption as resorption of more than 20% of root length. Brin et al[57] classified the degree root resorption into no discernable root resorption, mild (< 2 mm) root resorption and moderate/severe (≥ 2 mm) resorption. Levander et al[64] identified an index for assessment of EARR with four categories; irregular root contour, root resorption apically amounting to less 2 mm, root resorption apically from 2 mm to one-third of the original root length and root resorption exceeding one-third of original root length.

Because differences in the root lengths of various teeth make comparisons of EARR values difficult, the percentage value of EARR per tooth is a better comparative value. Therefore, this study emphasized the percentage value to determine EARR. The degree of EARR was classified into 3 categories according to percentage of resorption mild (≤10%), moderate (10-20%) and severe (>20%). The results were that 59.6% had mild EARR, 31.9% had moderate EARR and only 8.5% had severe EARR. This finding was difficult to compare with those of other reports because of the difference in classifications of degree of EARR. However, this study found severe root resorption in more patients (8.5% of total patients) than did the study of Sameshima and Sinclair,[79] which found severe root resorption in only 3% of total patients.

**Comparison of factors associated with EARR**

Many possible associated risk factors for EARR have been reported in previous studies.[3,4,6,8,9,39,43,57,65,75] It was indicated that EARR after orthodontic treatment is a consequence of a complex combination of individual biology and the effects of mechanical factors used during orthodontic treatment. Table 5.1 shows the comparison of factors associated with EARR between some previous studies and the present study.

The most frequently reported associated risk factors which have been reported are traumatized teeth,[6,10,44,45] teeth with adjacent impacted canines[50-52] and heavy force used.[62,63] Some associated factors are still controversial, such as sex, allergic condition, tongue-thrusting habits and use of class II elastics, etc. However, some associated factors, such as impacted canine, endodontically treated teeth, use of light or heavy force, or use of class II elastics, were not included in this study because few of the records studied included such cases.

In this study, the associated factors were divided into pre-treatment factors and treatment factors. Pre-treatment factors were identified as biological factors which were seen in the patients before orthodontic treatment. They included sex, age at start of treatment, overjet, overbite, root shape, history of facial trauma, tongue-thrusting habit, allergic condition and types of initial malocclusion. Treatment factors were identified as mechanical factors which depend on the mechanics of treatment. They included treatment planning (extraction/non-extraction cases), types of bracket and treatment duration.

The results indicated that factors which were significantly related to the EARR were age at start of treatment, overjet, pointed or dilacerated root shapes, history of facial trauma, allergic condition, treatment planning (extraction/non-extraction cases) and treatment duration. No significant association was found with sex, overbite, tongue-thrusting habit, types of initial malocclusion or types of bracket. Each associated and non-associated factor was discussed as follows.

**Table 5.1** Comparison of factors associated with external apical root resorption on previous studies and the present study

| Authors | Sex | Age at start of treatment | Overjet | Overbite | Root shape | History of trauma | Tongue-thrusting habit | Allergic condition | Type of malocclusion | Treatment plan (Ext. / Non-Ext.) | Bracket types (Standard edgewise vs Straight wire) | Treatment duration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Linge and Linge[6] | No | No | Yes | No | - | Yes | Yes | - | - | - | - | - |
| Mirabella and Artun[4] | - | - | No | No | Yes; long narrow, abnormal root | - | - | - | No | - | No | No |
| Baumrind et al[39] | Male | No | No | No | - | - | - | - | No | No | - | Yes |
| Levander et al[64] | No | No | - | - | Yes; apically bent | - | - | - | - | - | - | Yes |
| Mavragani et al[75] | No | Yes | No | No | - | Yes | No | - | - | - | Standard > Straight wire | No |
| Sameshima and Sinclair[3] | No | Adult > children | Yes | No | Yes; pointed, dilacerated | - | - | - | - | - | - | - |
| Brin et al[57] | - | - | No | - | - | - | - | - | Class II div 1 > Class I | - | - | No |
| Nishioka et al[84] | - | - | - | - | Yes; Root abnormality | No | No | Yes | - | No | No | No |
| Mohandesan et al[65] | Female | - | - | - | - | - | - | - | - | Yes | No | Yes |
| Present study | No | older > younger | Yes | No | Yes; pointed, dilacerated | yes | No | Yes | No | Yes | No | Yes |

**Sex**

In this study, there was no statistically significant difference in EARR between male and female patients. However, there are controversial reports from previous studies. According to the data from a previous meticulous review of a total of 13 relevant articles by Brezniak and Wasserstein,[8,9] five articles reported no significant correlation between sex and EARR, seven reported a significant difference, with more EARR in female than in male subjects. Only one reported more resorption in male subjects. For example, Harris et al[38] studied 206 orthodontically treated patients consisting of 84 boys and 122 girls. Mean age at the first examination was 14.1 for boys and 13.3 for girls. They found no statistical difference between amounts of root length during treatment. Baumrind et al[39] investigated a group of adult (>20 years) orthodontic patients. The mean root resorption in males was $2.29 \pm 0.35$ mm and in females was $1.09 \pm 0.18$ mm. They found that males had statistically greater prevalence of orthodontically-induced EARR than did females. In contrast Kjar,[40]found a greater prevalence of orthodontically-induced EARR in girls than in boys when investigating panoramic radiographs and additional dental films of 70 girls and 37 boys submitted by 35 orthodontists.

Because previous studies as well as this present study are still equivocal regarding the difference in prevalence of EARR between male and female patients, we concluded that sex does not play an important role in EARR after orthodontic treatment.

However, no reports specifically studied the difference in prevalence of EARR between male and female. In order to find whether sex plays an important role in EARR, a large number of cases should be investigated, while controlling for all of the factors associated with EARR.



**Age at start of treatment**

In this study, the patients' ages at start of treatment ranged from 10 to 46 years. The patients' records were divided according to growth into two ages groups; Group I ≤16 years old and Group II >16 years old, following the study of Nabangxang et al,[75] which studied the growth velocity of Northern Thai children. This showed, on average, that velocity of growth of male and female children was nearly completed at 16 years of age.

When age at start of treatment was divided into two groups, there were 111 patients (338 teeth) in ≤16 years old group and 70 patients (226 teeth) in >16 years old group. The result of this study showed a statistically significant difference in the occurrence of EARR between these two groups. This is in agreement with the study of Sameshima and Sinclair,[3] which used the same method of root resorption measurement as used in this study. They investigated 868 patient records and also divided age at start of treatment into 2 groups; adults (age >16) and children (age ≤16). But they found adults had statistical higher in occurrence in root resorption in maxillary anterior teeth.

However, Thilander[23] described the physiological changes, in adults, in tissues that may be involved in the root resorption process. In adults, the periodontal ligament becomes less vascular, aplastic and narrow, the bone more dense, avascular and aplastic and the cementum wider. Those changes are reflected in a higher susceptibility to root resorption in adults.

Although there is controversy in the results of our study and in those of others, we concluded that orthodontic treatment in adult patients (age at start of treatment >16 years) should be carefully evaluated during treatment.

**Overjet**

In the present study, overjet was significantly associated with EARR in maxillary incisors. We found significant differences between each group of overjet. Especially, the most severe overjet (>6 mm) was the most powerful predictor of root resorption. This was in agreement with some authors,[3,6] who found that overjet may be regarded as a risk factor for root resorption.

Sameshima and Sinclair[3] compared pre- and post-treatment radiographs in 868 patients. They found that the greater the overjet, the greater the root resorption for all maxillary anterior teeth. However, the correlation coefficients were week. Linge and Linge[6] used stepwise regression analysis to evaluate some factors associated with EARR. They reported that overjet had an effect on maxillary incisor root resorption in the first regression equation. However, these two reports did not divide the overjet into groups by severity.

Oppositely, there are reports that found that overjet was not closely related to change in root shortening of maxillary incisors.[5] Linge and Linge[5] examined 719 patient records. They explained that overjet can be corrected in several ways other than moving the roots of maxillary anterior teeth, such as growth adaptation in a growing person, anterior segment expansion of the mandibular dentition, or growth modification. This lack of correlation is in agreement with the finding of Brin et al.[57] They studied 138 children with Class II division 1 malocclusion. They divided phase of treatment into three groups; Group I: one phase with fixed appliances, Group II: two phases with headgear followed by fixed appliances and Group III: two phases with bionator followed by fixed appliances. The three groups were similar in age, sex, and malocclusion severity. They found that early growth modification reduces the severity of overjet in Class II malocclusion and might have a role in reducing EARR. However, the change of overjet during Phase 2 treatment by fixed appliance was significantly associated with EARR.

Comparing our study with those two studies (Linge and Linge[5] and Brin et al [82]), the treatment mechanics, such as functional appliance or headgear, played an important role in reducing EARR in cases with large overjets. Therefore, this study excluded cases involving growth modification and orthognathic surgery. The greater the overjet the greater the degree of EARR can be explained as follows. Fixed appliances are often used to correct severe overjets, cause maxillary incisors to move longer distances than they do in cases of less severe overjet. The protruded maxillary incisors are usually retracted to reduce upper anterior protrusion. Besides that, active torque with rectangular wire is also required to correct the inclination. Moreover, the severity of injuries to upper anterior teeth has been reported to be greater in children with extreme overjet (more than 6 mm) than in children with less overjet ranging from 0 to 6 mm.[78]

In further studies, besides the overjet, horizontal displacement should be examined as a factor associated with EARR.

**Overbite**

No statistically significant difference was found between the degree of overbite present at the beginning of treatment and the amount of EARR. This finding was in agreement with Linge and Linge[5,6] and Sameshima and Sinclair[3]. These studies were conducted on many hundreds of patient records and compared root length on pre-and post-treatment periapical radiographs to detect EARR after orthodontic treatment. They also found no correlation between overbite and EARR. However, they did not categorize overbite by severity.

Harris and Butler,[42] studied 32 adolescents with open bites and found that the roots of permanent maxillary central incisors were significantly shorter than those in a matched series with deep bites before treatment. They explained that long-term orthopedic forces resulting from tongue-thrusting habits, leading to anterior open bite, enhance the rates of osteoclastic activity. This enhancement causes destruction of root structure. However, that study did not exactly conclude that open bite is an important factor for EARR because there was another associated factor, tongue-thrusting habit that strongly influenced EARR.

But in this present study, a possible reason for the lack of correlation between overbite and EARR is that the correction of deep overbite depended on treatment strategies. Intrusion of maxillary incisors may cause more EARR in maxillary incisors. The hypothesis that intrusion of teeth is associated with EARR is supported by the study of Parker and Harris,[83] in which the sample consisted of 110 adolescents with similar pre-treatment malocclusions (Class I crowded or bimaxillary protrusive) and who were treated similarly (extraction of four first premolars). The lateral cephalograms were analyzed at the start, middle, and end of treatment. They found that incisor intrusion with increasing lingual root torque were the strongest predictors of EARR.

If the overbite correction involves the intrusion of mandibular incisors, root resorption is likely to occur not only in maxillary incisors, but also in mandibular incisors. Therefore, in further studies, it is suggested that both root length of maxillary and mandibular incisors should be measured, before and after orthodontic treatment, in order to test this factor. Moreover, vertical displacement of crown or root after orthodontic treatment should be investigated as factors associated with EARR.

**Root shape**

In this study, abnormal root shape was categorized into dilacerated and pointed root shapes. We found that dilacerated or pointed roots were highly significant factors for EARR. This finding was in agreement with the findings of previous studies.[3,4,7] Sameshima and Sinclair[3] found that dilacerated roots (particularly in maxillary lateral incisors) had the most EARR, followed by bottle-root shaped and pointed roots. Although there was no direct proof that the dilacerated root shape resorbed more easily, they explained that the deviant process causing the dilacerated root shape is the strongest possibility. A genetic component causing shape inheritance is also likely, but unproved.

Mirabella and Artun[4] studied 343 adult orthodontic patients and scored root form subjectively as normal, pointed, eroded, blunt, bent and bottle-shaped. They found that atypical root shapes were risk factors for root resorption in maxillary central incisors.

Smale et al[7] found that pointed or deviated root shapes were associated with increased root resorption. Moreover, they found that wider central incisor roots and the normal root form reduced the risk of root resorption.

Most studies, including the present study, agree that pointed or dilacerated root shapes are risk factors for EARR in orthodontic treatment. The reasons that explain why dilacerated and pointed root shapes induce more root resorption after tooth movement are described as follows. Dilacerated roots are more likely to be resorbed than normal roots because stronger forces are orthodontically applied to move or torque dilacerated roots than are applied with normal root shapes. Pointed roots are prone to have more root resorption because more stress is distributed at the apices of pointed roots when tipping or torque movement is used than is the case with normally-shaped roots. These increased stresses traumatize the PDL. This trauma is followed by an inflammatory process, which contributes to the resorption of the root apex.

However, we did not divide abnormal root shape into other categories such as pointed, dilacerated, blunt, short or long. Therefore, categories of root shape should be investigated in further studies.

**History of facial trauma**

EARR can occur in previously-traumatized teeth, even in the absence of orthodontic treatment.[49] Although few patients were recorded to have a history of facial trauma in this study (9 cases, 25 teeth), the results showed that previous trauma was significantly related to root resorption. This study also found one case with a history of facial trauma that had excessive root resorption. The resorption was 9.24 mm or a 66.43% reduction of root length. However, we did not have detailed information on intensity, location, and type of trauma, which minimizes the importance of this finding.

In agreement with many studies,[6,45,49] trauma was an important risk factor for EARR. Linge and Linge[6] used stepwise regression analysis and found that trauma was a powerfully predictive variable in both first and second runs. Malmgren et al[45] found that neither the intra-individual nor the inter-individual comparisons supported the idea that traumatized teeth had a greater tendency toward root resorption than uninjured teeth. Hamilton and Gutmann[49] reviewed and suggested that if a previously traumatized tooth exhibits root resorption, there is a greater chance that orthodontic tooth movement will enhance the resorption process. If a tooth has been severely traumatized (intrusive luxation/avulsion) there may be a greater incidence of resorption during tooth movement.

There are possible explanations for this finding. At the moment of impact, a significant amount of energy is transmitted through the tooth into its socket. Compressive forces compress the periodontal ligament and crush the alveolar socket wall. Resorption along the root surface following traumatic dental injuries is a sequel of wound healing processes, where periodontal ligament has been lost due to the effect of acute trauma. The goal of wound healing processes is removal of injured tissue from zones of trauma, thereby creating space for neovascularization. These processes have a potential for external root resorption.[44]

However, Malmgren et al[45] found that the risk of resorption in slightly or moderately traumatized teeth was not increased when the orthodontic treatment was started 4 to 5 months after trauma, and when no signs of root resorption could be observed. Consequently, a history of incisor trauma should be considered in the planning of orthodontic treatment.

**Tongue-thrusting habit**

In this study, sixty six patients (214 teeth) had a tongue-thrusting habit. The results showed that a tongue-thrusting habit was not associated with EARR after orthodontic treatment. This finding was in agreement with that of Sameshima and Sinclair,[79] who found no statistical difference in root resorption between patients with a tongue-thrusting habit and those without a tongue-thrusting habit. They compared a group of patients in whom all four maxillary incisors were resorbed at least 20% with a matched group without resorption. In their study, five of 25 severe cases were reported to have a tongue-thrusting habit compared with four of 50 controls.

In contrast, Linge and Linge[6] studied 485 orthodontically treated patients and used stepwise regression to resolve the complicated inter-relationships between the pre-treatment and treatment factors. They concluded that lip/tongue dysfunction was a powerful predictor for root resorption. Harris and Butler[42] studied 32 adolescents with tongue-thrusting habits leading to anterior open bites. They found that the roots of permanent maxillary central incisors in patients who had a tongue-thrusting habit with anterior open bite, were highly significantly shorter and exhibited higher modal grades of periapical root resorption than were the roots in a control group. They suggested that a tongue-thrusting habit could promote long-term force to anterior teeth and could enhance EARR.

However, the finding of no association between tongue-thrusting and EARR in the present study may be questioned in the validity of the chart record because details regarding severity or intensity of tongue-thrusting habits were not recorded. Therefore, the samples used may not be considered suitable to test this hypothesis. In further studies, controlling other associated factors and recording the severity of tongue-thrusting habits and the duration of the habit should be considered.

**Allergic condition**

The statistical analysis showed a highly significant difference in EARR between the allergic and non-allergic groups. Thirty patients (88 teeth) with allergic conditions were recorded following the criteria of the Department of Orthodontics.

The explanation for the association between allergic condition and root resorption is as follows. Osteoclasts originate in the immune system, and their mononucleated progenitors are derived from the monocyte/macrophage lineage. Odontoclasts and multinucleated cells are most likely derived from the immune system. Therefore, cells derived from the immune system are directly responsible for the resorption of alveolar bone that promotes tooth movement and for the excessive root resorption that sometimes accompanies the force-induced tissue remodeling. The occurrence of inflammation in the periodontal ligament in the early stage of tooth movement, and the presence of activated leukocytes, which originate in diseased organs and tissues in peripheral blood, support a possible association between root resorption and pathologic conditions. The present study suggests that allergic condition and asthma may be etiological factors for EARR. The same association was found in earlier studies.[31,84-85]

Davidovitch et al[31] hypothesized that those individuals who have medical conditions affecting the immune system may be at a high level of risk for developing excessive root resorption during the course of orthodontic treatment. In reviewing orthodontic patient records at the University of Oklahoma, they discovered that there was significantly higher excessive root resorption during orthodontic treatment in the patients who had experienced the incidence of asthma, allergies, and signs indicative of psychological stress compared with the group of orthodontic patients who had completed orthodontic treatment without suffering these medical conditions.

Nishioka et al[84] studied Japanese orthodontic patients. The records of 60 orthodontic patients (18 males, aged 17.7 ± 5.7 years; 42 females, aged 16.4 ± 6.0 years) and 60 pair-matched controls (18 males, aged 15.9 ± 4.5 years; 42 females, aged 18.5 ± 5.2 years), based on age, sex, treatment duration, and type of malocclusion, were reviewed retrospectively. Logistic regression analysis was used to test the association between excessive root resorption and allergic condition. They found that asthma may be a high risk factor for the development of excessive root resorption during orthodontic tooth movement.

Owman-Moll and Kurol[85] histologically analyzed extracted maxillary premolars after buccal movement in 96 adolescent patients. They selected 50 individuals (18 boys and 38 girls, mean ages 13.4 years) and divided them into two equal groups. The high-risk group was based on measurements of severe root resorption, and the low-risk group on measurements of mild or no root resorption. Their results were suggestive of a link between allergy and extent of root resorption, but no statistically significant difference was found between the groups.

On the other hand, McNab et al[86] reported that the incidence of EARR was elevated in the asthma group. However, both asthmatics and healthy patients exhibited similar amounts of moderate and severe resorption. In their study, records were obtained from patients treated with fixed appliances; 99 were healthy and 44 had asthma. Panoramic radiographs were used to measure EARR in all first and second premolars, mesiobuccal and distobuccal roots of the upper first molars, and mesial and distal roots of the lower first molars, giving four measurements per quadrant. A 4-grade ordinal scale was used to determine the degree of EARR.

It was difficult to compare our study with those previous studies because difference techniques were employed. Some authors[84,85] designed their studies as case control studies focusing on allergic condition so that. But the present study investigated all possible factors that could promote orthodontically-induced root resorption. However, neither the severity nor intensity of allergic conditions was classified. This lack of classification rendered the results less meaningful than they might otherwise have been. Therefore, it is suggested that a prospective study focused on the details of allergic condition should be conducted to test this hypothesis.

**Types of malocclusion**

This study found no statistical difference in EARR between patients with Angle's Class I, Class II or Class III malocclusions (130, 38 and 13 cases / 416, 107 and 41 maxillary incisors, respectively). This finding is in agreement with that of Baumrind et al[39]. They analyzed 30 orthodontically treated patients with Class I and 42 with Class II malocclusions (one subject designated as Class III was omitted from the analysis), and measured the root resorption as we did in our study. They used mid-incisal edge, mid-CEJ point and most apical point for measured crown and root length and then used correction factors for the calculation of EARR. The mean root resorption in the Class I and Class II groups were 1.16±0.27 mm and 1.49±0.23 mm, respectively. The results showed no statistical difference in root resorption between Class I and Class II malocclusions.

However, Taner et al[55] found a significant difference between patients with Class I and Class II division 1 malocclusions. They studied 27 patients with Class I and 27 with Class II malocclusions (16 girls and 11 boys) in all of whose treatment plans first premolar extraction was selected. The average ages at start of treatment were 12.54±1.88 years for the Class I group and 13.61±2.51 years for the Class II division 1 group. The amount of root resorption in maxillary central incisors was determined for each patient by subtracting the post-treatment tooth length from the pre-treatment tooth length measured directly on cephalograms. Their results showed that there was a mean of approximately 1 mm of apical root shortening in patients with Class I malocclusion, but in patients with Class II division 1 malocclusion the mean root resorption was more than 2 mm. The inter-group differences were statistically significant.

This study used molar relationships to define types of malocclusion. Most previous studies compared the difference in root resorption between Class I and Class II malocclusions because Class II malocclusions predominate in the Caucasian populations studied. Some studies used only molars relationships to define Class II malocclusion, and some used both molar and incisor relationships (Class II division 1) to define Class II malocclusion. However, even though the present study compared Class I and Class II groups, there was no statistical difference in root resorption between these two groups.

Other reasons for the differences in findings between studies are that numerous factors influenced the development and treatment of each malocclusion. These may have contributed to differences in EARR. It is, therefore, not surprising to find many conflicting and controversial conclusions.

**Treatment planning (extraction /non-extraction)**

Extraction pattern was also found to be a significant factor for EARR in the present study. Patients who underwent upper premolar tooth extraction to gain space for tooth movement had greater EARR than did those patients who were treated with non-extraction. This finding is in agreement with the recent report of Mohandesan et al.[65] They studied 151 maxillary incisor teeth of 40 patients (16 males, 24 females) aged 12–22 years, with different malocclusions. The root resorption measurement was performed on periapical radiographs, correcting for image distortion. They found that there was highly a statistically significant difference between extraction and non extraction groups.

However, Baumrind et al[39] found no difference in EARR between patients who had been treated without and with extraction. They analyzed 38 non-extraction cases and 35 premolar extraction cases in orthodontically treated adults. The EARR was measured on anterior periapical radiographs. The method for root resorption measurement and the correction factor for enlargement difference in calculating root resorption were the same in their study as in the present study.

There are no direct explanations for the association between a history of upper premolar extraction and EARR. However, in cases requiring tooth extraction, the remaining teeth are usually moved relatively greater distances, than in cases not requiring extraction, particularly when maxillary incisors are retracted to reduce a large overjet. On the other hand, if the extraction space is used to relieve crowding, the maxillary incisors are moved distally a relatively short distance. The degree of EARR in maxillary incisors may, therefore, depend on the objectives of tooth movement in cases of upper premolar extraction. It is possible that most previous studies did not consider the objectives of extraction before orthodontic treatment, thus there was is a difference between previous studies and this study, in the results in terms of whether or not extraction promoted EARR.

**Types of bracket**

In this study, no statistically significant difference was found in external apical root resorption on maxillary incisors between using standard and pre-adjusted brackets. In contrast, Mavragani et al[75] found greater external apical root resorption of maxillary central incisors in patients treated with standard bracket techniques than in patients treated with the straight-wire edgewise technique. (Pre-adjusted brackets are used in the straight-wire edgewise technique). However, they found no significant difference in external root resorption in lateral incisors. All subjects were classified as Angle Class II division 1 malocclusion and were treated with extraction of at least two maxillary first premolars. Root and crown length were measured on periapical radiographs. Then correction factors were used and for calculation of root resorption in each tooth.

The same method of root measurement was used in the present study and in that of Mavragani et al[75]. But more pre-adjusted bracket cases (66 standard bracket and 111 pre-adjusted bracket cases) were used in this study. However, this study did not control the associated factors controlled in the other study, minimizing the importance of the findings of the present study.

In order to find some difference in EARR among bracket types, matched case control studies or prospective design studies which control all associated factors such as types of malocclusion, extraction patterns and treatment mechanics should be considered in further studies.

**Treatment duration**

In this study, there was a highly statistically significant difference in EARR between each treatment duration group. The results indicated that the greater the treatment duration, the more the EARR. This finding agrees with the findings of Baumrind et al[39] and of Levander et al.[64]

Baumrind et al[39] analyzed the relationship in orthodontically treated adults between upper central incisor displacement measured on lateral cehalograms and EARR measured on anterior periapical radiographs. They used the enlargement difference for calculated root resorption, as was done in this study. They found that the increased length of treatment time was positively associated with increased root resorption. They concluded that 0.38 mm of resorption occurred during each year of orthodontic treatment.

Levander et al [64] studied 68 orthodontically-treated patients with aplasia. The degree of EARR was assessed before and after treatment from intra-oral radiographs of maxillary incisors using a scale of 0-4. Total treatment time was divided into three treatment duration groups: less than 1 year, 2 years and more than 2 years. There were 37, 114 and 35 teeth in each group, respectively. They found statistical differences between groups ($P < .05$) and concluded that the total treatment duration was significantly related to EARR.

However, in two other studies,[4,6] discriminate analysis indicated that total treatment time was not a significant factor for EARR. Mirabella and Artun[4] and Linge and Linge[6] explained that appliances may be present for long periods without creating pressure on the teeth. Therefore, treatment duration was not detected as a predictor for resorption.

The lack of agreement among present and other previous studies may be because many associated factors influencing EARR were not controlled to test the effect of treatment duration.

However, treatment duration is important primarily because the greater the treatment duration, the greater the distance the upper incisors are displaced. Therefore, active treatment duration is the better variable to investigate. Risk factors for EARR, such as previous incisor trauma, abnormal root shape, or overjet, should be controlled in further studies.