EXTERNAL APICAL ROOT RESORPTION OF THE MAXILLARY CENTRAL INCISOR IN ANTERIOR OPEN BITE MALOCCLUSION

by

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ABSTRACT

Orthodontic treatment provides many benefits to patients, but it not without risk. External apical root resorption is a pathologic process that can be caused by orthodontic treatment. While root resorption is generally mild when it occurs, it is still important to inform patients of their risk before treatment is initiated. In order to do this effectively, research must be done to evaluate which factors could predispose a patient to root resorption. The purpose of this study is to evaluate the incidence, severity and risk of root resorption of the maxillary central incisors of orthodontic patients with an anterior open bite malocclusion. This retrospective study used a randomly selected open bite and control sample, 32 in each group, screened from 800 orthodontically treated patients at Oregon Health and Science University, Department of Orthodontics. There were 9 males and 23 females in each group. The mean age of the open bite group was 18.7 years and the control group was 14.7 years. The open bite sample had no vertical overlap of their incisors prior to treatment. The control sample consisted of patients with 10-30% overbite. Confounding factors for root resorption were controlled for in the subject selection process by excluding subjects for the following variables: history of trauma to the maxillary central incisor, existing restoration of the incisal edge before orthodontic treatment, root canal therapy, incomplete root apex development, an obscured root apex, significantly malformed roots, greater than 7 mm overjet, maxillary anterior tooth impaction, supernumerary teeth in anterior maxilla, previous orthodontic treatment (including phase one treatment), sibling relationship with another subject, orthognathic surgery, reshaping or restoration of the incisal edge during or after orthodontic treatment,

and those subjects that requested early termination of treatment. Tooth length and changes in tooth position were measured from a tracing of the pretreatment and posttreatment lateral cephalogram for each subject. In addition, several treatment factors, such as the use of elastics, length of treatment time, and age that treatment was initiated, were recorded from the treatment records. The results of this study show that there is a significant difference in the amount of root resorption in patients with an open bite compared to patients with a normal overbite. The mean root resorption for the open bite group was 2.26 mm (8.87% of root length) and the mean root resorption for the control group was 0.93 mm (3.73% of root length). In addition, the presence of an open bite and a longer central incisor length were both found to be predictive of increased root resorption. There were no particular tooth movements or treatment factors that increased the risk for root resorption. In conclusion, this study suggests that a patient with an anterior open bite malocclusion who has undergone orthodontic treatment has more risk for root resorption, but the particular factor that leads to this increased risk was not elucidated.

INTRODUCTION AND BACKGROUND

Introduction

External apical root resorption is a common side effect of orthodontic treatment. While it is generally mild in nature, root resorption due to orthodontic treatment is still of concern to clinicians. One of the earliest reports of root resorption associated with orthodontic treatment was by Ketcham (1927). Since that time, there have been numerous studies on the etiology of this pathologic process.

Root resorption can occur on all surfaces of the root, but apical resorption is the easiest to diagnose. Root resorption is diagnosed via radiographs, such as a lateral cephalogram, a panoramic radiograph, or a periapical radiograph (Leach et al., 2001). Although orthodontic treatment is the most common cause of root resorption, it can occur in patients that have not received orthodontic treatment. Research has demonstrated that factors such as traumatic occlusion, nail biting and age can be non-orthodontic causes of apical root shortening (Odenrick, 1985; Massler and Perreault, 1954).

When orthodontic treatment is the cause of root resorption, the most commonly affected teeth are the maxillary incisors (Sameshima and Sinclair, 2001). Also, the research tends to show that the risk of severe localized resorption is greater for maxillary central incisors than for all other teeth (3% compared to <1%) (Proffit, 2000). Several factors such as degree of force used, direction of tooth movement, the shape of roots, the use of premolar extractions for orthodontic treatment, elastic usage during orthodontic treatment, and duration of orthodontic treatment have been implicated as playing a role in the process of root resorption. "Jiggling forces" from occlusion and elastic usage during orthodontic treatment has also been held responsible for causing root resorption, but this theory has not been specifically researched (Stuteville, 1938). Due to the variety of clinical and patient factors that have been associated with root resorption, some researchers believe that genetics play a larger role than previously thought (Al-Qawasmi et al., 2003; Harris et al., 1997).

Research results have been inconsistent with regard to extrusion of teeth as being a risk factor for root resorption. Neither Sameshima and Sinclair (2001) nor Mirabella and Artun (1995) found extrusion to be predictive of root resorption, although both studies had samples with minimal extrusion of the incisors (<2 mm). On the other hand, Horiuchi et al. (1998) did find extrusion to be predictive of root resorption, but this only accounted for 12% of the variation from the mean. Other studies have shown that significant movement of the root apex can predispose a patient to root resorption (Sameshima and Sinclair, 2001; Parker and Harris, 1998; Baumrind et al., 1996).

To date, there has been only one published study that specifically examined open bite patients and extrusion of incisors as a risk factor for root resorption. Using lateral cephalograms to measure maxillary central incisor length, Harris and Butler (1992) compared the difference in root resorption between 32 open bite and 31 deep bite patients. The open bite group had an average of -3.6 mm of overbite and the deep bite group had an average of 4.1 mm of overbite. This study found that before orthodontic treatment, the incidence of shortened roots for open bite patients was much higher than deep bite patients, with an average root length 1.7 mm shorter for the open bite patients. When root resorption was evaluated as categorical data, the open bite patients had more root shortening before and after orthodontic treatment. In addition, presence of an anterior open bite prior to treatment was one of three significant predictive factors for root resorption.

In an unpublished study, Frantz (1965) examined apical root resorption in a group of 38 anterior open bite patients compared to 45 patients without anterior open bite. The open bite subjects had a minimum of 2 mm open bite, as measured on a lateral cephalogram. Using periapical films and lateral cephalograms, Frantz found a highly significant difference ($0.001 < p < 0.01$) in the amount of root resorption between the anterior open bite and normal overbite groups. The mean root resorption was 2.4 mm for the open bite group and 1.5 mm for the control group. In addition, the anterior open bite group had increased moderate and excessive amounts of resorption (13.6%) compared to the normal overbite group (8.4%).

The purpose of this study is to compare the pretreatment root length of the maxillary central incisor between an open bite sample and a normal overbite sample. The amount of root resorption and the distribution of degree of root resorption in orthodontically treated open bite patients and an orthodontically treated control group will also be evaluated. In addition, certain treatment variables, patient factors, and pretreatment characteristics will be examined to determine if there are any predictive factors for root resorption.

Background

Bates (1856) published the first known report of root resorption of permanent teeth. He believed that the cause of root resorption was trauma to the periodontal membrane. Ottolengui (1914) made the first association between root resorption and orthodontic treatment. Ketcham (1927) published one of the first scientific articles on root resorption caused by orthodontic treatment. By the end of his data collection, he had analyzed over 500 patients, many of which were from his private practice. The overall incidence of root resorption in his sample was 21% and he found that maxillary anterior teeth were most susceptible to resorption. Some patients demonstrated shortened roots before treatment began. This emphasized the importance of pretreatment as well as posttreatment radiographs. Ketcham (1927) brought the issue of root resorption associated with orthodontic treatment to a forefront, and researchers have been attempting to reveal its etiology since that time.

Root resorption is one of the most common iatrogenic sequelae of orthodontic treatment. Research has shown a wide range of incidence, from 13-100% (McFadden et al., 1989; Stenvik and Mjor, 1970). While the incidence of root resorption is high, it is generally considered mild. The reported range of average root resorption is 0.99-2.3 mm (Linge and Linge, 1983; Harris et al., 1997). Root resorption greater than 3 mm is generally considered severe. It is estimated that the frequency of severe root resorption is between 10-20% of cases showing root resorption (Levander and Malmgren, 1988; Hollender et al., 1980).

While all teeth are susceptible to root resorption, studies show that maxillary incisors are the most commonly affected teeth. This was most recently verified by a retrospective study done by Sameshima and Sinclair (2001) that examined the entire dentition of 868 orthodontic patients using periapical radiographs from first molar to first molar. This study found that maxillary incisors and canines are the most affected, with 25% undergoing greater than 2 mm of resorption. On the other hand, the posterior dentition averaged less than 1 mm of resorption, which the authors concluded was an insignificant amount. This study indicates that the order of susceptibility to root resorption is maxillary centrals, maxillary laterals, and mandibular incisors. Although the incidence of root resorption of maxillary centrals is greater than laterals, this study demonstrated that when maxillary lateral incisors are affected by root resorption, it tends to be more severe. It is also of interest to note that this study did not find a significant difference in root resorption when comparing the right and left dentition.

While root resorption is considered a pathologic phenomenon, it is due to a normal cellular process created during orthodontic treatment (Brezniak and Wasserstein, 2002). During initial tooth movement, the periodontal ligament is compressed. If it is compressed to the point of tissue necrosis, the periodontal ligament becomes hyalinized and cannot protect the root against resorption (Rygh, 1977). Tooth movement depends upon bone resorption and apposition, a process that can also cause cementum to resorb. After cementum has been resorbed, there is potential for it to be repaired. When this healing occurs, root resorption is prevented. If there is no repair, there is non-reversible resorption of dentin. This leads to permanent root resorption (Brezniak and Wasserstein, 2002).

Most root resorption that occurs in orthodontically treated patients is considered mild. Research has shown that there is not necessarily an increased risk of tooth loss or hypermobility with root resorption and that the process of root resorption ceases once orthodontic appliances are removed (Remington et al., 1989; Tronstad, 1988). In an instance of excessive root resorption during treatment, an alternative treatment plan might be considered to avoid further resorption, although research has yet to demonstrate a routine protocol that should be used in this circumstance (Travess et al., 2004, Fuss et al., 2003; Vlaskalic et al., 1998). One concern with apical root resorption is the amount of attachment loss that occurs with the loss of root structure. Kalkwarf et al. (1986) examined this via a computer graphics program and found that 4 mm of apical root loss results in approximately 20% attachment loss. The authors concluded that mild apical root resorption would have less impact on periodontal support than minimal alveolar crestal bone loss. Remington et al. (1989) speculated that a tooth with increased root resorption would be less likely to withstand traumatic forces, but there have been no published studies to support this opinion (Vlaskalic et al., 1998). Although, in general, it does not seem to have severe long-term consequences, root resorption is still considered a pathologic phenomenon, and should be minimized whenever possible.

Histologic Studies: There have been numerous histologic studies that examine root resorption in response to different types of orthodontic tooth movement. Reitan (1974) conducted an experiment using premolars that would eventually be extracted for orthodontic treatment. There were 72 teeth studied from 32 patients. The premolars were divided into four groups based upon experimental orthodontic treatment provided: extrusion, intrusion, tipping, and a control group. Reitan found mild signs of resorption in 7 out of 30 extrusion patients. This was also the only group in which resorption lacunae were observed. Mild resorption was found in all four premolars of one patient in the tipping group. Finally, significant and moderate resorption was found in 8 out of 18 intrusion patients. As a whole, the amount of root resorption in all groups increased with increasing treatment time. Experimental treatment time was a more critical factor that the amount of force used, though the maximum treatment time was limited to 47 days.

In addition to the research done by Reitan (1974), other histologic studies have found an increase in root resorption with an increase in force duration. Stenvik and Mjor (1970) also studied first premolars that were to be extracted for orthodontic treatment. These teeth were subjected to intrusive forces. Root resorption was evaluated microscopically and was found in 60% of the experimental group. For experimental teeth that had force applied for at least 20 days, 93% experienced resorption. Harry and Sims (1982) used a similar experimental design of intruding premolars that were to be extracted for orthodontic treatment. After a certain time period, the teeth were extracted and examined. 100% of the premolars exhibited some degree of root resorption. The group with the longest force duration (70 days) demonstrated the most significant amount of resorption.

Treatment Factors: Most studies that have specifically examined whether different types of orthodontic appliances could predispose a patient to root resorption have concluded that it does not make a difference. Ketcham (1927) studied the difference in the incidence of root resorption for patients with four different appliances. In some of his earliest findings, Ketcham concluded that root resorption was more common in cases with pin and tube or ribbon brackets (Ketcham, 1927). His later reports dismissed this initial finding (Ketcham, 1929). Beck and Harris (1994) compared edgewise and Begg techniques. They found that the overall incidence of root resorption was 62%, but no difference was found between treatment groups. Parker and Harris (1998) used a sample of 110 orthodontically treated adolescents. The group consisted of patients treated with Roth, Tweed, or Begg techniques, and no difference was found between these different mechanical techniques. Finally, Alexander (1996) did not find a difference in root resorption in sectional arch versus continuous arch mechanics.

The effect of extractions on root resorption has also been analyzed, and does not seem to consistently increase the risk for root resorption. For the most part, clinical studies have found no significant difference in the amount of root resorption when comparing cases treated with and without extractions (Horiuchi et al., 1998; Baumrind et al., 1996; McFadden et al., 1989). The results of the research done by Sameshima and Sinclair (2001) differ from this finding. They found that patients with four first premolar extractions had greater root resorption than patients with no extractions as well as patients with only maxillary premolar extractions. There was no difference in root resorption found between the maxillary premolar extraction cases and the non-extraction cases. The four premolar extraction cases averaged 1.43 mm more root resorption than non-extraction cases, but these results are in contrast to most other studies.

Different directions of tooth movement have been well studied, but the results are varied. In his histologic study, Reitan (1974) demonstrated a certain degree of root resorption for each type of experimental tooth movement. The only movement that produced root resorption with clinically significant levels was intrusion. Since the duration of experimental tooth movement was short (10-47 days), there might not have been enough time to demonstrate significant clinical results with the other directions of movement. Out of all directions of tooth movement, intrusion and retraction are most often associated with increased root resorption (Parker and Harris, 1998; Beck and Harris, 1994; Harris and Butler, 1992; Phillips, 1955). Not as much research has found extrusion to influence root resorption, but many of these studies have used subjects with minimal extrusion (<2mm) (Sameshima and Sinclair, 2001; Mirabella and Artun, 1995). Horiuchi et al. (1998) found extrusion of the maxillary central incisor to be a significant predictive factor for root resorption, but it only accounted for 12% of the variation from mean values.

Elastics are an important treatment technique and are used frequently in orthodontics. The use of elastics has not been extensively studied in relation to root resorption. Sameshima and Sinclair (2001) found no significant difference in the amount of root resorption with the use of Class II elastics or finishing elastics. Linge and Linge (1983) found Class II elastics to be associated with increased root resorption. Mirabella and Artun (1995) examined Class II and anterior vertical elastics. For both types of elastics, there was increased root resorption for maxillary canines, which were the teeth that supported the elastics.

The effect that length of treatment has on the amount of root resorption has also been investigated. There are several studies that have found no significant difference when attempting to correlate the amount of root resorption with treatment time (Mirabella and Artun, 1995; Beck and Harris, 1994; Linge and Linge; 1983; Phillips, 1955). On the other hand, some studies have the opposite results. Brin et al. (2003) found that as treatment time increased, that the odds of root resorption increased. Sameshima and Sinclair (2001) found a significant correlation between the amount of root resorption of the maxillary central incisor and treatment time ($p < 0.05$). Taithongchai et al. (1996) and McFadden et al. (1989) both found a significant correlation between the amount of root resorption and treatment time, but stated that since the coefficient of determination was so small, the results were not clinically significant. The research tends to show that treatment time is not a risk factor for root resorption, but there is certainly some evidence to the contrary. This is most likely due to the fact that treatment time does not necessarily reflect the severity of the initial malocclusion, the amount of tooth movement needed to correct the malocclusion, or even the amount and duration of force placed on the maxillary incisors throughout the course of treatment.

Patient Characteristics: While many clinicians have speculated that the risk of root resorption increases with age, research has not generally supported this theory. Lupi, et al. (1996) collected an adult sample and found a similar incidence of root resorption to other studies that analyzed adolescent-only samples. Even research that shows a significant association between age and root resorption does not demonstrate a strong relationship. Sameshima and Sinclair (2001) found that adults had significantly more root resorption of the mandibular anterior teeth (1.26 mm) than children (0.63 mm). For maxillary anterior teeth, there was no significant difference. Taithongchai et al. (1996) found that increased root resorption was weakly correlated ($r = 0.1$) with age, and the authors concluded that this was not clinically significant. Linge and Linge (1983) found that their younger sample group experienced significantly less root resorption ($p < 0.001$) than their older sample group, but the study was limited to adolescent subjects. Harris and Baker (1990) found that adults had a shorter mean root length before and after orthodontic treatment than adolescents, but that the amount of root resorption was the same. Vlaskalic et al. (1998) suggested that the influence of age on root resorption could be more accurately examined by dividing groups in a more "biologic" manner, rather than by chronological age. Examples of this would be to use the onset of puberty or root apex development as maturity indicators.

Due to the multitude of factors that have been associated with root resorption, researchers are beginning to focus on genetic factors that might play a role. For example, Al-Qawasmi et al. (2003) evaluated the association between polymorphisms in the *IL-1* genes and root resorption in orthodontic patients, since these genes are known to be involved in bone resorption during orthodontic tooth movement. This study found a highly significant (p-value = 0.0003) linkage disequilibrium for the *IL-1B* marker for root resorption in the maxillary central incisor. They also found through regression analysis that 15% of the variability of root resorption could be accounted for by the genotype of the *IL-1B* marker. Harris et al. (1997) studied 103 sibling pairs and found that root resorption of the maxillary central incisors is correlated with a sibling relationship (r = 0.38). The heritability component of root resorption ranged from 60% to 80%. Another genetic factor, race, has also been analyzed. Sameshima and Sinclair (2001) found that Asian patients demonstrated significantly less root resorption than Caucasian and Hispanic patients. This difference was, on average, 0.7 to 0.8 mm less than Hispanic patients, who had the highest average of root resorption. The study also divided the patients by office, with six different offices providing orthodontic treatment. The office with the highest levels of root resorption also had the largest percentage of Hispanic patients. In addition, the two offices with the lowest levels of root resorption had the highest percentage of Asian patients. Since there wasn't enough data for analysis, it is unclear whether it was race or the office that provided treatment that had a greater role in root resorption.

Variations in root shape and size have been associated with root resorption, but not consistently. Sameshima and Sinclair (2001) found that maxillary lateral incisors with dilacerated roots had more root resorption than normally formed roots. They also found that increased root length was weakly correlated with increased root resorption. Mirabella and Artun (1995) studied adult patients and found that maxillary central incisors with atypical root shape had increased root resorption compared to those incisors with an average root shape. Brin et al. (2003) found that there was a slight increase in the frequency of moderate to severe root resorption among teeth with unusual morphology. It should be noted that panoramic radiographs were used in this study due to their availability, which introduces inaccuracies in the assessment of root resorption and root morphology (Sameshima and Asgarifar, 2001). Taithongchai et al. (1996) found that short roots and atypical root contour were both weakly correlated with increased root resorption. Short roots had correlation coefficients no greater than -0.157 and atypical root contour had correlation coefficients no greater than 0.148. The authors did not feel that these results were clinically meaningful. An unpublished study done by Capps (1999) demonstrated that increased root length was correlated with increased root resorption. Overall, the research tends to show that malformed roots are more prone to root resorption, but there is not a clear-cut answer for root length.

Pre-treatment Characteristics: Many researchers have attempted to find pretreatment characteristics that are predictive of root resorption without much success. In general, the characteristics studied are pretreatment and posttreatment cephalometric measurements. Increased overjet has been associated with an increased risk for root resorption in several studies (Mirabella and Artun, 1995; Harris and Butler, 1992; Linge and Linge, 1983). In the most recent study that examined this factor, Sameshima and Sinclair (2001) found that increased overjet was highly significant for root resorption in maxillary anterior teeth. Harris et al. (1997) demonstrated that anterior open bite was significantly predictive of root resorption of the mandibular molars. The authors postulated that in anterior open bite patients, there is more pressure on the mandibular molars due to the mechanics used to retract the maxillary anterior teeth.

Some authors have measured changes in pretreatment cephalometric measurements. Parker and Harris (1998) found that changes in overjet and the Frankfort mandibular angle were predictive of root resorption. Beck and Harris (1994) found that changes in overjet, anterior open bite, and overbite were predictive of root resorption of first molars. Clinically, Brin et al. (2003) demonstrated that increased change in overjet was significantly associated with the severity of root resorption. Most studies that have examined changes in other pretreatment characteristics have not found significant predictive variables (Parker and Harris, 1998; Beck and Harris, 1994).

There are two studies that have directly examined open bite patients. The first, by Harris and Butler (1992), compared patterns of maxillary central incisor root resorption of open bite patients to deep bite patients. The study consisted of 32 open bite and 31 deep bite patients. Before orthodontic treatment, the average overbite in the open bite sample was -3.6 mm and the average overbite in the deep bite sample was 4.1 mm. Maxillary central incisor root length was measured before and after treatment using a tracing of a lateral cephalogram. Severity of root resorption was also categorized according to a five-stage graded scheme. Finally, certain pretreatment cephalometric measurements were analyzed to see if they could predict root resorption. This study found that the open bite patients had significantly shorter roots pretreatment when compared to deep bite patients, with an average root length 1.7 mm shorter for open bite patients. The authors suggested that this might be due to the factors that cause an open bite malocclusion, such as a tongue thrust. After orthodontic treatment, there was not a significant difference in root length between the two study groups. Since intrusion has been shown to be an etiologic factor in root resorption, it is not unexpected that the deep bite patients in this study would experience a high level of root resorption. The categorical data demonstrated that the open bite patients had more severe root shortening before and after orthodontic treatment. Out of ten pretreatment cephalometric measurements, three were significant predictors of root resorption: the amount of anterior open bite discrepancy, an increased upward tipping of the palatal plane, and a steeper Downs' occlusal plane to Frankfort horizontal plane. Although this study compared open bite patients to deep bite patients, instead of using a control group with an average overbite, the results still demonstrate some significant factors present in open bite patients that can predispose this population to root resorption.

Frantz (1965), in an unpublished study, also examined root resorption in patients with anterior open bite. In this study, there was a test group with 38 subjects and a control group with 45 subjects. The test group consisted of patients with a minimum of 2 mm anterior open bite as measured by the distance of the incisal edge of the mandibular incisor to the maxillary incisor measured along the long axis of the mandibular incisor. The control group consisted of various malocclusions, which were not specified. Frantz examined periapical radiographs to categorize the amount of resorption as slight, moderate, and severe. Lateral cephalograms were used to make length measurements of the most anterior maxillary central incisor before and after treatment. This study found that the overall incidence of root resorption for the open bite and control groups were statistically the same. On the other hand, the amount of moderate and excessive root resorption in the open bite group (13.6%) was significantly different than the control group (8.4%). Also, the open bite group had a higher mean amount of root resorption (2.4 mm) compared to the control group (1.5 mm). This difference was highly significant ($0.001 < p < 0.01$).

MATERIALS AND METHODS

This retrospective study examined the influence of anterior open bite on root resorption. The records of approximately 800 consecutively treated patients at Oregon Health and Science University, Department of Orthodontics were evaluated for inclusion in the study. Initial patient photos, pretreament and posttreatment patient radiographs, and daily treatment records were used to screen potential subjects. Patients were selected on the basis of overbite as referenced from the occlusal plane. There was no consideration given to the apparent amount of root resorption, so that the amount of root resorption was selected for on a random basis. In addition, no subject was excluded from the study on the basis of age. Therefore, the sample groups included both adolescents and adults. Of the original group, approximately 55 open bite patients and 75 patients with normal overbite (10-30%) were selected for further evaluation. After excluding for confounding factors and incomplete records, 32 open bite patients qualified to be included in the study. 32 normal overbite patients were then randomly selected to serve as a control group.

Sample size was calculated using the data from Frantz' (1965) study, since it is the only study that compared similar populations to this current study. Therefore, sample data from the Frantz study was used to estimate population parameters. The sample size calculation is determined for the purpose of comparing the means of two normally distributed samples of equal size using a two-sided test with significance level 0.05 and power 0.80. According to the sample size calculation, both samples should have at least 32 subjects.

Variables

μ_1 : population mean, control group

μ_2 : population mean, test group

σ_1^2 : variance, control group

σ_2^2 : variance, test group

$z_{1-\alpha/2}$: inverse normal function of significance level

$z_{1-\beta}$: inverse normal function of power

$$n = \frac{(\sigma_1^2 + \sigma_2^2)(z_{1-\alpha/2} + z_{1-\beta})^2}{|\mu_2 - \mu_1|^2}$$

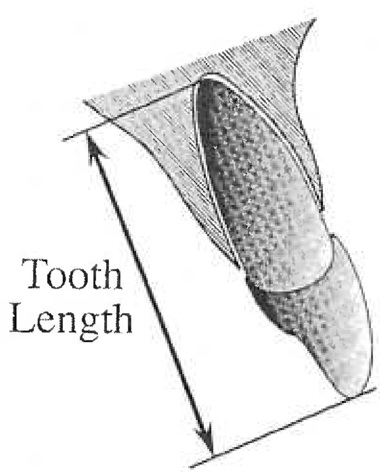
$$n = \frac{(1.08^2 + 1.45^2)(1.96 + .84)^2}{|2.4-1.5|^2}$$

$$n = 31.64$$

To be included in the open bite group, there had to be no vertical overlap of the incisors using the occlusal plane as a reference. The control group was limited to those patients with a pretreatment overbite of 10-30%. Potential confounding factors were controlled for by excluding patients with the following pretreatment characteristics and patient factors: history of trauma to the maxillary central incisor, restoration of the incisal edge prior to orthodontic treatment, root canal therapy, incomplete root apex development, an obscured apex, significantly malformed roots, greater than 7 mm overjet, maxillary anterior tooth impaction, supernumerary teeth in anterior maxilla, previous orthodontic treatment (including phase one treatment), and sibling relationship with another subject. Siblings were excluded in order to eliminate heritability as a confounding factor. In addition, subjects were excluded for the following treatment factors: orthognathic surgery, reshaping or restoration of the incisal edge during or after orthodontic treatment, and those subjects that requested an early termination of treatment. After the final samples had been selected, data collection was completed using pretreatment and posttreatment lateral cephalograms and daily treatment records.

Fine pencil tracings of the pretreatment and posttreatment lateral cephalograms were made of the maxilla, the most anterior incisors, and the first molars. Measurements of tooth length were made of the most anterior maxillary central incisor using an electronic sliding caliper (Harris and Butler, 1992). Tooth length was measured in millimeters from the incisal edge to the root apex, parallel to the long axis of the tooth (Harris and Butler, 1992).

Figure 1 – Measurement of Tooth Length



(Harris and Butler, 1992)

According to Leach et al. (2001) the lateral cephalogram provides an accurate reproducible view of the maxillary central incisor, although there is an enlargement factor of 5-12%. In this study, the same Broadbent Bolton cephalometer was used to take all of the lateral cephalograms. The pretreatment and posttreatment films of 10 randomly selected patients were used in order to measure the enlargement factor of the cephalometer. By comparing the fixed dimension of the nosepiece (14.70 mm) to measurements taken from the radiographs, it was determined that the enlargement factor for this cephalometer is 5.89%. The enlargement factor was not used in the calculations or measurements of this study.

Root resorption was recorded in millimeters by subtracting the posttreatment length of the most anterior maxillary central incisor from its pretreatment length. In addition to recording root resorption in millimeters, the amount of root resorption was classified into four categories:

a. No resorption: less than 1%
b. Mild: 1-10%
c. Moderate: 10-30%
d. Severe: greater than 30%

The tracings of the lateral cephalograms were also used to obtain molar relationship before orthodontic treatment and overbite before and after treatment. Molar relationship was determined from the pretreatment lateral cephalogram, and was used for descriptive statistics. The overbite was measured in millimeters with an electronic sliding caliper before and after treatment.

A maxillary superimposition was performed in order to quantify positional changes of the maxillary central incisor (Parker and Harris, 1998). Two reference planes were used for measurements: palatal plane and PNS-perpendicular. A line was drawn through the anterior nasal spine (ANS) and posterior nasal spine (PNS) to create the palatal plane. A line perpendicular to the palatal plane was drawn through PNS to create PNS-perpendicular. The distances were measured with an electronic sliding caliper and were recorded in millimeters. Angular measurements were made with a cephalometric protractor and were recorded in degrees. The following variables were collected from the tracings and superimpositions:

a. Distance of incisal edge to palatal plane

b. Distance of apex to palatal plane (adjusted for root resorption)

c. Incisal edge to PNS-perpendicular

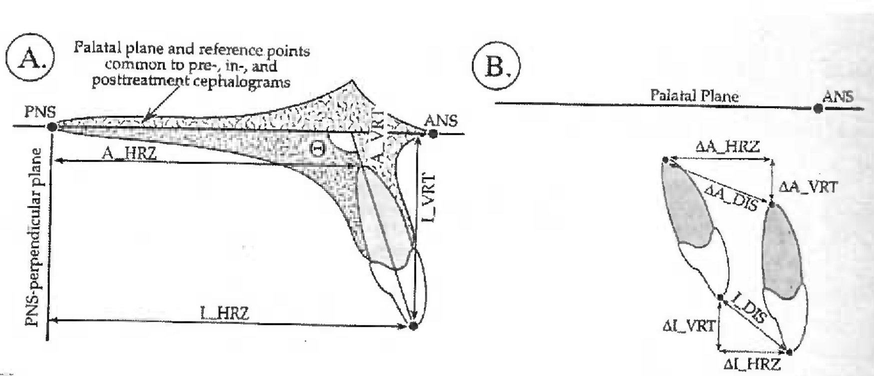
d. Apex to PNS-perpendicular

e. Incisal edge distance traveled

f. Root apex distance traveled

g. Change of angle: long axis to palatal plane

Figure 2 – Measurement of Directions of Tooth Movement



(Parker and Harris, 1998)

Daily treatment records were analyzed for the following information:

a. Treatment time (months)
b. Time in vertical elastics (months)
c. Time in Class II elastics (months)
d. Time in anterior cross elastic (months)
e. Age at the start of treatment (years)
f. Gender
g. Extraction of premolar or a lower incisor for orthodontic treatment (yes/no)

The data was analyzed with SPSS v. 12.0. Descriptive statistics of 24 categorical and continuous variables were calculated for each group. Most of these variables were then used in statistical analyses. A two-sample t-test for independent samples was used to determine if there is a difference in overbite before treatment, mean tooth length before orthodontic treatment, and if there is a difference in average root resorption after treatment between the open bite and control groups. A Chi-square test for RxC contingency tables was performed to see if there is a relationship between the two categorical variables (presence of open bite and degree of root resorption). Finally, multiple linear regression analysis was performed to determine if there are any factors that are predictive of root resorption. There were 6 categorical variables and 15 continuous variables that were included in the regression analysis.

RESULTS

Descriptive statistics for the open bite and control groups are given in Tables 1 and 2. These tables also indicate which variables were used as predictor variables in the regression analysis. Although the frequency of gender is identical and distribution of malocclusion is nearly identical between the two groups, this was coincidental and not due to study design. It is interesting to note that the frequency of vertical elastics use was nearly identical in the open bite and control groups, although the average number of months was greater for the open bite group (4.59 months versus 1.66 months). The central incisor length before treatment was longer for the open bite group (25.05 mm) compared to the control group (23.94 mm). Root resorption, when measured in millimeters or percentage, was greater in the open bite group (2.26 mm; 8.87%) than the control group (0.93 mm, 3.73%). In terms of tooth movement, the apex and incisal edge of the maxillary central incisor moved in a more incisal direction in the open bite group, but this difference was less than 1 mm for each measurement.

Table 1 – Frequencies of Categorical Variables

	Open Bite	Control
Gender*		
Male	9	9
Female	23	23
Extraction*		
Yes	22	14
No	10	18
Vertical Elastics*		
Yes	21	22
No	11	10
Class II Elastics*		
Yes	16	22
No	16	10
Anterior cross elastics*		
Yes	8	6
No	24	26
Malocclusion		
Class I	12	13
Class II	13	12
Class III	7	7

*Predictor variable

Table 2 – Mean, standard deviation, and range of continuous variables

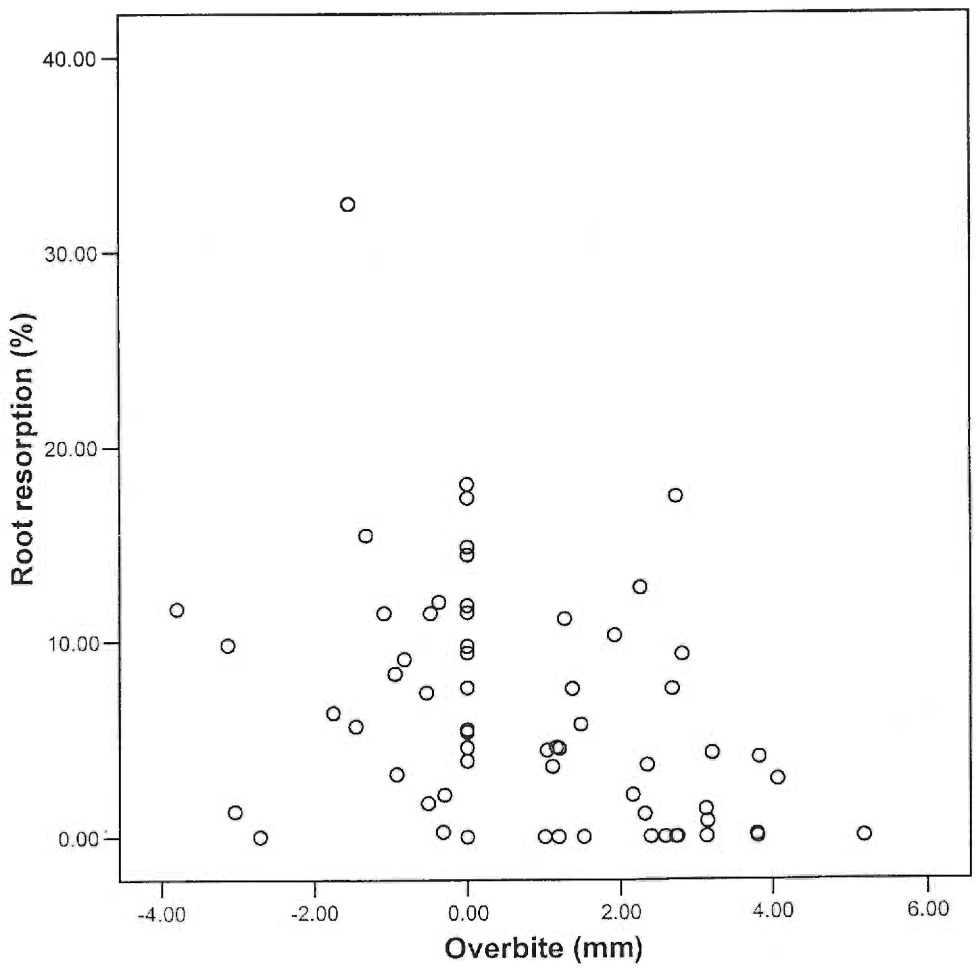
	Mean	SD	Range
Root resorption (mm)			
Open	2.26	1.76	0.00-8.87
Control	0.93	1.16	0.00-4.67
Root resorption (%)			
Open	8.87	6.66	0.00-34.47
Control	3.73	4.48	0.00-17.42
Age at start of treatment (years)*			
Open	18.66	7.02	11.30-40.09
Control	14.65	3.87	10.48-27.63
Total treatment time (months)*			
Open	25.84	10.33	10.07-59.97
Control	24.84	9.81	7.63-54.37
Vertical elastics (months)*			
Open	4.59	4.79	0.00-18.00
Control	1.66	2.12	0.00-11.00
Class II elastics (months)*			
Open	2.97	4.28	0.00-18.0
Control	2.75	2.85	0.00-9.00

Anterior cross elastics (months)*			
Open	0.78	1.68	0.00-7.00
Control	0.47	1.08	0.00-4.00
Overbite before treatment (mm)*			
Open	-0.78	1.09	-3.80-0.00
Control	2.47	1.07	1.01-5.18
Overbite difference before and after*			
Open	2.69	1.23	-0.05-5.22
Control	-0.34	1.17	-2.71-1.95
Central incisor length – before treatment (mm)*			
Open	25.05	1.98	21.42-29.57
Control	23.94	2.62	16.93-27.66
Central incisor length – after treatment (mm)			
Open	22.79	2.06	18.45-26.19
Control	23.11	2.56	16.93-26.79
Change in angle of incisor (degrees)*			
Open	2.03	6.84	-11.00-20.00
Control	0.53	4.80	-8.00-8.00
Change of incisal edge to palatal plane (mm)*			
Open	1.73	1.37	-0.63-5.60
Control	1.15	1.13	-1.49-3.28
Change of apex to palatal plane (mm)*			
Open	1.32	1.24	-0.84-4.40
Control	0.62	0.97	-1.15-3.77
Change of incisal edge to PNS-perpendicular (mm)*			
Open	-1.72	1.97	-6.28-3.45
Control	-1.16	2.03	-5.60-1.59
Change of apex to PNS-perpendicular (mm)*			
Open	-0.22	1.80	-4.52-3.12
Control	-0.86	1.15	-2.80-2.13
Incisal edge distance traveled (mm)*			
Open	3.02	1.58	0.60-7.17
Control	2.33	1.60	0.00-5.82
Apex distance traveled (mm)*			
Open	7.13	2.23	2.95-12.33
Control	6.58	2.71	2.32-11.64

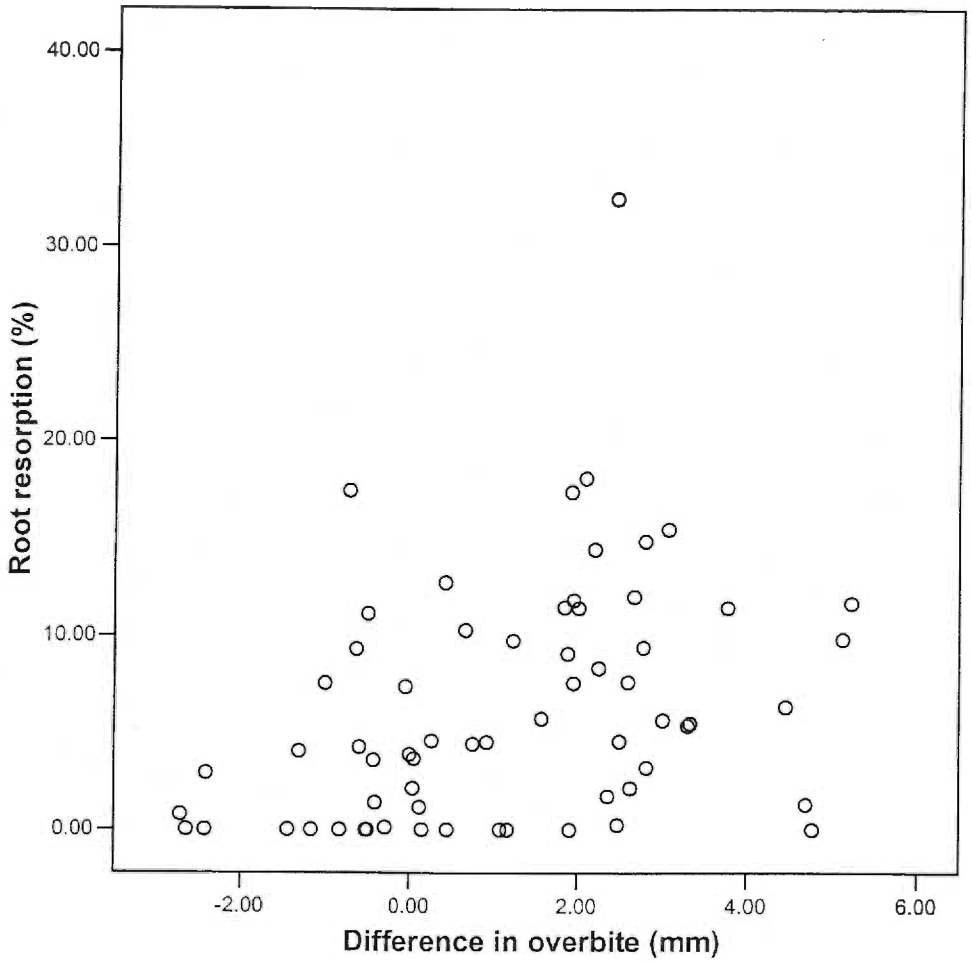
*Predictor variables

Two scatterplots were created to visualize the relationship between the amount of initial overbite and the percentage of root resorption as well as the change in overbite after treatment and the percentage of root resorption. Both of these graphs reveal a lack of pattern between these variables.

Graph 1 – Initial overbite versus percentage of root resorption



Graph 2 – Change in overbite after treatment and percentage of root resorption



Since the overall purpose of the study was to compare the difference between an open bite sample and a normal overbite sample, it was important for the groups to have a significant difference in the amount of overbite before orthodontic treatment. The average overbite for the open bite group was –0.78 mm and 2.47 mm for the control group. The results of the t-test were highly significant ($p < 0.001$). Therefore, the two samples had a statistically significant difference in the amount of overbite before treatment.

Three two-sample t-tests were performed to assess if there was a significant difference in mean tooth length before treatment, amount of root resorption (mm), and percentage of root resorption between the open bite sample and the control sample. The results are given in Table 3. There was no statistical difference in the average tooth length before treatment of the open bite group (25.05 mm) compared to the control group (23.94 mm). There was a highly significant difference ($p = 0.001$) in the amount and percentage of root resorption for the open bite (2.26 mm, 8.87%) versus the control group (0.93 mm, 3.73%).

Table 3 – Two Sample t-tests

	t	df	p-value
Central incisor length before (mm)	-1.93	62	0.059
Root resorption (mm)	-3.56	62	0.001*
Root resorption (%)	-3.62	62	0.001*

*Statistically significant

A Chi-square test for RxC contingency tables was performed to examine if there is a relationship between two categorical variables: presence of open bite and degree of root resorption. Degree of root resorption was divided into four categories (none, mild, moderate, and severe). The frequencies in each study group are given in Table 4. The open bite group had more patients with mild and moderate root resorption. On the other hand, the control group had more patients with no or mild resorption. The Chi-square test revealed that there is a statistically significant difference ($p = 0.01$) in the distribution of degree of root resorption between the open bite and control group. These results are given in Table 5.

Table 4 – Frequencies of degree of root resorption

Degree of root resorption	Open Bite	Control Group
No resorption (<1%)	3	13
Mild (1-10%)	16	15
Moderate (11-30%)	12	4
Severe (greater than 30%)	1	0

Table 5 – Chi-Square Test

	Value	df	p-value
Pearson Chi-Square	11.28	3	0.01*

*Statistically significant

Multiple linear regression was performed to determine if there are any factors that are predictive of the percentage of root resorption in an individual patient. The following predictor variables were tested:

<u>Categorical Variables</u>

Presence of open bite
Gender
Extraction
Use of vertical elastics
Use of class II elastics
Use of anterior cross elastics

Continuous Variables

- Age at start of treatment (years)
- Total treatment time (months)
- Vertical elastics (months)
- Class II elastics (months)
- Anterior cross elastics (months)
- Overbite before treatment (mm)
- Difference in overbite before and after treatment (mm)
- Central incisor length before treatment (mm)
- Change in angle of incisor (degrees)
- Change of distance of incisal edge to palatal plane (mm)
- Change of distance of apex to palatal plane (mm)
- Change of distance of incisal edge to PNS-perpendicular (mm)
- Change of distance of apex to PNS-perpendicular (mm)
- Incisal edge distance traveled (mm)
- Apex distance traveled (mm)

The first step taken in building the regression model was to analyze the univariate relationship of each variable individually with the outcome variable (percentage of root resorption). Variables were added to the model via forward selection. There were two criteria used to determine if a variable should be added to the model. First, the *p*-value had to be less than or equal to 0.05. Second, there must be an increase in the coefficient of determination (R^2). No other variables were added to the model when *p*-values were not significant and there was no or little increase in R^2.

The final regression model included two variables: the presence of an open bite and initial central incisor length. Refer to Table 6 for the parameters and relevant information in the final model. The R^2 for the final model is 0.244.

Table 6 – Parameters for final regression model

	ß	SE(ß)	p-value
Presence of open bite	4.35	1.41	.003*
Initial central incisor length	.71	.30	.021*

*Statistically significant

The final model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

$$Y = -13.25 + (4.35)X_1 + (.71)X_2$$

Variables
β_0: Intercept
β_1: Coefficient for X_1
X_1: Presence of open bite
Normal overbite = 0
Open bite = 1
β_2: Coefficient for X_2
X_2: Initial length of central incisor

The final regression model shows that there is an increase in the predicted root resorption with the presence of an open bite and an increasing incisor length. For example, a patient with an open bite and a 25 mm central incisor would be predicted to have 8.85% root resorption, while a patient without an open bite and a 25 mm central incisor would have a predicted 4.5% of root resorption.

$$Y = -13.25 + (4.35)X_1 + (.71)X_2$$

$$Y = -13.25 + (4.35)1 + (.71)25$$

$$Y = 8.85\%$$

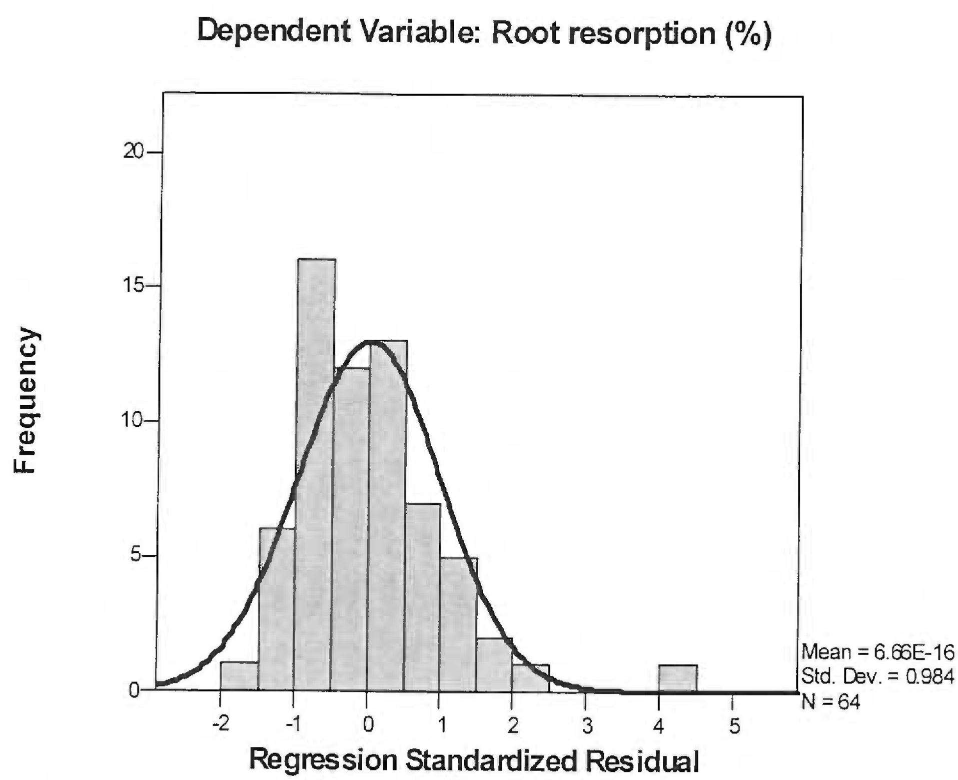
$$Y = -13.25 + (4.35)X_1 + (.71)X_2$$

$$Y = -13.25 + (4.35)0 + (.71)25$$

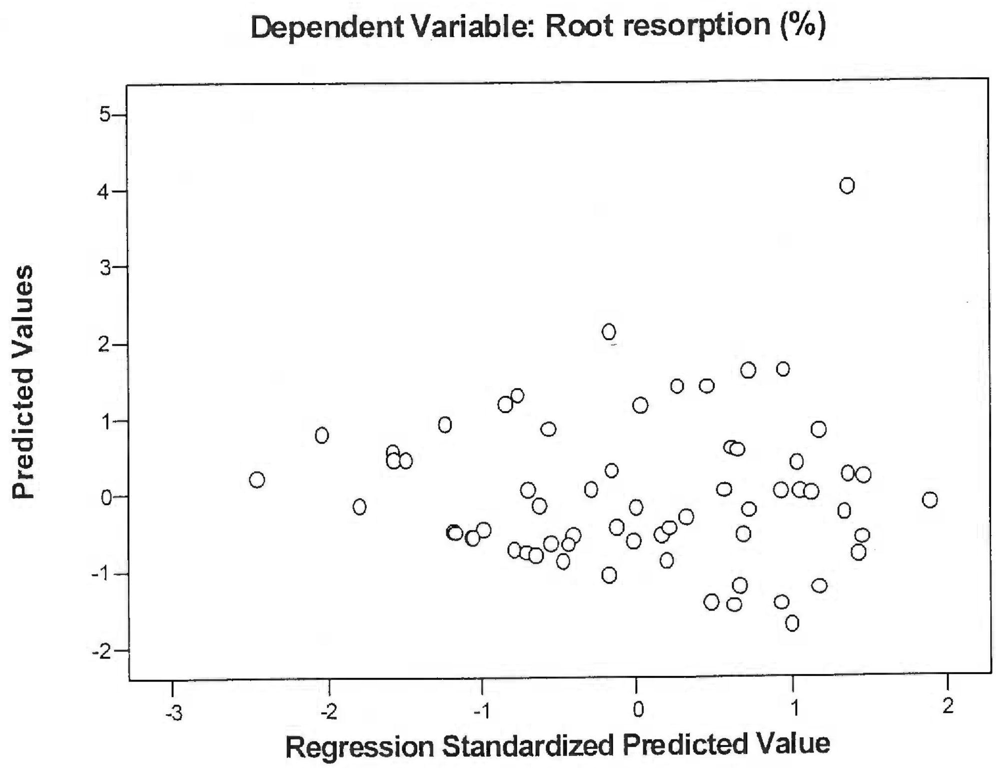
$$Y = 4.5\%$$

In order for regression analysis to be valid, there are four assumptions that must be met: linearity, normality of residuals, equality of variances, and independence of observations. The linearity and independence of observations were met by the study design. For example, none of the subjects were related, which makes each measurement independent. Normality was determined to be true by analyzing normality plots (Graph 3). Equality of variances was determined to be true since there was no significant pattern associated with a scatterplot of the residuals versus fitted values (Graph 4).

Graph 3: Standardized Residuals vs Frequency



Graph 4: Standardized Residuals vs Predicted Values



DISCUSSION

The amount of root resorption found in this study is comparable to the average numbers found in the literature. Most of the root resorption that occurs due to orthodontic treatment is mild to moderate. In fact, there was only one patient in this study that experienced severe root resorption (> 30%). This patient was in the open bite group. The mean root resorption for the open bite group was 2.26 mm (8.87% of root length) and the mean root resorption for the control group was 0.93 mm (3.73% of root length).

The results of this study indicate that there is a significant difference in root resorption for open bite patients compared to patients with a normal overbite. This was shown through several statistical analyses. First, the two-sample t-tests demonstrated that there is a highly significant difference in the amount of root resorption between these two groups. This held true for root resorption measured in millimeters as well as the percentage of root resorption that occurred. These results are analogous to the studies conducted by Harris and Butler (1992) and Frantz (1965), both of which demonstrated an increase in root resorption for an open bite sample.

This study did not show a significant difference in root length before treatment, as shown in the study done by Harris and Butler (1992). In that study, the open bite sample had significantly shorter roots prior to orthodontic treatment compared to a deep bite sample. In the current study, the open bite sample had a mean central incisor tooth length of 25.06 mm and the normal overbite sample had a mean central incisor tooth length of 23.94 mm. Although this trend is different from the Harris and Butler study, these two studies were not comparing the same populations. It is important to note that even though the t-test in this study did not have a significant result, the p-value was low (0.059), and did approach a statistically significant level.

Since many studies evaluate root resorption in categories, the data were grouped for the purpose of using a Chi-square test for RxC contingency tables. This tested the relationship between the presence of open bite and different categories of root resorption (none, mild, moderate, and severe). The results of this analysis were statistically significant. The open bite sample had a higher frequency of mild and moderate amount of root resorption while the control sample had a higher frequency of no resorption and mild resorption. The results of this study are similar to those of the Frantz (1965) study, in which the open bite group had increased moderate and excessive root resorption compared to a control group.

Regression analysis was performed to determine if there are any patient characteristics, treatment factors, or directions of tooth movement that can be predictive of root resorption. The data was collected from patient treatment records as well as measurements taken from cephalometric tracings and superimpositions. Out of twenty-one variables analyzed, only two were statistically significant: the presence or absence of an open bite and central incisor length before orthodontic treatment. The final model demonstrates that the presence of an open bite and an increasing incisor length are both predictive of an increased percentage of root resorption. The influence of an open bite on the amount of predicted root resorption is consistent with the other results obtained in this study (statistically significant t-tests and Chi-square test). It cannot be specifically compared to any other study, since this particular population has not been analyzed before using regression analysis. There have been other studies that show the influence central incisor length has on root resorption, but the results have been conflicting as to whether short or long central incisors tend to have more root resorption (Capps, 1999; Mirabella and Artun, 1995). Sameshima and Sinclair (2001) speculated that a longer root is displaced farther for an equal amount of torque, and would therefore be more susceptible to resorption. They also theorized that if a patient has shorter roots prior to orthodontic treatment a clinician might make a conscious decision not to move the root apex a great distance (Sameshima and Sinclair, 2001). This could theoretically be preventive of root resorption.

The regression analysis did not show any relationship between the direction of tooth movement or the use of elastics on the amount of root resorption experienced by a patient. In general, this agrees with the literature, which does not tend to show increased root resorption with particular directions of tooth movement or with the use of elastics (Sameshima and Sinclair, 2001). In this study, it was of specific interest to analyze the influence of extrusion on the amount of root resorption. Even though the presence of an open bite was predictive of root resorption, the vertical movements of the maxillary central incisor were not. These results are consistent with other studies (Sameshima and Sinclair, 2001; Mirabella and Artun, 1995). Treatment time was also not significant, and this follows the general trend in the literature (Mirabella and Artun, 1995; Beck and Harris, 1994; Linge and Linge; 1983; Phillips, 1955).

Although the regression analysis was statistically significant, the coefficient of determination (R^2) was 0.244. This means that the model produced by linear regression only accounts for 24.4% of the variability in root resorption. Because of the low R^2

value, the regression line should not be used in a clinical setting to make a prediction on an individual patient. As a general guideline, the R^2 x 100 of a regression line should be at least 80% in order to make a meaningful clinical prediction (Horowitz and Hixon, 1966).

There are many reasons why the regression analysis does not explain more variability in root resorption. First, there is always a certain amount of error in data collection. In this study, some of the data collected was from patients' daily treatment records. Since multiple clinicians complete the daily treatment records, there is a risk of omission or errors. Also, it is sometimes difficult for a clinician to evaluate compliance of elastic usage, which would also create an inaccuracy in the daily treatment record. In this study, there is also a chance of measurement error. Due to the availability of radiographs, this retrospective study utilized tracings of lateral cephalograms to measure root length and positional changes of the maxillary central incisor. Research has shown that there can be great variability in locating the apex of the maxillary central incisor on a lateral cephalogram (Baumrind and Frantz, 1971; Stabrun and Danielsen, 1982). In addition, there can be inaccuracies introduced by using a maxillary superimposition (Baumrind et al., 1976). Because of the variability in identifying the maxillary incisor apex on a lateral cephalogram, there was an attempt to control for this by excluding any patient with an obscured incisor apex.

In order to explore tracing, measurement, and superimposition inaccuracies, an error of method calculation was performed on the seven linear measurements made on the cephalometric tracings. Four months after the initial measurements were made, 10 patients were randomly selected for the error study group. Fine pencil tracings were made of the maxilla, the most anterior central incisors, and first molars. A maxillary superimposition was done of the pretreatment and posttreatment tracings. The following measurements were made on these tracings: central incisor length before and after treatment, pretreatment overbite, distance of incisal edge to palatal plane before and after treatment, distance of apex to palatal plane before and after treatment, distance of incisal edge to PNS-perpendicular before and after treatment, and distance of apex to PNS-perpendicular before and after treatment. The error of method was calculated with the following equation:

$$S_x = \sqrt{(\sum D^2 / 2N)}$$

where D is the difference between duplicate measurements and N is the number of double measurements (Dahlberg, 1940). The results are given in Table 7. Each error of method falls within an acceptable limit, and is comparable to other studies. Taithongchai et al. (1996) had .22 mm error of method for overbite and .23 mm for incisal edge to palatal plane. Mirabella and Artun (1995) had .32 mm error of method for overbite, .40 mm for horizontal movement of the incisal edge, and .61 mm for vertical movement of the incisal edge. In this study, the measurements of tooth length and overbite have less error than the measurements taken of tooth position. This is logical, since there are more chances for error in the latter, due to the potential for inaccuracies in the superimposition as well as drawing the reference line.

Table 7 – Error of method

Linear measurement	Error of method
Pretreatment central incisor length	.28
Posttreatment central incisor length	.27
Pretreatment overbite	.20
Incisal edge to palatal plane	.48
Apex to palatal plane	.60
Incisal edge to PNS-perpendicular	.52
Apex to PNS-perpendicular	.36

In addition to study design, there can be other explanations why a regression model does not explain a large percentage of variability. There can be other factors that have a greater influence on root resorption that were not tested in this study. For open bite patients, the tendency for increased root resorption might be related to the environmental factors that contribute to or cause an open bite malocclusion. Pressure from the musculature, such as a protrusive tongue posture or tongue thrust habit, could put more continuous pressure on incisors, which could lead to increased susceptibility for root resorption. It is also possible that this population is exposed to more "jiggling forces" via tongue pressure or increased use of vertical elastics. There is also a good chance that genetic factors play a role in the incidence and degree of root resorption. This is beginning to be explored more in the literature and some studies have already demonstrated that heredity has an influence on root resorption (Al-Qawasmi, 2003; Sameshima and Sinclair, 2001; Harris et al., 1997).

Finally, more significant predictor variables might have been revealed if the open bite group had a more severe average open bite. In this study, the mean pretreatment overbite for the open bite group was –0.78 mm. In contrast, the open bite group in the study by Frantz (1965) was limited to a minimum of 2 mm open bite. Frantz (1965) found that the open bite sample had a higher incidence of severe root resorption compared to the results of the current study. A more severe open bite group might also have demonstrated more vertical movement of the central incisor. The amount of extrusion in this study was similar to other studies that did not find extrusion to be a significant predictor of root resorption (Sameshima and Sinclair, 2001; Mirabella and Artun, 1995). Finally, a more severe open bite group might have had significantly more vertical elastic usage. If this is true, it is possible that verticals elastics and "jiggling forces" have more influence on root resorption than indicated by the current study.

Based on the results of this study, there are many areas of research that could be explored. First, it would be interesting to do a similar or identical study with a more severe open bite malocclusion. This could reveal if treatment differences or greater vertical tooth movement results in a difference in the amount of root resorption. The study could also be done using periapical radiographs to measure tooth length and root resorption. In order to analyze whether tongue pressure in an open bite patient would predispose this population to root resorption, an untreated sample could be compared to an orthodontically treated sample. The untreated sample could be obtained from various university growth studies. If there is no difference in the amount of root resorption between the treated and untreated groups, it would indicate that there is a local factor present in open bite subjects that would predispose them to root shortening. If the treated group has more root resorption, then further investigations should be done regarding the role of orthodontic treatment in root resorption.

CONCLUSIONS

According to the results of this study, there is a not a statistically significant difference in the pretreatment central incisor tooth length between patients with an open bite and those with normal overbite. Posttreatment, there is a statistically significant difference in the amount of root resorption in open bite compared to normal overbite patients. There is also a statistically significant difference in the distribution of degree of root resorption between the two sample groups. The open bite group had more subjects with mild and moderate root resorption. The control group had more subjects with no or mild root resorption. Finally, the regression analysis demonstrates that the risk of root resorption increases with the presence of an open bite and increasing central incisor length. This prediction is statistically significant, but can only explain 24.4% of the variability in the percentage of root resorption. Since there is a relatively low level of predictability, other confounding factors such as pressure from the musculature should be examined. In addition, analyzing a more severe open bite sample could reveal more information about the risk of root resorption in orthodontically treated open bite patients. Even though the predictability is low, the results from this study can still be helpful in order to give open bite patients a more accurate assessment of their risk factor for root resorption in relation to other types of malocclusions.

APPENDIX

Table 1 – Case summaries of central incisor length, open bite sample

Case Summaries

			Central incisor length (mm)
Open	1		24.05
	2		27.18
	3		24.53
	4		25.41
	5		23.38
	6		27.73
	7		22.80
	8		25.88
	9		23.87
	10		24.22
	11		26.49
	12		25.51
	13		21.42
	14		22.13
	15		24.53
	16		22.34
	17		25.42
	18		27.59
	19		27.32
	20		27.29
	21		25.71
	22		22.57
	23		24.13
	24		23.49
	25		27.67
	26		24.28
	27		24.37
	28		26.48
	29		22.26
	30		29.57
	31		25.94
	32		26.27
	Total	N	32
Total	N		64

Table 2 – Case summaries of central incisor length, control sample

Case Summaries

		Central incisor length (mm)
Control	1	20.73
	2	26.87
	3	24.47
	4	16.93
	5	22.96
	6	24.85
	7	26.28
	8	24.24
	9	23.91
	10	20.75
	11	24.54
	12	22.42
	13	27.66
	14	26.99
	15	22.19
	16	25.80
	17	21.10
	18	18.73
	19	24.74
	20	25.49
	21	22.48
	22	19.78
	23	23.28
	24	24.74
	25	25.65
	26	26.81
	27	27.45
	28	22.98
	29	25.15
	30	24.13
	31	25.11
	32	26.79

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